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Friedrich Stadler
Editor

Ernst Mach – Life, Work, Influence

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Editorial

Ernst Mach (1838–1916) ranks among the most significant natural scientists and philosophers of the nineteenth and twentieth centuries. In physics, he paved the way for Einstein's theory of relativity and was sceptical about Boltzmann's atomism; in biology, psychology, and physiology, he pioneered with an empiricist and "gestalthaft" "Analysis of Sensations"; in philosophy of science, he served as a model for the Vienna Circle with the Ernst Mach Society, as well as initiated an integrated history and theory of science. His influence extends far beyond the natural sciences—to the Vienna Medical School and psychoanalysis (R. Bárány, J. Breuer, S. Freud), to literature ("Jung Wien," R. Musil), to politics (F. Adler, Austro-Marxism and the Viennese adult education), to arts between futurism and minimal art, as well as to social sciences between the liberal school (J. Schumpeter, F. A. von Hayek) and empirical social research (P. Lazarsfeld and M. Jahoda). In today's pedagogy, his genetic theory of learning is just as respected as his method in historical epistemology. Mach's international impact already showed during his lifetime, in American pragmatism (W. James) and French conventionalism (P. Duhem, H. Poincaré). In 2016, on the occasion of the centenary of Ernst Mach's death, the Institute Vienna Circle organized an international conference on the life, work, and influence of this scientist and philosopher, who worked at the University of Vienna and the Austrian Academy of Sciences for many years and who exerted significant influence on several generations of scholars and scientists, as well as of cultural and political agents. The main goal was to make a critical inventory of Mach's lifework in line with state-of-the-art research and historiography.

The Ernst Mach Centenary Conference, June 15–18, 2016, was organized by the Institute Vienna Circle, University of Vienna, and the Austrian Academy of Sciences. This was certainly the biggest international conference dealing with the life, work, and influence of one of the most fascinating men, as a scholar and scientist with impacts up to the present.

We were pleased to have received an enormous amount of submissions from all over the world, from which the Program Committee chose some 60 papers, so that in addition to the invited speakers there was a presentation of nearly 90 papers in four parallel sessions, including three plenary lectures. A selection of these talks in English is presented in this volume. Another set of papers in German is being published at the same time by Springer in the series "Veröffentlichungen des Instituts Wiener Kreis," entitled *Ernst Mach – Leben, Werk und Wirkung*.

It was not by accident that this conference took place also on the occasion of the 25th anniversary of the Institute Vienna Circle as a nonprofit society and the 5th anniversary of the same Institute as a Department (subunit) of the Faculty of Philosophy and Education of the University of Vienna. Pleasingly, also the Vienna International Summer School—Scientific World Conceptions (USS/SWC)—has been active since its inception in 2001. As it is well known, Mach was one of the most important precursors of the later Vienna Circle around Moritz Schlick, which was also acknowledged by the naming of the "Verein Ernst Mach" (Ernst Mach Society) in parallel. This was only one reason why the Institute Vienna Circle served as the main local organizer for this huge event. In this regard let me thank again Sabine Koch and Robert Kaller, together with the members of the organizational staff (Josef Pircher, Olga Ring, Saskia Haber, and Eren Simsek).

One day before the official opening, the conference was started with a public lecture in the main building of the University of Vienna (Wiener Vorlesungen, organized by the City of Vienna) with a panel discussion on Mach's undeniable significance for the relation between natural, cultural, and social sciences, especially his contributions toward an interdisciplinary approach in the age of a growing specialization and differentiation in the sciences was on the agenda. In this regard the historical and empiricist conception of his "neutral monism" opens still further developments and innovations. Independently, Mach's significance in physics is still alive with the naming of the Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, in Freiburg/Br. (Germany), where his archives were located before its transfer to the German Museum in Munich. It is not possible to focus on the numerous contributions to both proceedings, which are dealing more or less with most of these aspects of Mach's lifework, mainly from a critical and present point of view.

I am grateful to the co-organizers and sponsors of the Centenary Conference: the University of Vienna, especially to the Rectorate and to the Deans of the seven faculties for their support of this representative conference, above all the Faculty of Philosophy and Education as the leading organizational unit, with its Dean, Elisabeth Nemeth. Furthermore, I thank Anton Zeilinger, the President of the Austrian Academy of Sciences, who enabled the cooperation and co-hosting of the conference. This was plausible given the fact that Ernst Mach was a professor at the University of Vienna and also a long-term member of the "Kaiserliche Akademie der Wissenschaften" (Imperial Academy of Sciences). Therefore, the conference ran under the auspices of Rector Heinz Engl and President Anton Zeilinger. Pleasingly, the ÖAW had established a new "Commission for the History and Philosophy of Sciences," where Mach is one of the topics to be investigated following his historical approach in the philosophy of science. Last but not least, it was the pleasing cooperation with Johannes Feichtinger and his collaborator, Cornelia Hülmbauer, from the Institute of Culture Studies and Theatre History of the ÖAW that facilitated a smooth and productive planning and organization. It is not by accident that this

Institute is running the so-called Ernst Mach-Forum for the sciences in dialogue. In this regard it is worth mentioning that the Austrian Agency for International Cooperation in Education and Research (OeAD) is awarding annually a worldwide Ernst Mach stipend.

Ernst Mach was also a professor at the Charles University of Prague (where he had served as a Dean and Rector before the division in a German and Czech university). In this regard we could experience a continuous appreciation of Mach in Czechoslovakia, where in February 2016 another commemorative plaque was unveiled in the centre of Prague by the Czech and European Physical Society, in addition to the already existing memorial site at Mach's birthplace in Chrlice near Brno. In this context, special thanks go to Martin Cernohorsky and his team in Brno for all these initiatives (e.g., the recurring "Ernst Mach Days") and their cooperation with our conference by contributing papers and the cultural tour to Mach's birthplace and to the beautiful City of Brno at the end of the conference.

Another cooperation was organized by Anastasios Brenner from the University of Montpellier, a symposium on Mach, Pierre Duhem, and French philosophy of science as part of the conference, also on the occasion of the centenary of the death of this renowned French philosopher-scientist. Furthermore, we are looking forward to another promising cooperative project, the electronic publication of Mach's correspondence at the *Leopoldina* in Halle/S. (Germany) conducted by Klaus Hentschel.

In this context I want to refer to the running "Ernst Mach Studienausgabe" (Ernst Mach Study Edition) published by the small Berlin publisher Xenomoi Verlag, for the publication of Mach's six main books in German to date.

In the meantime, we had to mourn the death of three prominent Mach scholars who passed away during the preparation of the proceedings: Erik C. Banks, Hayo Siemsen and his father, Karl Hayo Siemsen. These colleagues contributed significantly to the research on Mach between epistemology and genetic pedagogy. We are honored that their last manuscripts are being published in this volume as a sort of testimony of their unique expertise in this field.

The publication of both volumes of the proceedings was realized with the help of Robert Kaller and Josef Pircher, to both of them whom I am grateful for their continuous collaboration. Thanks go also to the representatives and the production team of Springer Publishers.

Vienna, Austria Friedrich Stadler
October 2018

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Part I
Mach and Austrian Philosophy

Chapter 1
Only a Philosophical "Holiday Sportsman"? – Ernst Mach as a Scientist Transgressing the Disciplinary Boundaries

Friedrich Stadler

Abstract Ernst Mach was already an international successful experimental physicist and scientist, when he, after professorships for Mathematics and Physics in Graz and Experimental Physics in Prague, took over the chair for "Philosophy, particularly for the History and Theory of the Inductive Sciences", at the University of Vienna in 1895. This turn from the natural sciences to philosophy was really an exception in the academic field.

Given his strong as well as controversial history of influence in philosophy and in the sciences Mach's own pessimistic statement about the emergence of aprioristic currents at the beginning of the twentieth century is surprising and in need of an explanation.

The article deals with Mach's appointment in Vienna and Mach's autobiographical fragments on his relation to academic philosophy from a today's point of view. It appears that Mach can be regarded as a pioneer and predecessor of a topical "historical epistemology", "history and philosophy of science", and above all as a theorist and practitioner of inter- and transdisciplinarity. If he is to be regarded a philosopher, it is mainly in the context of naturalism, pragmatism and common sense philosophy – as general theory of research.

Which were the motifs for Mach, the passionate natural scientist (*Naturforscher*), who saw himself lifelong as a mere "holiday sportsman" ("Sonntagsjäger") in philosophy, nevertheless to take over this important and contested chair in Vienna – a chair, which formed the basis for his successor Ludwig Boltzmann and Moritz Schlick as the founder of the Vienna Circle?

In order to answer this question one has to go back to Mach's intellectual development, esp. to his key experience with the reading of Kant's *Prolegomena*, the influence of the Kantian Eduard Beneke, as well as the philosophical commu-

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nication with his contemporaries: e.g., with Franz Brentano, Wilhelm Jerusalem, Theodor and Heinrich Gomperz, including Pierre Duhem and William James – which shows the family resemblance with French conventionalism and American pragmatism. At least we realize a pluralistic reception of Mach also within the Vienna Circle of Logical Empiricism (incl. Wittgenstein and Popper at the periphery), which manifests his (anti)philosophical heritage, partly documented in the activities of the Ernst Mach Society ("Verein Ernst Mach"). The late rediscovery and appreciation of Mach by Paul Feyerabend polarised in the same way as was the case with his provoking book *Against Method*.

1.1 Mach and His Times – An Extraordinary Intellectual Journey

Ernst Mach was an exciting man and fascinating scholar: he polarized the public and academic opinion from the *fin de siècle* to the present. He had an equal impact on philosophy, science and politics as well as on literature. In addition, he challenged the oppositions of materialism and idealism, realism and positivism, Bolshevism and Austro-Marxism, and impressionism and naturalism—and caused heated controversies about whether he was a forerunner and supporter of relativity theory or whether he rejected atomism for principled reasons? Mach's "positivism"—he himself did not use this name for his doctrine—stands at the beginning of a long dispute that has been going on since the turn of the century around 1900: from the alleged rivalry between Mach and Boltzmann, the dispute between Mach and Planck, and the frontal attack by Lenin and his comrades, via the differences between the Vienna Circle and the Frankfurt School in the inter-war period, up to the "positivism dispute" in German sociology in the 1960s. Alongside these public confrontations and their literary variations suggesting an eternal—and suspiciously ideological—controversy, Mach's work has enjoyed a quiet renaissance in the sciences: His works in the fields of philosophy, physics, and methodology—on concepts of measurement, the "Mach Principle", the "Mach wave", the "Mach number", "Mach band", or his "principle of economy"—opened up perspectives which still prove fruitful. In psychology Mach has been (re)discovered as a forerunner of gestalt theory, in the philosophy of science as one of the most original theorists because of his historical-critical method, and finally, as an intellectual precursor in present-day "evolutionary epistemology" ("historical epistemology", or "history and philosophy of science").

Mach appears to be relevant today at least for two reasons: first, as the central figure of intellectual life at the turn of the century, as reflected in his extensive correspondence, and second, as an experimental and theoretical physicist, a physiologist and psychologist of sensation, a philosopher and historian of science, and, last but not least, as an educationalist and an author of textbooks and curricula. His attempt to create a historical-social and evolutionary foundation for science corresponds to his social reform views and his political practice. He succeeded in conquering mechanical materialism and metaphysical system philosophy while the natural sciences were in the midst of a crisis, and in formulating his doctrine of the empirical unity of physics, physiology, and psychology within the framework of a monistic scientific world- view as follows (Mach 1872/1911, 91):

> Now, the problem of science can be split into three parts: 1. The determination of the connexion of presentations. This is psychology. 2. The discovery of laws of the connexion of sensations (perceptions). This is physics. 3. The clear establishment of the laws of the connexion of sensations and presentations. This is psychophysics.

Elsewhere Mach programmatically described the task of scientific cognition as the adaptation of thoughts to facts and to each other (Mach 1976, 120 ff.). The main epistemological and methodological problems initiated by the “second scientific revolution” were to be solved by means of unconventional ideas: the theory of elements, the principle of economy, and the historico-critical method on an evolutionary basis were central and at the same time controversial components of his Enlightenment conception of science. Just how much resistance Mach’s innovation encountered in the scientific community is shown not only by the dispute between him and Boltzmann and between their respective followers, or by his controversial correspondence with the scientific avant-garde of the time, but also by his own pessimism concerning the impact of his work (Mach 1883, XVI):

> At the end of the last century my disquisitions on mechanics fared well as a rule; it may have been felt that the empirico-critical side of this science was the most neglected. But now the Kantian traditions gained power once more, and again we have the demand for an a priori foundation of mechanics. (cited from Mach 1989, xxvii)

The past and the present reception of Mach’s ideas with its emotional and polemical overtones illustrate the explosive potential of an interdisciplinary scientific world view with a claim to the humanization of science and society. Mach himself lived up to this proposed ideal as a promoter of general education and school reform.

What was Mach’s intellectual development leading up to his monistic world view and interdisciplinary methodology? Which role played philosophy in this regard?

Already at the age of 15 (!) Mach had read Kant’s *Prolegomena*, which resulted in a lifelong divergence from metaphysics and idealistic philosophy. He himself reports in his autobiographical manuscripts on this key experience as follows (Mach 1913, cited after Blackmore 1992, 22 f.):

> The fifteen year-old youth eagerly gobbled down this clear and relatively uncomplicated work. It made a powerful impression upon him, destroyed the young man’s naive realism, stimulated an interest in epistemology, and with the help of Kant the metaphysician annihilated all tendency toward metaphysics within himself. In equal fashion, the book stimulated my thinking about scientific and psychological matters. I soon detached myself from Kant’s critical idealism. I recognized even as a boy that the thing-in-itself was a useless, metaphysical fabrication, a superfluous metaphysical illusion. I soon turned to the Berkeleyan ideas which had been latent in Kant and gradually came to a critical empiricism. If I could not remain loyal to Kant’s thoughts, I remained thankful to him for the manner in which he had stimulated me. Kant also helped my historical-critical treatment of mechanics possible. From the same spring came the Wärmelehre, the initial stages of the Optik, and so forth.

At the age of 17 Mach took his school-leaving certificate at the Kremsier grammar school and enrolled in mathematics and physics with von Ettinghausen, Grailich, and Petzval at the University of Vienna, where the ambitious student complained of shortcomings in the natural sciences. For this reason he had to undertake autodidactic studies, and he achieved his first experimental success with the construction of an apparatus proving the existence of the famous Doppler effect—an acoustic phenomenon, which was doubted at the time.

In January 1860, after 5 years of study, Mach obtained his Doctor of Philosophy with the dissertation *Über elektrische Entladung und Induktion* (On Electrical Discharge and Induction). The living situation of the young doctor was so miserable that he had to support himself by giving private lessons to school pupils—yet nonetheless in 1861 Mach was able to qualify as a *Privatdozent* for physics. He gave private lectures about Fechner's psychophysics and Helmholtz's doctrine of sound sensations. Contact with the physiologists Ernst Brücke and Carl Ludwig aroused Mach's interest in the physiology of sensation, and this encouraged him, as he later recalled, to carry out also epistemological investigations. The connections between physics, physiology, and psychophysics are one of the most characteristic features of Mach's "neutral monism". In this period as a *Privatdozent* he became acquainted with his lifelong friend, the writer, engineer, and social reformer Josef Popper-Lynkeus (1838–1921), with whom he shared the closest intellectual rapport (Belke 1978). Both of them supported the workers' movement and were active in the Vienna Fabian Society (Feuer 1974, 28). His early teaching work also led Mach to the

> opinion that the historical presentation of material was the simplest and the most understandable. Such general conceptual connections revealed the economic motives of cognitive theory and the conception of science as part of a general phenomenon of life and development, a view which finally rounded out his biological and economic epistemology. (Blackmore 1992, 24)

His orientation towards medicine and physiology inspired the talented experimental physicist to develop the theory of the pulse wave plotter, recording instruments, and, above all, numerous works about the sense of hearing, for which he received a small financial stipend from the Vienna Academy of Sciences in 1864. This led indirectly to the investigation of the auricular labyrinth, which was subsequently developed by Josef Breuer (Hirschmüller 1978; Swoboda 1988) – and led eventually to the achievements of the Nobel laureate Robert Bárány in (1914).

The year 1864 marked the beginning of Mach's scientific rise with his appointment to the Chair of Mathematics and, from 1866 to 1867, that of physics at the „somewhat neglected" University of Graz (Mach 1913, 415). There he lectured on differential and integral calculus, and also on analytical geometry. In Graz he became acquainted with the economist Emmanuel Hermann, who inspired his principle of economy; he also became accustomed to „describing the intellectual activity of the researcher as a commercial or economic one" (Heller 1964, 15; Haller 1988). The chair of experimental physics in Prague, to which Mach was appointed in 1867, was an ideal position for him, and he held the chair until his departure for Vienna in 1895. There Mach laid the foundation for his international reputation. Mach wrote in his own words: (cited after Blackmore (ed.) 1992, 25):

> I had thought out my epistemology early, but it ripened late; also, the order of presenting my lectures ripened slowly; the best manner of carrying out experiments, which I first had to learn myself, fell into place relatively quickly through working in common with the students, above all by means of acoustic investigations, which because of similarities to work carried out during my physiological period were more easily and readily learned. Many experiments conducted in this way were published under the auspices of the Vienna Academy, but most of them would appear under the names of my assistants.

As Dean of the Faculty of Philosophy in 1872/73 and Rector of the University of Prague in 1879–80, Mach got caught up in the emerging conflict of nationalities, which reached its peak (in 1882/83) with the division of the university into a German and a Czech University. Mach himself—an opponent of every kind of nationalism—objected in vain to this division, instead advocating the creation of a second Czech university (Heller 1964, 18 f.; Hoffmann 1991). In his first year in Prague he published a short report entitled „Über die Definition der Masse" (On the Definition of Mass), and among the most important publications from Mach's Prague period are *Optisch-akustische Empfindungen* (Optical-Acoustic Sensations) (1872) and *Grundlinien der Lehre von den Bewegungsempfindungen* (Outlines of the Doctrine of Sensations of Movement) (1875), as well as diverse stroboscopic investigations. At the same time Mach—due to an illness—resumed his historical-critical studies, which culminated in the publication of a programmatic study entitled *Die Geschichte und die Wurzel des Satzes der Erhaltung der Arbeit* (1872) (*The History and Root of the Principle of the Conservation of Energy*), in which he rejected any form of a metaphysical and one-sided mechanical conception of physics as well as the aprioristic, synthetic categories of absolute movement, absolute space, and absolute time as superfluous notions of substance. In these fundamental works the principle of thought economy was formulated and the groundwork laid for Mach's subsequent major works *Die Mechanik in ihrer Entwickelung historisch-kritisch dargestellt* (1883) (*The Science of Mechanics*) and *Die Prinzipien der Wärmelehre. Historisch-kritisch entwickelt* (1896) (*The Principles of the Theory of Heat: A Historical and Critical Treatment*). His *Mechanics* emphasized the historical analysis of knowledge as *the* method for understanding mechanics. By drawing on the works of Gustav R. Kirchhoff and Hermann Helmholtz, he elaborated his idea of *„the nature of science as one of an Economy of Thought*" (Mach 1888/1989, xxiii) which underlay his anti-essentialist methodology based on conception analysis and led to a fallibilistic epistemology (anticipating Karl Popper's falsificationalism) programmatically detailed in Mach's *Erkenntnis und Irrtum (Knowledge and Error)* (Mach 1989, 586 f.):

> The function of science, as we take it, is to replace experience. Thus, on the one hand, science must remain in the province of experience, but, on the other, must hasten beyond it, constantly expecting confirmation, constantly expecting the reverse. Where neither confirmation nor refutation is possible, science is not concerned. Science acts and acts only in the domain of uncompleted experience.

To promote these aims, Mach combined the criteria of scientific probity (Rechtschaffenheit), simplicity, and beauty with the principle of the economy of research. The historical-critical method as well as the biological-psychological model of explanation allowed Mach to describe mechanics from the „collected experiences of handicraft by an intellectual process of refinement" and produce the causal connection between history, the everyday world, and science in a longitudinal section (ibid., 485; also Thiele 1969; cited from 1989, 612). In his *Theory of Heat*, Mach explicated the basic concepts of temperature and heat capacity from a historical-genetic perspective and explained the principles of energy conservation and of entropy (Mach 1986). From as early as the 1870s he had been working sporadically on a history of optics, the publication of which he had repeatedly postponed, until he finally decided to have it published posthumously by his son Ludwig; it eventually appeared in 1921 with Ludwig's controversial preface against the theory of relativity. Ten years earlier his main work on epistemology, *Beiträge zur Analyse der Empfindungen* (1886; English 1959), had been published. It contained a critique of the Kantian "thing in itself" and the "unchanging ego" which was not only a rejection of the Christian dogma of personal immortality, but also allowed Mach to acknowledge an affinity to Buddhism.

On his basic concern in both his *Analysis of Sensations* and in his more mature *Knowledge and Error* (1905) Mach formulated the thesis that

> … the entire internal life of people breaks down into elements and that everything human beings experience or pass through represents the dependence of two groups of these elements, external experience, that is, the physical or perceptual life, and internal experience, that is, the psychical as conceptual life. The first kind of existence is no arbitrary creation of our fantasy as I believe that I have already sufficiently said. Therefore, there was no need for some physicists to have to misunderstand me, still less for certain philosophers to have helped guide them to that conception. I have also spoken about a monism of physical and psychical events. There are not two different worlds, and that is not what the issue is about. I am only concerned with examining the kind of dependence between the two. I am also required by this monism, however, to clarify the unity of human experience in light of the distinction between my ego and those of other people. (ibid., 416; cited from Blackmore (ed.), 1992, 26)

This pointed piece of self-presentation refers to psycho-physical monism, which has by now become classical, as well as a determined anti-idealism (with reference to Lenin, Planck, and others) and the natural, uniform notion of the world based on a pragmatist and an empiricist concept of knowledge (with reference to the criticism of his friend Wilhelm Jerusalem).

Mach explained the economic and biological theory of knowledge simply, and with typical modesty he also admitted the fundamental incompleteness of his theory as a basis for discussion, which he would present again in his *Popular-Scientific Lectures* (1895)/*Populärwissenschaftliche Vorlesungen* (1896)—a collection documenting the family resemblance with American pragmatism (from Peirce, James to Dewey).

In his *Analyse der Empfindungen* (1886) (*Analysis of Sensations*) Mach dealt with the central theme of a uniform, empirical foundation of science consisting of the integration of philosophy, physics, psychology (of sensation), and biology.

The anti-metaphysical doctrine of elements was elaborated under the influence of Berkeley and Hume and the psychophysics of Fechner and constituted his neutral monism (Mach 1918, VI; cited from Mach 1959, xl f.):

> The opinion, which is gradually coming to the front, that science ought to be confined to the compendious representation of the actual, necessarily involves as a consequence the elimination of all superfluous assumptions which cannot be controlled by experience, and, above all, of all assumptions that are metaphysical in Kant’s sense. If this point of view is kept firmly in mind in that wide field of investigation which includes the physical and the psychical, we obtain, as our first and most obvious step, the conception of the sensations as the common elements of all possible physical and psychical experiences, which merely consist in the different kinds of ways in which these elements are combined, or in their dependence of one another. A whole series of troublesome pseudo-problems at once disappears. The aim of this book is not to put forward any system of philosophy, or any comprehensive theory of the universe. It is only the consequences of this single step, to which any number of others may be attached, that are examined here. An attempt is made, not to solve all problems, but to reach an epistemological position which shall prepare the way for the co-operation of special departments of research, that are widely removed from one another, in the solution of important problems of detail.

Here, Mach’s antipathy to metaphysical system philosophy is documented once again and the fundamental incompleteness of the scientific world view once more emphasized.

In 1895 Mach was appointed to the chair of „philosophy, in particular the history and theory of the inductive sciences,“ which had been specially created for him at the University of Vienna (Mayerhöfer 1967, 12–25; Blackmore 1972, 145–63). This return to Vienna was made possible during the short period of a coalition of the ‘united left’ (the German Liberals, United Progress Party, and the German Conservatives and the cultural minister Madeyski-Poraj) and with the help of Theodor and Heinrich Gomperz at the university level, despite „the most vehement agitation from the clerical side“ (Mach to Meinong, in Kindinger 1965). However, Mach’s teaching and research in Vienna was greatly impaired in 1898, when the 61 year-old man suffered a stroke that severely paralyzed the right side of his body, although it left him in full possession of his mental faculties. In 1901, after several interruptions, he finally had to submit his application for retirement (Blackmore and Hentschel 1985, 29 f.).

Having been awarded the title of ‘Hofrat’ (a title awarded to long-standing, meritorious civil servants) in 1896, Mach was appointed as a life-long member of the upper chamber (Herrenhaus) of the Austrian parliament upon retirement, although—in accordance with his views—he did not accept the title of nobility such an appointment usually entailed. Despite his poor state of health he had himself taken to parliament in an ambulance in 1901 to vote on the nine-hour working day—a process he repeated for the vote on the universal franchise in 1907.

Mach resumed his attitude in his last major work, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung* (1905) (*Knowledge and Error*), in which he supplied a summary of his teaching and research activities in Vienna in particular, as well as of all of his previous work. Natural science was explained from a biological, psychological, and social point of view and the precedence of practical research over theoretical abstraction, (as dominat in philosophy following Mach) was emphasized. This rejection of metaphysical system philosophy alone allowed Mach to state that he was „not a philosopher, but only a scientist, " who "aimed not at introducing a new philosophy into science, but at removing an old and stale philosophy from science ... " (Mach 1917, VI, cited from Mach 1976, XXXII; Hiebert 1976).

Mach also provided a survey of the current state of research in psychophysics and the psychology of thought and perception. His treatment of the body-mind problem as a pseudo-problem and the hypothetical character of our knowledge points the way for the future of the Vienna Circle, when he concludes that "... the same mental functions, operating under the same rules, in one case led to knowledge and in another to error; from the latter, only repeated and exhaustive examination can protect us." (Mach 1917, 125; cited from Mach 1976, 90). This is obviously directed against a naive inductivism.

Together with the principles of empiricism and nominalism, of the economy of thought and enquiry, and, finally, with a concept of philosophy oriented towards critique of language, the intellectual basis for the development of logical empiricism was thus prepared.

After his early retirement, Mach was practically confined to his room in Gersthof in Vienna's 18th district, where he was still able to engage in intellectual work with the aid of a typewriter specially adapted to his disability, even though he was no longer conversant with the latest experimental research in physics. This was why Mach devoted himself primarily to historical and social or anthropological studies in the last years of his life. In his last small book *Kultur und Mechanik* (*Culture and Mechanics*) (1915) he reconstructed the development of mechanics and science since pre-historical times from a general socioeconomic perspective.

In May 1913 Mach moved to live with his eldest son Ludwig near Munich. He died amidst the turmoil of World War I on February 19, 1916, protected by his son. At the wish of the deceased, only the closest circle of friends and relatives were present at the cremation ceremony. This reminds us of the unity of life and work that Mach maintained until his death, about which he had stated generally but radically in the *Analysis of Sensations* (Mach 1900, 17, cited from Mach 1959, 24 f.):

> The ego must be given up. It is partly the perception of this fact, partly the fear of it, that has given rise to the many extravagances of pessimism and optimism, and to numerous religious, ascetic, and philosophical absurdities. In the long run we shall not be able to close our eyes to this simple truth, which is the immediate outcome of psychological analysis. We shall then no longer place so high a value upon the ego, which even during the individual life greatly changes, and which, in sleep or during absorption in some idea, just in our very happiest moments, may be partially or wholly absent. We shall then be willing to renounce individual immortality, and not place more value upon the subsidiary elements than upon the principal ones. In this way we shall arrive at a freer and more enlightened view of life, which will preclude the disregard of other egos and the over-estimation of our own

Now, let me turn to the complex and critical relation of Mach to philosophy:

1.2 Mach and Philosophy

Ernst Mach’s oeuvre continues to exert a remarkable interdisciplinary influence, covering philosophy, the natural sciences, and the social sciences, as well as on literature and art (Thiele 1963). From a chronological point of view his influence occurred in waves, from a geographical point of view it varied in intensity and it concentrated on specific subjects. In Austria-Hungary he was able to impress a large number of the representatives of the so called “scientific philosophy”—among them Wilhelm Jerusalem, Heinrich Gomperz, and Adolf Stöhr. For religious and political reasons the reception of Kant and Hegel in Austria was rather limited compared to that of the realistic and phenomenological traditions (Bolzano, Zimmermann, and the Brentano School).[1] Nevertheless, some exceptions served to prove these underlying trends: on the one hand, a distinct Kantian tradition in Austria right up until Robert Reininger, on the other hand an acceptance of Machian positivism in the German Empire by both researchers and philosophers in the natural sciences, for example Josef Petzoldt, Wilhelm Ostwald, Wilhelm Schuppe, Ernst Haeckel (the founder of the German Monist Society), and even some of the Neo-Kantians (Hans Vaihinger, Alois Riehl). And Mach himself – after his encounter with Kant’s *Prolegomena* – returned to Kant with the study of the German philosopher Eduard Beneke (1798–1854).[2]

Furthermore, his dealing with methodology between induction and deduction is an allusion to and variation of the famous response of Kant to Hume. But afterwards, in *The Science of Mechanics*, he rejected the absolute notions of space and time, again repeated in *Knowledge and Error* (1905). Most recently, from an epistemological point of view, there is a discussion, whether Mach can be also characterized in the frame of a realist empiricism (as an alternative to phenomenalism), as was proposed by Erik Banks in his book *The Realist Empiricism of Mach, James, and Russell. Neutral Monism Reconceived* (2014).

On the institutional level, there existed the “German Society for Positivist Philosophy”, the founding manifesto of which was signed in 1911 by Albert Einstein, David Hilbert, and Sigmund Freud among many other scholars like Wilhelm Jerusalem, Felix Klein, Wilhelm Schuppe.[3] In the Weimar Republic this scientific tradition continued in the Berlin Society for Empirical (Scientific) Philosophy, while in Austria during the First Republic Mach’s work was widely received in the Vienna Circle and in the Ernst Mach Society (Verein Ernst Mach), which—as the name suggests—was the Circle’s popular platform. These two related tendencies were nevertheless rather atypical, marginal traces of his reception in the Austrian and German philosophical landscape as a whole. Comparatively, Mach’s

[1] Topitsch 1949; Sauer 1982; Haller 1986.

[2] Siemsen 2015.

[3] Lübbe 1963; Blackmore 1972, 190 ff.; Holton 1993.

acceptance in the academic field was far smaller than it was in Vienna's cultural movement. (Glaser 1981).

Whereas almost all members of the Vienna Circle—as well as Boltzmann, Einstein, Russell, and Wittgenstein—drew on Mach to varying degrees (which by no means excluded taking a critical approach), it was the interdisciplinary concept of the anti-metaphysical scientific world view, above all, which was promoted in the Ernst Mach Society. Already the proto-Circle of the Vienna Circle before World War I, with Philipp Frank, Otto Neurath, and Hans Hahn, (and Richard von Mises in parallel) had begun to discuss with Mach the (un)scientific nature of philosophy, the possibility of a synthesis of empiricism and conventionalism, in particular, to bring together Mach with Duhem, Poincaré, Brentano, Meinong, Husserl, Helmholtz, and Freud.[4] Later the critique of the older positivism in all its different variations was continued by Rudolf Carnap, Karl Menger, Moritz Schlick, Herbert Feigl, Bela Juhos, and Viktor Kraft, and, above all, by Philipp Frank and Richard von Mises. In contrast, Karl Popper's *Logic of Scientific Discovery* (*Logik der Forschung* (1934)) develops an objectivism and realism which corresponded rather to Lenin's anti-Machian concerns. In his intellectual biography, Popper presented himself as continuing the Boltzmann-Einstein tradition in a way which precluded any positive reception of Mach and even led him to become the self-appointed destroyer of "logical positivism" (Müller et al. 1986).

But let's go to single members of the Vienna Circle of Logical Empiricism in more detail:

> By incorporating quantum theory and relativity theory, the physicist Philipp Frank was able to conceive of Mach's methodology as a keystone of logical empiricism, supplementing it with formal logic and axiomatics (Frank 1949b). With these instruments French conventionalism was modernized and developed together with the Machian empiricism into the scientific philosophy (Logical Empiricism) of the Vienna Circle. Thus a methodological holism, propagated by Duhem and Neurath, was present even before World War I, and would later be rediscovered by Quine (Haller 1982).

Otto Neurath advocated a coherentist standpoint and investigated the holistic and sociological dynamics of theories, which later led to the decisive criteria of empirical unified science, the 'encyclopedia.' His two letters to Mach dating from 1914 illustrate Mach's significance for relativity theory and his influence on Neurath's own work, whether in the history of science, the theory of value, or the theory of political economy (Thiele 1978, 99–101). The great esteem that Mach enjoyed could not be diminished by the fact that his skepticism towards atomic theory and his preference of the physiology of sensation as a foundation for physics were criticized later on in the Vienna Circle's manifesto. Neurath shared Mach's reservations towards an overemphasis on formalization and meta-theoretical orientation in empirical science.

The mathematician Hans Hahn was most responsible for the adoption of formal logic (and Wittgenstein's *Tractatus*) by the Vienna Circle, at the same

[4] Frank 1949a; Haller 1986a.

time vehemently advocating Mach’s anti-metaphysical principle of economy—in the form of Occam’s razor (Hahn 1930). The mathematician and logician Karl Menger discussed the possibility of a positivist geometry and the productivity of the mathematical concept of function in its application to science and provided the sixth English edition of Mach’s *Mechanics* with a historico-critical introduction, in which he pointed out the topicality of Mach’s history and theory of science (Menger 1979, 107–25; 1960, V–XXI).

The most effective, systematic reworking of these innovations in the theory of science and epistemology was undoubtedly supplied by Rudolf Carnap in his two books *Der logische Aufbau der Welt* (1928) and *Scheinprobleme der Philosophie. Das Fremdpsychische und der Realismusstreit* (1928) (*The Logical Structure of the World. Pseudoproblems of Philosophy* (1967a)). These central writings from the early Vienna Circle represent an attempt to create a hierarchical system of the constitution of scientific concepts on an empirical basis, namely proceeding by means of a phenomenalist language from the Machian ‘elements’ as building blocks with the aid of type theory. Its basic concepts were defined by the logical relationship between such elements (Carnap 1963, 1979, XI). However, in the 1930s a physicalist language was instead proposed by Carnap and Neurath to serve as the medium of a unified science—a development which cannot be discussed further here (Uebel 1992).

Moritz Schlick, a trained physicist, dealt with Mach in his first major work *Allgemeine Erkenntnislehre* (1918) (*General Theory of Knowledge* (1974)), in which he criticized “immanent positivism” from the point of view of his critical realism. After 1922, however, he changed his position, mainly as a result of the influence of Ludwig Wittgenstein, to that of an, to use his own terminology, „consistent empiricism.“ (konsequenter Empirismus). Einstein, among others, was skeptical of this “linguistic change” in their correspondence on the matter (Hentschel 1986).

Nor was Schlick’s reversal accepted by his pupil Herbert Feigl, who felt himself committed rather to a “critical realism”—following the same path as Kraft (Kraft 1912) and Karl Popper. Nevertheless, Feigl still considered Mach and Ostwald the idols of his youth, at least until he became enthusiastic about Boltzmann and Planck and their atomist views (Feigl 1981, 1969, 57–94).

This aspect only played a secondary role in the engineer and (applied) mathematician Richard von Mises’ view of Mach. He wrote overall surveys including *Ernst Mach und die empiristische Wissenschaftsauffassung* (*Ernst Mach and the Empirical View of Science*) (1938) and *Positivism. A Study in Human Understanding* (1968; *Kleines Lehrbuch des Positivismus* (1939)). In the former, von Mises provides a philosophical and historical excursus from Hume to Mach, whom he describes as „the most influential and, for our time, the most characteristic enlightenment philosopher of recent generations“ (von Mises 1963–64, 499). In his remarks in *Positivism*, von Mises described himself as a student of Mach, although he took a critical view of the problem of language (ibid., 524–29).

The philosopher, sociologist and historian of science Edgar Zilsel (1891–1944) played a special role within and outside the Schlick-circle, but also with strong references to Mach.

We can complete this short overview of Mach's influence in philosophy (of science) with his long-standing friend as well as his intellectual counterpart Josef Popper-Lynkeus (1838–1921). He was an engineer, writer, philosopher, and social reformer, and became the subject of much controversy for the socio-liberal middle-class at the fin de siècle.[5]

In his posthumous published fragments he draws on his (language critical) theory of knowledge (1932–33, 301–24):

> If one says, 'The world appears to me like this', and not, 'The world is like this', that already contains a hypothesis. Philosophy must not go beyond what is experienced. 'The rest is silence.' Thereby setting limits to skepticism. 'Learning to tolerate incomplete world-views', is how Mach once explained it to me very fittingly. One could also put it like this: Shut up and go on–living.

This statement provides some biographical, historical, and theoretical plausibility to the joint mention of Mach and Popper-Lynkeus in the Vienna Circle's Manifesto. And perhaps it is no accident that the two friends' busts can be found together in the park of Vienna's City Hall and not in the hall of fame at the University of Vienna, where the absence of Ernst Mach and Moritz Schlick is somewhat astounding.

Finally, it is worth mentioning that Paul Feyerabend, one of the most vehement critics of critical rationalism and of the analytical philosophy, referred to Ernst Mach's historical-critical methodology in order to favor the pragmatic-historical against the abstract-theoretical tradition in the philosophy of science (Feyerabend 1978, 51–60, 1981). This perspective seems to be an original attempt to modernize Mach's theory of science as a critique of current ideas and to overcome classic antagonisms such as philosophy *and* science, positivism *and* realism, and idealism *and* materialism by means of a historicizing approach (Feyerabend 1978, 202):

> While Mach's criticism was part of a reform of science that combined criticism with new results the criticism of the positivists and of their anxious foes, the critical rationalists proceeded from some frozen ingredients of the sciences (or modifications thereof) that could no longer be reached by the process of research. Mach's criticism was dialectical and fruitful, the criticism of the philosophers was dogmatic and without fruit.

Based on this explanatory approach, several variations of 'positivism' would vanish as conceptually determined misunderstandings, like those which arose in the controversy between 'positivists' and 'realists', namely between Mach and Boltzmann, Mach and Planck, and Schlick and Planck (Stadler 1983).

However, Ernst Mach's influence extended far beyond the field of pure philosophy, especially affecting the critique of language and the literature of his time. This does not come as a surprise, perhaps, considering Mach's fondness for the aphorist Georg Christoph Lichtenberg. Unfortunately, precisely Mach's ideas on language seem to have been left out of the research to date.[6] In this respect the correspondence between Mach and the young journalist and linguistic philosopher Fritz Mauthner

[5]Popper-Lynkeus 1917; Neurath 1918; Frank 1918; Schlick 1926; R. von Mises 1918, 1931; Loewy 1932; Frei 1971; Belke 1978; Hellin and Plank 1979.

[6]As positive exceptions, see Diersch 1977; Wunberg (ed.) 1981.

provides a unique chronicle of Mach's non-academic reception, exemplified in Mauthner's principal work *Beiträge zu einer Kritik der Sprache* (Contributions to a Critique of Language) (1901), which presents an anti-metaphysical and nominalistic critique of language.[7]

Mach's influence in Austria extends at least as far as Ludwig Wittgenstein's *Tractatus logico-philosophicus* and is directly related to Mauthner's position—even if Wittgenstein intentionally maintains his distance towards from latter's psychological and historical method: *„All philosophy is critique of language. (Though not in Mauthner's sense)"* (*Tractatus* 4.0031). This topos shows the intellectual affinity with thinkers such as Karl Kraus and Adolf Loos—both of whom were also great admirers of Lichtenberg, and who worked on a complex of problems including ethics, language, and society in various areas (Janik and Toulmin 1973, 120–32). Last but not least, there is also Wittgenstein's study of Mach, which can be discerned in some fragments of the *Tractatus* and the *Philosophical Remarks*.[8] The impossibility of a general statement concerning the world as a whole, neutral monism on a physical basis, the instrumentalist understanding of language, the genesis of language as a consequence of following rules, and the idea of thought experiments all represent convergent themes.

There can be no doubt about the extent to which Ernst Mach, together with Ludwig Botzmann, has influenced the current generation of physicists[9]—a fact confirmed by the frequently over-emphasized notion of the gigantomachy between the two thinkers. The communication between "positivism" and "realism" ran through all camps both in Austria and abroad: from Einstein to the Vienna Circle, from Friedrich Adler to Max Planck, and to the Monists and the Peace Movement in the Viennese late-Enlightenment, prior to the formation of the Ernst Mach Society. It is found in the extensive correspondence between the leading scientists of the time, especially in connection with quantum theory, and it has continued to the present day, with the relationship between Mach and Boltzmann and their influence on Einstein still being the subject of contemporary research. What is undisputed is the skepticism with which Mach, as a result of his empirical epistemology, viewed an atomism that seeks to be anything more than a hypothetical model for interpreting "reality". Towards the end of his life, Mach's attitude towards relativity theory appears to have been an open one, as the authenticity of the preface to the *Optics* can be questioned (Wolters 1987). After 1900, as a result of their correspondence on this matter, there was a considerable rapprochement in the views of Boltzmann and Mach. The correspondence between them is evidence of an intensive and, in the last analysis, convergent discussion, although one that excluded atomism. It reflects the untenable view that Boltzmann's rivalry with Mach was one of the main reasons

[7] Weiler 1970; Kühn 1975; Mauthner 1986. Cf. the correspondence between Mauthner and Mach in Haller and Stadler (ed.) 1988, 229–43; Leinfellner and Schleichert (ed.) 1995.

[8] Blackmore 1972, 185; Hayek 1966, 42; Feyerabend 1955; Gargani 1980; Visser 1983.

[9] Cf. the corresponding texts in Cohen and Seeger (ed.) 1970. Also see Haller and Stadler (ed.) 1988; Hoffmann and Laitko (ed.) 1991; Blackmore (ed.) 1992; Blackmore (ed.) 1995.

for the former's suicide in Duino near Triest in 1906. Despite undeniable epistemological differences, they had a common basis with regard to anti-metaphysical philosophy, Darwinism, and conventionalist methodology, against the background of an enlightened social-liberalism. Undeniable as well is Mach's significance as a precursor of relativity theory, as Albert Einstein himself testified, particularly in his criticism of Newton's classical mechanics, which inspired Einstein to "Mach's principle". It was not until the 1920s that Einstein distanced himself philosophically from Mach's 'positivism' and began to approach "realism" from the Planckian point of view (Feyerabend 1988). Many physicists, including the representatives of the "Copenhagen interpretation" of quantum theory, regarded Machian epistemology as an—ontologically neutral—methodical phenomenalism (just as Carnap and Schlick did) and placed much importance on the fruitfulness of his experimental physical and historical work, leaving any epistemological controversies to one side (Faye 1991). An additional psycho-social explanation of the fascination exerted by Mach upon a whole generation of physicists may lie in the cognitive and emotional identification of a group of young revolutionary scientists with Mach and Popper-Lynkeus as the destroyers of classical mechanics: in their eyes, there was an analogy between the social and the scientific revolution and between ethical and physical relativism (Feuer 1974, 42 ff.).

It seems, what Albert Einstein wrote in his obituary is still valid for the evaluation of Mach's work and influence today:

> The fact is that Mach through his historical and critical writings in which he followed the development of the individual sciences with so much love and traced historical details into the inner sanctum of the brain of path breaking scientists has had a great influence on our generation of natural scientists. I even believe that the people who consider themselves opponents of Mach, scarcely know how much of Mach's way of thinking they have absorbed, so to say, with their mother's milk. ... I at least know that I have been directly or indirectly aided by Hume and Mach. (cited. from Blackmore (ed.) 1992, 154 ff.)

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Chapter 2
The Specter of "Austrian Philosophy": Ernst Mach and a Modern Tradition of Post-Philosophy

Katherine Arens

Abstract This essay takes up "Austrian philosophy" as a tradition with broad implications outside narrower histories of philosophy in the Kantian tradition. This reading recovers a Kant focused on knowledge production and on critiques based on embodied, situated epistemologies and the agency embedded in them. This Kant was received in the pedagogies of two famous nineteenth-century textbook authors (the *Philosophische Propädeutik* [1852] by Robert von Zimmerman [1824–1898] and Ernst Mach's popular writings and physics textbooks). As educational propadeutics, they connect philosophy to epistemological critique, as practiced by philosophers from Bernard Bolzano (1781–1848) to Wittgenstein and the Vienna Circle within Austria, but also from the Wissenschaftsdebatte (Windelband and Rickert) to Dilthey and Cassirer. This tradition, culminating in French post-structuralism, requires that knowledge is seen as the product of community of knowing subjects rather than individual minds, given that it is produced by embodied group praxes (semiosis, social power, and communication).

The idea of an "Austrian philosophy" ghosts its way through the intellectual history of Europe, usually in reference to a very limited set of philosophical projects and significant players: Brentano, Mach, Wittgenstein, "Austrian Economics," the Vienna Circle, Carnap, or sometimes even referring to an era reaching from Bolzano to the Vienna Circle.[1] That term, however, reflects the Anglo-American-German canon of Idealist "continental" philosophies that prefers to see Kant as an idealist and Hegel as the source of historicist thought. The very idea of "Austrian philosophy," I contend as my point of departure, has been used to perpetuate a misreading of

[1] A classic account of the supposed tradition is Barry Smith, *Austrian Philosophy: The Legacy of Franz Brentano*. La Salle and Chicago: Open Court, 1994. At this point, I would also like to thank Professors Markus Weidler and Carlos Amador for comments on an earlier draft of this essay.

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nineteenth-century philosophical thought that obscures a second legacy of Kant that is represented in many of these "Austrian" philosophers, but which actually encompasses a set of philosophical projects with far broader implications than the Anglo-American-German accounts of "continental philosophy" or Europe's national philosophical identities admit.[2] In fact, by every measure (professorial appointments, projects, teacher-student relations), the map of philosophy in Central Europe was much broader that is remembered today by those who outline the mainstream of what more often appears in standard accounts of "German" philosophy.[3]

To illuminate one aspect of what is occluded in isolating from each other "German" and "Austrian" traditions of philosophy, this essay takes up the question of knowledge production as modeled in a tradition of Kantianism focused on embodied and situated epistemologies and the agency embedded in them. This alternate tradition, I argue here, understands this Kantian legacy as creating a kind of post-philosophy, a critical discipline redefining the disciplinary practices of post-Kantian philosophy. Tracing what is at stake in this evolution of philosophy (as central to a tradition labeled "Austrian") requires a fundamental return to the roots of very idea of philosophy as a discipline or set of sub-disciplines.

My goal is to offer a definition of what might be that *je ne sais quoi* of "Austrian" philosophy (albeit by no means *only* Austrian philosophy). To do so, I will first return to Kant himself in order to reread the structure of his model as an epistemological critique considerably less idealist than is normally done. This alternate Kant defines critique, and hence epistemology, as the central act in philosophical work and as his *Copernican revolution* that sets not just human mind, but the situated, embodied human being as central to it.

After that, I move to one of the projects growing out of this Kantian revolution: a project of education located outside nineteenth-century university neo-Kantianisms. Here, I sketch one prominent educational philosophy associated with early receptions of Kant, Herbartianism, which was in fact the official pedagogy of the Austrian and Austo-Hungarian Empires, and to one of the most famous textbooks in use in that context: the *Philosophische Propädeutik* (1852 and later editions) by Robert von Zimmerman (1824–1898). Finally, I will set Ernst Mach's popular writings and his great physics textbooks into the context of such educational propadeutics.

In joining Kantianisms to such practical projects of education, I argue for a Kantianism outside university philosophy that rejects any division between "German" and "Austrian" philosophy from each other. What emerges is a redefinition of a discipline embracing a progressive, social-critical and epistemologically critical

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[2]That occlusion was enabled in no small part by theoretical moves like Hans Reichenbach's now classic distinction (1938) between the contexts of discovery and justification; see Hans Reichenbach, *The Rise of Scientific Philosophy*. Berkeley: U of California P 1951.

[3]Martin Kusch. *Psychologism: A Case Study in the Sociology of Philosophical Knowledge*. New York: Routledge 1995, addresses this historiographic problem in chapter two, "Philosophical versus Nonphilosophical Histories of Philosophy," pp. 21–23. Sebastian Luft, *The Space of Culture: Towards a Neo-Kantian Philosophy of Culture (Cohen, Natorp, and Cassirer).* Oxford: Oxford UP 2015, also expands the canon.

Kantianism outside "idealism" that links directly into the more encompassing twentieth-century models of philosophical critique, including post-structuralism, that link ontology and logic to semiosis and social power.

2.1 Kant's *Begriffe*: The Act of Grasping as Localized, Embodied Knowledge Production

My project begins with a rereading of Kant's *Critiques* that takes them not just as expositions of a model, but as specifically rhetorical in nature – as specific attempts to redefine philosophy but also to communicate his acts of redefinition within inherited, more traditional categories of knowledge.[4] Eighteenth-century European philosophical thought still cast its models in terms deriving from Aristotle's transcendentals and their various reworkings in both religion and art, requiring address to the *one*, the *good,* the *true*, and the *beautiful* in reference to *being* and *beings* in various combinations.

The dominant description of Kant's project is familiar, if not hackneyed. In it, Kant's three critiques are seen as taking up these divisions, while fundamentally shifting the ground on which they worked. These volumes discuss *the true, the good, and the beautiful* not as properties of creation itself, since ontology is a speculative discipline, because it rests on data beyond the scope of human experience, but as descriptions of the dominant modalities in which human mind interacts with empirical experience to create knowledge. The three volumes thus interlink. The first *Critique* is read as discussing not only the potential of individual mind for structuring knowledge, but ultimately how mind functions within a broader set of human rationales and potentials, creating larger heuristic formalisms (specific disciplines, speculation, etc.) through reason. In it, Kant models the mind's ability to process sense data into coherent knowledge by the pattern-making acts of the understanding, and its subsequent evolution of knowledge through reason. The second and third *Critiques* move beyond the modality of logical judgment into ethical/moral reasoning, and finally aesthetically (implying "through the body," as A. G. Baumgarten's 1750 *Aesthetica* would have it, not just "beautifully").

I suggest, however, that Kant chose his order of presentation to conform to his era's conventions and expectations, wherein human mind was long considered the pinnacle of material creation. But we must be careful about what we are assuming. Such considerations of *intelligibility* (in rhetorical terms) need not imply *priority* (in logical ones): the *first* volume in a set may be "first" only in terms of rhetorical

[4]My approach thus differs from that of Willi Goetschel, *Constituting Critique: Kant's Writing as Critical Praxis*. Trans. Eric J. Schwab. Durham, NC: Duke UP 1994. Goetschel sets Kant at the start of the later tradition of Romantic writing experiments, as an author seeking a new form for his ideas. In contrast, I am assuming that Kant is explicitly using familiar textual and argument form to ease his readers' transitions into radically new ideas.

logic, not in terms of the hierarchy of the model it sketches. Kant had to take up the question of knowledge production and human rationality as defined since Descartes and Leibnitz, Hume and Locke: the legacy arguments about how knowledge is produced (either within the mind as direct revelation – through meditation, for example–, or as summoned forth within the mind by direct human experience of material revelation – "reading" the book of nature, for instance.

But putting these models into play against the rhetorical requirements of presentation that Kant faced can bring us to a different reading: to Kant's vaunted Copernican Revolution, the shift of the universe of understanding as he knew it. Moving beyond the obvious limitations of speculative, abstract accounts like Descartes' and Leibnitz' (which speak from the space of divine creation that we cannot know), I believe that Kant has found a way beyond them in seeking and finding a third way between Hume's fact /value distinction (which divides morality from other forms of knowledge, the *is* from the *ought*) and Locke's theories of natural rights.

The Kantian-Copernican turn I posit here starts by recognizing that both Hume and Locke offered philosophies more materialist than Descartes or Leibnitz, but that both models posit the *one* of creation as grounding inalienable rights or the consistency of the "naturally" given. If not calling this into question directly (and any number of his early commentators were indeed accused of atheism), Kant at least inserts greater distance between that creation, its status as *one*, and how it is known. With his description of the understanding, Kant points us at the very nature and status of "material data."

He does so by stressing that facts are actually *factum – made* entities–, not *ens* or *res* with the status of creation (unless *res* is taken to mean state of affairs).[5] In this sense, too, value and morality are always already *inherent* in facts because facts are *made*, not discovered or revealed. Kant's account of knowledge production does indeed trace how *data* depends on material experience, but that it is *not stable or self-identical,* nor part of revelation, but rather a product of mental processing. Similarly, the information or use value of such facts happens only in use, as a consensus that is neither arbitrary nor historically relative, but rather anchored within a shared *frame of reference* – a community's shared use of the narrative made from that data. There is, by implication, never only *one* understanding of facts, because they are *made* and *remade* always already implicating a point of view and shifts in them. Facts thus come into being as does the narrative which support them as useful, valuable – a conversation, a group understanding that can profitably equated with a *frame of reference which comprises the fundamental patterns that yield truths, those value structures held in place by belief systems, and the body of habits and traditions that condition how material evidence is grasped.*

[5] Barbara J. Shapiro, *A Culture of Fact: England, 1550–1720* (Ithaca, NY: Cornell UP 2000), argues that the English legal system established this norm of constructed truth as part of the emergence of a jury system; I believe it is echoed in Kant's own recommendations from *Was ist Aufklärung?*, in his differentiation between public and private uses of reason.

In this sense, Kant's three *Critiques* work though the *lives of* and *uses for* knowledge production, not knowledge's ontologies. The *Critiques*, in their structure, outline the basic interests inherent in what emerge as three basic modalities of understanding, each implicated in both a common frame and (as a specialized strategy of knowledge) its own frame of reference: respectively, the conditions for the possibility of generating knowledge used within frames of reference, and for critiquing that knowledge in terms of the logical character, the ethical/moral one, and/or the aesthetic/embodied one, based on experience (of the material) that are embedded in it at the sites where it is used. In Kant's era, as in our ouwn, sciences (as any systematic disciplines) are most often built in the logical mode; social and political systems, in the moral; religions, fictions, traditions, habits, and speculations, in the aesthetic (based on verisimilitude of experience).

Thus the first *Critique* actually models two *different* origins for knowledge, stemming from two projects of very different sorts. In the first, he describes how the concept comes into being, emerging into the world of signification as an element created by the understanding, material experience (thus echoing Herder). In this first account, the act of concept formation implicates all other acts producing knowledge, both in mind and through the body's acquisition of sense data as *sensible*; because all signification is also influenced by inheritance, those products of individual mind are anchored into collective memory and group communication, as well. Kant's account of the unity of the manifold of apperception, then, and his differentiation between perception and apperception as together leading to grasping (to the work of the understanding) thus actually should have been its own book. Alternately, it needs to be seen as a prolegomena (as Kant himself used the term).

This reading of Kant contains within it the seeds of an alternate reception of Kant, one that attends more closely to this a dual production of knowledge, much like Herder's two-fold origin of language (once in signification, once in communication). That reception starts from Kant's account of the *Begriff* as what becomes known in the nineteenth century as a psycho-physical act (an act *shaping* both mind and knowledge production) that grounds any use of reason in the big three modalities. This reading of Kant's "Copernican Revolution" also suggests that Kant does not simply correct the valuable but too-simple distinctions between mind and experience posited by Locke and Hume, but rather actually re-situates the production of knowledge as a dynamic interplay between (organized) fields of data and frames of reference, sponsored by the body and supported by the body and memory. In turn, this implies that the sensual manifold is not only unified in the act of perceiving/experiencing in the realm of the understanding, it is also *pre-ordered* as it is subjected to the act of grasping through the senses. When "sense data" becomes the data for cognition (and for further operations in the realm of reason), then, it already has a life of its own within what we term a frame of reference, but Kant sees as the field of action of the understanding, which pre-structures sense data not only in a formal-ontologically recovery of the sense of creation, but as part of a set of motilities that are stabilized by the understanding and ordered within the frame of reference.

When a specialized frame of reference emerges as a kind of "neighborhood" within the general frame of reference, a specialized praxis emerges. For the present purposes, we will pursue one kind of specialized frame: a discipline. With this specification, we return to Kant, and especially his *Conflict of the Faculties* (1798),[6] which notes the role of ongoing philosophical critique to prevent disciplines from ossifying. In that late essay, Kant pursues conflicts between disciplines' frames. Yet in this first *Critique*, Kant has already established the necessity of such critique, not only of the reason's products, but also of understandings, because of their motility: because of how concepts are formed, they impose their own force within frames of reference. Each field of data, in the form of *designations* for concepts, pre-orders further acts of sorting and designation (acts of understanding and acts of reason alike). The very act of what today we call semiosis (a combined act of demarcation and signification, a conjoint material and cognitive process) only has meaning within the constraints of a frame of reference and thus within a discipline and at a particular site, as anchored in custom (inheritance), usage, and habits.

This is Kant's true Copernican Revolution: making *all* logics (logos, moral, or aesthetic) contingent upon semiosis (not just demarcation) and thus also implicating forms of praxis as intentional structures inherent in the formalisms shared within communities. He goes further than simply requiring mind, the *logos*, to be triggered by sense data and experience. Instead, he here anticipates how Wilhelm von Humboldt describes language as both an *ergon* and an *energeia*, as a kind of knowledge that both is produced by and produces or reshapes mind.[7] With this move, then, Kant sets up not a solipsistic model of mind, but one that operates in a communitarian paradigm that insists that knowledge *is* not a thing, but that it *does* things within certain frames of understanding that exist only within communities (expert or otherwise). Knowledge is thus no closer to *logos* than it is to *praxis*. To critique knowledge, either at the level of concept production or all the way through disciplines, requires factoring in the conditions of its production, including knowing patterns of historical inheritance and weight of the signifiers for the concepts passed on, as well as accounting for what it does and is seen to do within the community. What is seen as the data of knowledge (*qua* signifiers) are also materialities with their own autopoesis – they have innate directions of drift, a kind of intentionality of the material, as well as a use or purpose (an ethic or morality of its praxis), and a logic.

Such a reading of Kant's project may seem to be overly modern to those used to seeing him over the accounts canonized since university NeoKantianisms of the latter nineteenth century. Yet as my allusions to Herder and Humboldt might already have suggested, this reading of the dual origin of knowledge (once in experience,

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[6] Immanuel Kant, *The Conflict of the Faculties (Der Streit der Fakultäten)*. Trans. Mary J. Gregor. Lincoln: U of Nebraska P 1992.

[7] See Wilhelm von Humboldt, *On Language: On the Diversity of Human Language Construction and its Influence on the Mental Development of the Human Species*. Ed. Michael Losonsky; trans. Peter Heath. Cambridge: Cambridge UP 1999. *Ergon* and *energeia* are defined in §8, p. 49.

once in community/disciplinarity and communication) seems to have been widely available both outside of and within German university philosophy in the nineteenth century. However, it took its firmest root in debates about the epistemologies of scientific disciplines rather than in philosophy proper (e.g. the evolving of the hermeneutics of specific disciplines, or the “Science Debate” associated with Wilhlem Windelband and Heinrich Rickert, or with the work of Gaston Bachelard almost a century later).

Thus the tradition posits a Kant who grounds the twentieth-century “post-structural” project (a term rejected by Michel Foucault), which is the true inheritor of the kind of critique I identify as central to Kant’s Copernican revolution. I propose that what Kant did was *reorder* the space for science and epistemology – with *order* being used in the poststructuralist sense. An *order* creates the conditions of the possibility for the emergence of structures of meaning; it is situated in a time and place without necessarily being overtly present, because it is a pre-structuring of a cognitive, experiential, or semantic field that will contribute to any understanding or reason built upon it – the force of the dynamic underlying the acts of the understanding or reason.[8]

Kant’s work not only re-ordered epistemology and ontology on the level of disciplinary priority, but most importantly, he moved *semiosis*, the act of grasping and signifying concepts, into the center of the knowledge project, moving beyond his era’s preferences of taking either creation/empiricism or mind/logocentrism as ground for the production of knowledge. Kant instead made an act central, with mind and materia-as-experienced as absolutely interdependent, equal, and mutually influencing participants in that act. On the one hand, he has redefined mind as the primary *site* for knowledge making (because of the ability to remember and make information present), but removed the existence of any permanent archive of knowledge. On the other hand, the material-grasped-as-concepts has an autopoetic force, as do any other semiotic systems – that force is a direction, a use, or even an ethic. Finally, any act of semiosis is embodied: the mind does not exist without the body, which retains some knowledge through habit and gains some through acculturation, which shapes (pre-orders) experience.

The Kant sketched here, I believe, is the Kant of all three *Critiques* together, redefining his epistemology as a critical discipline, aimed at analyzing the conditions for the possibility of knowledge production within indivisible but discrete frames of reference. Summing all three *Critiques* means that *all* knowledge production will proceed in light of not only logics, but also of morals (utilitarian and otherwise, in terms of values [vectors] and scalars), and the physical record

[8]Foucault’s work *Discipline and Punish: The Birth of the Prison* (trans. Alan Sheridan. New York: Vintage/Random House 1977), for instance, exemplifies how he uses the notion of the *order* to speak of a different biopolitical management of criminality (see also *The Order of Things: An Archaeology of the Human Sciences*. New York: Pantheon Books/ Random House 1971).

(aesthetics as defined by Baumgarten, the act of judging through the body).[9] But most critically, it acknowledges a two-fold origin for knowledge – once in the senses interacting with a mind and its body site to make *Begriffe*, concepts and their signification, and then within the action of the frame as defined by its autopoesis, intentionality, material drift, and inherited ordering. In a more radical description of Kant's achievement, what Kant has done is demount philosophy to create a post-philosophy that is a non-philosophy: a "discipline" that is actually a critique of other disciplines that seeks to delimit their strategies and intentionalities for producing knowledge, offering a unified account of knowledge production.

As the nineteenth century took up this project, this two-fold origin of knowledge production will ground separate projects, one a critique of scientific disciplines as specialized frames of reference, and other an investigation of the epistemological claims of group psychology. Neither is similar to the phenomenalism or phenomenology espoused by Heidegger, nor to the strands of Neo-Kantianism that accommodate pure idealism or Hegelianism; both found resonance in the emerging natural and social sciences of the latter nineteenth century. And both help us to understand the project that Mach engaged in as part of a tradition of critical epistemology and semiotic critique that has been mislabeled as "Austrian" philosophy.

2.2 Defining Disciplines Within an "Austrian" Tradition: Kantianism as Pedagogy

This account of Kant's project implicates not only concept formation, but also semiosis and signification, and in this way it leads us closer to the existing tropes defining "Austrian" philosophy, despite a significant historical fact: the official rejection of Kant's work in Austria for a time (Smith 349). Remember that the Kantianism traced here features a notion of critique and the situatedness of knowledge, which are assumptions can as easily ground a pedagogical project as it can an epistemological critique. And in fact, a version of this Kantianism introduced a new vision of what it means to teach and learn into germanophone Europe and beyond – a Kant practiced by scientists and psychologists instead of university Neo-Kantians.

As we shall trace in this section, that practical pedagogical project was deeply intertwined with the bureaucratic institutions of imperial-royal Austria-Hungary, concerned as it was with the improvement of what today we would call human capital, especially the bureaucrats who were defined as national assets, a special class of knowledge workers who ran the state. To cultivate this human capital, the

[9]Gilles Deleuze's *Kant's Critical Philosophy: The Doctrine of the Faculties* (trans. Hugh Tomlinson and Barbara Habberjam. Minneapolis: U of Minnesota Press 1985) starts from the premise that in fact the *Critique of Judgment* is the key to the other two, linked critiques.

Empire was relatively early in building up a comprehensive school system. The nineteenth century saw both a national curriculum and standard textbooks put into place, to implement this Austrian project of education. Ernst Mach's own textbooks were written for this framework, and they reflect the era's overriding concern for teaching individuals both how to produce knowledge but also to critique the frameworks and acts that produced that knowledge.

The Empire's planning was extensive, as its schools took up a pedagogical model based on a critique of knowledge and on the assumption of the plasticity of mind – a pedagogical model that evolved in the half-century after Kant's work, and that tried to transform what it meant to teach the minds that he described. What became the official pedagogy of the Empire was Herbartianism,[10] named after Johann Friedrich Herbart (1776–1841), who is remembered today as a philosopher and psychologist and as the founder of pedagogy as an academic discipline. He knew the work of Pestalozzi, the Swiss school reformer, but made his mark after 1809, when he assumed the university chair at Königsberg that was formerly held by Kant (with whom he had some fundamental disagreements); there, he ran a program in pedagogy until 1833. His pedagogy, however, always remained intertwined with philosophy: in educational contexts, he models how knowledge production begins with reflection on empirical concepts and then is elaborated, to make ideas more clear and distinct. Most critically, because he adapts Kant's notion of frames (for him, they are logic, metaphysics, and aesthetics), he also posits that "the real" is actually always plural, with each frame interconnected with others. This philosophical point of departure was elaborated into a pedagogy that stressed the multiplicity of knowledge based on empirical evidence and the need to explore multiple frames.

Herbartianism was massively influential in the West, even being taken up in the US, especially around and after the First World War[11] (and critiqued by Dewey in this incarnation, despite its relation to what became Montessori education). Within Austria-Hungary, Herbartianism was part of the framework used to think about curricula, because it assumed that human mind could be influenced, if not transformed, by education. In the second half of the nineteenth century, any number of Austrian intellectuals point to one official textbook in particular as a source for their interest in the critique of disciplinary knowledge: The *Philosophische Propädeutik* (1852 ff.)[12] by Robert von Zimmerman, a student of Bernard Bolzano and Franz

[10]Georg Jäger, "Die Herbartianische Ästhetik – ein österreichischer Weg in die Moderne", in: Herbert Zeman (Ed.), *Die Österreichische Literatur: Ihr Profil im 19. Jahrhundert (1830–1880)*. Graz: Akadmische Druck- u. Verlagsanstalt 1982, pp. 195–219.

[11]Jane E. Pollock, *Improving Student Learning One Teacher at a Time* (Alexandria, VA: Association for Supervision and Curriculum Development, 2007), pp. 61–62, who notes that Herbartian lesson plans are still being used. The standard introduction to Herbart in the Anglophone world is Harold B. Dunkel, *Herbart and Herbartianism: An Educational Ghost Story*. Chicago: U of Chicago P 1970.

[12]Robert Zimmermann, *Philosophische Propädeutik*. 2., umgearbeitete und sehr vermehrte Auflage. Wien: Wilhelm Braumüller 1860.

Exner who received his chair at Vienna in the same year Mach received his. This is the textbook that inculcated the *how to* of the critical epistemological tradition being presented here to three generations of the Austrian intelligentsia, one that operationalized Herbartianism in the service of general analysis.[13] Unfortunately, this textbook for the Empire's secondary schools is oft cited but has been little explored by scholars.[14] To judge its actual impact is somewhat difficult because the editions differed rather significantly in organization. Nonetheless, its strategy is indicative in the context of a tradition of epistemological critique.

Propädeutik means *Vorbildung* or preparatory knowledge (from the Greek πρo *pró* – "pro" – and παιδεύω *paideuō* – "bilden/to form"). The term was in use in the germanophone nineteenth century to refer to core courses at the *Gymnasium* (secondary school) and university, as "preparatory courses" for the real work of the scientific disciplines at later stages of curricula leading to disciplinary specialization. These courses seem to have been conceived as introductions to basic literacies of later education: the study of the conditions of possibility for the evolution of a discipline's systematic knowledge, for its specialized approach to knowledge creation. The goal of such courses is, loosely speaking, Herbartian: to inculcate and critique the ways of working and thinking inherent in and distinctive to each science. In the Austro-Hungarian context, this critique included what is called "moral education" in the literature today, but which is better described, using Kant's terminology, as the ability to make moral judgments – to evaluate socially and ethically, not just logically. In this joint approach to education, epistemology and psychology are brought together in a dynamic relationship:

"At its foundation, then, the entire *Propadeutic* is a study of the mind, because [the object of this study] is the mind and the forms in which it appears. However, its first part stresses the *psychic* side of psychology, the latter, its logical side; the first treats thoughts exclusively as acts of mind, the second, as an attempt to grasp truth. Thus the first part, which describes to us the tools [used], must precede the second, which teaches how to use them."[15]

I take this description of knowledge production as defining the "Austrian tradition of philosophical critique of knowledge production" (not an "Austrian philosophy"), because it draws attention to how knowledge (including disciplinary knowledge)

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[13] Note, too, that this strategy of critique closely resembles Gaston Bachelard, *The Formation of the Scientific Mind: A Contribution to a Psychoanalyis of Objective Knowledge*, trans. Mary Mcallester Jones. Manchester: Clinamen Press 2002.

[14] Zimmermann is known principally from Eduard Winter (Ed.), *Robert Zimmermanns Philosophische Propädeutik und die Vorlagen aus der Wissenschaftslehre Bernard Bolzanos*. Wien: Verlag der Österreichischen Akademie der Wissenschaften 1975. This reprint, however, only includes the second volume of Zimmermann's work and considers it derivative, no matter that Bolzano turned the textbook project over to Zimmermann.

[15] "Im Grunde ist daher zwar die ganze Propädeutik Seelenlehre, den ihr Gegenstand ist die Seele und ihre Erscheinungen; doch hebt ihr erster Theil die *psychische*, der letztere die *logische* Seite der Psychologie hervor; behandelt der erste die Gedanken ausschleisslich als Seelenacte, der zweite als Versuche die Wahrheit zu erfassen Der erste, der uns das Werkzeug beschreibt, muss dem zweiten, der den Gebrauch desselben lehrt, daher vorangehen." (Zimmermann, loc. cit., p. 6)

is produced (the cultural side of knowledge production) and to the effects of the conditions of its production on its status as truth (the cultural side of this production, based on culturally available logics).

In a real sense, modeling the production of knowledge as both a cognitive and cultural act can be seen as an evolution of classical hermeneutics that attends much more strictly to process as well as product. This is not a hermeneutic of suspicion, as the modern term would have it, nor is it the "linguistic turn" that is often assumed to be the heart of "Austrian Philosophy," unless one means that in Wilhelm von Humboldt's sense, as noted above. Zimmerman's *Propädeutik*, like Kant's work, reminds us that the objects of understanding have also themselves been created by prior acts of understanding, using evidence gathered perceptually-physiologically, but then processed into knowledge *within a specific frame of reference, situated culturally-historically*.

This emphasis on the situatedness of understanding is also reflected in how Zimmermann defines a philosopher: "not just a person learned in theory, but also a person of practical wisdom, that is, a man who does not only know what he is supposed to do, but one who also does it."[16] Even more significantly, he points out that "Philosophie" is a particular system of beliefs belonging to an individual, while *philosophiren* is the act of reflecting on things – and that *Philosoph*, *Philosophie*, and *philosophieren* are actually mutually defining moments within one set of socially defined disciplinary acts. This conclusion not only anticipates Deleuze's idea of philosophy as a discourse sponsoring a "conceptual persona"[17] as the subject controlling its knowledge production, but also reflects back on Kant's idea from *Conflict of Faculties* that philosophy cannot be taught, only the act of philosophizing.

Zimmermann's description of epistemological critique, I believe, finds a close parallel in Ernst Mach, starting with his textbooks on different part of physics. Remember that *Erkenntnis und Irrtum/Knowledge and Error* starts with the statement that Mach is "neither a philosopher, nor wishes to be one."[18] In this sense, Mach's *œuvre* may be read as an extended project of applied epistemological critique, in which the textbooks exemplify both how a discipline (here: a part of physics) is built up and where the limits of its knowledge production lie. Each is staged as a propadeutics for the study of its science, starting with a situated critique of notation. In more Kantian terms, he models in each textbook the conditions for the possibility of responsible – "true" – production of knowledge within the disciplinary

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[16]"ein nicht blos theoretischer Gelehrter, sondern praktischer Weiser, d. i. ein Mann, der nicht blos weiss, was er thun soll, sondern es auch thut." (Zimmermann, loc.cit., p. 3)

[17]From Gilles Deleuze and Félix Guattari, *What Is Philosophy?* Trans. Hugh Tomlinson and Graham Burchell. New York: Columbia UP 1994.

[18]Ernst Mach, *Erkenntnis und Irrtum: Skizzen zur Psychologie der Forschung*. Ernst Mach Studienausgabe, Band 2. Eds. Elisabeth Nemeth and Friedrich Stadler. Berlin: XENOMOI Verlag 2011, p. 1; all translations by the present author.

frame of physics, as conditioned by historically situations. "Truth," however, as Julia Kristeva underscores, is a property of systems, not of reality.[19]

In turn, Mach's popular writings can be seen as propadeutics for science in general,[20] starting with his best-known work, the *Analyse der Empfindungen/Analysis of Sensation* (1911).[21] The famous first pages include a drawing of the point of view of an observer, looking out of his eye across his feet, with the view of the room framed by the eye ridge and nose. This drawing is a literal representation of the point of view of that observer; the text moves on to the famous example of the "bent" pencil in water, used to explain how such "illusions" result from a false naturalistic point of view that does not account for all the facts encompassed in the frame of reference—the index of refraction of water is different than that of air, and so those facts need to be factored into any systematic understanding of the data of observation.

Here, too, the reader is introduced into what may be Mach's most quoted dictum about the "I" as a "provisory fiction." Yet this statement by no means implies that Mach has "lost faith" in the idea of the subject or the language it uses to produce understandings, as much of the intellectual history of Austria chooses to read it. Instead, Mach's drawing shows how the observer is factored into the frame of reference, as would be done in the physics of the early twentieth century; it enacts the fundamental intertwining of *Philosoph* and *philosophieren*, as Zimmerman differentiated the two. Thus this book serves as the earliest stages in a propadeutic for empirical sciences, a basic *Lehre* about epistemological critique. Here, as in the textbooks, Mach builds up not only the concepts commonly used in various subdisciplines of the hard sciences, but also how each imposes particular, limiting conditions on the data it choses, constructs, and the employs in its theories.

Mach thus is teaching science as critique, first slowly walking the reader out of the "natural standpoint" (a pre-philosophical, pre-scientific approach to empirical data) and into the revelation of how our sense data has built into it particular cultural-social engagements and value structures. In this way, Mach teaches each science as a specialized heuristic for a particular kind of knowledge production, not as referring to truths of nature, and as sponsoring site-based analyses within specialized frames of reference. The *Analysis of Sensations* is thus by no means incidental to textbooks because it builds up the fundamental critique of scientific data from the psychophysical side – from the first moment of interactions between mind and body that generate concepts out of empirical experience within a frame of reference, and through the process of understanding the multiple frames of analysis available in it.

On the other chronological pole of his popular writing, near the end of his writing life, Mach's *Knowledge and Error/ Erkenntnis und Irrtum* (1905) amplifies

[19]For an argument of this point, see Julia Kristeva, "The True-Real," trans. Sean Hand, in: Toril Moi (Ed.), *The Kristeva Reader*. New York: Columbia UP, 1986, pp. 214–347.

[20]Familiarly, Ernst Mach expressed a degree of skepticism about Kant (*Erkenntnis und Irrtum*, loc cit., p. 2). Yet it is probable that this reaction applies to various NeoKantians, a difference beyond the scope of the present essay.

[21]Ernst Mach. *Die Analyse der Empfindungen und das Verhältnis des Physischen zum Psychischen.* Ernst Mach Studienausgabe, Band 1. Ed. Gereon Wolters. Berlin: XENOMOI Verlag 2008.

and reaffirms, now overtly, that he speaks as a practicing scientist rather than a philosopher, especially since, he notes, the philosophers have lost their ability to speak with authority about science:

> The natural scientist can be satisfied *in recognizing the researcher's conscious psychic activity as a methodologically clarified, sharpened, and refined variation of the instinctive activity of animals and humans – a variation practiced daily in the lives of nature and culture.*
>
> We dare not underestimate the work of schematizing and ordering achieved in methodological knowledge, if it is used in appropriate degrees of development of knowledge and in adequate fashion. But we must emphasize that *practice in research*, to the degree that it can be acquired, is much better facilitated in the use of a few *living examples* than it can be in faded, abstract formulae, which themselves again need to gain concrete, comprehensible content through examples.[22]

In Mach's opinion, the philosophers of his day have over-relied on Kant, which has led them to be generators of impossible abstracts, on *transcendentals*[23] rather than producers of knowledge based on concretes. Significantly, just as he includes a critique of an *a priorist* reading of Kant, he also includes a critique of Herbart, who, he explains, assumed the unity of the soul,[24] although he did explore "the movements of representations *an sich*."[25]

Nonetheless, he notes that his work is best called "psychology of cognition" (*Erkenntnispsychologie*) because it pays attention to cognition as it progresses.[26] Like Zimmerman, he also acknowledges that interactions between *thinking* and *thought* do take place: "The representation of facts in thought, or the adaptation of thoughts to facts makes it possible for thinking to supplement carefully facts that are only partially observed, to the degree that the supplement is determined by the observed part."[27] But here, he again mentions the subject of knowledge: he terms consciousness *Bewußtsein*) an "extended I,"[28] again emphasizing that it is constructed.

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[22]"Der Naturforscher kann zufrieden sein, *wenn er die bewusste psychiche Tätigkeit des Forschers als eine methodische geklärte, verschärfte und verfeinerte Abart der instinktiven Tätigkeit der Tiere und Menschen wiedererkennt, die im Natur- und Kulturleben täglich geübt wird.*

Die Arbeit der Schmatisierung und Ordnung der methodologischen Kenntnisse, wenn sie im geeigneten Entwicklungsstadium des Wissens und in zureichender Weise ausgeführt wird, dürfen wir nicht unterschätzen. Es ist aber zu betonen, dass die *Übung im Forschen*, sofern sie überhaupt erworben werden kann, viel mehr gefördert wird durch einzelne *lebendige Beispiele*, als durch abgeblasste *abstrakte Formeln*, welche doch wieder nur durch Beispiele konkreten, verständlichen Inhalt gewinnen." (Mach, *Erkenntnis*, loc. cit., pp. 1–2).

[23]Ibid, p. 3.

[24]"*Einfachheit der Seele*," ibid., p. 19.

[25]"das Getreibe der Vorstellungen *an sich*," ibid., p. 19.

[26]"wie Erkenntnis fortschreitet", Ibid., p. 4

[27]Die *Abbildung* der Tatsachen in Gedanken, oder die *Anpassung* der Gedanken an die Tatsachen, ermöglicht dem Denken, nur teilweise beobachtete Tatsachen gedanklich zu ergänzen, soweit die Ergänzung durch den beobachteten Teil bestimmt ist." Ibid., p. 10.

[28]"*erweitertes Ich*"; ibid., p. 17.

Mach also echoes Zimmermann as he pursues how each field of science is a special region of knowledge production growing out of such actions with facts: "Scientific thought comes to us in two seemingly quite different types: the thinking of the philosopher and the thinking of specialized researchers.[29] The former tries to produce "a world-encompassing orientation, as complete as possible, into the totality of facts," "the other then deals with orientation and overview within a smaller region of facts."[30]

Mach calls what philosophers produce "Philosophemes," basic elements of philosophy, thereby showing his adherence to a kind of linguistic critique of concepts, to the critique of technical designations that become epistemic obstacles: "Such philosophemes (elements of philosophy) have probably earned nothing better than to be removed [because they are] not only useless in the natural sciences but also produce damaging, lazy pseudo-problems."[31] As Mach proceeds to describe this process, follows Zimmerman's distinctions among philosophy/philosopher/philosophizing, but with more modern terminology. He will, most notably, add the ideas of *U* (*Umgrenzung*, framing or cirumscription) and the *Umgrenzung unseres Leibes* (our bodies as frames), the limits on the knowable within a frame of reference.[32]

Just as critically for considering Mach's writings consistent over various types of texts, this late text again uses his notion of *elements*, most familiar from *Analysis of Sensations*. This time with no illustration, Mach follows the sequence of how elements are created and constrained to frames designated as "inside" or "outside" the body, and he again stresses that objects are not "appearances" from a reality behind the observed (*Schein dieser Wirklichkeit*, [15]), but rather products of the activity of knowing – they are a set of conditions, construals or findings (he uses *Umstand, Befund*, and *Konstatierung*). The result of this mental activity is not static knowledge, but a *Konstatierung* of the conditions of the possibility of designation itself.

Beyond these points of departure, the remainder of the volume provides examples of how observation is turned into knowledge, as he already demonstrated in *Analysis of Sensations*. Nonetheless, what is particularly striking about the arc between *Analysis of Sensations* and *Knowledge and Error* is how very consistent that account is with the reading of Kant's model of knowledge production and Zimmermann's pedagogy that I have offered above. I suspect it is no accident that Mach's volume echoes the title of §74 of Zimmermann's *Propädeutik*:"Begriff des Erkennens;

[29]"Das wissenschaftliche Denken tritt uns in zwei anscheinend recht verschiedenen Typen entgegen: dem Denken des *Philosophen* und dem Denken des *Spezialforschers*"; ibid., p. 11.

[30]"eine möglichst vollständige, weltumfassende Orientierung über die Gesamtheit der Tatsachen [. . .] Dem anderen ist es zunächst um Orientierung und Übersicht in einem kleineren Tatsachengebiet zu tun"; ibid., p. 11.

[31]"Solche Philosopheme, welche in der Naturwissenschaft nicht nur nutzlos sind, sondern schädliche müßige Pseudoprobleme erzeugen, haben wohl nichts Besseres vedient, als beseitigt zu werden." Ibid;, p. 4.

[32]Mach, loc. cit., 16.

Erkenntnis, Irrtum."[33] The two also use very similar terminology in differentiating between knowledge, error, and representation.[34] Zimmermann also differentiates the role of experience and inheritance (*Erfahrungskenntnis/Begriffserkenntnis*) in the production of knowledge, very much as Mach does in speaking of the cultures of various sciences.

These works, originating a half-century apart, point to what I believe is a shared underlying conception of knowledge produced within an *embodied, experiential* field of data that is held in place by designations, and built up of conventional elements. Various disciplines produce knowledge within very different frames of reference, according to acts of mind operating with empirical data (including objects, traditions, and designations/terminology), within a community of understanding. Overall, Mach's writings exemplify the desiderata that Zimmermann outlined in his *Propädeutik*: they represent acts of *critique* of the products of specialized forms of reason, based on situated engagements of the understanding with empirical experience, within particular limits for their possible truth-telling and sense-making (their frames of reference).

2.3 Some Conclusions: Remapping Philosophical Disciplines

Reaching this point, I have traced a tradition of Kantianism that is embedded in the rubric of "Austrian philosophy," while also suggesting its new identity as an intellectual tradition: a more radical turn towards critical epistemology that was relatively widespread in Central Europe, one that directly implicates a pedagogy, and that emerges as a fundamental transformation of the discipline of philosophy. While beyond the scope of the present essay, I would stress that this alternate tradition of philosophical critique or post-philosophy also encompasses otherwise hard-to-place or overlooked philosophy projects reaching from Bernard Bolzano (1781–1848) to Wittgenstein and the Vienna Circle within Austria, but also from the *Wissenschaftsdebatte* (featuring Windelband and Rickert, and associated today

[33] Zimmermann, loc. cit., p. 12; this is the summary title in the table of contents, not in the text itself, where individual paragraphs are not titled, only sections.

[34] "If the act of representing is considered with respect to the condition whether or not it corresponds to something outside the entity doing the representing, then it is *an act of cognizing*; and the representation which represents something situated outside of the subject is a *cognition* in the broader sense of the term."/"Wird das Vorstellen mit Rücksicht auf den Umstand betrachtet, ob demselben ausserhalb des vorstellenden Wesens etwas entspricht oder nicht, so ist es ein *Erkennen*; und die Vorstellung, welche etwas ausserhalb des Subjects Befindliches so vorstellt wie es ist, eine *Erkenntnis* im weitern Sinnes des Wortes." Zimmermann, loc. sit., §74, p. 57.

with the Baden School of neoKantians) to Wilhelm Dilthey and Ernst Cassirer (two German casualties in the Anglo-American-German histories of continental philosophy).

I began this essay with a reading of Kant that transforms both classical ontology and epistemology into a single critical discipline, one that attends to empiricism and praxis together. The critical discipline which evolved in this tradition of reading Kant addresses knowledge production, all sciences, as not only implicating logic, but also as instantiating innate purposes (e.g. praxis with an ethic), habit, and affect. This model also accomplishes what Windelband and Rickert suggest in their project: the need to bring contemporaneous advances in science and the humanities closer together – and eventually, also to include the social sciences. What Zimmermann and Mach exemplify is an epistemology that accepts a joinder between knowledge and power (in Foucault's sense), embodiment, and semiosis (designation, signification) as always already present in "logic."

This is not a "linguistic turn" in the sense that the term was used in the latter twentieth century to identify that mythical "poststructuralism" that was seen in Anglo-American spheres as breaking from philosophy. Instead, it is a turn towards making the basis for knowledge *the community of knowing subjects* rather than the powers of individual minds. This model makes all knowledge relativistic in the sense used in modern physics, encompassing something like the Heisenberg Uncertainty Principle, or the model of energy levels of electrons in the atom – knowledge is local, structured, and embedded in both minds and bodies – but it is not relativism, because it strictly attends to values in the frames of reference that make knowledge out of experience possible. Moreover, any knowledge is knowledge in more than one dimension, as Zimmerman's philosopher/philosophy/philosophize distinction, but also Mach's notion of situatedness and purpose in knowledge production both suggest. Finally, there is no rationality without an empirical (designated or signified) form, without engagement in a process of semíosis (in the sense used in Greek medicine, a connection between signs and the diseases they signify) – of expression and communication, understood as functioning within autopoetic constraints of material existence and praxis (especially as effects of embodied rationalities inculcated in groups by rule-governed practices).[35]

Both textbooks like Mach's and Zimmermann's and a corpus of more accessible popular science (by Mach and others) helped to establish philosophy's new identity in the twentieth century, a century after the old one was declared dead by Kant, even if mainstream university philosophy often avoided this particular Copernican turn, refusing to factor in the point of view of a situated observer in a frame of reference, rather than mind in and of itself. But that century later, this work, I believe, was seminal for the great epistemological critiques of Bachelard, Foucault, and Deleuze – for decentering both ontology and the ontological status of mind, as Kant had begun to do in his *Critiques*.

[35] And thus a quite other semiosis than that described by Charles Sanders Peirce, and more like what Julia Kristeva describes in *Séméiôtiké: recherches pour une sémanalyse,* Paris: Edition du Seuil, 1969.

Chapter 3
Brentano's Lectures on Positivism (1893–1894) and His Relationship to Ernst Mach

Denis Fisette

Abstract

Franz Brentano's criticism of Mach in his lectures on Positivism (1893–1894)
This paper is mainly about Brentano's commentaries on Ernst Mach in his lectures "Contemporary philosophical questions" which he held one year before he left Austria. I will first identify the main sources of Brentano's early interests in positivism during his Würzburg period. The second section provides a short overview of Brentano's 1893–1894 lectures and his criticism of Comte, Kirchhoff, and Mill. The next sections bear on Brentano's criticism of Mach's monism and Brentano's argument, based on his theory of intentionality, against the identification of mental to physical phenomena. The last section is about Brentano's proposal to replace the identity relation in Mach's theory of elements by that of intentional correlation. I conclude with a remark on the history of philosophy in Austria.

In his article "My last wishes to Austria", written just before he left Vienna in 1895, Franz Brentano (1929c, p. 10) recalls that, as he was appointed in Vienna in 1874, the Austrian minister entrusted him the task to implement, in Austria, "the seeds of a genuine philosophy" at a time when most philosophy chairs in Austria were occupied by Herbart's disciples. This project stands out clearly in several lectures delivered by Brentano during his Vienna period (1874–1895), particularly in his inaugural address at the University of Vienna entitled "On the reasons for discouragement in the field of philosophy". Brentano (1929a) addresses the prejudice that philosophy had become an obsolete discipline with regard to the remarkable development of natural sciences, and his purpose was to interest the young Austrians in a new program based on the principles of an empirical philosophy. As Oskar Kraus (Brentano 1929, p. 157) rightly pointed out in his edition of this writing, the philosophical program that Brentano outlines in his

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inaugural address is based, if not directly on Comte's positive philosophy as such, at least on the outcome of his research on Comte's and Mill's positivism during his Würburg period. This program has been systematically developed in Brentano's *Psychology from an empirical Standpoint* published a few months after his inaugural address. As Brentano makes it clear at the very beginning of this *work*, he advocates a philosophy of experience, which is akin to the task and method of natural sciences.

Brentano continued to attach much importance to positivism during the Vienna period and later in Florence as evidenced by the notes, which he dictated during the winter of 1905–1906 and published under the title *Über Ernst Machs 'Erkenntnis und Irrtum'* (Brentano 1988; Mach, 1976). Less known perhaps are Brentano's lectures "Contemporary philosophical questions" which he held in Vienna one year before he left Austria and in which he extensively discusses Mach's positivism. In these lectures, Brentano examines four versions of positivism, that of Auguste Comte, which he compares with Kirchhoff's descriptivism, and Mach's phenomenalism, which he compares with John Stuart Mill's empiricism. Brentano claims that the last two versions of positivism represent a progress over the other two versions, namely because they are up to date with respect to the development of natural sciences, and because they recognize the philosophical value of the field of mental phenomena, i.e. descriptive psychology.

Brentano's correspondence with Husserl (1994) and Mach (Brentano 1988) in 1895 testifies that, despite his reservations regarding the metaphysical positions advocated in these different versions of positivism, there remains, however, a "consensus on the method of research," namely with Brentano's methodological phenomenalism. What Brentano criticizes in Mach's monism, is the identification of physical and mental phenomena and he argues against Mach that the two classes of phenomena are irreducible to one another. Moreover, Brentano raises the question as to whether, with some modifications, it would not be possible to preserve the essential of Mach's theory of elements and he proposes to replace the identity relation between the two classes of phenomena by that of correlativity (*Correlativität*) through which he characterizes namely the intentional relation between a psychical phenomenon and its object.

3.1 Brentano's Background and the Sources of His Interests in Positivism

In 1869, Brentano held a series of public lectures on Comte and published, in the Catholic journal *Chillianeum*, an article entitled Auguste Comte and positive philosophy, which Brentano considered the first of a series of seven articles that he planned to write on Comte's philosophy (Brentano 1869). Even if this project has never been carried out, the question arises as to why the young Brentano was so much interested in positivism and in Comte's philosophy in particular. As a first approximation, there are several aspects of Comte's philosophy in Brentano's paper on Comte, which were already at the heart of his philosophical preoccupations in the first years of his professorship in Würzburg. First, according to the fourth thesis in Brentano's habilitation in 1866, philosophy must adopt the method of natural sciences. The importance of this thesis in Brentano's philosophy is attested at several places in his writings and namely in his paper on Comte where he emphasizes the importance of using the inductive method in philosophy. Secondly, Brentano's criticism of speculative philosophy in his early Würzburg period is akin to that which Comte directed against metaphysical and theological explanations in his three states law. This stands out clearly in Brentano's habilitation talk from 1866 in which he harshly criticises Schelling's speculative philosophy (Brentano 1929d).

A third important factor lies in Brentano's philosophy of history, which is known as the theory of the four phases in the history of philosophy and which is, in many respects, compatible with Comte's three states law (Brentano 1998). Brentano claims that there are regularities in the course of the history of philosophy since the pre-Socratics and one can observe, within each of the three major philosophical periods, four phases or moments: the first stage is ascending while the three following phases mark its gradual decline. Brentano considers that his time belongs to a state of decline as shown by the place assigned to German idealism in his theory. Brentano's evaluation raises the important issue as to what is likely to take over from this phase, which Brentano describes as one of extreme decline. We find a clear answer to this question in his paper on Comte where Brentano says that his time is ready for "a positive treatment of philosophy" (Brentano 1869, p. 133) Brentano saw in the positivist treatment of philosophy the signs of an ascending stage in the history of philosophy after the decline of idealistic systems.

But the most important factor lies in the importance he attached to British empiricism and to J. Stuart Mill's philosophy in particular. J. S. Mill's book *Auguste Comte and positivism* drew Brentano's attention to Comte's philosophy and it stands out clearly from Brentano's paper on Comte that his own interpretation owes much to Mill's work (Mill 1969). This is confirmed by a letter from Brentano to Mill (February 1872) in which he acknowledges his debt to Mill's scientific contribution and thanks him for having drawn his attention to Comte's philosophy and to have awakened in him a new hope for the future of philosophy (Mill 1972). Brentano complained to Mill of the deplorable state of philosophy in Germany and of his intention to undertake a reform of philosophy based on that of natural sciences along positivist lines. He was pleased to see that his ideas were, in many respects, similar to those of Mill, particularly with regard to the method and, as we shall see, to Mill's doctrine of permanent possibilities of sensation.[1]

In his article on Comte, Brentano (1869) examines several aspects of Comte's *Cours de philosophie positive* which had a direct impact on Brentano's philosophical program in his 1874 *Psychology*. The first aspect pertains to the nature of phenomena. The notion of phenomenon such as Comte uses it in his work is

[1]Moreover, in the summer of 1872, Brentano made a trip to England in order to meet J. Stuart Mill and several British philosophers. Unfortunately, this encounter with J. S. Mill never took place, but we know that he met H. Spencer and several influential British philosophers (Fisette 2018).

particularly important for Brentano in light of its central role in Brentano's *Psychology* where mental and physical phenomena constitute the object of psychology (mental phenomena) and natural sciences (physical phenomena) respectively. That is why P. Simons, and more recently Tim Crane (2014), attribute to Brentano a form of methodological phenomenalism whose origin is in Comte. Secondly, Brentano considers that, with some modifications, Comte's three states law is compatible with his own theory of the four phases that I mentioned above**.** Brentano further agrees with Comte that natural sciences are solely concerned with the discovery, through the observation of individual cases, of relations of similarity and succession between phenomena, which fall under general laws. The main task of science is therefore to look for general laws that govern these relations and to reduce them to the lowest possible number.

Finally, Comte has had a lasting influence on Brentano's classification of sciences. Brentano's main reservation regarding Comte's classification is clearly formulated at the very end of his paper where he criticizes Comte for not admitting, in his own classification, two disciplines which constitute the two main axes of Brentano's philosophy, i.e., metaphysics and psychology. Brentano opposes to Comte's classification that proposed by Aristotle and he refers to Aristotle's *De Anima* where psychology is considered the philosophical science *par excellence*. However, Brentano claims that the recognition of the status of science to psychology does not compromise the value of Comte's theory of the three states, nor the principles of his classification. On the contrary, says Brentano, it confirms them.[2]

3.2 Brentano's Lectures "Contemporary Philosophical Questions": An Overview

The main part of Brentano's 1893–1894 lectures "Contemporary philosophical questions" bears on positivism and monism in Comte, Kirchhoff, Mach, and J. S. Mill (p. 29376 et sq.).

The manuscript is divided into two parts. In the first part, Brentano compares Comte's positive philosophy with Kirchhoff's descriptivism, (p. 29378 f.) while in the second part (p. 29410 f.), Brentano compares J. S. Mill's philosophy with Mach's phenomenalism. I will first very briefly summarize Brentano's analysis of the three first versions of positivism before examining, more extensively, Brentano's position vis-a-vis Mach's phenomenalism.

First of all, these four versions of positivism have several points in common, beginning with the importance they attach to the description of phenomena. Brentano is in agreement with this aspect of descriptivism which favours the "how" question over the "why" question in the sense that the description of phenomena is

[2]I have argued elsewhere that all these elements are part of Brentano's program of a psychology as a science, which he develops during his Vienna period (Fisette 2018; see Münch 1989).

prior to, and a necessary condition to their explanation. This trait can also be found in Brentano's lectures on descriptive psychology, in which he distinguishes, within psychology, genetic or physiological psychology from descriptive psychology and in which he emphasizes the primacy of description and analysis of psychical phenomena over the causal explanations by genetic psychology. Descriptivism is mainly associated in these lectures with the school of Kirchhoff in physics and with the task assigned to mechanics to describe the movements in nature in the simplest possible way (p. 29381). The requirement of simplicity in description is also found in Comte, who assigns to sciences to fix the laws which govern the relations between phenomena and to reduce them to the smallest possible number. In Mach, it corresponds to the principle of economy of thought (Mach 1903, 1943).

What Brentano criticizes in his lectures is the unknowable nature of causes and the rejection of explanations based on the primary causes of observed phenomena. Brentano admits that Comte, for example, does not exclude the existence of causes, but he believes that Comte and Kirchhoff (1877) are unjustified to affirm that an advanced science must give up the search for causes (p. 29403). Brentano argues that natural sciences are not limited to what is given directly in experience and that the concept of cause can not be wholly excluded from the natural sciences as most positivists believe. Brentano claims that explanations in scences are irreducible to descriptions and they in fact require causality:

> Daß vielmehr 1. die Annahme der Existenz von Bewegungen <von bewegter Materie> zur Erklärung der psychischen Phänomene schon etwas anderes als Beschreibung von Bewegungen ist und 2. im besonderen nur unter zu Hilfenahme des Causalbegriffes begründet werden könnte (p. 29408–29409).

Brentano rejects these two versions of positivism advocated by Kirchhoff and Comte because, according to him, every advanced science does not renounce explanations which resort to causality and the first two versions of positivism are therefore lagging behind the development of sciences. Brentano then wonders whether, in view of these objections, one should rule out any form of positivism or consider other versions even if they are to be critically complemented. He opted for the second alternative and proposed to examine the versions proposed by J. S. Mill (1865) and E. Mach (1914, 1891, 1892). I shall first say a word about J. S. Mill's permanent possibility of sensation, and then turn to Mach's position in the next sections.

Brentano maintains that, for all four versions of positivism, the objects of experience are, in one way or another, reducible to one's own mental phenomena and to percepts in the case of sensory perception. For if phenomena are somehow related to experience, then they are necessarily related to mental states (sensory perception). In other words: *esse est percipii*. It follows that "only our own psychical phenomena deserve the name of facts of experience" (p. 29411). Through this doctrine, J. S. Mill seeks to account for the way in which one can believe in the existence of a spatial outer world from the data of sensory experience (p. 29423). According to Mill, our representation of the external world contains, in addition to the sensations which are momentary and fleeting, a multiplicity of possibilities of sensations which come to us, in part, from past experiences or observations and which indicate that under certain circumstances, one can experience it again. Mill further claims that sensations change while these possibilities persist or are permanent (1865, p. 237–238). Brentano argues that Mill's philosophy marks an improvement over those of Comte and Kirchhoff not only because he takes into account the domain of mental phenomena but also because he admits the possibility of the knowledge of causes and causal laws.[3]

3.3 Mach's Psychophysical Identity and His Theory of Elements

Brentano's position towards positivism is not very different from that which he adopted during the Würzburg period with regard to Comte and J. S. Mill. As it is clearly stated in his letter to Mach which I mentioned earlier, there is an "agreement on the method of research," in that both share methodological phenomenalism. However, Brentano unequivocally rejects phenomenalism associated with a kind of neutral monism, according to which the world is made of neither matter nor spirit, but of a neutral stuff, which can be treated according to the context, interests and the direction of research as mental or material. Neutral monism also refers to a metaphysical position which claims that the uniqueness of reality and its neutrality with respect to whether it is physical or psychical. Mach thus defends an anti-metaphysical position insofar as he believes that everything which goes beyond what is immediately given is metaphysical and any science which does not conform to pure description is merely dealing with *Scheinprobleme*. As Brentano explains:

> Mach erklärt darum die räumliche Außenwelt und alles was man von Bewegungsvorgängen in ihr anzunehmen pflegt verwerfen zu müssen, weil diese Annahmen innerlich absurd seien. Die Forscher, meint er, schienen allerdings in | der Verfolgung wissenschaftlicher Probleme in rechtmäßiger Weise zu ihnen zu gelangen. Aber dennoch sei es unvernünftig daran zu glauben (p. 29429–29430).

Mach's position rests on his doctrine of elements and involves a rejection of metaphysical assertions on the realities of the external world, and Mach's monism has the consequence of reducing the world and all that it contains to functional relations and combinations between sensations.

Brentano advocates instead a form of critical realism according to which the only access one has to the external world is by means of phenomena through which they are given to us; but these objects exist independently of being perceived. And this form of critical realism is compatible with methodological phenomenalism.

[3]In his *Psychology*, Brentano refers to Mill's doctrine in relation to his definition of natural sciences as a science of physical phenomena, and proposed a definition of the object of natural sciences along Comtian lines; in this context, he compares his concept of force to Mill's permanent possibilities of sensation (2009, p. 76).

Moreover, Brentano also denies Mach's thesis according to which the task of science is merely to describe and not to explain phenomena and argues, as he did against Kirchhoff and Comte, that "it is unfair to claim that advanced sciences renounces the search for causes" (p. 29403).

Brentano focuses on two important points in his analysis of Mach: the non-reality of a spatial world and the identity of the two classes of phenomena. Brentano claims that Mach's phenomenalism and his proof of the absurdity of a spatial external world are grounded on the identity of the mental and the physical in sensations, which Mach clearly stated at the very beginning of *The Analysis of sensations*: "I see no opposition of physical and psychical, but simple identity as regards these elements. In the sensory sphere of my consciousness everything is at once physical and psychical" (Mach 1914, p. 44; see p. 310). And this identity is based, in turn, on Mach's theory of elements and functional dependencies of sensory elements on one another.

Mach's theory of elements is a system of general principles on the immediate data of experience. The basic idea is to consider the psychological or physical objects as a complex of elements, which are bound together by functional relations of dependence of different kinds. The essential difference between these classes of relations, and namely, between the relation to a physical object and that to a mental state, for example, depends on whether the elements overlap the sensory surfaces or the periphery of our senses. To be more precise, the boundary that delineates what belongs to the physical and to the mental depends on what he calls "a spatial delimitation *U* of our own body" or the flesh. For, since the sensory world belongs simultaneously to the physical and to the psychical world, the difference between physics and the physiology of senses, for instance, depends primarily on the fact that the latter only takes into account our own body (i.e. our nervous system). The function *U* makes it possible both to present the functional relations between the elements and to distinguish the physical from the psychological in a non-substantialist way.

The three more important classes of relation structuring the elements are the following:

1a. Relations of physical dependence: relations between items A, B, C, etc. *outside of U*;
1c. Neurophysiological relations of dependence: relations between the elements K, L, M, etc. *inside of U*;
2. Psychophysiological relations: relations between elements *inside and outside of U*, i.e., relations between 1a and 1b;
3. Relations of psychological dependence: relation between elements a, b, c, etc. to which correspond mental states or mental phenomena such as presentation, feeling, judgment, etc.

Each variable takes its value only when it takes place in a physical or psychophysiological relation. For instance, the elements A, B, C refer to physical objects, physical properties, psychological objects, or sensations only insofar as they take place in a relation of physical dependence (i.e. relations 1a and 1b), a psychophysiological dependence (relation 2), or psychological dependence (relation 3). To quote Mach again:

> A color is a physical object as soon as we consider its dependence, for instance, upon its luminous source, upon other colors, upon temperatures, upon spaces, and so forth. When we consider, however, its dependence upon the retina (the elements K, L, M, etc.), it is a psychological object, a sensation. Not the subject matter, but the direction of our investigation, is different in the two domains (1914, p. 17–18).

This holds *a fortiori* for the subject, which Mach understands as a complex of functional relations of a certain kind. It follows that the subject matter of all sciences is the same, i.e. the elements and functional relations between them, whereas their differences rest on one's stance toward them and in the interests and orientation of the research.

3.4 The Argument of Brentano Against the Identity Thesis: Intentionality

As I said, Mach's doctrine of elements amounts to identifying what Brentano considers two irreducible classes of phenomena. It therefore does not account satisfactorily for the duality in the percept or in one's state of mind such as an emotion between the feeling and what is felt, or between perceiving and what is perceived. According to Brentano, to this duality correspond two classes of phenomena, which are bearers of heterogeneous and irreducible proprieties, and this identification is therefore absurd (Brentano 1988, p. 28; 67f.). For this identification would amount to identifying „das Sehen der Farbe und die Farbe und das Hören des Schalls und der Schall u.s.w. identisch seien. Wie keine Empfindung ohne immanentes räumliches Objekt, so könne also auch kein Räumliches anders denn als Objekt unseres Bewußtseins bestehen" (p. 29433).

In his *Psychology*, Brentano had already considered a similar hypothesis which he attributed to Alexander Bain and J. Stuart Mill in the context of the distinction between primary and secondary objects and it consists merely in identifying primary and secondary objects. Brentano's main argument against this identification rests on the view that the essential properties of the class of mental phenomena are not attributable to the other class and vice versa (2009, p. 94–95). There is thus irreducibility of the object seen to the vision of the object, and as Brentano explains in *Sinnespsychology*, when one says that the primary and secondary objects appear simultaneously to consciousness, "appearing simultaneously does not mean appearing as the same" (1907, p. 96).

Brentano's argument against this identification is systematically developed in the first chapter of the second book of his *Psychology* where he discusses several criteria for the delineation of the mental from the physical. Concretely, in the case of the color green, the vision of green is a psychical phenomenon, which is about the color green, while the seen color, which Brentano conceived of in 1874 as an immanent object of presentation, belongs to the class of physical phenomena (p. 29439). The following quote from Brentano's lectures summarizes Brentano's position on that issue:

> Sensing (*das Empfinden*) always has the general characteristic feature of a mental phenomenon, which is characterized as an intentional relation to an immanent object. It can be found similarly in memorising, desiring, enjoying, recognizing, negating, etc. However, what is felt [in sensing] has the general character of a physical phenomenon, which consists in the fact that the phenomenon is localized (p. 29441).

Brentano concludes that Mach's proof of the "absurdity of the assumption of a spatial outside world on the basis of the identity of the mental and the physical in sensations is a complete failure" (29443).

3.5 Identity Versus Correlation

Now, if one accepts with Brentano the irreducible character of these two classes of phenomena, the question arises as to whether, with some modifications, it might be possible to preserve the core of Mach's conception (p. 29444). Brentano responds positively, provided that one replaces the identity relation between the two classes of phenomena by that of correlativity (*Correlativität*), which Brentano (1982) has introduced in his lectures on descriptive psychology held in Vienna in the late 1880s. In these lectures, Brentano advocates a relational theory of intentionality, which relates mental states to its objects: "As in every relation, two correlates can be found here. The one correlate is the act of consciousness, the other is that <thing> which it is directed upon. Seeing and what is seen, presenting and what is presented, [. . .] etc."(1995, p. 23–24). Brentano maintains that what is specific to an intentional relation is that it includes a pair of correlates of which only one is real whereas the intentional correlate or the immanent object is not real (1995, p. 23 f.). To be more precise, the term correlation refers in this lecture to the bilateral relation of dependence between pairs like cause and effect, larger and smaller, etc. Brentano's proposal mainly pertains to this class of correlates which he calls intentional correlates (*intentionales Korrelat*) and which are involved in the relation between these two classes of phenomena. Examples of intentional correlates include the pairs presenting and presented, perceiving and perceived, sensing and sensed, judging and judged, loving and loved, etc. Brentano maintains that what is specific to this class of intentional relations lies in the fact that it includes a pair of correlates, of which "only one is real, while the other is not."

In short, Brentano considers in his lectures on positivism that this idea of correlation, broadly understood, is something similar but more appropriate to what Mach was looking for with his doctrine of elements.

> The relation is that between subject and object. And this certainly has to do with what others like Mach (and Lotze, for example) explained by saying that it is clear from the outset that there can be no color without an act of seeing (Sehen). But they finally say nothing about space, magnitude, gestalt and movement. However, let us consider that we also have

> a presentation of these items as we have a presentation of colors and sounds (. . .) through sensation; then it seems that, to be consistent, one must also maintain, in the same way, that magnitudes, gestalt, movement, in short, all that is spatial, would never be able to exist (bestehen) if not as correlates of sensations and to entertain a subject-object relation with the latter. The opposite would be absurd. And we will have something essentially similar to what Mach wanted [with his doctrine of elements] (p. 29444–29445).

3.6 Final Remarks

Brentano referred to his lectures on positivism in a letter to Mach from May 1895. This letter has a particular significance because it is addressed to the one who was called to succeed him in Vienna as Chair of history and theory of the inductive sciences, left vacant since Brentano's resignation in 1880. Brentano informed Mach about his lecture on positivism:

> You probably do not know that, by happenstance, in the first part of the lecture I taught last winter on the theme of positivism and monism, I addressed your positions on that theme in detail. I considered Comte and Kirchhoff as the representatives of a thoughtless positivism, whereas I considered J. Stuart Mill and Mach as the representatives of an evolved positivism. However, I attempted to show why one form or another of positivism proves to be untenable. [. . .] I am and always have been convinced that consensus on mere wording—even if its significance is great—is of less import than consensus on research methods" (1988, p. 204).

This excerpt shows that despite his reservations with respect to positivism, his views regarding research methods, i.e. methodological phenomenalism, remained similar to that he adopted upon has arrival in Vienna.

There are also reasons to believe that Brentano's students in Vienna shared his opinion about Mach. Indeed, in September 1894, Mach was invited to the congress of the Association of German physicists and naturalists held in Vienna and he gave a talk entitled "The principle of comparison in Physics". Alois Höfler, a student of Brentano and Meinong, invited Mach to discuss his talk at a meeting of the Philosophical Society of the University of Vienna. This discussion aroused so much interest that two further sessions were organized by Josef C. Kreibig, another student of Brentano.[4] These discussions have convinced several members of the Philosophical Society of the interest of Mach's candidature to occupy Brentano's chair. Mach began his teaching in Vienna in 1895 and we know the influence he had on the course of the history of philosophy in Austria (Stadler 1997). But Brentano's contribution to this chapter is not to be overlooked.

Indeed, Brentano's program that I mentioned earlier constitutes the philosophical program, which Brentano, despite his precarious academic situation in Vienna, sought to establish in Austria. This program represents the starting point and the

[4]The young Husserl was also very much interested in Mach and he reviewed Mach's 1893 paper on the principle of comparaison in physics. (see Fisette 2012).

basis of the philosophy of his students in Vienna, although Meinong, Ehrenfels, Twardowski, Hillebrand, and Husserl, for example, have departed significantly from Brentano's original program. However, this program constitutes one of the main axis in the history of philosophy in Austria and it also represents an important reference for the Austrian members of the Vienna Circle. In any case, it is clear that when Neurath (1935) claims, in his remarkable book on the development of the Vienna Circle, that the latter is nothing but a radicalization of the empiricists trends in Vienna, he not only had Mach and his followers in mind, but also Brentano and his successors in Austria.

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Chapter 4
From Brentano to Mach. Carving Austrian Philosophy at its Joints

Guillaume Fréchette

Abstract In many respects, Mach's arrival in Vienna in 1895 marks the beginning of a new era in Austrian philosophy, paving the way for young philosophers and scientists like Hahn and Neurath and preparing the soil for the Vienna Circle. While this understanding of Mach's contribution to the development of Viennese philosophy seems correct to an important extent, it leaves aside the role of Brentano and his school in this development. I argue that the Brentanian and Machian moments of Austrian philosophy are jointed. I propose a description of the nature of these joints based on institutional, methodological, and philosophical aspects of these phases, and suggest a diagnosis that supports what I take to be the right carving between these two moments.

It seems to be widely acknowledged that the development of scientific philosophy in Vienna started more or less with Mach and culminated in the philosophy of the Vienna Circle. If we take this account as a starting point in reconstructing the history of Austrian philosophy, as it has often been done in the historiography, then it seems natural to see the "Brentanian phase" and the "scientific phase" inaugurated by Mach as two somehow disjointed moments. Such a reading was already suggested by Hahn, Neurath, and Carnap in the *wissenschaftliche Weltauffassung*, where they characterized Brentano's influence on Vienna philosophy as coming "from quite a different quarter [than Mach's and Boltzmann's influence]" (Neurath 1979, 302). This characterization had itself a decisive influence in the early histories of the Vienna Circle. The name of Brentano doesn't appear once in Frank (1949); Brentano's name is mentioned only three times in Kraft (1950); and in his 1950 address for the unveiling of Brentano's monument in the arcade of the University of Vienna, Kraft (1952) insisted exclusively on the influence of Brentano on the phenomenology of Husserl, but doesn't say a word on the connections with the philosophers of the Vienna Circle.

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Although the role of Brentano in the early development of the Vienna Circle came into discussion in the historiography only recently, most notably in the works of Stadler (e.g. Stadler 1997, 2015; Stadler and Haller 1988; Stadler and Dahms 2015), Uebel (2001), Blackmore (1995, 1998) and Fisette (2014), the nature of the connection between the Brentanian and the Machian phases of Austrian philosophy remains obscure still today. In the following lines, I shed some more light on this connection by focusing on three aspects of the link between Brentano and Mach, which challenge the received view according to which the Brentanian and Machian phases of Austrian philosophy are disjointed moments. I will argue that the changing of the guard in Vienna in 1895 overshadows three instances of continuity between these two phases:

(a) given the difficulties to appoint a student of Brentano to the chair, the appointment of Mach represented for many Brentanians in Vienna the next best alternative to Brentano;
(b) the philosophical programs defended by Mach and Brentano in the 1890s share many common concerns, first and foremost in the field of descriptive psychology, which was developed by Brentano partly in reaction to Mach (1886). A further common concern is
(c) the significance of natural sciences for philosophy, which Brentano and Mach acknowledge equally.

4.1 The Received View. *Wissenschaftliche Weltauffassung*

With the foundation of the Verein Ernst Mach in 1928, a first version of the history of academic philosophy in Vienna at the turn of the twentieth century made its apparition. For the authors of the manifesto – Hahn, Neurath, and Carnap – Mach's seminal contribution to the *wissenschaftliche Weltauffassung* was mainly to be found in his critique of metaphysics and in his construction of scientific concepts out of the elements (the sense data):

> He was especially intent on cleansing empirical science, and in the first place, physics, of metaphysical notions. We recall his critique of absolute space which made him a forerunner of Einstein, his struggle against the metaphysics of the thing-in-itself and of the concept of substance, and his investigations of the construction of scientific concepts from ultimate elements, namely sense data. (Verein Ernst Mach (ed.) 1929, 10; Neurath 1979, 302)

Following the *Weltauffassung*, Mach's contribution to scientific philosophy in Vienna is in a strong contrast with the philosophy conducted by Brentano, the "catholic priest with an understanding of scholastic philosophy":

> The activity of the physicists Mach and Boltzmann in a philosophical professorship makes it conceivable that there was a lively dominant interest in the epistemological and logical problems that are linked with the foundations of physics . . . As a catholic priest Brentano understood scholasticism; he started directly from the scholastic logic and from Leibniz's endeavours to reform logic, while leaving aside Kant and the idealists system-builders. (Verein Ernst Mach (ed.) 1929, 11; Neurath 1979, 302)
>
> By the choice of its name, the society wishes to describe its basic orientation: science free of metaphysics. (Verein Ernst Mach (ed.) 1929, 14; Neurath 1979, 305)

The narrative of the prehistory of the Verein Ernst Mach proposed by the authors of the manifesto doesn't sound very plausible: Mach's rejection of metaphysics was certainly a source of inspiration for the philosophers of the Verein, but this is hardly a sufficient reason to call their philosophical society by his name: many other philosophers of various allegiances rejected metaphysics in a way similar to Mach at this time, and even before. For this reason, the rejection of metaphysics appears to be a mere political or ideological motivation in the narrative, while the real motivation lies mainly in the importance of physics as a model for the development of a scientific point of view in philosophy, especially in logic and epistemology.

In this context, Brentano's contribution to scientific philosophy in Vienna – more or less labeled here as a scholastic reform of logic (!) – looks particularly antiquated. It is therefore easily understandable that the early histories of the Vienna Circle, relying mostly on the manifesto, made no particular place for Brentano's program of a scientific philosophy. The more recent histories of philosophy in Austria at the turn of the twentieth century mentioned earlier did consider Brentano's role more carefully, but the characterization of his position in the whole of Austrian philosophy at the turn of the twentieth century still remains problematic. Somehow in the lines of Kraft (1952), Stadler (1988, 31) speaks for instance of an "objectivistic-phenomenological paradigm" in Austrian Philosophy that would be represented among others by Brentano, while Smith (1994), following Haller's reading of Neurath, rather suggests to see Brentano's scientific philosophy, Mach, and *wissenschaftliche Weltauffassung* as parts of one single whole:

> [I]f [the] Neurath-Haller thesis can be accepted, if, in other words, it can be accepted that there exists a separate and internally coherent tradition of Austrian philosophy within German-language philosophy as a whole, then it follows that the Vienna circle itself comes to be linked, via Brentano, to Catholic scholasticism. (Smith 1994, 17)

I do believe that the Neurath-Haller thesis is correct; and I have nothing to oppose to the idea that there might be different competing paradigms in Austrian Philosophy, such as the objectivistic-phenomenological paradigm suggested by Stadler. In some cases, however, relying too much on such paradigms tends to minimize some phenomena that in fact contribute to the unity of the whole, as it is the case of Mach's appointment in Vienna.

4.2 Mach as Brentano's Successor

It still remains almost unnoticed today that Mach's appointment in Vienna was made possible at least to some extent by Brentano himself. In 1894, a last attempt was made to reinstate Brentano in his professorship, which was held vacant since the 1880s. The attempt was rejected by the Minister of Education, the Pole Madeyski. This rejected attempt was made public by Brentano himself during his lecture "on Optimism and Pessimism" of November 29, 1894, which started the 'affaire Brentano' which was to be heavily discussed in liberal newspapers.

After this last failed attempt, Zimmermann, holder of the 1st chair and at that time 1 year before his retirement, prepared then a first emergency plan, which wasn't successful: he suggested Brentano to abandon his hopes on the 2nd chair, in order to make place for one of his students (for example Marty). Madeyski rejected however all propositions of Brentanian philosophers for the 2nd chair, which left the field open to such an outsider as Ernst Mach.

After Zimmermann's failure to instate a Brentanian successor to Brentano, the faculty proposed a deal (or a 2nd emergency plan, to which Brentano obviously agreed[1]) to Madeyski that they would appoint a natural scientist for the 2nd chair if they can appoint a *Geisteswissenschaftler* for the 1st chair. Theodor Gomperz (professor in classical philology) also agreed on this plan and proposed the name of Mach to the Education Ministry on November 4, 1894. This paved the way to Mach's coming to Vienna, which was felt by many philosophers of that time, and even still today by some, to be one the many scandals of philosophy in Vienna:

> Die Geschichte der Philosophie der Wiener Universität ist voll von großen und kleinen Skandalen . . . Einer dieser Skandale ist die Berufung des Physikers und A-Philosophen Ernst Mach auf eine philosophische Lehrkanzel unmittelbar nach dem erzwungenen Abgang von Franz Brentano aus Wien 1895. (Schmied-Kowarzik 1993, 181)

Seen from this perspective, Mach's coming to Vienna might very well appear to some to be a break from a traditional conception of philosophy.[2] But given the background history of the failures to reinstate Brentano in his chair and the emergency plans developed by Zimmermann, Gomperz, and Brentano, Mach's appointment in Vienna should rather be understood as the very best 2nd alternative (after a Brentanian candidate, of course), and the very best alternative *tout court* to pursue the program of scientific philosophy started by Brentano in 1874. Indeed, from a Brentanian perspective, the instatement of Mach as a successor to the chair was by no means considered as a scandal.

This doesn't mean however that Mach's succession to Brentano is not accompanied by any kind of change or evolution in the development of philosophy in Vienna. This was noticed very early in 1904 by Alois Höfler, a student of Brentano, Meinong, and Boltzmann, who offers a quite different diagnosis of the nature the evolution of philosophy in Vienna from Brentano to Mach than the one proposed in the *wissenschaftliche Weltauffassung*:

> Ein deutlicher Wandel [in the interest for natural philosophy] zeigt sich von dem Zeitpunkte, da Ernst Mach . . . nach Wien auf die Lehrkanzel des Philosophen Brentano berufen wurde. Von da an datiert ein fast ebenso plötzliches allgemeines Erwachen für die Sache der Naturphilosophie. (Höfler 1904, 4)

[1]See Mach's letter to Brentano from May 14th, 1895 (in Blackmore and Hentschel 1985, 23; reprinted in Brentano 1988, 203) which implicitly confirms Brentano's agreement to the second emergency plan. See also Brentano's letter to Mach from May 20th, 1895 (Brentano 1988, 204).

[2]According to Theodor Gomperz's son, Heinrich Gomperz, this was the opinion of Zimmermann himself, who saw a „disrespect to philosophy in calling a physicist to fill a chair in philosophy" (Gomperz 1916, 325). See also Blackmore 1972, 150ff.

Höfler's diagnosis makes two things clear: first, Mach's appointment didn't represent a change in direction of scientific philosophy, since scientific philosophy was already part of the program conducted by Brentano in Vienna since 1874. Second, the nature of the change that operates between Brentano and Mach (and later Boltzmann) is a change towards natural philosophy, an evolution that Höfler saw very critically after Boltzmann's *Antrittsvorlesung* from December 1903.[3] Following Brentano in the main lines, Höfler opposed this conception: Natural sciences are independent from philosophy, he argues, but this is not the case the other way around. Where natural sciences investigate phenomena, philosophy investigates metaphenomena such as causality, categories, etc. (the term 'metaphenomenon' is borrowed from Breuer, as quoted in Höfler 1904[4]). In this, he follows to some extent the Brentanian distinction between two kinds of phenomena and thereby rejects Mach's monism.

However, the rejection of monism by Höfler (and by most of the Brentanians) alone is not as such a substantial difference in the eyes of Brentano's students in Vienna at the time of Mach's appointment, and even before. This is confirmed by the enthusiastic discussions, at the Philosophical Society at the University of Vienna – an institution founded by Brentano's students in 1887 – of Mach's Vienna lecture on the Principle of Comparison in Physics. Two lengthy discussions on this lecture were held at the Philosophical Society in December 1894 and on the 24th of January, 1895. Interestingly, Brentano's students enjoyed that last meeting very much, and even sent a poem to Mach, written as a quite lengthy *Trinkspruch* at a late hour after the session in honor to the great physicist[5]:

Wien, Hotel Residenz, 24. Januar 1895,
¾ 11 abends.

Des Physikers indirekte Beschreibung
Verursachte eine direkte Reibung
In der Gesellschaft der Philosophie
Wie sie vorkam hier noch nie

Auch die theoretische Idee
Machte den weisen Köpfen Weh. –
Sie stritten hin und her
Und wussten schließlich nicht mehr
Ob der Gardasee kein Fjord,
Ob 'roth' ein rosiges Wort

Der Aral vertrocknete Lacke

[3] „Ein Antrittsvortrag zur Naturphilosophie". See Boltzmann (1979, 199ff.).

[4] See also Höfler 1920, 24; 1921, 140ff.

[5] I thank the Deutsches Museum in Munich for the permission to quote this document, which is catalogued under the number NL 174/1517. For reasons that are explained below, Füßl and Prussat (2001, 193) are wrong in mentioning that it was sent to Mach on the occasion of his appointment in Vienna.

Vorhanden der Stoff von Blacke
Und wie der Professor Mach
In *einem* Satze – ach! –
Solch Geister mit Fetischen
Gewusst hat aufgetischen

Die instinktive Gewalt im Genie,
Der substantielle Charakter auch,
Mechanische Arbeit und Stoffverbrauch
Sie quälten die Geister, wie nie.

Und alles das ganz anschaulich,
Für Philosophen erbaulich:
In den Hut des Systems zu bringen
Das war ein dreiabendlich Ringen!

Und die Brücken sind geschlagen
Und wir wollen es jetzt wagen,
Auf der inneren Verwandtschaft
Künft'gen Trost
Ihnen zu bringen ein kräftiges
Prost!

Josef B. Bubeck
Karl Neisser
Kasimir Twardowski
Konrad Zindler
Josef Clemens Kreibig
Alois Höfler
Robert von Sterneck
Paul Prazak
Egon von Schweidler
N.N.

Given the fact that the Faculty proposed Mach to the Ministry already a few weeks before the poem was written, and that this fact was known by at least three of the *Dozenten* who signed the poem (Twardowski, Kreibig, and Höfler), it is natural to understand the last strophe of the poem as a premature welcome – Mach's appointment will be officialized only on May 5, 1895 – addressed to Mach by the Brentanians and their heirs: among the signatories, these are Karl Neisser, Kasimir Twardowski, Konrad Zindler, Josef Clemens Kreibig, and Alois Höfler.

4.3 Descriptive Psychology and the Natural Sciences

On the background of this reconstruction of the reception of Mach as a successor of Brentano, let's now turn to the last two instances of continuity mentioned in the introduction:

(a) The common concerns of the philosophical programs defended by Mach and Brentano in the 1890s, for instance in the field of descriptive psychology, and

(b) the significance of natural sciences for philosophy, which Brentano and Mach acknowledge equally.

Brentano's descriptive psychology programme was already formulated in 1870s as an investigation on the content of our mental states.[6] It was developed as an alternative to Wundt's and Herbart's psychology. Brentano's student Carl Stumpf gave a very clear account of this programme in his review of Brentano (1874):

> Überhaupt also, um es nochmals zu erinnern: für die empirische Psychologie gibt es nicht absolute Grenzen noch Principien. Man hat sich Regeln gebildet, denen zu folgen im Durchschnitt nützlich ist, und das Ganze dieser Maximen ist es, was wir als den Charakter der gegenwärtigen empirischen Psychologie bezeichnen. Gelangt einer auf mathematischen, physischen, metaphysischen oder was immer für Wegen und Umwegen auch zu Resultaten, umso besser. Hier soll jedes Mittel, nur mystisch-unklare Speculation ausgenommen, durch den Zweck geheiligt sein; und wer am schlauesten seine Seele um das Wort betrügt, das ihren Zauber löst und ihr Gesetz enthüllt, der soll den ersten Preis empfangen. (Stumpf 1874, 206)

Brentano also believed that the programme was applicable even to sociology:

> Auf ihr gründet das Vertrauen derjenigen empirischen Psychologen, welche, wie Mill und Brentano, die praktischen Ziele ihrer Wissenschaft noch höherstecken: sie solle, vereinigt mit Geschichte, Socialstatistik und Nationalökonomie, und deren Ermittlungen in ähnlicher Weise befruchtend, eine Sociologie im großen Stile schaffen; eine Lehre vom menschlichen Zusammenleben, von den Bedingungen der Ruhe und Bewegung psychischer Massen, eine sociale Statik und Dynamik. Es ist die stolze Aufgabe, an welche nach wenigen Versuchen des Alterthums (man sehe das glänzende 5. Buch der aristotel. Politik) in unsrer Zeit ein Comte und viele andere edel Denkende ihr Leben gesetzt. (Stumpf 1874, 221)

That the laws of descriptive psychology shouldn't be considered as a closed theory but rather as a research programme is clear also at other places:

> Hingegen muß zugegeben werden, daß wir in der theoretischen Psychologie von 'Gesetzen' im strengsten Sinne zu sprechen kein Recht haben, solange man einen veränderlichen Factor außer Augen läßt . . . denn dann werden die Folgen oft andere sein, als das Gesetz verlangt, ein Gesetz aber hat keine Ausnahmen. (Stumpf 1874, 222)

It took Brentano some time to systematize the ideas behind the research programme he had in mind already in the 1870s. I suspect that the publication of Mach's *Contributions to the Analysis of Sensation* might have been a motivation for Brentano to systematize his thoughts. Shortly after the publication of the *Analysis*, Brentano announced his lectures on Descriptive Psychology for the Winter-Semester 1887/88. But according to a letter addressed to Marty in the Fall of 1887, he regretted soon enough to have announced the lectures:

[6] See for instance Brentano (1982), where descriptive psychology is also characterized as "phenomenology" or "psychognosy". The main lines of this programme are formulated in the Würzburger metaphysics lecture of 1867, where phenomenology is described as an investigation on the content of our presentations (See Brentano M96, 31739). Similar considerations are also formulated in Brentano's metaphysics from the Vienna period, see for instance Brentano (Mx1).

> Meine Vorlesungen sind im Gange. Bezüglich der deskriptiven Psychologie bereue ich aber eigentlich schon im Herzen, dass ich gewagt, sie anzukündigen. Es ist der Arbeit zu viel, und meine Nerven sind nach den Schönbühler Strapazen sehr angegriffen. Den Gesamtstoff habe ich in folgenden Abschnitten zergliedert:
>
> 1. Über den Inhalt der Empfindungen
> 2. Über den Inhalt der ursprünglichen Associationen
> 3. Über den Inhalt der inneren Wahrnehmung.
>   i. Mannigfaltigkeit der intentionalen Beziehungen (Grundklassen, Arten und Modifikationen psychischer Tätigkeiten)
>   ii. Constante Verflechtungen (Angebliche Zweiseitigkeit, Dreifachheit des inneren Bewußtseins).
>   iii. Psychisches Substrat
>   iv. Einheit der psychischen Realität
> 4. Inhalt der Begriffe, s.g. Phantasievorstellungen, angebliche apriorische Anschauungen und angeborene Ideen.
>
>   Schon der erste Abschnitt bringt mich aber wegen meines unzulänglichen Wissens in Verlegenheit. Wie soll es mit den anderen gehen? Mir fehlen Werke, um die Lücken genügend zu ergänzen. Wie weit reichen Herings Arbeiten dafür aus? Bietet Mach gar nichts? Wo findet sich sonst Stoff? Es ist zu viel verlangt, wenn man alles aus den Fingern saugen soll.[7]

When one looks closer at the structure of the lectures, one finds in it an interesting parallel with the structure of Mach's *Analysis of Sensation*, confirming that Brentano not only hoped to learn from Mach (as suggested in his letter to Marty), but that he also found inspiration in Mach's book. For instance, what Brentano calls the "content of original association" is directed against Mach's chapter on the sensation of time in Mach (1886). Where Mach begins his book with *Antimetaphysical preliminary remarks*, Brentano opens his lectures on *descriptive psychology* in 1887 with the remark that he will not propose here any metaphysics, that he is not interested in metaphysics. The way he does so is quite interesting, since he refers to Preyer's account of sensations (Preyer 1877) as a metaphysical account, where, in Mach's Analysis, Preyer is actually praised for offering quite the 'anti-metaphysical' account that Mach has in mind (Mach 1886, 21ff.). In some sense, we could see here Brentano as proclaiming descriptive psychology as the right anti-metaphysical investigations that the philosophically ill-informed Mach wants to conduct. Brentano rejects Preyers view (in *Elemente der reinen Empfindungslehre*) according to which sensations *are* the Kantian *Dinge an sich*. He rejects this view because, according to him,

> das gehe den Metaphysiker, nicht den Psychologen an. Wir wollen auf die metaphysische Frage nicht eingehen. Aber als Psychologen die Erklärung prüfend, können wir uns unmöglich damit zufrieden geben. (Ps76, 58185)

It is actually often the case in the lectures that Brentano presents descriptive psychology as an improvement of Mach's conception of sensations:

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[7] Letter from Brentano to Marty, September 1887.

> Wir haben also die tiefgreifendsten Meinungsverschiedenheiten in der descriptiven Psychologie in Folge der Schwierigkeit zu erkennen ob im einzelnen Fall ein wirkliches oder scheinbares Beispiel einer (gewissen) Empfindung gegeben sei" (Ps77, 59045)

What this tells us is that Brentano's teachings between the foundation of the Philosophical Society in 1887 and his departure from Vienna in early 1895 not only showed interest in the works of Mach, but was also, to some extent, influenced by the questions and problems discussed in Mach's *Analysis of Sensations*.[8] Brentano's generally positive, albeit also critical attitude towards Mach's work seems to have convinced many of Brentano's students that the programme of descriptive psychology was contiguous with the perspective developed by Mach.

Indeed, it was during Brentano's lectures in descriptive psychology in 1887 that his students Höfler, Twardowski and Schmidkunz started the project of a philosophical society that would address some of the issues discussed by Brentano in his lectures. These lectures were influent on two different levels: they were the main motivation for a series of publications on descriptive psychological investigations[9], but they were also the main source of inspiration for the programme of the Philosophical Society, which gave an important place to the kind of interdisciplinary investigations which was called for by Brentano in his lectures on descriptive psychology.[10]

The concern of Brentano and his students with *Grenzfragen*, or what we would call today interdisciplinary questions, took an important place in the activities of the Philosophical Society.[11] Engaging with the works of Mach, in this context, was

[8] It is also interesting to note that Brentano's manuscripts on 'Mach's *Psychognosy*' are precisely from the period of the descriptive psychology (N14). See also Brentano (1988).

[9] See for instance Höfler (1891, 1897), Schmidkunz (1892), Kreibig (1897).

[10] See for instance this passage of Brentano's lecture on descriptive psychology from 1887, on the method (Ps76, 58165): "1) Vorführen von Beispielen, wo ist und wo nicht ist; 2) Darlegung der Consequenzen; 3) Nachweis der Versuchungen. Sie [die Methoden der deskriptiven Psychologie] verlangen ferner eine eigentümliche Übung, zu welcher aber wieder die wesentlichen Vorbedingungen fehlen, so lange ebenso viel oder noch mehr unmethodisch oder nach schlechten Methoden Versuche gemacht werden. Sie verlangen endlich insbesondere eine gewisse *Theilung der Arbeit*, wie sie auf philosophischem Gebiet fast nie geübt wird." A similar consideration is expressed in Brentano (1895): "Die Philosophie ist eine Wissenschaft wie andere Wissenschaften und muß darum, richtig betrieben, auch eine mit der Methode anderer Wissenschaften wesentlich identische Methode haben. Die naturwissenschaftliche Methode (ich verweise dafür auf meine eben erwähnte Schrift) ist, das ist heute ausgemacht, auch für die Philosophie die einzig wahre. Und so allein wird sie sich dann auch mit den anderen Wissenschaften im Kontakt erhalten; denn nirgends sind die von uns unterschiedenen Wissensgebiete scharf begrenzt, alle greifen vielmehr irgendwie ineinander über." (Brentano 1895, 32).

[11] See for instance some of the papers presented at the Philosophical Society that were written in this spirit: Felix Klein in 1905, *Grenzfragen der Mathematik und Philosophie;* Alois Höfler in 1908, *Fragen der Physik an die Philosophie;* Kazimierz Twardowski in 1914, *Funktionen und Gebilde. Einige Bemerkungen zum Grenzgebiet der Psychologie, Grammatik und Logik*. This interest for interdisciplinary question was also present in many publications of Brentano's students as early as 1890, for instance in Kerry (1890), Marty (1893), Kreibig (1909), and Twardowski (1911/1979/1996).

therefore completely natural for Brentano's students in the 1890s. In this context, the programme announced by Mach in his inaugural lecture in Vienna in 1895 was, at least for the Brentanians, in direct continuation with the efforts that they carried on under the guidance of Brentano since the late 1880s:

> So bricht sich allmählich auch unter den Philosophen die Überzeugung Bahn, daß alle Philosophie nur in einer gegenseitigen kritischen Ergänzung, Durchdringung und Vereinigung der Spezialwissenschaften zu einem einheitlichen Ganzen bestehen kann . . . Diese der heutigen Generation nicht mehr fremde Auffassung denke ich zu vertreten". (Mach 1896, 277)

4.4 The Objectivist-Phenomenological Paradigm

I said earlier that I have nothing to oppose to the idea that there might be different competing paradigms in Austrian Philosophy, such as the objectivistic-phenomenological paradigm suggested by Stadler. It would be wrong, however, to see in Mach alone the starting point of this paradigm. I provided some reasons against this conception in the last pages, showing that the beginnings of scientific philosophy in Vienna are closely linked not only to Mach, but also to Brentano. But what about the beginnings of phenomenology? Historians of phenomenology like Lübbe (1972) or Sommer (1985, 1987, 1988) usually see the early connection between phenomenology and positivism as essentially bridging Mach directly to Husserl.[12] If the reasons presented here are correct, then they will also have an incidence on this narrative of the history of phenomenology.

One might oppose to my reconstruction that it downplays some important differences between Mach and Brentano. After all, Brentano is usually acknowledged as a metaphysical dualist, since he believes in a distinction between minds and bodies, a distinction rejected by Mach. Furthermore, the kind of epistemological foundationalism advocated by Brentano doesn't fit well with Mach's views on the nature of knowledge. However important these differences might be, they were obviously not perceived by Brentano's students in Vienna in the 1890s as hindering the kind of endeavor that was launched by descriptive psychology and its continuation through Mach's (and later Boltzmann's) teachings in Vienna.[13]

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[12] See for example Lübbe (1972, 36): „Für die Tradition der Phänomenologie ist das Werk Machs ein Anfangspunkt."

[13] This paper has been written as part of the Austrian Science Fund (FWF) project P-27215, "Franz Brentano's descriptive Psychology".

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Chapter 5
Mach, Wittgenstein, Science and Logic

John Preston

Abstract The received view is that Ernst Mach should not be counted as among the important influences on Ludwig Wittgenstein's philosophical thought. Recently, though, some affinities between their works have been brought to light, and two scholars, Henk Visser and Jaakko Hintikka, have gone beyond this to claim that Wittgenstein took specific and important philosophical ideas about science and logic from Mach. These claims have not been addressed by Wittgenstein scholars, but they do deserve attention. I argue that strong and *general* claims of positive influence are false, and also that Mach's influence was not, *pace* Visser, on the most important aspects of Wittgenstein's philosophy. But a more accurate picture of the Mach-Wittgenstein relationship will be an ambivalent one, and the received view is untenable.

5.1 Introduction

What relationships might there be between Ludwig Wittgenstein's work and that of one of the greatest naturalistic thinkers, his fellow-countryman, Ernst Mach? This question is important not only in determining for Wittgenstein's general intellectual location, but also in assessing his relationships to philosophical positions (such as naturalism, positivism, and scientism), philosophical activities (such as metaphysics), and philosophical methodology, relationships which have been

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controversial. What follows is a bit of philosophical detective-work in which I argue that certain existing claims about the relationships either go too far, or not far enough.

5.2 The Received View of the Mach-Wittgenstein Relationship

Very few scholars of Wittgenstein's work have pronounced on his relation to Mach.[1] Gilbert Ryle's very definite, perhaps even pointed comment that Wittgenstein 'was influenced by Frege and Russell, not by Mach' (Ryle 1951, reprinted in Fann 1978, p. 118) is representative. Most books on Wittgenstein, if they mention Mach at all, do so only in discussing the general intellectual background that Wittgenstein was exposed to, often going on to insist or imply that Mach was a part of that background which Wittgenstein either ignored or rejected.

This attitude, it has to be said, is usually due to the very strong (and persisting) general association of Mach with positivism, and an equally strong disinclination on the part of Wittgenstein scholars (especially recent ones) to believe that Wittgenstein had any deep affinity with positivism. For them, any demonstration that he was significantly influenced by Mach would constitute a strike against Wittgenstein.

This situation has not been improved by the fact that there has been a 'turn' in Mach scholarship recently. From the mid-1970s onwards philosophers such as Larry Laudan and Paul Feyerabend, reacting against the previous generation of Mach scholars, prepared the way for a figure we might think of as 'the *new* Mach'. Presented in most detail in the work of Erik Banks (especially his 2003 book), the new Mach is not so obviously committed to the views (notably phenomenalism) which had led earlier scholars not only to categorise Mach as a positivist, but to take him as the epitome of crude, pre-Logical positivism. His most important philosophical contribution is not positivism, but neutral monism. This new Mach hardly makes a bedfellow for Wittgenstein more congenial to Wittgenstein scholars, though, since he appears as a metaphysician *malgré lui*.

Those Wittgenstein scholars who have devoted any more than a moment to the Mach-Wittgenstein relationship, seem to agree with Ryle. In *Wittgenstein's Vienna*, for example, Allan Janik and Stephen Toulmin went to some lengths to contrast Mach's positivism, and its Humean background, with the Kantian views of thinkers such as Heinrich Hertz and Ludwig Boltzmann, whose influence upon Wittgenstein they were keen to play up. They also berated Mach's successors, the Vienna Circle,

[1] Visser (2001, p. 140), lists several people who had done so: Friedrich von Hayek (a distant relative of Wittgenstein's), Philip Wiener, Stephen Mason, Nicola Abbagnano, John Blackmore, and John W. Cook. Few of these are Wittgenstein scholars, though, and their associations of Wittgenstein with Mach are almost always made in offhand comments, not as a result of sustained investigation. In his book *Wittgenstein's Metaphysics*, however (Cook 1994), Cook presents Wittgenstein as an adherent of Mach's 'neutral monism'.

for distorting our understanding of Wittgenstein's *Tractatus Logico-Philosophicus* by presenting it as 'an epistemological exercise in Machian empiricism' (Janik and Toulmin 1973, p. 145).

Rom Harré, too, has recently insisted that the *Tractatus* has its roots in the tradition of great German-language philosopher-scientists as it stood *before* the advent of Mach's sensationalism and positivism: '[T]he *Tractatus* is not in any way phenomenological... It is in the spirit of the physics of Hertz's *Principles of Mechanics* and not of Mach's *Analysis of Sensations*' (Harré 2001, p. 224). The main characteristics of the logical doctrines of the *Tractatus*, Harré claims, 'can now be seen as generalizations of pre-Machian German philosophy of physics' (ibid.).[2]

5.3 Affinities, and More Specific Claims – the Heterodoxy

Certain general affinities between Mach's views and Wittgenstein's have already been pointed out, perhaps most effectively by Aldo Gargani (Gargani 1980, 1989) and by Brian McGuinness (McGuinness 1988, 1989, 2002), although neither of them regard these as matters of actual influence. In recent years, though, specific claims of influence have been made by three Wittgenstein scholars: Henk Visser, Jaakko Hintikka, and John W. Cook.[3]

In a series of provocative but interesting articles (Visser 1981, 1982, 1983, 2001), Visser has claimed that Wittgenstein got some of his most important philosophical ideas directly from having read certain works by Mach. Visser portrays Wittgenstein as a philosopher in the vein of certain anti-Kantians, notably Mach and Bertrand Russell. He supposes Wittgenstein to have taken his *Tractatus* views on space and time, the principles of physics, causality, and logical necessity directly from Mach's writings, and claims that in his later work, Wittgenstein adhered to what Visser calls 'Mach's method'.

Hintikka, very much in line with Visser, claims that 'if we subtract Boltzmann's and Hertz's influence, what remains of Wittgenstein's philosophy of science in the *Tractatus* is Mach's philosophy' (Hintikka 2001, p. 91), and specifically that Mach and the Wittgenstein of the *Tractatus* shared three major assumptions:

- That the *a priori* truths of logic and mathematics are empty
- A common take on solipsism
- And the idea that empirical science is purely descriptive

[2]This last claim, though, which is an exaggeration, I have addressed in (Preston 2006).

[3]Cook regards Mach's influence on Wittgenstein as disastrous, and interprets Wittgenstein as an empiricist, phenomenalist, behaviourist, and Humean. Because my concern here is only with logic and philosophy of science, and Cook's reading of Wittgenstein goes far beyond these, I leave that reading to be considered elsewhere.

These claims seem not to have been addressed by Wittgenstein scholars, but they do deserve attention, since Visser does present evidence, sufficient (I have found) to surprise such scholars, that Wittgenstein was well-acquainted with some of Mach's views. Here I intend critically to evaluate these claims insofar as they bear on logic and the philosophy of science,[4] and to show that their plausibility varies greatly. I shall argue that strong and *general* claims of positive influence are false, and also that Mach's influence was not, *pace* Visser, on the most important aspects of Wittgenstein's philosophy. But a more accurate picture of the Mach-Wittgenstein relationship will be an ambivalent one, and the received view is untenable.

5.4 Visser's General Picture of Wittgenstein as a 'Non-Kantian Philosopher'

The final chapter of one of the earliest books on the *Tractatus*, by Erik Stenius (Stenius 1960), was entitled 'Wittgenstein as a Kantian Philosopher'. Visser, partly on the basis of noting that Mach opposed some of the central conclusions of Kant's philosophy, claims that Wittgenstein was a '*non*-Kantian philosopher', considering anyone a Kantian 'when they agree with Kant's views on space, time, causality and ethics' (Visser 1981, p. 399). One might, of course, take issue with this criterion of being a Kantian. So, for example, some of those who have presented Wittgenstein's philosophy as having affinities with that of Kant (e.g., Hans-Johann Glock (Glock 1997)), have done so on the ground that he endorsed something like *Kant's conception of philosophy*, rather than any particular philosophical conclusions. But I think that, given Wittgenstein's own remark that it is in the notions of space, time and deity that 'the great problems of philosophy lie' (O'Drury in Fann 1978, p. 68), it would be churlish to disallow Visser's criterion of being a Kantian from the very outset. So while this criterion of being Kantian is partial and entirely optional, I propose to let it pass.

Inverting this criterion into a test for what it is to be a *non*-Kantian philosopher, though, is misconceived. Departing from the letter of his own criterion, Visser in effect takes philosophers to be *non*-Kantian if they reject the thing-in-itself, and then proceeds as if this is *enough* to label them Machian. But there are, to put it bluntly, far more ways of being a non-Kantian than by being a Machian: this criterion would make Machians of almost all of us (Hegelians would clearly count as such, for example).

Visser recognises that Wittgenstein did sometimes make Kantian noises, but claims that 'Wittgenstein's knowledge of the Kantian philosophy was not even based on first-hand study' (Visser ibid.). Strictly speaking, this is untrue. Wittgen-

[4]The idea that Wittgenstein's *Tractatus* follows Mach in its treatment of solipsism is certainly important, perhaps more so than the issues I am dealing with here. But I must leave that for another occasion.

stein is known to have read the *Critique of Pure Reason* when he was a prisoner of war in Como in the last months of 1918 (Monk 1990, p. 158). However, Visser has a good point here vis-à-vis the *Tractatus*, since Wittgenstein had finished the manuscript of that book a couple of months before he was taken into captivity by the Italians.

Visser also claims that 'for those of his remarks where a relation with Kant is suggested, it's easier to point to a later source than to Kant's writings' (Visser ibid.). This is a more plausible claim, but it does not *dissolve* the link between Wittgenstein and Kant.

One could, of course, try to reply to Visser's claim that Wittgenstein was a non-Kantian philosopher by showing that Kant was a significant positive influence on him. Newton Garver (Garver 1994) and Glock (Glock 1997), for example, have both argued this in some detail. But this doesn't constitute a reply to Visser's claim about *Mach* and Wittgenstein. To reply to this claim merely by showing that Wittgenstein was in some respects Kantian would be to beg the question against this particular opponent. One needs to show *either* that Wittgenstein got his supposedly Machian ideas from some Kantian source (Schopenhauer, Hertz, or Boltzmann, perhaps), *or* that these ideas were *not* Machian. And, surely the possibility that some of Wittgenstein's ideas were original to him should not, *pace* Wittgenstein himself, be dismissed!

5.5 Mach's Status, and the Nature of Visser's Claims

Visser's claims are *not* merely to the effect that Wittgenstein assimilated Machian views by general intellectual osmosis, as it were. It wouldn't be that surprising if Wittgenstein were thus influenced by Mach, since Mach was one of the most important intellectual figures during the last days of the Austro-Hungarian Empire, a towering figure at the turn of the nineteenth to twentieth century. As Professor of the History and Theory of the Inductive Sciences at the University of Vienna from 1895, he was *the* dominant figure in philosophy of science at the beginning of the twentieth century and a very prominent figure in Viennese intellectual culture at the time. 'Seldom has a scientist exerted such an influence upon his culture as has Ernst Mach', Janik and Toulmin quite rightly say (1973, p. 133).

Hintikka has even suggested that Mach was also '*the* central figure in the genesis of twentieth-century philosophy' (Hintikka 2001, p. 81, emphasis added). He has a better claim to this title than Frege, Hintikka argues, because his work influenced both analytical *and* phenomenological philosophies, and because 'Frege's direct influence on philosophy proper outside logic and the foundations of mathematics was minimal' (ibid.). Where Frege was, as Hintikka remarks, intellectually something of a loner, alienated from the main philosophical currents of his day, Mach, despite not being a professional philosopher, was at the centre of those currents because of his profuse links with other intellectuals. He was the central figure in the philosophical movement known as 'monism' (which gave rise to the journal, *The Monist*), devising the view later known as 'neutral monism' which was taken up by figures as important as William James and Bertrand Russell.

Mach was, by profession, an experimental physicist. But he was among the least narrow physicists there have ever been, since he regarded physics as having overreached itself, and as standing in urgent need of amendment and supplementation by other sciences, notably physiology, psychology, and biology. (This is what lay behind his idea of 'the unity of science', a slogan which the Logical Positivists took up, but which they understood differently). The question which concerned Mach most, as Hintikka says,

> the question of whether all our knowledge is based on what is directly given to us in sense perception – and perhaps even reducible to it – was *the* overarching issue in the philosophy of science in the early years of [the twentieth] century. It was not merely an issue concerning philosophy as an academic discipline. At issue was to a large extent the question of how natural sciences like physics should be done. (ibid., pp. 81–2, emphasis added).

Mach's views on this issue, as well as his contributions to that era's debates on sub-microscopic particles and on Einstein's theory of relativity, meant that he was the figure against whose background other scientists and philosophers took their bearings.

Visser's claims are to the effect that that there are *direct* and *specific* influences of Mach on Wittgenstein (see, for example, Visser 2001, p. 141). These are the claims that will be evaluated here.

5.6 The Motivation for Rejecting any Claim of Mach's Influence

In January 1913, Wittgenstein replied to two recent letters from Russell (letters that have not been preserved). Russell must have mentioned that he was reading Mach's *Contributions to the Analysis of Sensations*,[5] and Wittgenstein replied

> I was *very* interested to hear your views about matter, although I cannot imagine your way of working from sense-data forward. Mach writes such a horrid style that it makes me nearly sick to read him; however, I am very glad that you think so much of a countryman of mine (Wittgenstein 1995, p. 25).

While, in the light of this comment, and of his character, it is *a priori* implausible that Wittgenstein should have read *much* of Mach's work, I agree with Visser that Wittgenstein commentators have promoted this one relatively casual comment about Mach's style into a reason to ignore the question of influence. Whatever Wittgenstein had in mind when he made this comment, it doesn't veto the issue of possible influence.

[5] I am grateful here to Professor Kenneth Blackwell, of the Bertrand Russell Archives at McMaster University, who confirmed to me that Volume 7 of Russell's *Collected Papers* shows him using this book of Mach's early in 1913.

5.7 Philosophy of Physics – Visser's Central Claim

Visser claims that Wittgenstein was directly influenced by having read Mach: '[T]he similarity of Wittgenstein's remarks with some of Mach's popular-scientific arguments is so striking that one cannot but conclude that Wittgenstein had read at least some of the articles in Mach's *Populär-wissenschaftliche Vorlesungen*' (Visser 1982, p. 102). In fact he goes further, explicitly claiming that 'Wittgenstein in his philosophy of physics did little more than summarize parts of a few articles Mach wrote in his *Populär-wissenschaftliche Vorlesungen*' (ibid.), and thus that 'Wittgenstein's (early) "philosophy of science" was anything but original'.

5.8 Incongruous Counterparts

Visser's first topic is Wittgenstein's comments on what the latter calls 'Kant's problem' of the right and left hand which cannot be made to cover one another. Wittgenstein argues (Wittgenstein 1921; 6.36111) that this problem occurs already in the plane, and even in one-dimensional space; that the right and left hand are in fact completely congruent; and that a right-hand glove could be put on a left hand if it could be turned in four-dimensional space.

Visser supposes that Mach, in his article '*Eine Betrachtung über Zeit und Raum*' (Mach 1910), reprinted in the fourth edition of his *Populär-wissenschaftliche Vorlesungen*, made similar remarks. Visser says:

> according to Mach, [German mathematician and astronomer August Ferdinand] Möbius remarked about 1827 'that a linear figure *abc*, that can be seen as the symmetrical counterpart of $a'b'c'$ mirrored in *SS* on the same straight line, can never be made to cover the latter *on* this line; for this purpose one has to take the figure out of the straight line and turn it; in order to do that at least two dimensions are needed, so a plane' (Mach 1910, pp. 502–3). In addition Mach mentioned Möbius' generalisation, not only for triangles in a plane, but also for congruent three-dimensional bodies, that cannot be made to cover each other in any way in space: 'But one could do it, Möbius thinks, if one had a fourth dimension of space at disposal' (Mach ibid., p. 504) (Visser ibid., pp. 102–3).

Visser remarks that 'the correspondence with 6.36111 is so conspicuous that we may assume that Wittgenstein had read Mach's article' (ibid., p. 103, plus Visser 1981, p. 402), and that Wittgenstein 'borrowed his insights on this point from Ernst Mach' (ibid., p. 402).

Kant's discussion of incongruous counterparts occurs in his early writings and the *Prolegomena*, but *not* in the *Critique of Pure Reason*, the only work of his that Wittgenstein is known to have read. So Visser might seem to be on strong ground in suggesting that Wittgenstein read about this issue in Mach, not in Kant. It's possible that Wittgenstein read Kant's *Prolegomena*, even before the *Tractatus* was written. He does mention 'Kant's question "How is pure mathematics possible?"' early on in his notebooks, in a remark from October 1914 (Wittgenstein 1979a, p. 15), and not only is this question the 'main transcendental question' in the first part of the

Prolegomena, but it stands at the head of the group of paragraphs in which Kant introduces his 'paradox' of incongruous counterparts. However, that question also figures in the Introduction to the *Critique of Pure Reason* (Kant 1781/1787/1929, p. 56), and in the chapter on 'Kant's Theory of Space' in Russell's book *The Principles of Mathematics* (§433).

Neither need Wittgenstein have read Kant's works, or Mach's, to have encountered 'Kant's problem', for it was discussed in at least two texts he knew well, Schopenhauer's *Fourfold Root of the Principle of Sufficient Reason* (Schopenhauer 1813/1974), and Russell's *The Principles of Mathematics*.[6] Schopenhauer merely mentions the issue (in §§15, 36), and doesn't there present any solution, but two of the three central thoughts about this problem that Wittgenstein expresses are clearly already present in Russell's text. Russell writes:

> It is this distinction [between two different figures whose metrical properties are identical] which puzzled Kant, who, like most of his contemporaries, supposed all geometrical facts to be metrical. In itself, the fact would be no more puzzling than the distinction between the stretches *AB* and *BA*, which are metrically indistinguishable. (Russell 1903, §404).

This is what Wittgenstein means when he says (and tries to show, with his diagram) that Kant's problem exists even in one-dimensional space. In addition, Russell clearly expresses the view that to insist that no motion could transform a tetrahedron *abcd* into a tetrahedron metrically equivalent in every respect but with the opposite handedness would be 'merely a result of confining ourselves to three dimensions' (ibid.). This is picked up in Wittgenstein's final remark that 'A right-hand glove could be put on the left hand, if it could be turned round in four-dimensional space'. Interpretive simplicity ought to incline us to think, therefore, that Wittgenstein learnt of this issue from, and that his thoughts about it were under the influence of, his former mentor and collaborator Russell, rather than Mach.

Visser is aware of Russell's text, of course, but thinks Mach's book the more plausible source of the ideas in question, partly because Wittgenstein did not have Russell's book 'at hand' when he wrote the *Tractatus* (Visser 1981, p. 399). This is a curious reason for, firstly, we do not know exactly when Wittgenstein first formulated these ideas about incongruous counterparts (no ancestors of them appear in his *Notebooks*). And, secondly, whatever the period in question, there can surely be no *greater* presumption that Wittgenstein had Mach's *Popular Scientific Lectures* 'at hand' than Russell's book.

Visser could, of course, respond by claiming, not implausibly, that Russell himself was influenced by Mach in this respect. Mach's book was first published in 1896, Russell's in 1903. After all, the two thoughts I have ascribed to Russell *are* clearly present in the quotation from Mach. But although we know that Russell had read some of Mach's works, there is no evidence that he had read the essay in question here, and he does not seem to have owned a copy of Mach's book.

[6]Russell does mention Mach in this book, of course, but not any part of Mach's works in which this issue is discussed.

Another possible line of resistance against Visser would be to argue that Wittgenstein's thought is one that *ought* to have occurred to him, and could plausibly have done so *without* him having read Mach's article. However, the ideas being credited to Mach, Russell and Wittgenstein here have seemed weak to some commentators, and hence not ideas that *ought* to have occurred to Wittgenstein.

In the *Tractatus*, the context of the remark is a series of remarks in which Wittgenstein is trying to rule out non-tautologous necessary truths. It's fine to point out that the problem also occurs in two dimensions and even in one dimension, of course. But Robert Fogelin has argued that to go on to insist that right- and left-hands *are* congruent, even though they cannot be made to coincide (except by turning them inside out in a higher dimension) is tantamount to *redefining* the term 'congruent'. As a reply to a Kantian claim that the proposition that right- and left-hands are incongruous counterparts has a special status (e.g. that it is synthetic *a priori*), this might be seen as disappointing, for it involves an *ignoratio elenchi* (Fogelin 1987, p. 90) – it fails to address the original claim. (It also introduces a *new* proposition whose status is as unclear as the original: that right- and left-hands can't be transformed into one another *in three-dimensional space*). Whatever we decide to mean by 'congruent' (we can give Wittgenstein that term), it does seem that there's *some* failure to coincide which 'incongruous' counterparts exhibit, and their exhibiting it does look like a necessity. Wittgenstein's resort to the idea of turning the glove inside out in a higher dimension doesn't successfully show that the original claim was contingent. He would surely have been better advised to try to argue that the kind of necessity involved is (despite appearances, perhaps) logical. That he doesn't try to do so probably reflects the narrowness of the only notion of necessity available to him, the notion of a tautology (disguised or otherwise).

However, perhaps this reconstruction misses what Wittgenstein had in mind. He may instead have meant that 'Kant's problem' is a *pseudo*-problem, since it is (in his slightly technical sense of the term) *nonsense* to say that 'a right hand and left hand can't be made to coincide'. That is, it's nonsense in the same way as the way in which the alleged proposition 'one cannot hear a colour' is nonsense. There's no such thing as *hearing* a colour, and if (as Wittgenstein thought) meaningful propositions must at least give expression to *logical possibilities*, to say 'a right hand and left hand can't be made to coincide' is not even meaningful, even though, in ordinary terms, necessarily true.[7]

This *is* tempting, and it gives Wittgenstein an original point, beyond the ones he shares with Mach and Russell. The point is Machian in spirit, too. But two questions will swiftly arise. First, why would Wittgenstein say it is 'quite irrelevant' that 'they cannot be made to coincide'? If there's no such thing as 'making them coincide' that's not *irrelevant*, but nonsense since, for something to be 'quite irrelevant' it must at least be meaningful. Second, why would he have added the *final* clause of 6.36111, to the effect that one could put a right-hand glove on the left hand 'if it

[7]Here I am grateful to my colleagues Severin Schroeder and David Mutch. For a change in Wittgenstein's attitude towards such 'nonsense', see Wittgenstein 1975, p. 53.

could be turned round in four-dimensional space'? If the idea of a fourth dimension is *conceivable*, and not itself a nonsense, this remark makes the original idea that right and left hands 'cannot be made to coincide' look *contingently* false! I'm not convinced, therefore, that this way of getting Wittgenstein out of the difficulty will work.

5.9 Time, Difference, and Changes

Visser continues thus:

> But there is still more: in 6.3611 Wittgenstein speaks of time-measurement and on the necessity of asymmetries in world-descriptions. These remarks also seem to be inspired by Mach, who remarked in the aforementioned article [Mach 1910] that the time-measurements of the natural scientist rest upon comparison of mutual changes and that nothing happens without differences (Visser 1982, p. 103, plus Visser 1981, p. 403).

Wittgenstein *is* making a point about the necessity of differences in 6.3611, although that point doesn't occur in that proposition's remark on time. On the subject of time, Wittgenstein simply says:

> We cannot compare a process with "the passage of time" – there is no such thing – but only with another process (such as the working of a chronometer). Hence we can describe the lapse of time only by relying on some other process.

Visser is absolutely right about there being a connection with Mach's views here though. First, although Visser does not mention it, the thought expressed in the paragraph just quoted clearly occurs in a long paragraph of *The Science of Mechanics*, where Mach says that, on the Newtonian conception, which he opposes

> Time . . . appears to be some particular and independent thing, on the progress of which the position of the pendulum depends, while the things that we resort to for comparison and choose at random appear to play a wholly collateral part. But we must not forget that all things in the world are connected with one another and depend on one another, and that we ourselves and all our thoughts are also a part of nature. It is utterly beyond our power to *measure* the changes of things by *time*. (Mach 1883/1960, p. 273).

By speaking of this as 'beyond our power' Mach is being ironic – he soon makes it amply clear that 'the question of whether a motion is *in itself* uniform, is senseless', and that the notion of absolute time is 'an idle metaphysical conception' (ibid.).

Second, Visser argues that what Mach says in this same 1910 article '*Eine Betrachtung über Zeit und Raum*' makes clear the connection between proposition 6.3611 and its immediate forerunner, 6.361, a connection which has sometimes eluded commentators. In 6.36, the parent of both remarks, Wittgenstein declares that the law of causality cannot be said, but makes itself manifest. Proposition 6.361 then seems to find a thinkable thought in the aftermath of this realisation, that thought being that 'only connections that are *subject to law* are *thinkable'*. Visser takes this to be illuminated by Mach, who said in that article:

> Should something happen in the physicalistic world, should changes be introduced, then differences are quite necessary, as J.R.Mayer already knew: differences of temperature, differences of pressure, of electric charge, differences of height of heavy bodies, chemical differences, etc. Without differences nothing happens, nay we could not think out a reasonable rule, according to which something would occur in this world, without differences. Therefore Mayer has called these differences simply forces (Mach 1910, pp. 499–500).

Visser claims, not implausibly, that Wittgenstein's idea in proposition 6.3611 merely changes Mayer's 'difference' into 'asymmetry' and 'force' into 'cause', giving us the thought that without asymmetries there can be no causes (Visser 1982, p. 103).[8] It is true that Wittgenstein goes on to give us a *diagnosis* of this situation. According to him, unless there is some difference between two events, we are simply unable to describe, and thus unable to *conceive*, the one as opposed to the other. But the idea with which Mach credits Mayer ('we could not *think out* a reasonable rule, according to which something would occur, without differences') already contains this. Does Wittgenstein add anything extra? He could, I suppose, be thought of as adverting to a sort of Leibnizian context for the view in question. And he does, of course, in 6.36 and 6.361 explicitly state a general *rationale* for the view, which Mach does not begin to do.

However, although Visser doesn't mention it, the remarkable thing about 6.3611, as we shall see, is its similarity to what Mach does in chapter II of his book *Die Principien der Wärmelehre* (Mach 1896/1986), a chapter we know that Wittgenstein had encountered. (As we shall see later, what we know is that Wittgenstein had read that chapter *by* 1946. Of course it is possible that he read it after the *Tractatus* had been published. But the idea that he read Mach between 1920 and 1946 doesn't comport well with his 1913 declaration to Russell that reading Mach nearly made him sick).

5.10 Physical Principles

Visser then claims that in order to demonstrate his thesis that the *a priori* certain is only something purely logical (6.3211), Wittgenstein discusses the form of certain physical principles, and that Mach anticipated Wittgenstein's discussion when he showed that the principle of energy conservation also has a logical root (Visser 1982, p. 103). He quotes these passages from Mach's essay 'On the Principle of the Conservation of Energy', where Mach discusses this principle in the form of the principle of the excluded *perpetuum mobile*:

> Let us assume on the basis of experience, that a group of sensuous elements $\alpha, \beta, \gamma \ldots$ unequivocally determines another group $\lambda, \mu, \nu \ldots$ and that experience also teaches that changes of $\alpha, \beta, \gamma \ldots$ can be undone. Then it is a logical consequence of this, that every time, when $\alpha, \beta, \gamma \ldots$ take the same values, so do $\lambda, \mu, \nu \ldots$ or, that merely periodical

[8]The connection between these remarks and Wittgenstein's later discussions of plants of different kinds coming from identical seeds is striking.

> changes of α, β, γ ... cannot have a lasting change on λ, μ, ν ... Now if the group λ, μ, ν ... is a mechanical one, then thereby the *perpetuum mobile* is excluded. (Mach 1895, p. 181).

> Thereby the logical root of the principle of the excluded *perpetuum mobile* is indicated too, that is, the general conviction, which even existed before the elaboration of mechanics and which had its effects on it. It is natural that the principle of the excluded *perpetuum mobile* came to be recognized first of all in the simpler field of pure mechanics. (ibid., p. 182).

We should grant that this does show that Mach, like Wittgenstein, thought of certain high-level physical principles as having a *logical* aspect. When Mach speaks of that logical aspect being a 'root' undoubtedly what he has in mind, though, as exhibited in the second passage quoted above, is partly a certain *genetic-historical* relation – much of Mach's work, after all, consisted in tracing such historical connections. This might seem deeply un-Wittgensteinian, but actually the idea is not totally foreign to Wittgenstein. *A propos* of a similar physical principle, the 'law of least action', he remarks that people surmised that there must be such a law even before they knew exactly how it went, and it is immediately after this that he adds that this knowledge 'proves to be something purely logical' (6.3211).

That there is a similarity between their ideas here I think is evident, so Visser is right to say that Wittgenstein's idea would be 'nothing new for anyone who read Mach in his evaluation of the conclusion that the principle of the excluded *perpetuum mobile* has also a logical root' (Visser 1982, p. 104). But we ought not to go further to say that they had the same view. For that, should be precluded both by the fact that, for Wittgenstein, this past history could only be weak evidence for the law of least action's being a 'purely logical' principle and, as as we shall soon see, by reflection on what Mach *meant* when he spoke of 'logical consequence'.

5.11 Logical Necessity

In the *Tractatus* Wittgenstein famously says 'There is only *logical* necessity' (6.37). Visser (Visser 1982, p. 104) contends that this important thought is prefigured by Mach, who in his *Wärmelehre* wrote that 'Any other than a logical necessity – a physical one, say – does not exist' (Mach 1896/1986, p. 395).

Visser is right that Mach and Wittgenstein would both have insisted that there is only logical necessity. Mach was just as vociferous as Wittgenstein in denying the existence of *other* supposed kinds of necessity. Discussing Hertz's critique of previous systems of mechanics, he says:

> The agreement of [...] concepts with one another is a requirement that is logically necessary, and this logical necessity, furthermore, is the only necessity that *we* have knowledge of. The belief in a necessity obtaining in nature arises only in cases where our concepts are closely enough adapted to nature to ensure a correspondence between the logical inference and the fact. But the assumption of an adequate adaptation of our ideas can be refuted at any moment by experience. (Mach (1883/1960), p. 318).

And again, in *The Analysis of Sensations* Mach claims that even if we acquire ‘conceptions which we think correspond to the facts universally’, and ‘we are logically bound to expect that any particular fact which may present itself will correspond to these conceptions .... this implies no necessity in nature’ (Mach 1886/1914, pp. 86–7).

Is there, though, any evidence that Wittgenstein got the idea that logical necessity is the only kind of necessity *from Mach*? Mach’s explicit pronouncement is, after all, buried away in the *Wärmelehre*, and one might well think that there is no reason whatever to think that Wittgenstein read this particular book of Mach’s. One might well protest that it’s not hard to imagine *other* possible sources for the view in question. One might, for example, think that Wittgenstein could have got the view that there is only logical necessity straight from Kant. Kant’s view was that any necessity in things is put there by us, imposed by the mind: ‘[a]bsolute necessity is a necessity that is to be found in thought alone’ (Kant 1781/1787/1929, A617/B645). ‘The concept of necessity is only to be found in our reason, as a formal condition of thought; it does not allow of being hypostatised as a material condition of existence’ (ibid., A620/B648).[9] However, although the idea does not occur in Wittgenstein’s *Notebooks*, it *does* occur already in the *Proto-Tractatus* (Wittgenstein 1971, 6.37), which was written significantly earlier than the point at which Wittgenstein was captured as a prisoner of war, and therefore earlier than when he read the *Critique of Pure Reason*. So Kant cannot be its source.

A more plausible alternative is that Wittgenstein might have got this view of necessity, not from Kant himself, but from the post-Kantian thinkers whose works he knew. So, might he have found it in Schopenhauer, or Hertz, or Boltzmann?

The same text which I mentioned earlier, Schopenhauer’s *On the Fourfold Root of the Principle of Sufficient Reason*, supplies ample evidence that this view could not have come from him. In §49 of that book Schopenhauer clearly states that there are four kinds of necessity: logical, physical, mathematical, and moral. Even if we set aside mathematical necessity (on the grounds that it might reduce to logical necessity) and moral necessity, Schopenhauer’s inclusion of *physical* necessity makes his view diametrically opposed to Wittgenstein’s.

Hertz does talk about necessary consequences of our images, ‘necessities of thought’, and ‘necessary consequences of our thought’ (pp. 1, 5, 8, 9), but he also talks of ‘necessary consequents *in nature* of the things pictures’ (p. 1, emphasis added). While he nowhere discusses kinds of necessity, his admission of necessities in nature means he cannot be the source of Wittgenstein’s view. Neither, finally, could Wittgenstein have got his conception of logic or logical necessity from Boltzmann. Boltzmann’s conception of logic is fully naturalistic, much more like Mach’s than like Hertz’s (or Kant’s).

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[9] Visser claims that *Russell* endorsed the idea that the only necessity is logical necessity, and also claims that this is ‘an un-Kantian view’ (Visser 1981, p. 400). But what he quotes from Russell there does not establish the former claim, and the latter characterisation is mistaken.

Mach still stands, therefore, as the most plausible precursor of Wittgenstein's whose insistence that logical necessity is the only kind of necessity Wittgenstein *might* have encountered. This suggestion of Visser's is as yet undefeated.

5.12 Mach's Traditional Conception of Logic, and his Psychologism

More important than these matters of possible direct influence, though, is the fact that in saying that there is only logical necessity, Mach and Wittgenstein *could not have meant the same thing*.

Hintikka's first claim, that Mach and the Wittgenstein of the *Tractatus* shared the idea that the *a priori* truths of logic and mathematics are empty is acceptable as far as it goes. Mach does occasionally express the familiar idea that the 'forms of logic', which he thinks as as abstracted from instances of scientific thought, are 'empty' or 'purely formal' (e.g., Mach 1896/1910, p. 140; Mach 1905/1976, p. 131). However, this idea simply doesn't go very far, since it was a commonplace, being an aspect of the familiar idea that logic is, as far as finding new lines of thought goes, infertile. This is the burden of the first sections of Mach's most extended discussion of logic, the chapter of *Knowledge and Error* entitled 'Deduction and Induction, Psychologically Viewed'. Mach argues that syllogistic inference (which he contrasts with induction) gives no new knowledge, that 'the rules of logic . . . serve only to examine whether findings drawn from other sources agree or disagree, and, if the latter, to point to the need to secure full agreement' (Mach 1905/1976, p. 225. See also p. 231). He agrees with John Stuart Mill's observation that such inference cannot give us insights that we did not have already, and he finds the value of deduction to lie in making it easier to grasp ideas by identifying their separate elements (ibid., p. 227).

As soon as we strengthen the idea that logic is investigatorily infertile into the idea that truths of logic are *tautologies*, the difference between Wittgenstein and his predecessors becomes clear. When Russell, for example, talks of 'tautology' and 'tautologies' in *The Principles of Mathematics* he is either referring to what he calls the 'law of tautology', according to which 'no change is made when a class or proposition is added to or multiplied by itself' (Russell 1903, §26), *or* he is taking pains to suggest that the logical axioms he is discussing are *not* tautologies (e.g., §§153, 264, 322, 457). It was Wittgenstein who, towards the end of 1913, first explained in a letter to Russell that the set of propositions of logic and the set of generalizations of tautologies are co-extensive (see also Kneale and Kneale 1962, pp. 629–30).

What's more, the bare idea that the truths of logic are empty is only a fraction of the story about logic, since it ignores Mach's *psychologism* about logic, a theme which, as I shall now show, persists throughout his published writings. One of its clearest expressions occurs in *The Science of Mechanics*, in response to the animadversions against Mach's method of mental economy which Edmund Husserl presented in his *Logical Investigations* (1900). There Mach says, of his own method of inquiry:

> In this inquiry, I found it helpful and restraining to look upon every-day thinking and science in general, as a biological and organic phenomenon, in which logical thinking assumed the position of an ideal limiting case. I do not doubt for a moment that the investigation can be begun at both ends. I have also described my efforts as epistemological sketches. It may be seen from this that I am perfectly able to distinguish between psychological and logical questions, as I believe everyone else is who has ever felt the necessity of examining logical processes from the psychological side. But it is doubtful if any one who has read carefully even so much as the logical analysis of Newton's enunciations in my *Mechanics* [pp. 298–305], will have the temerity to say that I have endeavoured to erase all distinctions between the 'blind' natural thinking of every-day life and logical thinking. Even if the logical analysis of all the sciences were complete, the biologico-psychological investigation of their development would continue to remain a necessity for me, which would not exclude our making a new logical analysis of this last investigation. (Mach 1883/1960, pp. 593–4).

It would be difficult to argue that Mach had any *clear* conception of logic. But this is because (by our lights, of course) no-one had such a conception prior to Frege. Mach was one of the last figures for whom 'logic' referred primarily not to formal or symbolic logic but to the epistemology and methodology of scientific thinking. Major figures in this tradition such as Aristotle, Francis Bacon, and John Stuart Mill devoted works to 'logic' which we now think of as works in the philosophy of science. (These are just the figures which the aforementioned chapter XVIII of *Knowledge and Error* discusses. John Dewey's *Logic: The Theory of Inquiry* was perhaps the last major work to understand itself in this way). For Mach 'logic' would therefore have encompassed some things we might think of as related to logic (his 'logical analysis of Newton's enunciations', as mentioned above, falls within what we think of as conceptual analysis, for example). But he conceived logic as a *process* or *activity* that forms part of science (e.g., Mach 1886/1914, p. 365, Mach 1896/1910, p. 190). The ideal he takes to govern scientific activity, for example, mental economy, he calls a 'very clear logical ideal' (Mach 1883/1960, p. 594).

When he goes into matters in more detail, Mach's psychologism becomes even more apparent. In his *Wärmelehre*, he explicitly declares that logical analysis is 'founded upon' psychological analysis (Mach 1896/1986, p. 67). Mach does sometimes contrast logical with physical necessity, it is true (as we saw above, from Mach 1896/1986, p. 395; see also Mach 1886/1897, p. 87), but by the former he clearly means *psychological* necessity since (as Kevin Mulligan and Barry Smith notice (Mulligan and Smith 1988, p. 146)) he explains it in terms of defeasible expectations:

> There is only logical necessity: if certain properties hold of a fact... then I cannot simultaneously ignore this. That they hold is simply an experiential fact. There is no such thing as physical necessity. (Mach 1896/1986, p. 437 (here given in Mulligan & Smith's translation)).

Finally, in the last and most developed presentation of his epistemological views, *Knowledge and Error*, Mach still envisages a link between logic and psychology:

> Since logic has to use language it has to make do with the historically transmitted grammatical forms, which are not at all parallel to psychological events. How far a logic that uses an artificial ad hoc language can free itself from this mismatch and follow psychological events more closely will not be discussed here. (Mach 1905/1976, pp. 82–3).

Footnotes to this passage contains references to logic texts by Stöhr, Boole, and Schroeder. Mach was aware of the new developments he called 'symbolic logic' – he even mentions Russell (ibid., pp. 131–2). But the last clause of the passage shows amply how psychologistic was his conception of logic, and the issue is surely sealed with his declaration that logical facts are included among 'mental facts' (ibid., p. 90, note 13).

As a result of taking on the traditional conception of logic, Mach just didn't have a *clear* enough conception of logic to enable us to claim any real kinship with the (exceptionally clear) conception present in the *Tractatus*.

Erik Banks has claimed, further, that Mach thought of the laws of logic as 'very general natural laws, proved for large classes of objects' (Banks 2004, p. 32). This is exactly the conception of logic which Wittgenstein very clearly *opposed* in the *Tractatus*. In the group of propositions where he explains the nature of logic (TLP 6.1 onwards), Wittgenstein insists that the propositions of logic must be *absolutely distinct from all other kinds of propositions*: 'The correct explanation of the propositions of logic must assign to them a *unique* status among all propositions' (6.112, my emphasis; see also 6.111, 6.113, 6.1222), and he takes the opportunity specifically to renounce this aspect of the conception of logic that Mach shared with Russell and Frege: 'The mark of a logical proposition is *not* general validity. To be general means no more than to be accidentally valid for all things' (6.1231, emphasis added).

So even if one can, as Visser rightly claims, identify similar formulations in Mach and Wittgenstein, these amount to common *views* only if their conceptual situations have enough in common. But with Mach and Wittgenstein, they don't. Mach had a conception of logic that was traditional, *pre-Fregean* and, frankly, primitive compared to that of Wittgenstein. I don't mean to single him out unfairly here: all the other post-Kantian thinkers I mentioned shared the psychologistic conception of logic, which was still popular until the end of the nineteenth century.[10] Even Frege, who clearly opposed psychologism, still thought that logic had a subject-matter. But Wittgenstein's distance from these ideas does mean that he can't be saddled with the same view of logic or, consequently, of logical necessity as Mach, even though they used very similar slogans. One of the early Wittgenstein's best claims to originality lies in his conception of logic.

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[10]Martin Kusch's in-depth study *Psychologism* (Kusch 1995), shows that this psychologistic conception wasn't ubiquitous. But Kusch supplies no evidence that Mach wasn't psychologistic, and his chart (p. 97) shows that Mach was one of a long list of thinkers most often labelled psychologistic (fourth most often, behind only Husserl, Theodor Lipps, and J.S.Mill).

5.13 Science as Descriptive

Hintikka's third claim was that Mach and Wittgenstein share the idea that empirical science is purely descriptive (Hintikka 2001, p. 91). Visser, likewise, claims that 'both Mach and Wittgenstein held that scientific laws merely describe and do not explain' (Visser 2001, p. 153). Both of them, it's true, treat straightforwardly low-level empirical propositions as descriptions ('*Bilder'*, for Wittgenstein). And to characterize their conceptions of science *in general* as descriptive also seems unproblematic. However, this is not to say that either of them would have thought of all categories of statements deployed in science as descriptive. The ways in which they understand laws of nature, in particular, need to be noted, since they do not all fit Hintikka's picture.

5.14 The Laws of Nature – Mach

When it comes to the laws of nature, Mach does not always run the same line, and interpretations of what he is saying vary quite widely.

Banks, for example, has suggested that for Mach science is 'a mere tabulation of experiences, *and should not involve laws at all*' (Banks 2004, p. 40, emphasis added). Although Banks is undoubtedly right to understand Mach as some kind of anti-realist about laws, I don't think this can be the right reading of what he says about them.

First, the evidence Banks refers to for this 'no laws' view is slight. In the place in question, Mach argues that there are two ways of bringing someone to know any phenomenon or process of nature: allowing them to observe the matter for themselves, and describing those phenomena or processes to them. The second route, Mach argues, involves the communication of laws, since '[d]escription . . . is only possible of events that constantly recur' (Mach 1883/1960, p. 6). But to point out that there is *another* way of knowing about phenomena, other than the one involving laws, is not to say or imply that science can do without laws.

In a later discussion of a specific law, from the same book, Mach assures us that 'In nature there is no *law* of refraction, only different cases of refraction' (Mach 1883/1960, p. 582). If we generalise this, is it another piece of evidence for the 'no laws' view? It does comport with his refusal to endorse what he thought of as the 'usual' idea that the laws of nature are 'rules, which processes in nature must obey' (Mach 1905/1976, p. 351). No doubt it is correct to think of Mach as resisting the idea that laws exist *in rerum natura*. That, for him, would undoubtedly sound metaphysical. But this is not to say that for him science shouldn't, or doesn't, involve laws.

Second, Mach's works, early and late, simply contain too many non-dismissive discussions of and references to laws. So, for example, in the 'General Remarks' at the end of his first book, on the history and root of the principle of energy conservation, Mach says that the problem of science can be split into three parts, two of which involve laws:

> 2. The discovery of the laws of the connection of sensations (perceptions). This is physics.
>
> 3. The clear establishment of the laws of the connection of sensations and presentations. This is psychophysics. (Mach 1895, p. 91).

It's strange that Visser doesn't notice a point which would be grist to his mill, that the account of the laws of nature in the *Tractatus* has a parallel in Mach. This sounds *a priori* unlikely, for Wittgenstein's treatment of laws there contrasts them with the category into which Mach often put laws, that is, the category of descriptions. When he discusses the nature of laws (rather than merely discussing individual laws, which of course his 'critical-historical' books do in great profusion) Mach sometimes pretty clearly runs the 'descriptivist' line (derived from Gustav Kirchhoff), according to which scientific laws and theories are (maximally economical) descriptions of facts. So, for example, in his flagship essay 'The Economical Nature of Physical Inquiry', the *locus classicus* for his general philosophy of science, he explicitly conceives laws as concise, abridged descriptions, 'comprehensive and condensed reports about facts' (Mach 1882, pp. 193–4):

> The communication of scientific knowledge always involves description, that is, a mimetic reproduction of facts in thought, the object of which is to replace and save the trouble of new experience. Again, to save the labor of instruction and of acquisition, concise, abridged description is sought. *This is really all that natural laws are*. Knowing the value of the acceleration of gravity, and Galileo's laws of descent, we possess simple and compendious directions for reproducing in thought all possible motions of falling bodies. A formula of this kind is a complete substitute for a full table of motions of descent (ibid., pp. 192–3, emphasis added).

In 'On the Principle of Comparison in Physics', likewise, laws are characterised as 'not essentially different from descriptions' (ibid., p. 254).

At other times, though, Mach seems to conceive of laws as rules or as norms. So, for example, in *The Science of Mechanics*, trying to show that the principle of the conservation of energy is a general condition of sound logical and scientific thought, he says

> The business of science is the reconstruction of facts in thought, or the abstract quantitative expression of facts. The rules which we form for these reconstructions are the laws of nature. In the conviction that such rules are possible lies the law of causality. The law of causality simply asserts that the phenomena of nature are *dependent* on one another. (Mach 1883/1960, p. 604).

In that same book, discussing the economical character of sciences, he says

> The so-called descriptive sciences [Mach has in mind geometry and mathematics] must chiefly remain content with reconstructing individual facts. Where it is possible, the common features of many facts are once for all placed in relief. But in sciences that are more highly developed [and Mach undoubtedly considered mechanics to be one such], rules for the reconstruction of great numbers of facts may be embodied in a *single* expression (ibid., p. 582).

He then gives as an example the formula we think of as expressing the law of refraction. I quoted the first part of this passage above, but what it goes on to say is notable:

> In nature there is no *law* of refraction, only different cases of refraction. The law of refraction is a concise compendious rule, devised by us for the mental reconstruction of a fact, and only for its reconstruction in part, that is, on its geometrical side (ibid.).

(Perhaps the occasion on which he talks of laws as 'mere means of facilitating' the representation of facts in thought (Mach 1886/1914, p. 315), should be included here, too. For another occasion on which he conceives of laws as rules see Mach 1896/1986, p. 396, and for one where he assimilates to norms see Mach 1886/1914, p. 316).

There are also occasions on which Mach seems to conceive of laws as at the same time both descriptions *and* rules (e.g., Mach 1896/1910, p. 256, plus Mach 1886/1914, pp. 58, 316). This is confusing for us since twentieth-century philosophy has emphasised a distinction here. If one had to sum up the conception which Mach generally held to, though, I think it would be right to say that his governing idea is that scientific laws do have a rule-like character, but that although they cannot be thought of as rules which phenomena themselves obey, rules which 'govern' the phenomena themselves (Mach 1905/1976, p. 351), they can be thought of as rules governing our *own* (scientific) activity, viz., rules for reconstructing descriptions of facts.

Mach does also seem to have had a change of mind about the nature of laws, and this was a move away from the 'descriptivist' conception. In his last major discussion of the matter, the chapter from *Knowledge and Error* on 'The Sense and Value of the Laws of Nature', Mach consciously and explicitly distanced himself from applying the term 'description' to laws, by suggesting instead that laws are 'restrictions... which we prescribe to our expectations' (Mach 1905/1976, p. 351). This expression, he declared, points to 'the biological importance of the laws of nature' (ibid., p. 352). Although this final, psychological conception is clearly incompatible with thinking of laws as descriptions, it seems to me not incompatible with thinking of them as rules for reconstructing descriptions.

5.15 The Laws of Nature – Wittgenstein

What about Wittgenstein, specifically, the Wittgenstein of the *Tractatus*? Wittgenstein did not endorse the descriptivist reading of laws there. However they are rightly interpreted in detail, propositions 6.34ff. clearly put the laws of mechanics (at least) into a non-descriptive category, since 'The possibility of describing the world by means of Newtonian mechanics tells us *nothing* about the picture' (6.342, emphasis added). And the category into which these remarks put the laws of mechanics seems to be an 'instrumental' one: they are not descriptions but *description-generators*.[11] The role of the laws of mechanics is to 'impose a unified form on the description of the world' (6.341), so although there *is* such a thing as describing the world using mechanics, it is not mechanics itself that describes the world.

In the passages from Mach concerning laws of nature there are *two* ideas that bear comparison with the *Tractatus*. First, Mach's idea that 'The law of causality simply asserts that the phenomena of nature are *dependent* on one another' seems to express the same attitude that Wittgenstein takes to causality, especially in propositions 6.32, which says that 'The law of causality is not a law but the form of a law', and 6.36, which tells us that 'If there were a law of causality, it might be put in the following way: There are laws of nature'. This, I believe, is a *better* connection between Mach and *Tractatus* 6.32 than the one Visser supposes on this issue, which is with Mach's discussion of the logical root of the principle of energy conservation (Visser 1982, p. 103, plus Visser 2001, p. 144).

Second, Mach's identification of laws of nature as *rules* (rather than descriptions) seems eminently comparable to propositions 6.341 and 6.342 of Wittgenstein's text, in which he discusses Newtonian mechanics. It is true that those sections do not explicitly involve the conception of laws as rules. But this conception is implicit in the idea that laws are our means for generating descriptions (for any such means will have the character of a direction or rule). And the rule-conception became explicit quite soon after Wittgenstein returned to philosophy, for instance in a lecture of 1932–1933 in which he declared that

> [when] we believe we are dealing with a natural law *a priori*... we are dealing with a norm of expression that we ourselves have fixed. Whenever we say that something must be the case we have given an indication of a rule for the regulation of our expression (Wittgenstein 1979b, p. 16).

Wittgenstein seemed to think that this conception was to be found in Hertz's book *The Principles of Mechanics*, for it arises, within his own lecture, out of a discussion of Hertz's 'invisible masses'. In an earlier paper (Preston 2008) I argued that this conception is not really present in Hertz's text. If one insists on finding a plausible ancestor for this alternative, 'instrumentalist' conception of laws, Mach is the better candidate. Whether or not he was aware of Mach's discussions of laws, Wittgenstein's innovation could be said to have been to tease apart the two incompatible conceptions of scientific laws which Mach had not really distinguished.

[11] I would argue that this is a general idea Wittgenstein hangs onto in his transitional works, where he uses various metaphors to explain the general idea that 'hypotheses' are, as it were, *of a higher dimension than* 'propositions'.

5.16 Wittgenstein's Use of 'Mach's Method'?

Finally, the main claim that Visser makes about Wittgenstein's middle and later philosophies is the most easy to deal with. The central claim of his 1983 article is that Wittgenstein's post-*Tractatus* philosophies follow 'Mach's method', by which he means the method of thought-experiments. Taking this 'method' to cover Wittgenstein's use of language games, Visser finds that 'nowhere are more thought experiments to be found than in Wittgenstein's later writings' (Visser 1983, p. 529). And he claims that Wittgenstein also endorsed a certain 'principle' which Mach had discerned in the development of science, the principle that science grows by means of comparisons (ibid., p. 531).

I will argue that (a) Wittgenstein did sometimes use what we now think of as philosophical thought-experiments, but that this should not be thought of as resulting from Mach's influence, and that (b) *another* philosophical method, which Wittgenstein associates with Hertz, is the one that he himself (also) associated with Mach.

Wittgenstein was certainly aware of Mach's discussions of thought-experiments. In the *Philosophical Remarks* he says 'What Mach calls a thought experiment is of course not an experiment at all. At bottom it is a grammatical investigation' (Wittgenstein 1975, p. 52). And a footnote here (by Rush Rhees) refers us to pages 186 and 191 of Mach's *Erkenntnis und Irrtum*, which fall within his chapter XI, 'On Thought-Experiments'.

Mach first published most of the material in this chapter as an article in Poske's *Zeitschrift für den physikalischen und chemischen Unterricht*, in 1896 (see Mach 1905/1976), p. 146, note). Wittgenstein would not have come across this in his family home, since they did not receive journals or offprints. But perhaps he could have read it during his time (1906–1908) at the Technische Hochschule in Berlin (which is where that journal was published). It would, after all, be surprising if Germany's major technical college did not subscribe to that journal. Or perhaps the Wittgenstein family owned a copy of *Erkenntnis und Irrtum*, the first and second editions of which were published in 1905 and 1906.

One cannot deny that Wittgenstein often introduced what we now think of as philosophical thought-experiments. But this should not be thought of as resulting from Mach's influence, for several reasons. First, Mach was primarily concerned with the use of thought-experiments in *science*, not in philosophy. Although he did occasionally advert to philosophical thought-experiments (e.g. he contemplates the idea of what we would call a 'cerebroscope' (Mach 1886/1914, p. 242)), Mach was *far* more concerned with thought-experiments in science and its history. (The example Visser gives, in which Mach asks us to imagine swimming in a stream of positive electrons (Visser 1983, p. 529, citing Mach 1910b) is one such). So when Visser says that Mach 'was the first to estimate the methodological significance of these thought experiments' (Visser ibid., p. 529), his claim is implausible if by 'these' he means thought-experiments in *philosophy* (as the context seems to suggest). Second, the historical prevalence of thought-experiments in philosophy (e.g., in Plato, Descartes, Locke) makes it anachronistic and presumptuous to call their use 'Mach's method'. Mach's attitude to thought-experiments was not always positive, either. Sometimes he was suspicious of their use as, for example, when he objected to Newtonians who ask us to consider a universe in which only the earth exists that 'the universe is not *twice* given, with an earth at rest and and earth in motion; but only *once*, with its *relative* motions alone determinable' (Mach 1883/1960, p. 284). Third, to count any philosopher who uses thought-experiments as a Machian too quickly makes Machians of us *all*, at least all 'analytic' philosophers and Wittgensteinians. Fourth and finally, Wittgenstein, like contemporary philosophers, used thought-experiments to make points about what is *logically possible*, which was not Mach's concern (see Mach 1905/1976, p. 139). This is absolutely clear from the reference Wittgenstein makes to Mach in the *Philosophical Remarks*. What Wittgenstein says there, that Mach misconceives the nature of thought-experiments, adds no weight to Visser's case that he was positively influenced by Mach. And the points that emerge from Wittgenstein's use of thought-experiments are often of a kind that an empiricist as staunch as Mach could not accept.

5.17 Hertz's Method, and Mach's

Nevertheless, Visser is right to flag up the issue of a similarity in philosophical method between Wittgenstein and Mach. There are two slim pieces of evidence here that none of the commentators who have pronounced on Mach and Wittgenstein have discussed. At a meeting of Cambridge University's Moral Science Club, on November 14th, 1946, Wittgenstein is reported as having said that a philosophical question is addressed not by giving an explicit answer to it, but by showing how it is muddled, and therefore should not have been asked. The general form of a philosophical question, he said, is 'I am in a muddle; I don't know my way'. And he went on to give as an example what Mach did in connection with the muddle about 'temperature' (Wittgenstein 2003, p. 399).

And then again, shortly afterwards, in one of his 'Saturday discussions', Wittgenstein is reported to have compared problems concerning temperature (e.g., what is temperature?) to philosophical problems:

> Scientists puzzled themselves about temperature, as to why one substance (say, water) should expand so irregularly with increase of temperature, and others not. However Mach pointed out that all they were doing was to compare the expansion of one substance with another, the water with the mercury in the tube, etc. Notice how the perplexity vanishes when what was a problem appears in this new light (ibid., p. 402).

These reports establish that Wittgenstein had, by 1946 at least, read the relevant part of Mach's *Wärmelehre* (pp. 53–6 of Mach's book, in its 1986 English translation).[12] It is worth taking time to see what Mach did there 'in connection with the muddle about "temperature"'.

In the chapter in question, the second chapter of his *Principles of the Theory of Heat*, Mach is discussing how humans came to move beyond the mere fact that we have sensations of heat and cold to the point at which we are able to *measure* temperatures. Scientists discovered that the *volume* of certain substances, being temperature-dependent, could be used as a measure of temperature. There was still the question of which substances to choose, though. The scientists Mach has in mind chose *gases* as their thermoscopic substances. Mach comments:

> When attention was directed to the like behaviour of gases under the same thermal conditions, the choice of a gas as a standard thermoscopic substance was, by reason of this property, regarded as less conventional and as having roots in the nature of things. But while it will appear that this opinion is erroneous, yet there are other reasons which make sense for this choice, which was a felicitous one though at the time it was made no one could have been aware of this fact. (Mach 1896/1986, p. 51).

A little later, we see why Mach deems the first-stated reason for choosing gases, their offering a more natural and less conventional measure, erroneous:

> It is remarkable how long a period elapsed before it definitely dawned upon inquirers that the designation of thermal states by numbers rests on a convention. Thermal states exist in nature, but the conception of temperature exists only by virtue of our arbitrary *definition*, which might very well have taken another form. Yet until very recently inquirers in this field appear more or less unconsciously to have sought after a *natural* measure of temperature, a real temperature, a sort of Platonic Idea of temperature, of which the temperatures read from the thermometric scales were only the imperfect and inexact expression. (ibid., pp. 53–4).

The point Mach is making here is perhaps best made by one of the scientists he quotes, Johann Heinrich Lambert: 'Inquirers doubted whether the *actual* degrees of heat were in reality proportional to the degrees of the expansion [of the thermometric substance]' (ibid., p. 54). Mach then lists several physicists whose investigations into temperature involved this misconceived doubt, and the list includes some of the best-known researchers in the field, such as John Dalton, Joseph-Louis Gay-Lussac, and Rudolf Clausius. These are the 'scientists [who] puzzled themselves about temperature' that Wittgenstein mentions. The one person (other than Lambert) to whom Mach credits a clear understanding of the conventionality of temperature is William Thomson (Lord Kelvin).

[12]Chapter II of Mach's book, 'Critical Discussion of the Concept of Temperature' was also published in stand-alone form, in a two-part English translation in the philosophy journal *The Open Court* (Mach 1903). Its translation there differs slightly from that of the published book-chapter.

Finally, in a remarkable passage, Mach makes the central philosophical point which Wittgenstein adverts to:

> We start in our investigations from the sensation of heat, and find ourselves later obliged to substitute for this original property of the behaviour of bodies other properties. But between these properties, which differ according to circumstances, no exact parallelism obtains. For this very reason, latently and unconsciously, the original sensation of heat, which was replaced by these not exactly conforming properties, remains the nucleus about which our ideas cluster. Then, on our discovering that this sensation of heat is, in its turn, nothing but a symbol for the collective behaviour of the body, which we already know and shall later know better, our thinking compels us to group these varying phases of collective behaviour under some single head and to designate them by a single symbol called state of heat. Scrutinising our procedure closely, we again discover as shadowy nucleus of the symbol this same sensation of heat, which is the initial and the most natural representative of the whole group of conceptions. And to this symbol, which is after all not entirely our arbitrary creation, we appear to be forced to attribute reality. Thus, the impression arises of an 'actual temperature', of which that read from the thermoscope is only a more or less inexact expression (ibid., p. 56).

Mach then immediately links the point he makes here to the objection he famously made (in *The Science of Mechanics*) against Newton's conceptions of 'absolute space' and 'absolute time'. I call this passage remarkable, not just because it contains the point Wittgenstein adverts to, but because of the way it echoes in many respects a famous passage from Hertz's *Principles of Mechanics* that is known to have inspired Wittgenstein. Hertz says:

> With the terms 'velocity' and 'gold' we connect a large number of relations to other terms; and between all these relations we find no contradictions which offend us. We are therefore satisfied and ask no further questions. But we have accumulated around the terms 'force' and 'electricity' more relations than can be completely reconciled amongst themselves. We have an obscure feeling of this and want to have things cleared up. Our confused wish finds expression in the confused question as to the nature of force and electricity. But the answer which we want is not really an answer to this question. It is not by finding out more and fresh relations and connections that it can be answered; but by removing the contradictions existing between those already known, and thus perhaps by reducing their number. When these painful contradictions are removed, the question as to the nature of force will not have been answered; but our minds, no longer vexed, will cease to ask illegitimate questions (Hertz 1956, pp. 7–8).

Hertz's book was originally published in 1894, Mach's only two years later. I cannot help thinking that the passage from the later book is a sort of *hommage* to that from the earlier.

One thing to note here is that the philosophical method that Wittgenstein gestures towards at the meeting of the Moral Science Club, the method of *dissolving* philosophical perplexities, is the method that he (there and in several other places) associates with Hertz. Several Wittgenstein scholars have been very keen to point out that link, there being no shame to any association between Wittgenstein and Hertz, of course. But it is notable that Wittgenstein *here* associates this method with *Mach* as well, and gives a specific example of Mach's use of it. Claims that Wittgenstein took on board and applied one or more philosophical methods suggested by Hertz should respect this connection.[13]

The passage from Wittgenstein's 'Saturday discussion' may be thought to suggest no more than a *comparison* or analogy between a scientific problem and philosophical problems.[14] But this suggestion faces two problems. First, the slightly earlier passage from the Moral Science Club definitely makes an exemplar-connection, that is, it specifies 'what Mach did in connection with the muddle about "temperature"' as an example of the treatment of a philosophical question. And secondly, the problem the scientists in question were dealing with was undoubtedly the problem of the nature of temperature, and if Wittgenstein counted 'what is force?' as a philosophical problem (as he certainly did, following Hertz), he surely would have put this 'puzzle about temperature' in the same boat.

Of course, there are other places where Mach also discusses temperature, especially the two rival theories of heat as stuff and heat as motion. He does so in his early book *History and Root of the Principle of Conservation of Energy* (Mach 1872/1911, pp. 35–48), as well as in section 4 ('The Conceptions of Heat') of his essay 'On the Principle of the Conservation of Energy' (1894), and in 'On the Principle of Comparison in Physics' (also 1894). However, none of these other locations contain the point with which Wittgenstein credits Mach. We should also note that the idea of comparing the expansion of one substance with another really *is* the same thought as the one Wittgenstein had about 'comparing a process with the passage of time' (6.3611) – discussed above, *and* space (in the final paragraph of 6.3611). I take this to be further confirmation of Visser's suggestion (Visser 1982, p. 103) that that Tractarian proposition may well have a Machian ancestry.

As regards Visser's claim about philosophical methodology, then, it's not that there's *no* connection between methods used by Wittgenstein's and by Mach, but simply that the connection Visser supposes is significantly weaker than this connection which Wittgenstein himself flagged up.

5.18 Conclusion

Somewhat surprisingly, then, in light of received views of the Mach-Wittgenstein relationship, suggestions that Mach might have influenced Wittgenstein (either directly or indirectly) are fairly plausible in the case of *some* of the topics Visser mentions (notably time and space). When it comes to 'Wittgenstein's (early) "philosophy of science"' (if the *Tractatus'* remarks on science deserve that title) Visser *does* have a point, although it is notable that he says little or nothing about several *other* remarks on science in the *Tractatus* (6.33, the very important 6.34s, 6.35, and 6.36). Furthermore, if we allow that there is a connection between

[13] I have addressed the claim that Wittgenstein used Hertz's method in (Preston 2008).

[14] For this suggestion I am grateful to my colleague Maximilian de Gaynesford.

Wittgenstein's method and that of Hertz, we should allow the same connection with a method which Mach uses. However, Visser's claim that Wittgenstein got some of his most *important* philosophical ideas directly from having read certain works by Mach is not sustainable. With respect to the claims dealt with here, at least, Visser's most plausible claims of influence concern relatively peripheral aspects of Wittgenstein's work.

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Chapter 6
Mach's "Sensation", Gomperz's "Feeling", and the Positivist Debate About the Nature of the Elementary Constituents of Experience. A Comparative Study in an Epistemological and Psychological Context

David Romand

Abstract In the present article, I compare Ernst Mach's and Heinrich Gomperz's contributions to the German-speaking positivist tradition by showing how, in trying to refound epistemology on the basis of one definite category of experiential element, namely, sensation *(Empfindung)* and feeling *(Gefühl)*, respectively, they each epitomized one major trend of *Immanenzpositivismus*. I demonstrate that, besides Mach's "sensualist" conception of positivism – in light of which historians have tended thus far to interpret all German-speaking positivist research of that period – there also existed an "affectivist" conception of positivism, which originated in Avenarius's empiriocriticism and culminated in Gomperz's pathempiricism *(Pathempirismus)*. Here I aim to provide a new perspective on the history of positivism by highlighting the role played in it by psychological concerns. First, I revisit the notion of *Immanenzpositivismus*, the form of positivism that prevailed in both Germany and Austria between the late nineteenth and early twentieth centuries: in addition to addressing the definition of this philosophical school of thought, I discuss the issue of "pure experience", from which the positivists tried to reinterpret the foundations of knowledge. Second, I deal with Mach's sensation-based approach to *Immanenzpositivismus* by commenting on his ontological and typological analysis of the constitutive elements of experience and emphasizing the fact that his concept of *Empfindung* is a relatively ill-defined notion in light of contemporary psychological standards. Moreover, I show that, despite his pretense of confining his epistemological developments to the analysis of sensations, Mach did not deny the involvement of feelings in epistemology, as clearly evidenced by some passages of *Erkenntnis und Irrtum*. Third, I analyze Gomperz's feeling-based conception of *Immanenzpositivismus*, that is, pathempiricism, by highlighting how he strove to radically refound epistemology on the basis of the most recent

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advances of affective psychology. Focusing on the question of language sciences, I also discuss how he considered the role of feelings in the various forms of theoretical knowledge, the only field of investigation that he revisited in detail in his unfinished book, *the Weltanschauungslehre*. Fourth and last, I contrast Gomperz's with Mach's positivist model and argue that the former is more coherent and has a higher explanatory power than the latter. In conclusion, I insist on the importance of revisiting pathempiricism within the broader framework of affective epistemology.

6.1 Introduction

This paper aims to confront Ernst Mach's positivist thought with pathempiricism *(Pathempirismus),* the special form of positivism advocated by Heinrich Gomperz (1873–1942) in the first decade of the twentieth century.[1] More specifically, I will show how both authors addressed the question of the elementary constituents of experience, a crucial issue for the German-speaking positivist philosophy of that period, by showing that they embodied two opposite epistemological tendencies. In the *Weltanschauungslehre*,[2] Gomperz assumed the provocative idea that epistemology should be refounded on the basis of the psychological concept of *feeling (Gefühl)*. Here, I will revisit the centrality of the issue of affectivity in the *Weltan-*

[1]Gomperz remains a neglected figure in the history of Austrian philosophy and has given rise to a limited number of publications: Wolfhart Henckmann, "Bewußtsein und Realität bei Külpe und Gomperz": Zwei Alternativen in der philosophischen Grundlegung der Semasiologie", *Zeitschrift für Semiotik, 4,* 1988, 377–397; Karl-Friedrich Kiesow, "Aussageinhalt bei Gomperz, Bühler und Popper", in: Achim Eschbach (Ed.), *Karl Bühler's Theory of Language*. Amsterdam-Philadelphia: Viennese Heritage/Wiener Erbe, John Benjamins, 1988, pp. 349–367, "Das sprachphilosophische Werk von Heinrich Gomperz", in: *Allgemeine Zeitschrift für Philosophie,* 15, 1990, pp. 19–42; Clemens Knobloch, *Geschichte der psychologischen Sprachauffassung in Deutschland von 1850 bis 1920.* Berlin: De Gruyter, 1988; Martin Seiler, "Heinrich Gomperz (1873–1942), Philosophie und Semiotik", in: Ludwig Nagl/Elisabeth List/Jeff Bernard/Gloria Withalm (Eds.), *Philosophie und Semiotik*. Wien: ÖGS/ISSS, 1991, pp. 101–124; Martin Seiler/Friedrich Stadler (Eds), *Heinrich Gomperz, Karl Popper und die österreichische Philosophie, Beiträge zum internationalen Forschungsgespräch des Instituts "Wiener Kreis" aus Anlaß des 50. Todestages von Heinrich Gomperz (1873–1942) und des 90. Geburtstages von Sir Karl Popper (*1902), 8. bis 9. Oktober 1992 in Wien.* Amsterdam-Atlanta: Rodopi, 1994; Malachi Hacohen, Karl Popper: *The Formative Years. Politics and Philosophy in Interwar Vienna*. Cambridge: Cambridge University Press, 2000, pp. 149–155; Friedrich Stadler, *Der Wiener Kreis. Ursprung, Entwicklung und Wirkung des Logischen Empirismus im Kontext. Veröffentlichungen des Instituts Wiener Krei*s. Wien: Springer, 2015, pp. 241–283, 531–534.

[2]Heinrich Gomperz, *Weltanschauungslehre, Ein Versuch die Hauptprobleme der allgemeinen theoretischen Philosophie geschichtlich zu entwickeln und sachlich zu bearbeiten. Erster Band: Methodologie.* Jena-Leipzig: Diederichs, 1905, *ibid., Zweiter Band: Noologie, Erste Hälfte: Einleitung und Semasiologie.* Jena-Leipzig: Diederichs, 1908. The 1908 book was in reality the first part of the second volume of the *Weltanschauungslehre,* the *Noologie,* whose second part, the so-called *Alethologie,* was never published. The *Weltanschauungslehre* was supposed to consist of two further (never published) volumes entitled *"Ontologie"* and *"Kosmologie"*.

schauungslehre by analyzing the way in which Gomperz conceived the nature and the function of feelings within the framework of his epistemological thought. I will demonstrate how different Gomperz's conception of positivism is from that advocated by Mach, who famously tried to elaborate his epistemological model on the basis of another category of experiential entity, *sensation (Empfindung)*. Here, my intention is to show that, in spite of belonging to the same philosophical school, namely, *Immanenzpositivismus*, Mach and Gomperz share very different views about the nature of the mind and the foundations of knowledge. In addition to shedding new light on Machian thought and contributing to the rehabilitation of Gomperzian thought, I hope to reassess the positivist philosophy as it developed in German-speaking countries between the late nineteenth and early twentieth centuries by insisting on the variety of its approaches and its close relatedness to psychological concerns.

6.2 The German-Speaking Paradigm of *Immanenzpositivismus:* A Brief Reassessment

6.2.1 Some Terminological and Conceptual Clarifications

Mach and Gomperz are considered two typical representatives of what Karl Acham called *"Immanenzpositivismus"*,[3] the peculiar form of positivism that developed in German-speaking countries between the late third of the nineteenth century and the early 1910s. *Immanenzpositivismus* has sometimes been branded as "older positivism" by modern historians, in contrast to the so-called neo-positivism of the 1920–30s,[4] while, ironically, contemporaries commonly referred to it as "modern positivism",[5] in contrast to earlier positivist tendencies. Past and present commentators have often spoken of *Immanenzpositivismus* as "empiriocriticism" or "the philosophy of pure experience",[6] two expressions that, strictly speaking,

[3]Karl Acham, "Immanenzpositivismus", in: Joachim Ritter/Karlfried Gründer (Eds.), *Historisches Wörterbuch der Philosophie, Band 4*. Basel-Stuttgart: Schwabe, 1976, pp. 238–240. The term *"Immenzpositivismus"* is sometimes said to have been coined by Schlick, who, although using cognate expressions such as *"Immanenzgedanken", "Immanenzphilosophie",* or *"Immanenz-standpunkt",* does not seem to have used it. See in particular: Moritz Schlick, *Allgemeine Erkenntnislehre*. Berlin: Springer, 1925 (second edition).

[4]Hartmut Przybylski. "Positivismus", in: *Ibid., Bd. 7,* 1989, pp. 1118–1122.

[5]Alois Riehl, "Logik und Erkenntnistheorie", in: Paul Hinneberg (Ed.), *Die Kultur der Gegenwart, Teil 1, Abteilung 6, Systematische Philosophie.* Leipzig-Berlin: Teubner,1921, pp. 68–97.

[6]Riehl, *ibid.;* Traugott Konstantin Oesterreich, "Die philosophische Strömungen der Gegenwart", in: *Ibid.,* pp. 352–395; Acham, "Immanenzpositivismus"; *op. cit.;* Wolfgang Röd, "Empiriokritizismus und Konventionalismus", in: Pierfrancesco Basile/Wolfgang Röd (Eds.), *Geschichte der Philosophie, Band 11, Die Philosophie des ausgehenden 19. und des 20. Jahrhunderts, 1, Pragmatismus und analytische Philosophie.* München: Beck, 2014, pp. 39–55.

refer to Avenarius' specific conception of positivism.[7] Finally, it is worth noting that, in his *Wörterbuch der philosophischen Begriffe,* Eisler distinguished "idealist positivism", as instantiated by contemporary German-speaking philosophers, from "realist positivism",[8] as epitomized by Auguste Comte.[9]

It is difficult to say exactly what *Immanenzpositivismus* is[10]; in fact, the definitions proposed in dictionaries and manuals of philosophy are inaccurate. Here, suffice it to say that, in the late nineteenth- and early twentieth- century German-speaking context, a "positivist" was a philosopher who espoused the six following founding principles: (a) a *"Monismus des Geschehens"*, also referred to as "neutral" or "epistemological" monism, according to which the mental and the physical are only by-products of primitively ontologically undifferentiated phenomena; (b) a radically immanentist conception of knowledge, the latter being identified, in the final analysis, with what is effectively experienced in consciousness; (c) the idea of a clear-cut distinction between science and metaphysics, and a strong antimetaphysical stance; (d) an overt hostility to traditional philosophical concepts such as cause, substance, matter, or the self; (e) the centrality of the notion of economy of thought; and (f) an evolutionary conception of thought and theoretical knowledge.[11] Mach and Gomperz were "genuine positivists" who clearly met the six above-mentioned criteria, but there were many contemporary philosophers who met them only partially, and who can be called, according to Eisler's expression, "half positivists".[12]

6.2.2 *The Issue of Experience in* Immanenzpositivismus

As the name indicates, *Immanenzpositivismus* ascribes a central role to the issue of immanence, which is the core tenet of its theory of experience. Positivists like Mach and Gomperz advocated an all-encompassing conception of experience *(Erfahrung)*, which they regarded as the manifestation of all forms of knowledge as they can be effectively apprehended in consciousness. By equating experience with the fact of being conscious, they assumed a purely immanentist view of knowledge:

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[7]Richard Avenarius, *Kritik der reinen Erfahrung, 2 vol.* Leipzig: Reisland, 188–1890. On the uses of the term "*Empiriokritizismus"*, see: Chiara Russo Krauss, *Il sistema dell'esperienza pura. Struttura e genesi dell'empiriocriticismo di Richard Avenarius.* Firenze: Le Cáriti Editore, 2013.

[8]Rudolf Eisler, "Positivismus", *Wörterbuch der philosophischen Begriffe, historisch-quellenmässig bearbeitet, Band 2.* Berlin: Mittler, 1910 (third edition), pp. 1031–1041.

[9]Auguste Comte, *Cours de philosophie positive, 6 vol.* Paris: Bachelier, 1830–1842.

[10]Acham, "Immanenzpositivismus", *op. cit.*; Przybylski, "Positivismus", *op. cit.*

[11]Eisler, "Positivismus", *op. cit.*; Riehl, "Logik und Erkenntnistheorie", *op. cit.;* Jürgen Blühdorn/Joachim Ritter (Eds.), *Positivismus im 19. Jahrhundert. Beiträge zu seiner geschichtlichen und systematischen Beudeutung.* Frankfurt/Main: Klostermann, 1971; Acham, *Ibid.*; Przybylski, *Ibid.*

[12]Eisler, *Ibid.*

knowledge does not correspond to anything outside what we experience consciously and it is only in conscious experience that it is likely to find its justification. As a "philosophy of pure experience", *Immanenzpositivismus* aims to identify the primitive experiential facts that theoretical knowledge consists of by rejecting as metaphysical, and thus ungrounded, all assumptions that cannot be justified on the basis of an analysis of the conscious givenness.[13]

The great merit of the German and Austrian positivists of that time was to have renewed the concept of experience by going beyond the traditional conceptions regarding the origin and the nature of knowledge (empiricism, rationalism, intellectualism, criticism, etc.). For instance, they criticized the idea that there may be a form of knowledge coming "from outside" and one originating or retrieved "from inside", because, in their view, there is basically neither an external nor an internal side of experience, but only one level of immanence. For the same reason, they refused any primitive distinction between *Anschauung* (perceptual experience) and conceptual thought. Moreover, they rejected the idea that psychological and physical phenomena may be ontologically different, the difference between the two being, according to them, a question of "point of view", not of nature: the given appears to us as a manifestation of our own consciousness when apprehended in immediate experience (point of view of psychology) and as existing independently from us in the external world when apprehended in mediate experience (point of view of natural sciences).[14] When all is said and done, the theorists of *Immanenzpositivismus* rejected the possibility of founding the philosophical inquiry on distinctions such as "exteriority" and "interiority", "intuition" and "concept", "sensibility" and "thinking", "inner sense" and "outer sense", "subjective experience" and "objective experience", etc. They did not deny the phenomenal reality and the epistemological importance of such distinctions, but they refused to consider them as pre-established categories of experience that epistemology should begin with. Here, we have to do deal with, not with primitive, but with secondary experiential data, which, instead of being postulated, should be explained through the analysis of pure experience.

Ultimately, *Immanenzpositivismus* raises the question of what experience is actually made of; that is, what are the elementary constituents that reality pertains to and to which knowledge should be referred? In Acham's words: "only sensations and representations are given as 'elements', or complexes of elements, of all what is real".[15] The idea that, for *Immanenzpositivismus*, experience basically boils down to

[13]On the nature of "pure experience", see: Russo Krauss, *Il sistema dell'esperienza pura, op. cit.,* especially pp. 48–56.

[14]On the notion of "immediate" ("inner") and "mediate (outer) experience" (or "perception") in the German-speaking psychology and philosophy, see: David Romand, "La théorie herbartienne de la représentation: une dialectique de l'acte et du contenu", in: Anton Hügli/Janette Friedrich/Guillaume Fréchette (Eds.), *Intentionalität und Subjektivität – Intentionnalité et subjectivité, Studia Philosophica,* 75, 2016, pp. 175–188.

[15]Acham, op. cit., p. 239. All translations are mine.

the question of sensations *(Empfindungen)*[16] and representations *(Vorstellungen)*,[17] the mind's cognitive elements, is accepted by virtually all modern commentators. My intention is to show that such an assumption is, in reality, mistaken, and that historians have neglected the question of *feelings (Gefühle)*,[18] the elements that underpin the affective dimension of experience.[19]

6.3 Mach's Sensation-Based Epistemology

6.3.1 Mach's Concept of "Element"

Mach called "elements" *(Elemente)* simple entities of which experience, that is, "the ultimate components *(Bestandteile)* that have not been likely to be analyzed further thus far".[20] As the irreducible (established) constituents of reality, they correspond to the only ontological properties that scientific investigation has to cope with. In the various editions of *Die Analyse der Empfindungen,* Mach repeatedly identified elements with sensations *(Empfindungen)*, that is, "colors", "sounds", "pressures", "spaces", "times", etc., and many other properties that occur in consciousness together with a definite quality. Although basically defined as manifestations of conscious experience, sensations are not supposed to be originally primitive mental states. In accordance with his monistic claims, Mach regarded them as something ontologically "neutral", neither mental nor material, neither psychological nor physical. When perceived in relation to the subject, sensations are experienced as the immediate data of consciousness, whereas they are spontaneously experienced as qualities of the objects of the external world when they are perceived as something

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[16]For a historical and conceptual survey of the concept of *Empfindung*, see: Eisler, "Empfindung", in: *Wörterbuch, op. cit., Band 1,* pp. 271–281.

[17]In line with a number scholars of his time, Mach used *"Vorstellung"* in its restrictive sense, referring to internally generated mental contents, that is, sensory data or complexes or sensory data as they are reproduced in consciousness. For the double (generic and restrictive) acceptation of the term *"Vorstellung"* in the German-speaking psychological tradition and a historical-theoretical survey of the corresponding concept, see: Eisler, "Vorstellung", in: *Ibid., Band 3.,* pp. 1690–1699. See also: Romand, "La théorie herbartienne de la représentation", *op. cit.*

[18]Eisler, "Gefühl", in: *Ibid., Band 1*, pp. 391–400; David Romand, "Külpe's affective psychology: The making of a science of feeling (1887–1910)", in: Chiara Russo Krauss (ed.), *La scienza del pensiero. Il realismo filosofico di Oswald Külpe, Discipline Filosofiche,* 27, 2, pp. 177–204.

[19]On the difference between cognitive and affective processes in a German-speaking context, see: David Romand, "Theodor Waitz's theory of feelings and the rise of affective sciences in the mid-19th century", *History of Psychology,* 18, 4, 385–400, "Külpe's affective psychologie: The making of a science of feeling (1887–1910)", *op. cit.*

[20]Mach, "Analyse", *op. cit.,* pp. 14–15.

occurring independently from the subject.[21] According to this view, subjectivity and objectivity, interiority and exteriority, far from being inherent to the nature of the constituents of experience, are properties that are secondarily added to them.

In *Die Analyse der Empfindungen,* Mach distinguished in reality between three "groups of elements", which he defined on the basis of definite phenomenological and functional properties.[22] First, Mach identified the group of sensory data *(Sinnesempfindungen),* that is, basically, sensations as they are effectively mediated by the so-called objective senses, vision and hearing. These elements, which he referred to with the symbols "A, B, C", correspond to the more or less vivid impressions apprehended in *Anschauung*, the perceptual experience. Second, Mach referred to as "K, L, M" what contemporary psychologists often called "subjective sensations", that is, bodily or organic sensations. Mach called the third group of elements "α, β, γ", which, according to him, encompasses all reproduced sensations, which he called "representations" *(Vorstellungen)*,[23] and evanescent and purely subjective states such as feelings, volitions, desires, etc. Each of these three groups of elements has to do with, respectively, the world, the body, and the self. The fact of establishing functional relationships between them results in, according to Mach, the differentiation of various forms of practical or theoretical experiences. As Gereon Wolters explained in his introduction to *Die Analyse der Empfindungen* in the first volume of the *Ernst-Mach Studienausgabe:*

> So, sensory physiology studies regular relations between world-elements *(Weltelemente)* and body-elements *(Leibelemente),* while physical sciences concern regular interrelations between word-elements. If we focus on intrapsychical elements *(innerpsychische Elemente)* only, we are dealing with psychology.[24]

Here, Mach explicitly assumed the view that sensations are inherently heterogeneous and that this heterogeneousness underpins the phenomenal and semantic variety of experience, an assumption that, in all likelihood, directly contradicts his monistic views on the primitive indeterminacy of elements and the ontological unicity of the givenness. According to this view, not all elements are likely to be contemplated from the physical point of view; only the so-called word-elements (*Weltelemente)* and, to a lesser extent, body-elements *(Leibelemente)* are endowed with an objective value. By contrast, intrapsychical elements *(innerpsychische Elemente)* are properties that cannot be objectivized, that is, purely mental states, that have no other function than that of subjectivizing the complexes of sensations.

[21] See in particular: *Ibid.,* pp. 23–24, 40, 46–49; Mach, "Erkenntnis und Irrtum", *op. cit.,* pp. 14–22, 28.

[22] Mach, "Die Analyse der Empfindungen und das Verhältnis des Physichen zum Psychischen", in: Gereon Wolters (Ed.), *Ernst-Mach-Studienausgabe, Band 1* (reprint of the 1911 eleventh edition). Berlin: Xenomoi, 2008, pp. 17–18, 20–24, 38–40.

[23] See note 17.

[24] Wolters (Ed.), "Einleitung", in: *Ernst-Mach-Studienausgabe, op. cit.,* p. XVII.

6.3.2 The Psychological Definition of Sensation

Neither in *Die Analyse der Empfindungen* nor in *Erkenntnis und Irrtum*[25] did Mach propose a clear definition of sensation. Although he directly handled the issue of sensations as an experimentalist, his approach was basically that of a psychophysiologist and clearly not that of a psychologist or an epistemologist. Significantly enough, he did not discuss the ontological status of sensation compared to the other kinds of mental states and, in particular, he did not try to differentiate the two concepts of *Empfindung* and *Gefühl*. Moreover, he was particularly unclear about what the phenomenological and functional properties of sensations may be. Finally, except for his above-mentioned developments on the three "groups" of elements, he did not propose any clear typological analysis of sensations.

Mach conceived sensations in a very general way, as the sensory qualities that consciousness pertains to, and, in fact, *"Empfindung"* was for him synonymous with "mental state". This psychological definition of *Empfindung* appears particularly vague and confused, especially when compared with the developments on sensation encountered in contemporary manuals of psychology.[26] Here, Mach is indebted to the empiricist and associationist psychology that prevailed in German-speaking countries in the first two thirds of the nineteenth century and, even more strikingly, to the eighteenth-century sensualist tradition.[27] Mach's tendency to refer to (relatively) out-of-date psychological views is obvious when considering the developments on association, reproduction, memory, the formation of concepts, or the process of abstraction expounded in *Erkenntnis und Irrtum.*[28]

6.3.3 The Place of Feelings in Mach's Epistemology

Feeling *(Gefühl)* was only a second-rate issue in Mach's sensation-based theory of knowledge. As previously mentioned, Mach regarded affective processes, that is, basically pleasure and displeasure, as belonging to the third group of elements, what Wolters calls the "*innerpsychische Elemente*".[29] In fact, he explicitly assumed the view that feelings are, not mental states of their own kind, as the vast majority of contemporary psychologists and philosophers maintained, but peculiar forms of

[25] Ernst Mach, "Erkenntnis und Irrtum", in: Elisabeth Nemeth/Friedrich Stadler (Eds.), *Ernst-Mach-Studienausgabe, Band 2* (reprint of the 1906 second edition). Berlin: Xenomoi, 2011.

[26] Eisler, "Empfindung", *op. cit.*; Eduard von Hartmann, "Die moderne Psychologie. Eine kritische Geschichte der deutschen Psychologie in der zweiten Hälfte des neunzehnten Jahrhunderts", *Ausgewählte Werke von Eduard von Hartmann, Band 13.* Leipzig: Haacke, 1900, pp. 174–279.

[27] Eisler, "Sensualismus", in: *Wörterbuch, op. cit., Band 3,* pp. 1324–1325.

[28] Mach, "Erkenntnis und Irrtum", *op. cit.*

[29] Wolters (Ed.), *Ernst-Mach-Studienausgabe, op. cit.,* "Einleitung".

sensations.[30] Mach endorsed what Titchener called the "sensationalist theory of feelings",[31] the view according to which affective states are basically nothing but more or less undefined sensory data.

Although feelings are not supposed to be instrumental in Mach's epistemology, some excerpts of *Erkenntnis und Irrtum* tend to prove the contrary: (a) in the chapter "Gedankenexperimente": "when turning back to the domain in question after a long rest, one can notice that most of what has not been conceptually fixed, *the subtle feeling for the meaning of accessory circumstances (des feine Gefühle für die Bedeutung der Nebenumstände)*, the skill of the hand, must be, as a rule, acquired anew"[32]; (b) in the chapter "Das physische Experiment und dessen Leitmotive": "A continuity of *expectation (Erwartung)*, with regard to experimental outcomes, corresponds to a continuity of the variations of circumstances"[33]; and (c) in the chapter "Hypothese": "Representations that we have built on the basis of observations arouse *expectations (Erwartungen), manifest themselves actively (wirken aktiv)* and constructively, *urge (drängen)* new observations and new experiments.[34] Here, and in many other places, Mach identified a variety of abstract and intuitive mental states involved in the acquisition and maintenance of theoretical knowledge (feeling of meaning, feeling of search, feeling of expectation), implicitly admitting the centrality of affective states in epistemology.

6.4 Gomperz's Feeling-Based Epistemology

6.4.1 The Basic Tenets of Pathempiricism

The idea, suggested by Mach in *Erkenntnis und Irrtum*, that the analysis of affective states may be instrumental in understanding the origin and the modalities of knowledge, was the core of Heinrich Gomperz's own version of *Immanenzpositivismus,* the so-called pathempiricism *(Pathempirismus),* which, as the name indicates, was an attempt to develop an affectivity-based theory of experience. As Gomperz emphasized: "pathempiricism is the line of thought that strives to solve cosmotheoretical problems by identifying feelings underpinning our concepts of form, and thus on the basis of psychological investigations"[35]

It is worth noting that for Gomperz, the question of "the elementary constituents of experience" does not boil down to the issue of feelings *(Gefühle),* but also

[30]Mach, "Analyse", *op. cit.,* pp. 27–28.

[31]Edward Bradford Titchener, *Lectures on the Elementary Psychology of Feeling and Attention.* New York: Macmillan, 1908.

[32]Mach, "Erkenntnis und Irrtum", *op. cit.,* p. 196 (my emphasis).

[33]*Ibid.,* p. 226 (my emphasis).

[34]*Ibid.,* p. 256 (my emphasis).

[35]Gomperz, *Weltanschauungslehre, Erster Band*, *op. cit.,* p. 305.

concerns representations *(Vorstellungen)* – an expression that should be taken here in its generic sense, as a synonym of "content of consciousness".[36] As he explained, pathempiricism basically consists of investigating how feelings relate to representations: "(. . .) the use of the pathempiricist method is based on the assumption that representations and feelings always occur, not only simultaneously, but also by interacting associatively with each other".[37] By being interrelated at a given moment with definite representations, feelings induce what Gomperz called their "characterization" *(Charakterisierung)* or "differentiation" *(Differenzierung)*; they give, in other words, a specific experiential significance to phenomenologically and semantically neutral contents of consciousness.[38] "Changes in the association of feelings*"* are, in Gomperz's view, so many changes in the way of apprehending representations, and therefore the ultimate source of what he called "the forms of experiential consciousness" *(die Formen des Erfahrungsbewußtseins)*, "the forms of experience" *(Erfahrungsformen),* or "the ways of experiencing" *(Erlebnisweisen).*[39]

The *Weltanschauungslehre* was supposed to be the complete exposition of Gomperz's pathempiricist doctrine, which was itself supposed to constitute a philosophical system.[40] It was expected to consist of four volumes: a methodology *(Methodologie)*, a noology *(Noologie),* an ontology *(Ontologie),* and a cosmology *(Kosmologie).*[41] The fact is that the project remained largely unachieved, and of the four volumes in question, only the *Methodologie*[42] and the first part of the *Noologie*[43] were effectively published, in 1905 and 1908, respectively.[44]

In the *Methodologie,* Gomperz devotes much space to demonstrate that it is only on the basis of the psychological concept of feeling that one can hope to fully account for the so-called preliminary concepts *(Vorbegriffe),* namely, substance, identity, relation, and form – the four major categories that, in his view, underlie

[36] See note 17 and Eisler, "Vorstellung", op. cit.

[37] *Ibid.,* p. 378.

[38] In the *Methodologie*, Gomperz identifies four types of "characterizations", namely, "endopathy", "adjection", "determination", and "concomitance", whose analysis is beyond the scope of the present article. Cf. Gomperz, *Weltanchauunsglehre, Erster Band, op. cit.,* pp. 378–394. Here it is worth emphasizing that the capacity of feelings to modify the experiential significance of representations depends not only on the modalities of interactions between the two categories of affective states, but also and above all, as we will see in the next section, on the qualitative property of each kind of affective state.

[39] e.g. Gomperz, *Weltanschauungslehre, Erster Band, op. cit.,* pp. 285, 303, 378–379.

[40] Gomperz, *Weltanschauungsehre, Erster Band,* op. cit., pp. 2–43, 395–412. See also: Seiler/Stadler, *Heinrich Gomperz, op. cit.*

[41] Gomperz, *Weltanschauungslehre, Erster Band, op. cit.,* pp. 395–412.

[42] Gomperz, *Weltanschauungslehre, Erster Band, op. cit.*

[43] Gomperz, *Weltanschauungslehre, Zweiter Band, op. cit.*

[44] The reason that Gomperz abandoned his pathempiricist project is probably to be found in the fact that he changed his mind about epistemology after 1908, within the context of a growing disinterest of German-speaking philosophers in psychology and the rise of logicist concerns, especially among the Austrian *milieu* that he belonged to. For some clues about this question, see: Seiler/Stadler, *Heinrich Gomperz, op. cit.* and Stadler, *Der Wiener Kreis, op. cit.*

all kinds of theoretical knowledge. According to him, pathempiricism, as a feeling-based explanatory system, appears to be the dialectical overcoming of the four preceding evolutionary stages of philosophical thought ("animism", "metaphysics", "ideology", "criticism") and their historical-theoretical culmination. Although not denying the role played by representations, he basically regarded affective processes as the core of all epistemological and, more generally speaking, philosophical forms of knowledge.

6.4.2 Gomperz's Concept of Feeling

Of note, the concept of *Gefühl,* as used by Gomperz in the *Weltanschauungslehre*, is not a fuzzy philosophical notion, but a well-defined issue that directly echoes the contemporary psychological studies carried out in German-speaking countries.[45] At the end of the *Methodologie*, Gomperz devotes no fewer than 50 pages to the psychology of feelings: not only does he have an excellent knowledge of the literature in the field, but his theoretical contribution can be regarded as that of an authentic affective psychologist.[46]

In line with the vast majority of German-speaking psychologists of his time, he regarded feelings as belonging to a definite category of mental states, ontologically distinct from representations and sensations.[47] As phenomena of a non-sensory nature, they constitute, according to him, not "the content" *(Inhalt)*, as representations do, but "the form *(Form)*" of experiential consciousness.[48]

Gomperz also proved to be in line with the German-speaking psychological community in that he identified feelings with metacognitive factors, that is, conscious properties that when added to representational contents alter their experiential significance.[49] The question of metacognition is at the heart of the theoretical developments on feelings proposed by Gomperz in the *Methodologie*. According to him, affectivity is a "reaction" *(Reaktion)* against representations, a psychical process by which means representations, as stated earlier, are "characterized" or "determined" in a definite way.

Another crucial dimension of Gomperz's theory of feelings consists of identifying them with well-defined epistemic entities. Unlike many contemporary

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[45]Romand, "Theodor Waitz's theory of feelings", *op. cit.* and "Külpe's affective psychology", *op. cit.*

[46]Gomperz, *Weltanschauungslehre, Erster Band, op. cit,* pp. 344–394.

[47]*Ibid.,* pp. 344–378.

[48]*Ibid.,* p. 379–380.

[49]*Ibid.*, pp. 378–394. On the metacognitive function of feelings in German-speaking psychology and epistemology, see: David Romand, "La théorie herbartienne de la représentation", *op. cit,* "Sentiments épistémiques et épistémologie affective chez Theodor Lipps", in: David Romand/Serge Tchougounnikov (Eds.), *Theodor Lipps. Philosophie, psychologie, esthétique.* Dijon: Editions Universitaires de Dijon (forthcoming).

psychologists,[50] but in line with the most recent advances in the phenomenology of feelings, especially the contributions by Avenarius,[51] Petzoldt,[52] Lipps,[53] and, to some extent, Wundt[54] – four authors who are much discussed in the *Weltanschauungslehre* – he argued that affective life, far from boiling down to pleasure and displeasure, consists of countless elementary qualitatively determined properties. Besides "hedonic" or "emotional feelings" *(hedonische/affketive/emotionelle Gefühle)*, he distinguished "intellectual" feelings also called "non-hedonic" or "non-emotional feelings" *(intellektuelle/nicht-affektive/nicht-emotionelle Gefühle),* which are characterized by the fact of expressing "an abstract form of cognizance".[55] In other words, affective states correspond for him, as a rule, to what modern scholars call "cognitive" or "epistemic" feelings.[56] Here Gomperz's originality lies not in the fact of discussing the question of epistemic feelings per se – which, as I demonstrated elsewhere,[57] was a very common issue at the beginning of the twentieth century – but in the fact of identifying the feelings in question with a class of affective processes *sui generis* and a pivotal and ubiquitous dimension of conscious life.

Gomperz's developments on metacognition and the epistemic nature of feelings are essential to remember to understand the role ascribed to affectivity in pathempiricism.

6.4.3 The Epistemological Significance of Feelings in the Weltanschauungslehre

According to Gomperz, an essential epistemological function of feelings is to determine the phenomenological forms of consciousness, that is, basically to differentiate the way the self relates to itself and the way it relates to the external world. Although not discussed at length, since the planned volume devoted to "ontology" was never written, this issue is the subject of interesting developments

[50] Romand, "Külpe's affective psychology", *op. cit.*

[51] Avenarius, *Kritik, op. cit.*

[52] Joseph Petzoldt, *Einführung in die Philosophe der reinen Erfahrung, Erster Band: Die Bestimmheit der Seele.* Leipzig: Teubner, 1900.

[53] Theodor Lipps, *Vom Fühlen, Denken und Wollen. Eine psychologische Skizze.* Leipzig: Barth, 1902. See also: Romand, "Sentiments épistémiques", *op. cit.*

[54] Wilhelm Wundt, *Grundriss der Psychologie*. Leipzig: Engelmann,1896, *Grundzüge der physiologischen Psychologie, Band 2.* Leipzig: Engelmann, 1902 (fifth edition).

[55] The issue of epistemic feelings in German-speaking psychology and epistemology is discussed at length in: Romand, "Sentiments épistémiques", *op. cit.*

[56] Romand, "Theodor Waitz's theory of feelings", *op. cit.* and "Sentiments épistémiques", *op. cit.*

[57] *Ibid.*

in the *Weltanschauungslehre.*[58] Gomperz identified various categories of affective states, e.g. "the feelings of objectivity" and "subjectivity", "the feelings of immediacy" and "mediacy", "the feelings of activity" and "passivity", "the idiopathic" and "the endopathic feelings", etc., which he regarded as the foundation of the difference between perception and internal states, the self and the apprehension of objects, receptivity and spontaneity, self-awareness and awareness of others, etc. Nevertheless, it is first and foremost in consideration of language that Gomperz discussed in detail the role of feelings, seeing that the *Noologie* was the only volume of the *Weltanschauungslehre* that was (partially) implemented.

Gomperz regarded noology – the domain of the pathempiricist system devoted to the study of thought – as consisting of two clear-cut fields of investigation: (a) "semasiology" *(Semasiologie)*, the theory of thought contents, and (b) "alethiology" *(Alethologie)*, the theory of thought values.[59] While alethiology has to do with the question of epistemic justification (the truth value of statements), semasiology is basically conceived as semiotics and semantics, and it appears to be more closely related to linguistic concerns than to epistemology, strictly speaking. This is the only part of the noology discussed in detail by Gomperz, in the second, and last, published book of the *Weltanschauungslehre.*

Semasiology's core concept is the notion of statement *(Aussage),* which Gomperz defined as "[a] "linguistic form plus [a] thought" *(Sprachform plus Gedanke).*[60] By "statement", he refers to all grammatically organized, meaningful linguistic entities, that is, "not only concepts and sentences, but also addresses, orders, wishes, proclamations, assumptions, questions, inferences, reasonings, and proofs (. . .)".[61] According to Gomperz, every statement comprises three "primary elements"[62] (Fig. 6.1): (1) "the statement sound" *(Aussagelaut)*, that is, the linguistic form of the statement; (2) "the statement content" *(Aussageinhalt),* that is, the logical content or the sense *(Sinn)* of the statement; and (3) "the statement foundation" or "basis" *(Aussagegrundlage)*, that is, facts *(Tatsachen)* that relate to the statement. Gomperz called "expression" *(Ausdruck)* the relation between the statement sound and the statement content, "denotation" *(Bezeichnung)* the relation between the statement sound and the statement basis, and "apprehension" *(Auffassung)* the relation between the statement content and the statement basis. The complex formed by the statement content and the statement basis constitutes "the state of affairs" *(Sachverhalt)*, of which the statement as a whole is the meaning *(Bedeutung).*

[58]Gomperz, *Weltanschauungslehre, Erster Band, op. cit.,* pp. 158–178, 274–283, 300–304, *Weltanschauungslehre, Zweiter Teil, op. cit.,* pp. 258–266.

[59]Gomperz, *Weltanschauungslehre, Zweiter Band, op. cit.,* pp. 2–53.

[60]*Ibid.,* pp. 55–56, 65.

[61]*Ibid.,* p. 75.

[62]*Ibid.,* pp. 61–78; see also: Henckmann, "Bewußtsein und Realität bei Külpe und Gomperz", *op. cit.*; Knobloch, *Geschichte der psychologischen Sprachauffassung, op. cit.*; Kiesow, "Aussageinhalt bei Gomperz, Bühler und Popper", *op. cit.* and "Das sprachphilosophische Werk von Heinrich Gomperz", *op. cit.;* Seiler, "Heinrich Gomperz (1873–1942), Philosophie und Semiotik", *op. cit.*

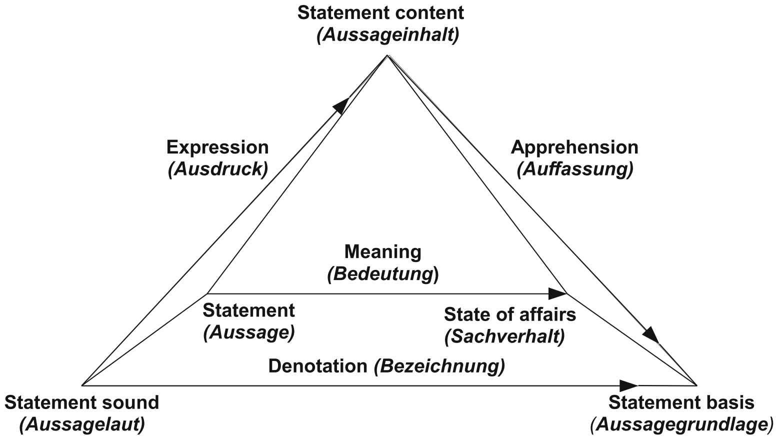

Fig. 6.1 Gomperz's psychological model of the statement. (Adapted from an original figure by Gomperz, 1908, p. 77)

Among the three basic components of the statement identified by Gomperz, the statement sound and the statement basis are supposed to consist of representations and the statement content of feelings.[63] Although for him the question of the statement, and, more generally speaking, of language, do not boil down to the issue of affectivity, the concept of feeling proves to be the core of his semasiological analysis,[64] which basically has to do with the psychological foundations of the meaning of logical statements. By "logical statement", Gomperz referred to any kind of statement whose basis arouses "a general-typical total impression" *(eine generell-typische Totalimpression),* that is, a state of consciousness that "emphasizes what is common from many individual cases"[65] and that occurs, not in one single individual, but "in several similar thinking beings".[66] General-typical total impressions, which correspond to the meaning of words *(Wortbedeutung)*, originate in a definite category of affective processes, the so-called *material logical feelings (logische Materialgefühle).*[67] Here we are dealing with all affective factors that, according to Gomperz, determine word stems and logical definitions, or, to put it differently, "the categorematic parts of the speech" *(die kategorematischen Redeteile).*[68] Besides the material logical feelings, which constitute "the matter of linguistic consciousness", one should identify *the formal logical feelings (die*

[63] See in particular: Gomperz, *Weltanschauungslehre, Zweiter Band, op. cit.,* pp. 91, 206, 220.

[64] As a matter of fact, Gomperz explicitly championed "an approach of language based on affective psychology" *(eine gefühlspsychologische Bearbeitung der Sprache).* Cf. *Ibid.,* p. 238.

[65] *Ibid.,* p. 227.

[66] *Ibid.,* p. 220.

[67] See in particular: *Ibid.,* pp. 229–232, 236–237.

[68] *Ibid.,* pp. 231–232.

logischen Formalgefühle), which, as the name indicates, underpin the appearance of the "linguistic form" *(Sprachform, sprachliche Form)*, the non-factual aspects of meaning.[69] What Gomperz called "formal logical feelings" consist of all affective processes that are specifically involved in the making of the morphosyntactic properties of language, that is, not only syncategorems, but also "the simple grammatical forms of word stems" and "the status and emphasis of simple words".[70] As he highlighted, the role of this category of logical feelings is to join together various general-typical total impressions and to specify their significance, thus contributing to the rise of global content of the logical statement and structuring it as one meaningful unit. Although at the beginning of the *Noologie*, Gomperz insists on the fact of not confounding logic with psychology and dismisses the label of "psychologism",[71] the developments that he proposes in the third chapter of the *Semasiologie* appear to be an attempt to systematically revisit semiotics, semantics, and, more generally speaking, the logical determinations of language in light of affective psychology.

Moreover, as stated earlier, it should be kept in mind that the *Semasiologie* was also supposed to be a theory of epistemic justification. Although the corresponding book, the *Alethologie*, was never written, there is little doubt, considering the programmatic developments found here and there in the *Weltanschauungslehre*, that Gomperz's intention was also to refound the "hardcore" aspect of epistemology on the basis of the psychological concept of feelings.

6.5 Mach's "Sensualist" vs. Gomperz's "Affectivist" Positivism: A Critical Comparison

Taking everything into consideration, I would like to briefly compare the way in which Mach and Gomperz addressed the question of the elementary constituents of experience:

a. Mach's philosophy is mostly based on the concept of sensation, whereas Gomperz's pathempiricism is based on the concept of feeling: they can be said to be the representatives of, respectively, a *sensualist* and an *affectivist* positivist tradition of research.
b. Mach's notion of sensation is a relatively ill-defined concept that has only superficially to do with contemporary psychological research, whereas Gomperz's notion of feeling appears to be directly in keeping with recent advances in affective psychology. More generally speaking, Gomperzian affective positivism

[69] *Ibid.,* pp. 228–232.
[70] *Ibid.,* pp. 230–232.
[71] *Ibid.*, pp. 6–43.

is more closely related to psychological concerns than is Machian sensualist positivism.

c. Mach remained relatively unclear about the nature and the function of the elementary sensory data he speaks about, and, in fact, the issue of the elementary components of experience plays a limited role in the explanations proposed in *Die Analyse der Empfindungen* and *Erkenntnis und Irrtum*. By contrast, in the *Weltanschauungslehre*, Gomperz proposed a systematic typological and functional analysis of affective processes and he analyzed in detail how these elements interact with each other and with representations in order to give rise to experience and theoretical knowledge.
d. As a model of immanentist philosophy, Gomperz's feeling-based positivism appears to be theoretically more satisfactory and epistemologically more consistent than Mach's sensation-based positivism. Based on the notions of epistemic immediacy and metacognition, pathempiricism provides tantalizing explanations regarding the origin of the phenomenological forms of consciousness or the foundations of theoretical knowledge.

6.6 Conclusion

This paper has permitted me to revisit the history of positivism and to reappraise the place of affectivity in the Austrian philosophy of the late nineteenth and the early twentieth centuries. I showed that, besides the sensation-based approach epitomized by Mach, one should identify a feeling-based form of *Immanenzpositivismus,* of which Gomperz was the main representative. Of course, no clear-cut distinction can be made between the "sensualist" and the "affectivist" paradigm of positivism, and neither Mach nor Gomperz tried to ground his epistemological inquiry on only one category of experiential components. By reassessing the role ascribed to cognitive and affective processes in Mach and Gomperz, I hope to have contributed to paving the way to a new typological analysis of the positivist school and to have shown that the paradigm of *Immanenzpositivismus* should not be confounded with the research program elaborated by Mach, which represents only a particular tendency of the positivist school. Gomperz's philosophy can be shown not only to be as genuinely positivist as that of Mach, but also to be theoretically more convincing than the latter. Nevertheless, in my view, it is important not to confine pathempiricism to the issue of positivism and to resituate it within the broader framework of *affective epistemology.*[72] The idea that feelings are instrumental in the acquisition and manifestation of knowledge was widely accepted by German-

[72] Georg Brun/Dominique Kuenzle, "Introduction. A new role for emotions in epistemology?", in: Georg Brun/Ulvi Doğuoğlu/Dominique Kuenzle (Eds.), *Epistemology and Emotions.* Aldershot-Burlington: Ashgate, 2008, pp. 1–31.

speaking philosophers at the beginning of the twentieth century.[73] The originality of the *Weltanschauungslehre* lies, not in the fact of admitting a link between affectivity and epistemology, but in the assumption that the latter should be reduced to affective psychology. Such a radical conception of affective epistemology is found again in Avenarius[74] and his disciple Petzoldt,[75] but also in Lipps, who, in the first edition of his booklet *Vom Fühlen, Wollen und Denken*,[76] tried to explain the differentiation of the forms of conscious experience and the origin of theoretical knowledge on the basis of the psychological concept of feeling.[77] The views expounded in the *Weltanschauungslehre* are in reality much older, since they were clearly outlined by Beneke in his *Skizzen zur Naturlehre der Gefühle*, issued in 1825.[78] My hypothesis is that the model of affective epistemology called "pathempiricism", far from being an idiosyncratic expression of Gomperz's *Weltanschauungslehre,* is a genuine research program that developed in Germany and Austria between the early nineteenth and early twentieth centuries. Moreover, it may be fruitful to reassess pathempiricism in the light of modern philosophical thought by highlighting its close relatedness to recent advances in affective epistemology[79] and the internalism/externalism debate in epistemology and semantics.[80]

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[73] Romand, "Theodor Waitz's theory of feelings", *op. cit.* and "Sentiments épistémiques", *op. cit.*

[74] Avenarius, *Kritik, op. cit.*

[75] Petzoldt, *Einführung, op. cit.*

[76] Theodor Lipps, *Vom Fühlen, op. cit.*

[77] Romand, "Sentiments épistémiques", *op. cit.*

[78] Friedrich Eduard Beneke, *Skizzen zur Naturlehre der Gefühle, in Verbindung mit einem erläuternden Abhandlung über die Bewußtwerdung der Seelenthätigkeiten herausgegeben.* Göttingen: Vandenhoeck & Ruprecht, 1825.

[79] Brun/Doğuoğlu/Kuenzle (Eds.), *Epistemology and Emotions., op. cit.*

[80] Kornblith (Ed.), *Epistemology: Internalism and Externalism*, Malden-Oxford: Blackwell, 2001; Goldberg (Ed.), *Internalism and Externalism in Semantics and Epistemology*, Oxford-New York: Oxford University Press, 2007.

Part II
Mach, Methodology, and Philosophy of Science

Chapter 7
Ernst Mach: Science and Buddhism. A Misunderstanding Under Globalization's Signature

Ursula Baatz

Abstract Ernst Mach was one of the most influential intellectuals in Vienna's cultural life during the fin de siècle. His assumption of the self as a complex of transitory elements has influenced poets like Hoffmannsthal, Schnitzler and Musil. During these years, Buddhism, which shares some of the same assumptions, was discovered by Western intellectuals, among them also intellectuals who were critical of religion. At that time, Buddhism was hardly known and frequently misinterpreted. Nevertheless, the apparent parallels between Mach's thought and Buddhism – especially in his "Analysis of Sensations" – has inspired contemporaries to bestow Mach the title "Buddha of Science"(Gomperz).

Today, the close connection of Buddhism and science is almost commonplace, especially in neuroscience. Sometimes science is used to substantiate Buddhist claims and at other times it is vice versa. The current trends of the relationship of science and Buddhism have a long history. Sinhalese and Japanese Buddhists as well as American freethinkers have featured the idea of Buddhism's affinity to Science as early as in the nineteenth century. One of the most important intermediaries in this process was Paul Carus, Mach's translator and editor in the US.

A closer look at Ernst Mach's "Analysis of Sensation" could prove that the supposed relationship is a category mistake, even though there are in fact certain parallels and isomorphisms. The "Scientific Buddha" (Lopez) is the result of a complex process of the reception of Buddhism in Europe, the US and Asia. Western representations and interpretations of Buddhism were turned into anticolonial propaganda in the course of the struggle of Sri Lanka and Japan against Western colonial powers and their ally, Christianity. This modernized Buddhism was then re-exported to Europe and the US as its authentic version, where it was welcomed as a form of traditional wisdom. Thus, any attempts to equate or verify Buddhism with or by science is a naturalistic fallacy.

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The past years have seen a strong increase in the fad to connect science and Buddhism. At first, it was all about quantum physics, beginning with Fritjof Capra's notorious "The Tao of Physics" (1977). Today, it is all about neuroscience, the psychology of meditation as well as scientists and the Dalai Lama in conversation on the nature of consciousness. However, the supposed connection between Eastern religions, especially Buddhism, and contemporary advanced science is not new but was already a topic as early as end of the nineteenth century. In this time, one of the first scientists to be connected to Buddhism was Ernst Mach, despite the fact that he might seem an unlikely candidate for such a connection.

To some of his Viennese contemporaries, the renowned scientist seemed to be a "Buddha of Science." The title was bestowed upon Mach in the autobiography of the philosopher Heinrich Gomperz, who, together with his father, the philosopher Theodor Gomperz, was instrumental in moving Mach from Prague to a position in the philosophy of science ("Philosophie, insbesondere Geschichte der induktiven Wissenschaften") at the University of Vienna in 1895. Heinrich Gomperz initially met Mach in person on the occasion of his final exams (Rigorosen) in 1896. "He appeared to me as the incarnation of the scientific spirit," Gomperz wrote later (Gomperz 1953, 18).

Today, the Buddha image is more or less omnipresent: from cosmetic stores to food items to brochures for gardening tools you can find Buddha images; and you can even train to develop "a Buddha brain" and "Buddhism and Business" seems to go well together etc. Some positions in neuroscience even seem to support Buddhist practices, for example when the neuroscientist Tania Singer develops a training manual for loving kindness (Singer and Bolz 2013).

Thus, the stage is set to ask a couple of questions. First of all: why would people like Gompertz call an eminent philosopher and scientist like Mach "a Buddha"? Furthermore: why do contemporary neuroscientists engage in research on "Buddhist brains" (Gilsinan 2015)? Does neuroscience prove Buddhist claims? And, if so, would it lead to the conclusion that Buddhism is a scientifically verified religion? Recent discussions about the significance of neuroscientific findings on Buddhist meditation cast doubt on these claims (Kellner 2016; Purser 2016), but nevertheless it remains a very popular view. To call someone "a Buddha of Science" today seems a little strange, while around 1900, however, only the educated elite knew about the name of the Buddha and it was a honorific title. But still, why would someone call an eminent philosopher and scientist "a Buddha"?

7.1 What Mach's Contemporaries Knew

The gestalt of the Buddha as well as his teachings had come to Europe as a contraband of colonialism. Since the seventeenth century, porcelain, richly ornamented cloth and lacquer ware arrived to Europe together with tea and spices (Berg 2005). Orientalist fashion at the end of the eighteenth and beginning of the nineteenth century shaped the taste of the salons (Crill 2004; Sargent 2004). By the end of the eighteenth century, the first translations of Sanskrit texts were provided by the East India Company. However, at that time, Buddhism was not perceived as a distinct religious entity. The colonial functionaries – the "Britishers" as they are still called in India today – initially took the teaching of the Buddha to be a simple variety of the numerous Hindu traditions. Even the preface to the first 1819 edition of Schopenhauer's "The World as Will and Representation"– by far the most influential work disseminating Buddhism in the West –mentions not Buddhism but the Upanishads as seemingly parallel to his thought. It is only in the second edition of 1844, 24 years later, that Buddhism is mentioned here. This corresponds to the slow recognition on behalf of European colonialists and scholars of Buddhism as a tradition in its own rights, and, in fact, it took quite some time for them to find out that the Chinese "Fo" and the Singhalese "Bauddha" were the same person. The term "Buddhism" seems to first appear as an English term around the 1820s, whereas the German philosophers of the time talked about "Buddhaismus". Thus, Buddhism as a unifying concept is a Western product from the very outset, as stated also by Richard Almond in his study on the British discovery of Buddhism: "Buddhist scholarship was not only the cause but also the effect of that which it brought into being – Buddhism" (Almond 1988, 19). Only in around 1880, Japanese Buddhists began to construct a unified Buddhist doctrine (Kleine 2011b, 480/1, Kleine 2011a) and to critically and historically investigate the Buddhist tradition.

In writing the first edition of "The World as Will and Representation," Schopenhauer had no access to Buddhist texts, since Pali texts were made available to Western scholars only by roughly the second half of the nineteenth century. European scholars long ignored the fact that Buddhism was a living tradition, and they treated Buddhist scriptures like Latin or Greek texts and thus as remains of an extinct culture. Furthermore, their colonial mindset dismissed the experience and expertise of living Buddhist practitioners who were seen as colonial subjects. (Lopez 1995). In effect, they constructed a "pure Buddhism" according to European taste, without reference to meditation practice or rituals, in which Buddhism was seen not as a religion, but as a philosophy or Weltanschauung without a savior and as an antagonist to the Jewish-Christian-Muslim traditions.

Schopenhauer's work had sparked great enthusiasm for Buddhism among artists and intellectuals who were critical of religion, i.e. of Christianity. One such prominent example is Richard Wagner, who in 1856 already planned to write an opera about the Buddha titled "The vanquisher" (*Der Sieger*), and, indeed, motifs from this preliminary work were later included in his "Parsifal" (see Zotz 2000, 84 ff).

In the second half of the nineteenth century, the Buddha and Buddhism became a fashionable and relevant alternative to Christianity. In Gustave Flaubert's satirical work "Bouvard et Pécuchet" (1881), one of the protagonists, Pécuchet, refers to this positive prejudice by stating that he wishes to become a Buddhist, because Buddhism is "better than Christianity, and before it" (Flaubert 2014, 363).

Another important contribution to the dissemination of Buddhism among the educated classes was Edwin Arnold's "Light on Asia: The Great Renunciation"

(1879), a narrative poem about the life of the Buddha. It appeared as a popular edition in German as "Die Leuchte Asiens: Erzählungen eines indischen Buddhisten" in 1892, a Reclam pocketbook (new edition 1995). Its first translation, however, was already published in 1887 by the industrialist Arthur Pfungst, a typical German supporter of Buddhism at the end of the nineteenth century: an engaged freethinker, a translator of Pali texts and member of the Royal Asiatic Society with good contacts to Buddhists in Asia. Another important source for the spread of a popular version of Buddhism was the Theosophical Society, founded by Mme. Helena Blavatsky and Colonel Olcott in New York in 1875, with chapters in Germany since 1879 and in Austria since 1887. The Theosophists promoted a mixture of science, evolutionary thought, esoteric teachings and Buddhism, a mixture which did not suit everybody but proved to be very influential for the twentieth century (von Stuckrad 2004, 156f). Olcott published a "Buddhist Catechism" in 1881, which appeared in German as "Buddhistischer Katechismus nach dem Kanon der Kirche des südlichen Indiens" in 1887. In Germany and Austria, sympathizers or supporters of Buddhism were members of the Theosophical Society, freethinkers or joined the newly founded Ethical Society. Of course, there were critical publications as well, emphasizing like Max Nordau or Friedrich Nietzsche that Buddhism was nihilistic, pessimistic and even a special kind of degeneration.

The aesthetics of Japanese arts and crafts displayed at the world exhibitions in Paris and Vienna had a huge appeal to the protagonists of modern art and sparked a fashionable Japonism in Europe. Especially the Greek-American writer Lafcadio Hearn, a naturalized citizen of Japan since 1895, excited writers such as Hoffmannsthal but also the young Erwin Schrödinger (Moore 1994, 87). Hearn's books were "a kind of sensation" in Vienna around 1900 (Askew 2009, 48).

In this atmosphere, one of the most important voices was that of Paul Carus, the translator of Ernst Mach's writings into English and one of the most influential persons in the transfer of Buddhism to the West (Henderson 1993). Carus, the son of a German pastor, was an engaged freethinker and convinced atheist, and these two reasons forced him to leave Germany in 1883 and emigrate to the US. He became the editor of two important monthly journals, both founded and sponsored by the German-born industrialist Edward C. Hegeler. Hegeler, who was close to the freethinker movement, saw both journals, "The Open Court" (since 1887) and "The Monist" (since 1890), as a platform for the discussion of science, philosophy and religion. They were high-end publications, featuring articles by William James, Leo Tolstoy, Ernst Haeckel, Bertrand Russell, Albert Einstein and Ernst Mach among others.

Carus was an active participant in the World Parliament of Religions in Chicago in 1893, where Buddhists from Japan and Sri Lanka (then Ceylon and a British Colony) as well as Hindus from India presented their religions to a Western audience for the first time, mostly Christians of different denominations as well as people like Carus. Carus was impressed by the Buddhist monks, and the following year he published "The Gospel of the Buddha" (1894), a best seller and long seller which was also translated into German (1895). Here, Carus presented Buddhism as a scientific religion and the Buddha as an enlightened rationalist, freethinker and humanist. His book was read not only in the West but also in Japan, where Sokei-an, a renowned Zen-master of the time, recommended the book to his students and considered the study of Carus' compilation over and above the study of the Buddhist canon – and among his students was D. T. Suzuki, later godfather of Zen in the West.

7.2 Mach, a Buddhist in Disguise?

At the beginning of the twentieth century, it is plausible that for a European elite the Buddha had become a kind of "ideal human being" and an archetypical humanist teacher with an intelligent and reasonable worldview. Especially in a country like Austria, with its "protracted enlightenment" (Benedikt 1995) and where reading Kant was forbidden at school (*Gymnasium*) until the 1880s, Buddhism seemed to be a welcome antidote to the rigid mindset upheld by the alliance of church and state. When people compared Mach with the Buddha or found parallels between Buddhism and his epistemology, it was not to turn Mach into an esoteric crackpot but rather to honor "his serene and clear mind" (Gomperz).

The physicist Anton Lampa, a strong supporter of Mach's epistemology, felt attracted to Mach's ideas pacifism as well as to the idea that Mach's epistemology was somehow Buddhist. This becomes obvious when Lampa notes in his biography of Ernst Mach: "Mach's thoughts show a remarkable agreement in its main characteristics with those of Buddha in his exclusion of metaphysics and the concept of substance" (Lampa 1918, 60).

Mach himself had read Schopenhauer quite early in his life, in that he is not different from many of his contemporaries. He had also acquired an early interest in Asian cultures, especially the Chinese. He was also acquainted with Indian mathematics and literature, to the extent that in 1876 he encouraged a musical-minded student of his, Wilhelm Kienzel (well-known for his opera "The Evangelimann", 1894) to compose an opera based on the fifth century Indian play "Urvaśi" by Kālidāsa, which premiered in Dresden in 1886. In other words, like many intellectuals of the time, Mach was interested in Eastern cultures, however Buddhism had obviously not been in his sight before he learned about it in the 1890s. (Baatz 1992, 1996)

Arguments for a proximity between Buddhist philosophy and Mach's epistemology may refer to his work "The Analysis of Sensations." The "Unrettbarkeit des Ich," i.e. the negation of the metaphysical concept of an "I" as well as of a "thing in itself" (*Ding an sich*) makes Mach a candidate for parallels to Buddhist thinking. (Baatz 1992) The perceived closeness seemed so convincing that, according to Theodor Beer, one of Mach's friends (Blackmore 1972, 288/9), in around 1911 there even were translations of Mach's "Analysis" and other texts into Sinhala – the language of the Buddhists in Sri Lanka, then Ceylon and a British colony, and one of the focal points of Buddhist anti-colonial fight, in which, according to Beer, the brochures of Mach's writings were used as propaganda and teaching materials.

Mach himself acknowledges a certain proximity of his epistemology to Buddhism. In a footnote to the 1902 edition of "The Analysis of Sensations," he emphasizes that the ego as a complex of transitory elements "for thousand years past Buddhism has been approaching this conception from the practical side," and refers to Carus' books "Gospel of the Buddha" and "Karma: A story of early Buddhism" (Mach 1918, 105). Both books had been published in 1894 and Carus sent them to Vienna in the fall of 1894 (Blackmore 1972, 287).

Ten years later, in a letter to Mauthner in 1912, Mach denies any links between Buddhism and his epistemology: "Ever since I learned about it, I have had the greatest sympathies for Buddhism, even if my Analyse der Empfindungen was not stimulated by Buddhism but originated from the most naïve reflections. Certainly, I can make no claims to originality vis-à-vis Buddhism. Indeed, David Hume in his Treatise on Human Nature had already carried through an analysis of the self and destroyed the illusion of its perseverance long before me. Actually, I owe this insight neither to Buddhism nor Hume, but to familiarity with Lichtenberg's 'it thinks,' though he probably had some acquaintance with Hume." (Haller/Stadler 1988, 242/3).

7.3 Parallel Isomorphisms

In the first paragraph of "The Analysis of Sensation," Mach himself describes the origins of his thinking: "Out in the open on a bright summer day, the world once appeared to me together with my self as one interrelated mass of perceptions, only more strongly connected with the self. Although the essential reflection [on that moment] was only added later, the original experience became decisive for my whole world view (*ganze Anschauung*)" (Mach 1918, 24). The "naïve reflections" of an incident in his boyhood were autobiographical (experiential) motivated foundations of Mach's critique of a metaphysical entity "I" and a Kantian "Ding an sich." (Baatz 1992)

Mach identifies the "I" as a complex consisting of different sensations: sensations of perception, likes and dislikes, memories, evaluations, concepts and conclusions. Sensations can be distinguished by their distinctiveness and intensity (*Deutlichkeit*). They appear in a hierarchical order according to their degree of interconnectedness. The world outside is represented in the inner world through cognition and so that survival is possible. Cognition is based on sense organs and neuronal structures of the brain, which act like an interface between us and the surrounding world. In 1910, Mach writes in his notebook: "the frontier between objective and subjective runs right through the middle of sensation and consciousness" (Haller/Stadler 1988, 208). The complex of sensations and thoughts manifests itself and is accessible through language, since language labels the basic sensations such as red, warm, noisy etc. (Leinfellner 1988, 117). The principle of "Denkökonomie" – Mach's version of "Ockham's razor" – is the organizing principle of knowledge, i.e. scientific knowledge, which supports survival. "Denkökonomie" is also the guiding principle for realizing the "ideal of a moral order with the help of our psychological and physiological insights" (Mach 1920, 463), together with our ability to humanize the world.

Mach relates to his personal experience: "alternating my attention back and forth between physics and physiology of the senses, together with historical investigation into physics, which allowed me, after having vainly attempted to free myself from conflict by adopting a psycho-physical monadology, to attain greater stability in my views (approximately since 1863)." (Mach 1918, 24)

The Buddhist teachings of *anātman* or "non-self" are rooted in the reflection on certain meditative practices which acknowledge the transitory nature of all phenomena to attain "awakening" or liberation (Steinkellner 2002). The development of the theory of *anātman* goes against Brahmanic, i.e. non- Buddhist, teachings which saw the *ātman* or "self" as an unchanging absolute and divine unity and fundamental to everything in time and space. For Buddhists, such a view is detrimental to the attainment of liberation. According to Buddhist teachings, liberation is the experiential insight that everything, including myself, is conditioned and therefore "empty," i.e. without any permanent or metaphysical substance. Healthy knowledge is supportive of liberation and unhealthy knowledge is obstructive to liberation. When dealing with the arising and passing-away of the world, Buddhism refers to dependent co-arising (*pratītyasamutpāda)*. Dependent co-arising is seen as a circle of conditions, which includes ignorance (*avidy*ā or not knowing) about emptiness and clinging (*upadāna*) as the driving force of the cycle of birth and death. Liberation would consist in the extinction of *tṛṣṇā* or "thirst", which is the driving force and manifests itself in greed, hatred and ignorance. *Nirvāṇa* is the extinction of greed, hatred and ignorance, an unconditioned and deathless state. This realization of *nirvāṇa* is the normative goal of Buddhism.

The relationship between nirvana and dependent co-arising is interpreted differently in different schools of Buddhism, however it is fair to say that an overall deeper knowledge of wordly affairs, such as, for example, biological processes of becoming and decay, is not a relevant goal in itself. Indian philosophy is less interested in contingent objects underlying change and more in knowledge which transcends time and space.

In contrast, Mach sees the biological world as a given and is not interested in jeopardizing the biological, i.e. psycho-physiological processes. He is interested in the reconstruction of the multiple dependencies which are basic for the development of biological structures.

In the details, however, there are many parallels: the self dissolves into elements according to both Mach and Buddhist teachings of the psychophysical aggregates (or *skandha*). According to Mach, what usually is called "inside" and "outside" both consists of sensations, our body, our perceptions and representations as well as color, time and space and so on – everything is conditioned and "unconditioned invariability does not exist..." Only the "relation" between conditioned entities is invariable ccording to Mach, as a second order concept or connecting laws (*Verbindungsgesetz*).

Similarly, according to Buddhist teachings, the world consists of "instantaneous phenomena" (*dharma*), which are non-substantial and follow the law of dependent co-arising. These *dharmas* include – next to sense perception, thinking, desires, ethical and unethical attitudes –space and time as well as concepts like holiness or differentiation and also those that refer to meditation practice. Generally speaking, only one *dharma* is unconditioned: *nirvāṇa* .

This insistence on the interdependence of related phenomena as a basic notion in scientific research is where Mach seems to touch upon the realm of Buddhist teachings. However, a basic difference is obvious: Mach describes "elements" and "sensations," while Buddhist texts speak of "instantaneous phenomena." While their similarity is deceptive, the underlying cognitive interest is fundamentally different.

Mach aims at a scientific viability, while Buddhist teaching aims at liberation or *nirvāṇa*. According to Buddhist thought, Mach describes phenomena from a wordly (*lokiya*) perspective, whereas the Buddhist description of phenomena aims ultimately at *lokuttara*, that which is not worldly but refers to *nirvāṇa*. Buddhism is normative, whereas Mach is descriptive. In the end, I doubt that Mach, if he had more in-depth knowledge of the Buddhist tradition, would have truly appreciated any claims of a close relationship between his epistemology and Buddhism.

7.4 The Modernization of Buddhism

Why does it seem so intriguing to bring Buddhism and science into a close relationship? One answer can be found in the history of globalization: the interpretation of Buddhism as a secular, rational and scientific as well as humanist world view was due to the initial disregard of the living traditions of Buddhism by Western scholars. When British colonial officers and missionaries in Sri Lanka intended a re-education of the Sinhala people to comply with Western standards which included Christianity as a part of the "colonial package", the Sinhala Buddhists opposed. In the famous Panadura debate, held in a small town at the southern coast of Sri Lanka in 1873 between a Christian pastor and a Buddhist monk, the latter proved to be the better orator. This debate had local as well as international consequences: in Sri Lanka, then Ceylon, it boosted the identity of the Sinhala population and Buddhism became one of the nationalistic means in the anti-colonial fight against the British. In the US, Colonel Olcott, the co-founder of the Theosophical Society, was so impressed by the news that he and Mme. Blavatsky travelled to Sri Lanka in 1880 to formally and publically convert to Buddhism. His "Buddhist Catechism" (1881) became an influential tool of Buddhist revivalism. Olcott translated Buddhist teachings into a modernist and quasi-scientific language, for example when he rendered *pratītyasamutpāda* (dependent co-arising) as "causation," which led to an interpretation of dependent co-arising as "a law of cause and effect," a translation widely used even today.

Buddhist modernism was a strong force in developing national identities both in Sri Lanka and Japan. The Western interpretations of the Buddha as a secular humanist and of Buddhism not as a religion but rather a worldview superior to Christianity was well received as a means in the anticolonial fight and effectively turned into a self-portrayal by Asian Buddhists (Sharf 1995). The Meiji era from 1868 initiated the rapid modernization of Japan, which was supported by invitations of Western specialists, from train engineers to philosophers. Buddhism, as the dominant religion of the pre-Meiji-era, was in disregard as outdated and corrupt, thus young Buddhist apologists "drew upon Western philosophical and theological strategies to adapt their faith to the modern age" (Sharf 1995). "Japanese intellectuals, seeking to bring their nation into the 'modern world,' were naturally drawn to the European critique of institutional religion – the legacy of the anticlericism and antiritualism of the Reformation, the rationalism and empiricism of the Enlightenment, the romanticism of figures such as Schleiermacher and Dilthey, and the existentialism of Nietzsche." (Sharf 1995, 109).

In this context, Paul Carus, the German freethinker, atheist in exile and friend and translator of Ernst Mach figured as an important hub for the transfer of Western ideas into Buddhism as well as for the transfer of a modernized Buddhism to the West. He acted as a kind of "midwife" for the birth of "the Scientific Buddha" (Lopez 2012), i.e. a view of Buddhism that conforms to whatever is the prevalent scientific theory. One example is a quote widely attributed to Albert Einstein: "If there is any religion that would cope with modern scientific needs, it would be Buddhism." As Lopez can show, the quote is a concoction. "And since the time when Einstein didn't say this, intimations of deep connections between Buddhism and science have continued, right up until today." (Lopez 2008, 154).

The translation of the revered Buddha of centuries into the Scientific Buddha in the nineteenth century was a reaction to European colonialism and Christian missionaries. That Ernst Mach's epistemology was not only compared to but sometimes by Sri Lankan Buddhists even identified as Buddhist teachings was a spinoff of the invention of the Scientific Buddha.

For the Buddha to be identified as an ancient sage fully attuned to the findings of modern science, he had to undergo a transformation from the Buddha who had been revered by Buddhists across Asia for many centuries, identified with many different names. European scholars set out on a quest to find the "historical Buddha", just as there was a quest to find the "historical Jesus". This new Buddha was portrayed as a prince who had renounced his throne, who proclaimed the truth to all who would listen, prescribed a life dedicated to morality and without the need for God, teaching in accordance with modern science. This Buddha would become the "Scientific Buddha" (Lopez 2012, 15), the one who is today a kind of patron saint for part of research in neurophysiology.

In the 1990s Francisco Varela (1946–2001), a renowned biologist, philosopher and neurobiologist, founded the "Mind and Life Institute" as a venue for the dialogue of Buddhism, more accurate the 14th Dalai Lama with cognitive science. The interest of the Dalai Lama to engage in dialogue with science results of his personal interests, but it is a result of globalization as well. Tibetan culture and Tibetan Buddhism is threatened with extinction since the invasion of the Chinese in 1959 into Tibet, which forced more than hundred thousand of Tibetans to emigrate, among them leading religious and intellectual figures. To survive as a culture and religious tradition in exile needs preservation and at the same time the actualization of tradition and inculturation into the West. A dialogue between Buddhist traditions and advanced Western science could be part of the inculturation and preservation of Tibetan Buddhist knowledge under new historic conditions. Throughout the years a lot of Tibetan monasteries and Tibetan Buddhist groups sprang up in the West and Westerners became Tibetan Buddhist monks or teachers. Francisco Varela, a Chilean in exile living in the US and Europe, was one of them: not only was he a renowned researchers, but also a practicing Buddhist. He was just the right person to establish a bridge between Buddhist traditions and an advanced Western scientific approach, which today is neuroscience (see Boyce 2005). The neurobiological research focuses on mindfulness and other Buddhist practices, especially as since the 1990s with the "decade of the brain" research in brain activities is broadly supported by governments.

But again, the basic category mistake is the same as in Mach's time. Buddhism is aiming at the end of the "cycle of life and death" and therefore at the extinction of egoism in all forms. Buddhism is a moral teaching aiming at transcendence in the form of *nirvāṇa*. Science can prove that certain cutouts of Buddhist meditation practices are effective. But this does not prove neither that Buddhism is a scientific religion nor can science prove that there is a state like *nirvāṇa*. To try to equate or verify Buddhist tradition with or through science is a naturalistic fallacy.

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Chapter 8
Some Remarks on Mach's Philosophical Doctrines

Sandy Berkovski

Abstract In his general philosophical remarks, scattered across different oeuvres, Mach subscribed to a number of doctrines. First, the thesis of the economy of science: The primary, perhaps the only legitimate goal of scientific theories is to achieve the economy of thought. Instead of recording many facts, science codifies them under the heading of laws. Instead of attending to individual diverse sensations, science postulates the existence of bodies. Then we have evolutionism: Human activities must ultimately be understood in terms of Darwin's theory. A man is a biological product of evolutionary development. But only human activities: history of knowledge, ideas, thoughts is only intelligible by the lights of evolutionary theory. Finally, phenomenalism: Sensations are denizens of the world, whereas bodies (material substances) are symbols constructed in thought, chiefly to serve the purposes of economy. Are these views jointly consistent? I argue that the role of naturalism, prominent in the endorsement of the evolutionary theory, creates an unresolved tension among those views. Phenomenalism in particular is deeply revisionary. It appears to be a remnant of empiricist metaphysics casting doubt on pretty much every area of scientific discourse. The adoption of full-fledged philosophical naturalism should be able to resolve the tension without ruling out the possibility of a methodological critique of scientific theories.

8.1

If we take seriously the idea that humans are part of the natural world, that their capacities were fashioned in the constant struggle for survival and reproduction, then the whole body of their practices must be thought of as a product of their practical engagement with the material environment. Occasionally practitioners of different disciplines might entertain a pleasing thought that their own activities pursue more elevated goals. Truth and beauty would be among the most prominent candidates.

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It is entirely plausible that people can be motivated better to engage in science and art by setting themselves goals couched in those nobler terms. While this is never more than a pretence, it can lead to a false speculation. A critical reflection on the nature of a particular practice should be able to reveal its roots and do away with the metaphysics born out of excessive ambition.

8.2

Take literature. Save for a few genres on its extreme fringes, no writer and no poet would think of its output as having primarily a practical purpose, or any practical purpose at all. Writers write simply because they have an irresistible urge for writing, or perhaps because they are driven by the desire to discover the 'logic of life', as Marquez put it. Regardless of the individual inclinations of the writers, the readers do not normally approach works of prose and poetry with a hope of being taught how to solve practical tasks in their lives. Aesthetic curiosity and aesthetic pleasure, the desire for aesthetic education, are their more usual motives. In what sense, then, can we talk of literature being practical? Perhaps in this: as the modern sophisticated genres evolved from ancient storytelling, they share among them the purpose of delivering pleasure to the readers. In turn, our capacity to derive pleasure from storytelling evolved to promote bonding between members of the community. Certainly, hardly any literature practitioner, a reader or a writer, is expected to approach novels and poems with the aim of bonding with his fellows. No matter: literature as a cultural component came to occupy its place due to its bonding capabilities. And it will cease to be a cultural phenomenon as soon as it stops playing that role. This is its ultimate cause, and it acts as a constraint on the practice of that particular activity. The individual attitudes of its practitioners are the proximate causes of the continued practice of literature. They need not be reduced to the ultimate ones.

8.3

The scientific enterprise can be subjected to the same examination. The activity of science, so far as it can be located within a natural history of mankind, should be assigned practical goals. Indeed, it will be assigned the pre-eminent such goal, physical survival. Scientific activity, at its origins, has the purpose of recording and processing observations in the most efficient way, its efficiency judged by the contribution it makes to our survival. It really goes all the way down to our most basic capacities for interaction with material environment. Our minds are bombarded with different sensory impressions, coming in different shapes and colours. It is an elementary scientific activity undertaken by our minds to isolate similar impressions to form a conception of a material body. Instead of recording the similar manifold impressions we experience on two different occasions, we simplify the task by labelling them 'the body X'. No longer do we need to track the similarity of those temporally separated sets of impressions, and a major economy of effort and notation is the obvious benefit.

There is more to come. Survival is not served until prediction is mastered. Discovery of regularities, assisted by observation and memory, is a starting point for the formulation of natural laws. Of course the idea that there can be a real repetition of events is fanciful. All events are unique. We pretend that there are event-types only because we choose to attend to some aspects of their similarity, while our choice is in turn guided by practical concerns. In any case, in formulating laws we simply record our observations in abbreviated form. Our expectations will accordingly be preserved in thought with a lesser effort. And moreover, few of our predictions are of our own making. Most are the product of learning and instruction. Formulating natural laws enables communication between individuals, a vital condition of survival.

As with literature, science satisfies intellectual curiosity. First there is the desire of knowing the nature of the world we live in, the what-question. And then there is also the desire for explanation, asking and answering why-questions. Two obstacles apparently stand in the way of satisfying both desires. On one hand, the external bodies are constructions of our own thought. On the other hand, we do not have any insight into the relations in the world external to our senses. But we have to ask the right questions. Once the description of the fact has been provided, in all of its relevant particularities, there is nothing more to say about what there is. To say what an earthquake is to assemble in thought all the different experiences associated with an earthquake. More precisely, and even more radically, the term 'earthquake' stands for all of these experiences. To explain an event is not to identify its causes, some other events located in the external world. It is to derive the ideas representing these events from other ideas. Which ideas will perform the explanation? Those that are experienced with greater constancy—that is, those that are experienced on a greater number of occasions. These ideas at the same time are also more familiar to us. In explaining the unfamiliar is replaced with the familiar.

8.4

I hope you have recognised in the above brief remarks a partial reconstruction of some of the threads of Mach's reasoning. There are some very intriguing suggestions here, explored in later discussions in the philosophy of science. Among them is the idea of explanation as reduction to the more familiar phenomena, and the idea of explanation as unification. I do not want to dwell on these subjects here. Instead I propose to look at the larger doctrines embraced by Mach. Here is a summary:

Economy of science The primary, perhaps the only legitimate goal of scientific theories is to achieve the economy of thought. Instead of recording many facts, science codifies them under the heading of laws. Instead of attending to individual diverse sensations, science postulates the existence of bodies:

> It is the object of science to replace, or *save*, experiences, by the reproduction and anticipation of facts in thought. Memory is handier than experience, and often serves the same purpose. This economical office of science, which fills its whole life, is apparent at first glance; and with its full recognition all mysticism in science disappears.
>
> Science is communicated by instruction, in order that one man may profit by the experience of another and be spared the trouble of accumulating it for himself; and thus, to spare posterity, the experiences of whole generations are stored up in libraries. (*Science of Mechanics*, 481)[1]
>
> The grandest principles of physics, resolved into their elements, differ in no wise from the descriptive principles of the natural historian. The question, "Why?" which is always appropriate where the explanation of a contradiction is concerned, like all proper habitudes of thought, can overreach itself and be asked where nothing remains to be understood. (*On the Economical Nature of Physical Enquiry*, 199)[2]

Evolutionism A man is a biological product of evolutionary development. Human activities must ultimately be understood in terms of Darwin's theory. And not only human activities: history of knowledge and of ideas is only intelligible by the lights of evolutionary theory:

> For the human being, with his thoughts and his impulses, is himself merely a piece of nature. (*Analysis of Sensations*, 334)[3]
>
> Man is governed by the struggle for self-preservation: his whole activity is in its service and only achieves, with richer resources, what the reflexes accomplish in the lower organisms under simpler conditions of life. Every recollection, every idea, every piece of knowledge has a value originally only in so fa as it directly furthers man in the direction indicated. (*Wärmelehre*, 336)[4]
>
> [K]nowledge, too, is a product of organic nature. And although ideas, as such, do not comport themselves in all respects like independent organic individuals, and although violent comparisons should be avoided, still, if Darwin reasoned rightly, the general imprint of evolution and transformation must be noticeable in ideas also. (*On Transformation and Adaptation in Scientific Thought*, 217–218)[5]

Phenomenalism Sensations are denizens of the world, whereas bodies (material substances) are symbols constructed in thought, chiefly to serve the purposes of economy[6]:

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[1] Cited from Mach (1919).

[2] Cited from Mach (1898).

[3] Cited from Mach (1959).

[4] Cited from Mach (1986).

[5] Cited from Mach (1898).

[6] Recent scholarship has largely challenged the attribution of phenomenalism: see, e.g., Banks (2014). I recognise the force of its arguments, but remain unconvinced. The least one can say, it seems to me, is that there are many passages in Mach that one would expect to find in Berkeley. It is true that Mach explicitly denied the affinity with Berkeley in Mach (1891), but the denial is as passionate as it is cryptic. At all events, the present discussion proceeds on the assumption

> Nature is composed of sensations as its elements. Primitive man, however, first picks out certain compounds of these elements—those namely that are relatively permanent and of greater importance to him. The first and oldest words are names of "things". (*Science of Mechanics*, 482)

> [B]odies or things are compendious mental symbols for groups of sensations symbols that do not exist outside of thought. Thus, the merchant regards the labels of his boxes merely as indexes of their contents, and not the contrary. He invests their contents, not their labels, with real value. The same economy which induces us to analyse a group and to establish special signs for its component parts, parts which also go to make up other groups, may likewise induce us to mark out by some single symbol a whole group. (*On the Economical Nature of Physical Enquiry*, 201)

> [T]here is no such thing as a specific *electrical* fact, that every such fact can just as well be regarded, for example, as a chemical one, or as a thermal one, or rather that all physical facts are made up, in an ultimate analysis, of the same sensuous elements (colors, pressures, spaces, times), and that we are merely reminded by the term "electric" of that particular form in which we first became acquainted with the fact. (*On the Economical Nature of Physical Enquiry*, 168)

At the first sight, these views appear to be in harmony. The thesis of economy fixes the essentially practical goals of science. Theories are charged not with discovering entities in the external world or worldly relations, but only with assisting our activities. That this should be the case is strengthened by reflections on the genesis of knowledge. Human theorising emerged as an instrument for self-preservation. Human species honed their intellectual tools in order to better adapt to their environment, to survive and reproduce. As for phenomenalism, we find no evidence for the existence of substances. Our experience furnishes us only with sensations. Yet the introduction of substances has its salutary role in aiding the economy of thought.

On a second look, things are a little more complicated than that. Begin with evolutionism. Why should anyone, at the end of the nineteenth century, accept Darwin's theory? Not because it congrues with one's ordinary experiences. If anything, ordinary experiences tell against it. When originally proposed, and at the time of Mach's writings, very little concrete evidence could be cited in its support. Rather, the reasons for its acceptance were for the most part pragmatic: better explanations, increased generality, greater simplicity. Mach, on the other hand, is on most occasions content with assuming, enthusiastically so, the truth of Darwinism. This acceptance—e.g., in the *Analysis of the Sensations*—is essentially naturalistic. By the end of the nineteenth century the theory of evolution has come to dominate the field of biology. Mach simply follows the practitioners of the discipline in endorsing its leading theory.

The case is very different with the thesis of the economy of science. Though discussed on several occasions, notably in the *Science of Mechanics* and in

that phenomenalism, broadly conceived, can be ascribed to Mach. The assumption, I think, even if stands in conflict with *some* of Mach's claims about sensations and complexes, is not altogether fanciful.

the *Popular Scientific Lectures*, it receives hardly any substantive defence. And what kind of defence would be possible to offer even in principle? It is not a scientific claim: the economy of physics or mathematics cannot be established by mathematical or physical means. It is a meta-scientific, methodological claim. But is it empirical or normative? If it is a merely empirical claim, then we have to turn to the history of science to substantiate it. It is very unlikely though that every scientific enterprise was deliberately created with the purpose of 'economy'. Much more plausibly, the claim is a normative one with a direct link to evolutionism already sketched. Man is part of organic nature. Human knowledge evolved as an adaptation to assist people in improving their biological fitness. Ease of expression, efficient management of experiences contributes to achieving that purpose. Relative to this purpose it becomes a norm.

One immediate problem with this conclusion is that it relies on a rather narrow understanding of fitness. Bonding, curiosity, honour, pleasure, fighting boredom are other factors capable of improving fitness. Scientific activities can and indeed do play a role in each one of them. It is not clear why economy of thought must be given an overriding significance.

There is another concern too: it seems we are moving in circles. We adopt the evolutionary approach guided by the principle of economy. But that principle itself is defended by appeal to the workings of evolution. The authority of the evolutionary knowledge is as strong as any other theory's authority, that is, it is evaluated by its success in the economy of thought. The latter criterion of success is established by tracing the evolutionary origins of science, and the circle resumes. The circularity is damning only if we hope to cling to some one fixed principle arrived at by pure speculation. But if the hope is abandoned, the circularity is virtuous and necessary. I return to this issue in Sect. 8.9.

8.5

Turning to phenomenalism, one argument given by Mach (and strongly reminiscent of Berkeley) is the rejection of the distinction between primary and secondary qualities. Mechanical physics, as well as mere 'habit', incline us toward believing in greater permanence and higher reality of spatial and temporal relations, as compared to odours, sounds, and colours. But a proper analysis of the physiology of perception should dispel the illusion of ontological difference: spatial and temporal relations are sensations no less than colours and sounds are.

Notice two features of this argument. First, it ensures that the most fundamental intellectual curiosity will never be satisfied. We do not only want to manipulate the environment we are in. We do not only want to have an elegant and efficient arrangement of our sensations. We also desire to know where the sensations come from. The discovery of their source will never be warranted either by reason or by senses. Hume welcomed this conclusion, while Berkeley escaped it at the cost of arbitrary theology. Mach believes that nothing is left to explain when the most complete description of fact is given and the economy of thought is achieved. But one is left wondering whether this misses the point.

Secondly, we observe that science, along with mathematics, uniformly adopts realist vocabulary. Then, if phenomenalism is correct, much of science, perhaps all of it, when taken literally is in error. What conclusion are we supposed to draw from this fact? One might propose to reform scientific discourse based on his own metaphysical preferences. Physical theories, for them to be true, will no longer speak of bodies. Their statements will have to be paraphrased into statements about complexes of sensations. We are in the terrain of the *Aufbau*, and one supposes the project will not carry us very far.

I did not see evidence that Mach himself would be sympathetic to this strategy. And there is, I think, no reason for him to be so sympathetic. If science's purpose is to serve the economy of thought, if its purpose is essentially practical, why should there be a *concern* about the literal truth of scientific statements in the first place? Science emerges as an especially effective way of arranging our interactions with external reality. It is not a way of discovering what that reality consists in. Nor is it even a way of tracking our sensations. Its ultimate all-justifying purpose is in improving our chances of survival.

8.6

The proposal, then, is to approach science as craftsmanship, as skill. Whatever gets the job done is legitimate. There is no other source of legitimacy. But there are signs that Mach did not take up this proposal. At the heart of his critique of various branches of science, notably mechanics and thermodynamics, is the conviction that should be metaphysical notions should cleared away. The Newtonian concept of mass, for example, is said to be not properly based on experience: the 'quantity of matter' used in its definition is obscure. And absolute time is dismissed because it cannot be measured by any actual motion.[7] No indication is given how these notions damage the economy of thought, or how they hinder the practical purposes of physics. More plausibly, the motivation of these criticisms comes from the commitment to phenomenalism, the demand that every fundamental notion is traced to experiences, or sensational complexes.

Similarly with atomism.[8] Atoms are not constituents of phenomenal reality. As any other theoretical entity, they are convenient symbols useful in the economy of thought, heuristic devices, on a par with mathematical symbols. But they can never be used in explaining psychological phenomena. The reason, as far as I can see,

[7] See *Science of Mechanics* II.v–vi.

[8] See *Analysis of Sensations* XIV.1–2 and especially page 313. Mach's engagement with atomism is confusing and multifaceted. See Banks (2003, 2014) for some details. I only attend to a particular discussion in *Analysis of Sensations*.

is not in any special disability of the atomic theory in physics and chemistry. It is in the insistence that those 'devices' of physics and chemistry not be used in explaining psychological phenomena. The reason seems to be that, if they are so used, then physics and psychology are of apiece, and reduction is under way—which is unacceptable. This ban on atomism is especially bizarre, since at the same time Mach envisages a future convergence of physics and psychology.

Some metaphysical notions, on the other hand, escaped the purge. The concept of material body was admitted, as was the concept of cause.[9] Presumably the reason was that, while they failed the strictures of phenomenalism, they could still be paraphrased into a language meeting those strictures. But would such a paraphrase be necessary? If the economy of thought is served by a theoretical discourse containing reference to bodies and causes, this discourse should be admissible. We should not be reminded of the possibility of paraphrase, and we should not care about it, since from the outset we do not approach our theory as a source of knowledge of what there is. We approach it as a useful instrument in bookkeeping, with the ultimate goal of aiding our survival.

With the same sleight of hand the previously purged Newtonian concepts, as well as 'atom', should also be restored. If the complaint were about their bungling of our experiments or about some other undesirable *practical* consequence ensuing from their use, then fair enough. But the complaint does not seem to be about these matters, or if it was, it was never sufficiently developed.

8.7

On a very central issue, phenomenalism leaves our curiosity unsatisfied. As phenomenalists, we begin with sense-data, with introspective examination of our phenomenal experiences, and we further insist on the irreducible reality of the content of these experiences (that is, sense-data, sensations, or ideas). *But we cannot stop there.* We must recognise the existence of some other kinds of entities beside the phenomenal content. This move is very clear in Berkeley. Ideas do not generate themselves. They come from some independent source. So we have to postulate the existence of minds, whose sole function intelligible to us is production of ideas.

Berkeley's testament was a grand mystery. We can investigate the relations of ideas with other ideas. The operation of spirits, however, is unfathomable, beyond the scope of any human enquiry. It is peculiar how we can be absolutely certain of the existence of spirits, of their production of ideas, but unable to say anything at all about their ways of existence and operation. This mystery accompanies us daily. We do not need to direct our thoughts to exotic and esoteric questions of the divine intelligence: our own minds are destined to remain locked from us forever.

[9] See, e.g., *Wärmelehre* XXX.

Does Mach allow a similar mystery? It seems so. Indeed, there is not one mystery, but several. In the first place, his putative version of phenomenalism simply leaves out the question about the origins of sensations. Matter is not such an origin, since it is nothing but a symbolic construction of our thought.[10] And if not matter, it is hard to see what else it could possibly be, given the positivist tenor of Mach's theorizing.

Whatever the origin of sensations, can we at least investigate the workings of our brain with the methods of physical science? The aim of every science, physical or psychological, to serve the economy of thought. One thinks that physical methods at least might, one day, be proven useful in describing neurophenomena. Not so, Mach sternly warns us. The methods of physics are to be restricted to the domain of physics.

This situation is ironic. It is ironic, first, given Mach's own critique of Newtonian physics. A major motive of that critique was Newton's ostensible failure to respect the available evidence and his willingness to engage in metaphysical speculations. Of course here the situation initially seems to be reversed: phenomenalism pretends to draw its conclusions strictly upon observation. But, in the conflict between a scientific practice and a metaphysical belief, the belief wins. It is also ironic because of the integration of the methods of physics and chemistry in the neuroscience research. Thirdly, it is ironic because of the prominence of the specifically mechanistic explanations in neuroscience.

8.8

Unrepentant phenomenalism, combined with Mach's methodological scruples, produces one other mystery. If man is part of the natural world, and more specifically, of the animal kingdom, then his abilities must be explained in the way continuous with the explanation of the abilities of other members of that kingdom. At the very least this means that his mental abilities are subject to evolution. His consciousness is an evolutionary adaptation, just as any other ability. Presumably, however, all the concepts of the evolutionary theory are there for the economy of thought, not unlike atomistic concepts. Thus, again, they will be deemed inappropriate for the analysis of sensations. We have already been deprived of the physical methods in investigating the proximate causes of psychological phenomena. We are now also deprived of a proper understanding of their ultimate causes, of their evolutionary history.

8.9

Of the three doctrines mentioned Mach's weakest commitment, judging by textual evidence, is to the theory of evolution. We have now seen how Darwinism may directly clash with phenomenalism. Perhaps then we should simply abandon, on

[10] See, e.g., *Analysis of Sensations* XIV.14.

Mach's behalf, the commitment to Darwinism. Among other reasons why this should be a bad move I want to highlight this one: Darwinism may offer the strongest support for the thesis of the economy of thought. I have already gestured earlier at the reasons why that might be the case; let me now restate the idea.

All elements of our intellectual life, just like the biological capacities of our organism, are adaptations. Science was not handed down to us: it has evolved with us. If it is an evolutionary adaptation, then what is it adapted for? Not for the discovery of truths about the universe. Rather, it has evolved to endow us with efficient means to increase the chances of survival and reproduction. Viewed under this angle, the alleged theoretical significance of science is moot. Its only significance can be practical. This, as I see, offers the strongest support yet for the thesis of the economy of thought.

But as we saw, this support may be illusory in the first place because of the threat of circularity. The evolutionary theory itself, as any other discipline (save perhaps for psychology), must be justified by reference to the economy of thought. The threat is real only so far as we portray ourselves standing outside the scientific enterprise and surveying its elements from a standpoint immune to scientific conceptions. The truth evidently is, we are not. We are fully immersed: our reasoning, our notions, our very language, are all continuous with science. Methodological maxims we use in examining scientific theories are themselves products of scientific theories, rather than bits of a priori knowledge. Thus, embracing a full-fledged naturalism, possibly of the Quinean variety, would lift the threat of circularity.

Yet, even with that threat lifted, it is now time to ask the most uncomfortable question of all: what can the thesis of the economy of thought help us achieve? In many instances it is used as a claim in the history of science, necessary to explain the emergence of certain scientific concepts. On other occasions, however, it is used as an anti-metaphysical hammer to crush metaphysical notions. Thus, for example:

> [Natural science] has to resolve the more complicated facts into as few and as simple ones as possible. This we call explaining. These simplest facts, to which we reduce the more complicated ones, are always unintelligible in themselves, that is to say, they are not further resolvable. … The ultimate unintelligibilities on which science is founded must be facts, or, if they are hypotheses, must be capable of becoming facts. If the hypotheses are so chosen that their subject can never appeal to the senses and therefore also can never be tested, as is the case with the mechanical molecular theory, the investigator has done more than science, whose aim is facts, requires of him—and this work of supererogation is an evil. (*History and Root of the Principle of the Conservation of Energy*, 55–57)[11]

The normative employment of the thesis of the economy of thought is suspect. Let me circle back for a moment to the example of literature in Sect. 8.2. Literature may have originated in storytelling, and storytelling may have fulfilled a vital task of bringing different individuals, developing their social ties. Conceivably, the essential social purpose of storytelling is what made its institution an enduring mark of every minimally developed culture. Literature, even while emancipated from storytelling,

[11] Cited from Mach (1911). The same claim is in *Science of Mechanics* IV.iv.9.

inherited the same function. Its institution continues to fulfil the function of bonding: it creates the common intellectual and emotional frame of reference for otherwise distant individuals within a society.

Some such analysis may be true, but what should it tell us about individual works of literature? Nothing very much. Using it in evaluating those works would be in bad taste. One cannot police literary practice and condemn those works that ostensibly fulfil no social purpose. Grading novels based on the number of readers it 'brought together' would reveal an absurd lack of literary education.

By the same token, the economy of thought may have been the function of nascent science, and may continue to be the function of mature science. Unlike the function of literature, and for reasons already mentioned in Sect. 8.4, the function of science might not be a proper subject of an empirical discovery. But even assuming science as an institution to have such a function, one cannot use it for evaluating individual scientific claims. Just like novels, theories should be evaluated by their internal norms. An external norm can be used perhaps in extreme cases when the institution seems to malfunction—when, for instance, science as a whole, for the most part, has become a mere intellectual game. Under those, and only those, conditions a philosophical revision may be necessary to redirect science to its original purpose.

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Chapter 9
Mach's Post-Kantian Empiricism. For a New Concept of Givenness

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Abstract Mach's positivism shares with Husserl's phenomenology the anti-metaphysical requirement to debunk experience from the categories we have projected in it. However, when it comes to determine its content, are raised issues that, even today, we strive to tackle. Whether Mach is blamed for renewing with the empirical myth of atomically impressions, or he is praised for anticipating the G*estaltpsychologie*, it seems to us that the essential point was missed. *A contrario*, we would like to insist on the radical subversion of the Kantian concept of givenness (*Gegebenheit*). In the first place, he distances himself from the representational conception of givenness and frees it from a double myth (subject and object). In the second place, Mach dissociates givenness from transcendental philosophy and liberates it from the problem of objectivity and of constitution. This deconstruction of the *hylemorphic* schema enables Mach to deliver a new concept of givenness, construed as the irreducible experience of what happens (events): thus his post-Kantian empiricism turns out to be singular in the history of occidental philosophy. Neither logical givenness (Marburg School) nor operative concept, the meaning of which depends on the global context (logical positivism), for Mach givennness can only be restored once categorically neutralized.

9.1 Givenness, an Old-Fashioned Concept?

Following Kirchhoff, Mach refuses to introduce explicative entities in the physical analysis and this requisite of purification of the concept of givenness of all metaphysical data has no doubt played an essential part in the genesis of phenomenology. Husserl marked his debt in the playful § 20 of his *Ideen*, conceiving Mach's descriptivism as a form of proto-phenomenology of which the *Strenge Wissenschaft* would be the radicalization and the accomplishment: if positivism is to be understood as the endeavour toward a foundation of sciences devoid of

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prejudices, on the original basis of experience, then it must be ascertained that phenomenology has a positivist root[1] and that at the same time the first one stayed *behind*, still fascinated by an empirical concept of empiricism which already sounded in the second part of the nineteenth century a bit naïve and old-fashioned comparing to the problem of the relativity of sensation and his relation to judgment which was at the centre of the philosophical and psychophysical debates.

Obviously one century after Mach's death it seems like nothing has changed. Does Mach defend a new version of Hume's sensual atomism? The exegetical debate lies on the first chapter of the *Analysis of sensations*, which makes a difference between the *elements* and the sensorial *complexes*. If the first one is connective and relational and that what is given is always a complex of sensations (and not an isolated one), why would it be necessary to keep the lexicon of elementary? On the one hand it could be said with Cassirer in the first part of the *Philosophie der symbolischen Formen* that Mach's *datum* comes from the importation in the *locus empiricus* of an atomistic physics, which the author had yet dismissed in the prospect of his denunciation of the substance. Mach would be guilty of inheriting a former concept of givenness that he did not take the time to redesign whereas he should have addressed the same critics to the psychological concept of element as he had done for the physical concepts of atomism: inasmuch as the physical notions are not descriptive notions (not reflecting the immediate experience) but mere auxiliary concepts stemming from the *Denkökonomie*, the idea of an isolated sensation (or element) amounts to be a mere myth whose sole purpose lies on its theoretical utility. On the other hand Ehrenfels insists in his paper published in Avenarius's *Vierteljahrsschrift für wissenschaftliche Philosophie* in 1890, the famous "Über Gestaltqualitäten", on the leading role Mach played in the genesis of the Gestaltpsychologie, in so far as the sensorial complex seems to be a proto-*Gestalt*: the thirteenth chapter of the *Analysis* on the "Tonempfindungen" would back up Ehrenfels's reading, since it brings out a common form between two melodies whose musical content however differs. This second reading has the advantage of getting rid of the supposed naivety allotted to Mach's concept of givenness by its inclusion of the relations in the data of experience whereas classical empiricism excluded the relations from it. As Mach wrote on his Notebook in 1882 of April, "Verbindung auch gegeben. Die Elemente und der Zusammenhang. Der Zusammenhang ist auch eine Tatsache".

However, if the first reading misses the thesis on the sensorial complexes, the second one, which sees in them pre-formed *Gestalten*, cannot account for the lexicon of elementary, which appears then to be artificial and useless. In this case, where it is defended that Mach was a precursor of the philosophy of the *Gestalt*, what is then the interest of his *datum*, in so far as to be a precursor also means that

[1] Lübbe H., Positivismus und Phänomenologie: Husserl und Mach", in *Bewustsein in Geschichten. Studien zur Phänomenologie der Subjectivität*, Freiburg, 1972, pp. 33–62; Fisette D., "Phenomenology and Phenomenalism: Ernst Mach and the Genesis of Husserl's phenomenology" *in Axiomathes* 22 (1):53–74, 2012.

the one such designed did not go very far and that the truth of his doctrine is based on a future which relativizes the very originality of it? In these two predominant readings Mach loses the battle. If everyone is right, then obviously the essential lies beyond this (false) debate. In the following I would like to defend the idea that Mach had actually seen that the concept itself of givenness was *metaphysical* (metaphysics does not only refer to what is "beyond" experience) and that it had to be purified and dissociated from the problem of the constitution (from the transcendental) and thus from the duality of subject and object.

9.2 The Naturalization of the Transcendental

What is the philosophical context of Mach? Since each science had its object and its method, to philosophy was allotted the task to an *Erkennentnistheorie,* knowledge of knowledge itself. It is a Kantianism called to open itself to the tradition of the Anglo-Saxon empiricism in order to break up with German idealism, as was required by Beneke in 1832 in *Kant und die philosophische Aufgabe unserer Zeit*. In other words, empiricism appears to serve the criticism, which is testified by the naturalization of the transcendental which Helmholtz popularized in 1855 with *Über das Sehen des Menschen*. This reference is all the more important as it is emblematic of all a period where it is a matter of putting back Kant on stage and defending the transcendental device from the point of view of the physiology of senses. The *impetus* of Helmholtz is his master Müller's thesis on the specific energy of nerves according to which the perceiving subject is not so related to the world as it is related to himself. According to his *Zur vergleichenden Physiologie des Gesichtssinnes des Menschen, und der Tiere nebst einem Versuch über die Bewegungen der Augen und über den menschlichen Blick*, all object-oriented sensation is first and foremost self-sensation, *i.e*. I do no perceive the light, the colours, the sounds, but it is my nervous system, which is related to itself. This idea that the subject cannot escape from his own representations provided by his nervous system goes hand in hand with a form of i*gnorabimus*, such as developed by his other disciple, Emil du Bois-Reymond.

Between the object and the perception lies the specific action of the nerves. Helmholtz reactivates the Kantian *Ding an sich* and dispels all temptation of knowing the object in itself since the sensation naturally depends on the nature of the apparatus by which the effect is produced. Our sensation is not an *image* of the object, which requires a relation of likeness whereas the object lies beyond the subject's reach, but a *sign* of it. The author invokes in his *Tatsachen in der Wahrnehmung* the *a priori* principle of causality (established on the regularity of perceptions in certain circumstances which enables to infer the regularity of the objects which cause them) in order to deliver a nomological discourse on the Real. The semiotic theory of perception postulates that the perception results from the way the nerve reacts but that it also, according to the principle of causality, participates from the nature of the object in-itself, which causes it.

But what does transform a sensation into a sign of the object, into an organized perception? It is a process of translation of the sensorial impact or intellectual elaboration of the material of the pure impression which Helmholtz calls the "unconscious inferences". The issue comes from the fact that this Kantian physiology keeps two elements. As well as Kant supersedes both empiricism and idealism by borrowing from each one, Helmholtz conserves the act of synthesis and the sensible diverse, between a judicative operation of interpretation (the unconscious inference[2]) and a pure material of impression (the unelaborated sensation which is not yet referred to an object).[3] The psychophysiology has the disadvantage to take for granted what has to be questioned, the external world with the physical stimuli and the inner world of representations. The idea that the perception is a sign and not an image and that there is no possibility consequently to compare the representation to the external object (the colour for instance belongs to the sign and no to what is signified) appears like a *deus ex machina* and a rhetorical device. Indeed Helmholtz judges that it is absurd to compare what cannot be compared but this thesis lies on the principal division between what is "inside" and what is "outside". Besides the Kantian duality between the sensibility and the understanding is accompanied by a somewhat paradoxical transformation of the *Ding an sich*. Whereas it is for Kant a *Grenzbegriff* of which we cannot even say if it is possible or not, Helmholtz applies the category of causality, which is nonetheless reserved to the application to the domain of the sensibility, to it, succumbing to a contradiction.

If it is necessary to reconceive the concept of givenness for Mach, it is because the idea that all knowledge of object is mediated by the physiological apparatus combines two things which go hand in hand, an extreme realism (the one of the real independent of the subject) and an extreme subjectivism (a perception refers to the subject himself). Hence the following question: what is givenness as soon as it has been delivered from the prejudice Mach denounces in his *Analysis*, that of the boundary between psychical and physical, between *innerness* and *outerness*?

9.3 Mach and the Transcendental Device

Mach confronts criticism to its own limits. He assumes the Kantian critics of metaphysical as what is beyond the reach of experience, but whereas Kant, to save

[2]Bouveresse, J., *Langage, perception et réalité. Tome 1: la perception et le jugement*, Paris, Editions Jacqueline Chambon, 2000, p. 47. « La tendance de H., lorsqu'il ne parvient pas à concevoir lui-même un mécanisme physiologique susceptible d'expliquer de façon plausible certains effets ou n'est pas convaincu de l'existence de ceux que d'autres croient nécessaire de postuler pour ce faire, est de reporter l'explication au niveau du psychisme et de transférer au jugement et à l'expérience le rôle que certains croient pouvoir attribuer à un donné physiologique préconstitué. »

[3]Cf. Hatfield, G., Gary Hatfield, *The Natural and the Normative. Theories of Spatial Perception from Kant to Helmholtz*, Cambridge, The MIT Press, 1990.

objectivity of knowledge, made a compromise, reconciling the *hyle* of empiricism and the *morphe* or categorial synthesis of idealism, Mach refuses to collaborate with the transcendental device, which lies on the conditions of experiences which, as such, are beyond experience itself and indicate an operation of categorial unification of the wild material of sensation – explaining givenness by what is not given. Thus Mach refuses to put a foot in what he calls in *Erkenntnis und Irrtum* the "country of the transcendental". The discrepancy between the pure sensation and the organized perception inscribes itself in an epistemological context whose purpose is to question givenness from the outside (what make it so, determined in a this way, in the object-format). To refuse the transcendental amounts consequently to firstly stopping justifying experience from what is outside and would play the role of conditioner (the *a priori*), and secondly and more generally, to refusing to regress from the conditioned to what is supposed to condition.

It is true that Mach repeatedly invokes the classical empiricism of Hume and Berkeley, but this reference has nothing to do with the debate that consisted to determine whereas the entire knowledge was derivable from the sole experience or if reflexion could itself form a second source. Besides Locke's *Essays* initiated this problem due to the amphibious status of reflexion as reducible to the sensorial material and at the same time constituting a second source of knowledge next to the sensation. However the reader should not be deluded by such a reference since it is massively used in order to tackle the issue of what has been called the "transcendence" (what is beyond the given), which is associated with the positivist ambition to return to the pure level of givenness by getting rid of the representational issue, that of the adequacy of the subjective representation to an external world: the so-called theory of images, such as the one exposed by Descartes in his *Meditations*, raised an issue for instance typical of the representational issue, since how could I know I have an image if I cannot compare it to what is beyond it and have the non-image? Hume and Berkeley were thus seen at the end of the century as the prefiguration of the *Immanenzphilosophie*, as they refuse to ask the false question of the accordance of the subjective and of the objective after having laid down their principal discrepancy. But whereas Locke did begin with what is given but, in order to distinguish it from fantasy, supposed as a *petitio principii* an external world of objects which affected the soul, explaining the immediate (experience) by what is not given (the objects), and Berkeley dispelled the matter outside of perception but did refer to the divine in order to save the objectivity of the ideas, Mach does not invoke a transcendence: givenness consequently must be seized by itself, without the need to *explain* it, *i.e.* cutting off with the so-called issue of "knowledge" (*what* can I know – the object itself or the effect of the supposedly external object – and *how* can I know – if to known involves the seminal idea of *ob*-ject, what is related to a subject and possesses and identity, then what is the cognitive process by which it is formed) which forgets that subject and object have been abstracted from a the same givenness.

The abolition of the duality leads consequently to a major conclusion: Mach's *datum* cannot be interpreted on the basis of the epistemological distinction between pure sensation and organized perception since it is founded on a transcendental device – even when, as for Helmholtz, it is naturalized – construction on which are based the two main lectures we hinted at, that or the organized perception and that of atomism. What does it mean to construe Mach's givenness as a categorial naked sensorial material if not justifying the necessary intervention of a meta-empirical subject who will take care of its synthesis? In others words, an idealism which has so much caricaturized the pre-critical empiricism with the mocked idea of "pure" sensation that it thus justifies itself? Consequently if Mach abolishes the ontological distinction between subject and object and opposes himself to the transcendental philosophy, we can neither talk about a synthesis (and, therefore, an agent of synthesis), nor about a synthesisable. Repudiating the *synthesisable* (not in the case where there *could* been some unsynthesisable, but in the sense synthesis lies on a impressional material which does not belong yet to the order of objects), it is repudiating the whole idea of *synthesis*. Interpreting Mach's givenness as a *hyletic* material would require a *positive* subject, either materiel (the soul) or formal (the "I think" which in the § 16 of the Transcendental Analytic of the first *Critique*, as unity of apperception, accompanies all our representations).

Only by this context can we explain Mach's original gesture: returning to givenness without trying to explain it from outside means the abandonment of the issue of the *constitution* of the perceptive object which lies on the hylemorphic schema and consequently the question of what is subjective in my perception and what is objective. Mach sends back the presupposition of the naturalized transcendentalism, that of a double myth, one of the independent object (which causes the sensation), and the other one of the subject (who organizes the pure sensation), which links givenness to what is *internally* experienced. The metaphysical realism of the *Ding an sich* appears to be the correlate of a metaphysical subjectivism: if I cannot access to the thing as it is independent of ma perception, thus I cannot say what in my experience is not from me since in its concept is wrapped the very idea of its defining relation to a subject. Therefore, Mach refuses the Kantian heritage of a subjective experience (which is precisely qualified of subjective, in the sense of being related to a subject, because of the "true" thing which is not an object for a subject and outflanks the boundaries of correlationism), *i.e.* frees givenness from the subjective grammar: it is no more what faces the subject and, as intermediary, refers to an outer object, but what is prior to any metaphysical distinction between subject and object, innerness and outerness.

9.4 Neutrality of Givenness

This indifference of givenness to the distinction of subject and object, position baptized by Russell in his 1913 Manuscript *Theory of knowledge* "neutral monism", means that sensation is neither physical nor psychic. The metaphysical distinction is reported on a *functional* distinction: what is given as a physical object or as a subject depends on the interconnectedness of the elements and not on an intrinsic propriety of theirs. "Nicht der Stoff, sondern die *Untersuchungsrichtung* ist in beiden Gebieten verschieden".[4] However the neutrality at stake here differs from the one in the *Immanenzphilosophie* of Schubert-Soldern in his *Über Transzendenz des Objekts und Subjekts* and von Leclair. In the second case in order to bypass the metaphysical problem of transcendence rather than accepting the terms of the representational issue (that of the adequacy of representation to what is represented and supposed to lie beyond the regime of representation), what is put forth is the interdependence between the subject and the object. The two poles cannot be separated, which leads to a monistic *Erkenntnistheorie* where the thought is a thought-of-object, and the object an object-of-thought, to the extent that the question concerning what is non-given appears to be devoid of meaning, a mere *contradictio in adjecto*, since it would mean to "have" what is beyond the limit. The Kantian correlationnism is thus adopted but deprived from its transcendental device (the question of the constitution of the object by the non-given categories of understanding) and from its realism of the *Ding an sich* which testifies the divorce between the thought (since nothing is given before being thought) and the being itself. This is not the correlation subject-object which is erroneous, the fact that there can be no subject without object and no object without subject, but the fact that its stands against a metaphysics of the unreachable transcendence comparing to what (and only to it) what is given (correlated) is construed as a *Vorstellung*: I can only know the object such as it is for me, which consequently leads to couple givenness with egology. This correlation is then neutral (*ne-uter*) in so far as no pole benefits from any ontological priority over its correlated pole, the subject is given at the same title as its object. As writes the founder of empiriocriticism, Richard Avenarius, in the § 143 of his *Menschliche Weltbegriff*:

> Das Ich-Bezeichnete ist selbst nichts anderes als ein Vorgefundenes, und zwar ein im selben Sinn Vorgefundenes wie etwa ein Baum Bezeichnetes. Nicht also das Ich-Bezeichnete findet den Baum vor, sondern das Ich-Bezeichnete und der Baum sind ganz gleichmäßig Inhalt eines und desselben Vorgefundenen. So ist auch nicht der Raum mir gegeben; sondern, wenn von Gegebenen überhaupt gesprochen werden darf, so ist in der Gegenüberstellung *Ich-Baum* das Ich-Bezeichnete bereits im selben Sinn ein Gegebenes wie das als Baum Bezeichnete; und umgekehrt: Ich und die Umgebung – beide Elementenkomplexe, wenn sie gegeben sind, stehen hinsichtlich ihres Gegebenseins vollständig auf gleicher Linie.[5]

This is not the tree, which is given to me, as in the phenomenology where givenness in construed in terms of "donation" (the grammar of donation implies a subject who benefits from it, there is a *dative*: to give *to* someone), but it is with the self *co*-given. Consequently experience is not *mine* in so far as it offers an impersonal structure where it is meaningless to separate the subject from his object.

But for Mach the neutrality of givenness does not relate to the correlation between the subject and the object but to the suspension, the *dissolution* of it.

[4] Mach, E., *Die Analyse der Empfindungen*, Berlin, Ernst-Mach-Studienausgabe Band 1, Xenomoi Verlag, 2008, p. 24.

[5] Avenarius, R., *Der Menschliche Weltbegriff*, Leipzig, O.R. Reisland, 1905, p. 82.

The functionalization of the two poles implies that it stands against a *factum* ontologically beneath the division itself. Whereas for the philosophy of immanence and Avenarius the boundary is well traced insomuch as the subject only plays a role as a *Zentralglied* related to a *Gegenglied,* for Mach, because the subject and the object are made of the same ontological stuff, they can extend their borders and even dissolve into one another. This "*dispersion mystica*", as Manfred Sommer calls it, can take two directions. 1/the extension of the self to the world, which the author briefly describes in a note of the first chapter of his *Analysis*. "An einem heiteren Sommertag im Freien erschien mir einmal die Welt samt meinem Ich al seine zusammenhängende Masse von Empfindungen, nur im Ich stärker zusammenhängend".[6] It is no coincidence this anecdote is related immediately after Mach makes it clear that this experience happened 2 or 3 years after he had read Kant's *Prolegomena*. At the time Kant had freed Mach from what he called in his « Die Leitgedanken meiner naturwissenschaftlichen Erkenntnislehre » his naive realism: the thing is independent from the subject but when it is perceived, it is perceived as it is. The realist lumps together the thing in itself (*die Dinge*) and the thing as it is related to the subject (the word object etymologically denotes the position of something *in front* of me as well as the German one, *Gegenstand*, though its prefix also encompasses a second meaning – of a more Hegelian use -, that of a confrontation). On the contrary, Kant's transcendental idealism removes this confusion between the object (for the subject) and the thing (without any subject). Hence the high significance of Mach's summertime experience which leads him to give up this second step which had been acquired: the dropping out of the *Ding an sich*. This all-encompassing experience of self-expansion seems then to lead to the extreme opposite of the two previous realisms (naïve and metaphysical): idealism, which has been so attributed to Mach by his detractors, such as Lenin in his violent *Materialism and Empiriocriticism*. This would be true if the subject was *something* whereas he differs from the world only by functional, *i.e.* practical, degrees. 2/The opposite direction, not of expansion, but of dissolution of the self into the world. This thematic of the diffusion had a huge impact on the "impressionist" literature such as epitomized in Hofmannsthal's *The Lord Chandos Letter*, where the narrator, under the unbearable pressure of sensations, is threatened to dissolve into their indistinct flow. However the result is the same in the two cases, since it abolishes the idea of *Ding an sich*. Why then the neutrality by suspension and not correlation? Because Mach's opponent is the physiological transcendentalism. The state of ontological indifference between the subject and the object revokes the framework of the transcendental device, i.e. the intellectual meaning of perception (to perceive is to know an object) and the power of the transcendental subject to legislate and apply his low to the chaotic and hyletic material. Where the subject rules because he his *outside* the world, for Mach the subject cannot organize the sensible because he is nothing else than a part of the world: he is *immanent* to the world.

[6]Mach, E., *Die Analyse der Empfindungen, op. cit.,* p. 35.

But *what* is this neutral givenness? This question goes way to far since it wants to determine what is *undetermined* from the point of view of the categories and uses an objectifying language. In this prospect it seems also meaningless to wonder if givenness is one or many, since to talk of multiplicity implies a prior process of identification (*this* is a *what*) and differentiation (*this* is not *that*). As Manfred Sommer says in his *Evidenz im Augenblick* (the fifth chapter "Was sind Empfindungen?"): « je mehr die Empfindung sinnlich gegeben, unmittelbar präsent, evident erlebt ist, desto weniger ist sie identifizierbar, begreifbar, benennbar, desto weniger auch von anderen noch unterscheidbar. Die Evidenz, *dass* es Empfindungen gibt, wächst mit der Unfassbarkeit dessen, *was* es da gibt".[7] To the one who asks what are sensations, Mach tirelessly produces the same answer ("Farben, Töne, Wärmen, Drücke, Räume, Zeiten"). Thus the concept of element in no way refers to a hyletic content which would not have been subdued yet to the power of categories but it tries to captures (as a word) the neutrality to which he refers, to be half-way the subjectivist notion of *Vorstellung* and the well-too heavily charged notion[8] of *Erscheinung*. As well as the pre-Socratic element of the Ionians thwarts the division between the objective value and the sensorial quality, Mach's element, far from denoting a psychological atom of sensation, aims at escaping from the duality of subject and object.

Husserl, had I say, thought that he had accomplished the proto-phenomenology of Mach whereas it was in fact a betrayal by the importance given to the transcendental device and to the role played by the proto-transcendence of the *hyle* which, once animated by noetical acts, delivers the transcendence of the object as a regulative idea and presumptive unity imperfectly given through *Abschattungen*. On the contrary Mach defends an empiricism expurgated from the transcendental problem of the constitution of the object of perception. In this prospect, if Mach exerted such a tremendous influence on the future formation of the Vienna Circle, he still keeps his place apart. Where Schlick adheres in his *Allgemeine Erkenntnislehre* to a kind of critical realism based on the distinction (of principle) between *Erkennen* and *Erleben*, form and content, Carnap in his *Aufbau* seems to reactivate Mach's thesis of neutrality of givenness by dissociating the auto-psychological basis from egology, nonetheless, due to the project of translation of a language into another, the given gets a meaning only relatively to the constructional system and the chosen language. Moreover, what can been seen in it, is an integral structuralism where, as is exposed in the § 61, what comes first is the *relation*. Carnap enacts a kind of grammatical (operational) reinterpretation of the transcendental device by dissociating it from its more "subjective" counterpart such as it appears in the intentional performance. If the primacy of structure may partially derive historically from the notion of *Gestalt* or sensorial complex, the disappearing of the lexicon of elements goes hand in hand with a transition from an ontological neutral monism (the given is below the division subject-object) to a mere *methodological* one. In that

[7] Sommer, M., *Evidenz im Augenblick*, Suhrkamp, 1987, p. 92.

[8] Cf. Thiele, R., *Zur Charakteristik von Mach's Erkenntnistheorie*, George Olms Verlag, 1914.

sense two historical lines could be drawn. One that renewed the Kantian program (the idealist side – Cohen, Natorp – and the empirical one – Müller, Helmholtz). The other, what can be called, following the expression of an admirer of Mach, William James, a “radical empiricism”, which frees itself from the foundational aim of the transcendental device. In the same way the idealist builds a swollen and caricaturized image of empiricism in order to reject it, it seems like the prohibition today of the word “givennes”, well to suspicious, stems from a resistance to this kind of radical empiricism (when it is not qualified, in a rather pejorative way, of “phenomenalism”). That could make us wonder when we realize that the major condemnation of what has been labelled the “myth of the given” largely comes from a neo-Kantian analytical background.

Chapter 10
The Transdisciplinary Legacy of Ernst Mach: From the Analysis of Sensations to the GPS Inside the Brain

David Dahmen, Ronald Villa, René J. Campis, and Eduardo Bermúdez Barrera

Abstract Ernst Mach's writings remain as thought provoking today as when he first produced them but not so much for his treatment of physics as for the epistemological implications inherent in his vision of how sensations unify the physical with the psychical. For over a hundred years the breach between the objective and subjective or theory and the empirical has been widening due to the increasing abstraction of mathematical frameworks necessary to conceptualize the ever smaller scale of elementary particles contemplated by present day theory.

In contrast to that widening gap, neuroscience has simultaneously been creating the basis for a deeper understanding of the physiological basis of sensations that when united with the investigations of cognitive science concur surprisingly well to Mach's theory of how sensations make possible the discovery of the concepts of science without resorting to metaphysics. This paper attempts to draw together the threads of Mach's thought that anticipate present day insights such as the functioning of the hippocampus and contingent cortical modules, innate spatial maps and the innate structures of the developing mind that lead to innate proclivities underlying the formation of concepts.

Now, 100 years after his death, it is still difficult to put one's finger exactly on what makes Mach such an indispensable topic of study, just as it was toward the end of his life at which time he had also attracted a mix of eminent supporters as well adversaries. The motives for extravagant praise as well as questioning or even opposing his positions for over more than a century persist. Part of the reason for this is the unusual diversity of his work ranging over several branches of both theoretical and experimental physics, physiology, psychology and philosophy of science as well as that of mind. In all of these areas Mach was tremendously energetic and inventive, which in itself generates controversy. Over time, when the intensity of

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one controversy diminished, that of another unexpectedly built up. Much of his work was remarkably prescient, so his themes constantly return to active debate even when they are not ostensibly attributed to him. It is never boring to turn to him as an original source since as a colleague of mine once remarked, “Why can’t other philosophers and scientists write with Mach’s clarity and elegance?”

Given the immense trans-disciplinary scope of Mach’s output, this paper must select a single vein of his thought in an attempt to penetrate beyond the merely superficial. One vein that is particularly active today, and one where Mach’s position is of particularly active interest pertains to the origin of concepts and the dynamics of how the generation of new concepts shapes the development of scientific thought. This topic, basically epistemological, was central for Mach because he was one of the first scientists totally committed to fuse the implications of Darwin’s theory of evolution with the empiricist theory of mind of British philosophers such as John Locke, David Hume and Berkeley. As a very successful experimental physicist, he naturally had a deep interest in the origin of his insights which led to the construction, for instance, of a clever apparatus for demonstrating the Doppler Effect and another for capturing the first images of shock waves generated by a projectile traveling faster than the speed of sound.

The nature of his inventions immediately called his attention to the predominance of the *configurational content* of the spatial concepts he used and to which he continually referred as an instinct, which he thought was due to the emergence of evolutionary adaptations of living organisms even before *Homo sapiens* had evolved. Today, due to the rise of artificial intelligence and the influence of investigators such as Marvin Minsky and Herbert Simon among many others, theory of mind tends to emphasize a seemingly incompatible perspective corresponding to the construction of a hierarchy of computational structures such as it is possible to emulate with programs like LISP[1]. Predominately, in the currently popular analogue, the human brain is compared to a means for information processing, usually based upon the model provided by a Universal Turing Machine.

This approach greatly devaluates the importance of any non-symbolic processing prior to computational processing. The importance of possible preprocessing of sensory information within a spatial and temporal configurational framework (that would set the stage before symbolic processing[2] begins) would thus be devalued.

The rejection of mental preprocessing shifts the burden of the development of physical theories to focus then on their algorithmic aspects without leaving much room for intuition, which was Mach’s strongest talent. It was a tendency that Mach often opposed, since he always emphasized the role of sensations in the development of scientific theories and attributed a reduced relevance to mathematics. Perhaps

[1] Specified in 1958, LISP became the preferred language for research in artificial intelligence since its structure facilitated the management of linked lists.

[2] Such a complementary neural preprocessing structure was proposed early on by McClelland, McNaughton & O’Reilly, “Why There Are Complementary Learning Systems in the Hippocampus and Neocortex: Insights From the Successes and Failures of Connectionist Models of Learning and Memory”, in: *Psychological Review* 102, 3, 1995, 419–457.

mathematics didn't go for him much beyond the relations expressed in algebraic formulas and calculus as a sort of shorthand for economically capturing and communicating a condensed presentation of concepts that had taken form thanks to a train of sensations where the unconscious mind, aided subsequently by reflection, had a lot to do with establishing the vital connections.

In order to substantiate the above claim it is convenient to comment on Mach's use of the term "sensations", because it differs substantially from much modern usage and because the term is absolutely central to his epistemology and concept of science. From his perspective, *sensations* cover a far more extensive domain than just qualia, which seems to come closer to contemporary usage. In the first chapter of *The Analysis of Sensations*, sections 4 to 12, he seems to be referring to something closer to the presentational content of what William James referred to as the *stream of consciousness*, expanded to include a considerable degree of abstraction condensed from sensations (such as when Mach referred to the sensation of space or the sensation of time). He even includes his sensations of other people's sensations. It is best to quote directly what he said, since his somewhat eccentric use of the term easily permits misinterpretation:

> Colors, sounds, temperatures, pressures, spaces, times, and so forth, are connected with one another in manifold ways and with them are associated dispositions of mind, feelings, and volitions. Out of this fabric, that which is relatively more fixed and permanent stands prominently forth, engraves itself on the memory, and expresses itself in language. Relatively greater permanency is exhibited, first, by certain complexes of colors, sounds, pressures, and so forth, functionally connected in time and space, which therefore receive special names, and are called bodies[3].

Sensations are the whole fabric which Mach refers to in the above quote, and the way dispositions of mind, feelings and volitions connect aspects of the unfolding of the fabric in time is what he investigates in *The Analysis*. He claims that it is always possible to refer back to relations between the varying presentational states of the fabric in a way that directly permits the construction of concepts. His emphasis on the process of identifying recurrent patterns shifts the burden of epistemology from algorithmic processing to cognitive aspects of pattern recognition, thus facilitating the drawing of analogies with pronounced spatial structure. That corresponds to what he regards as an *instinctual level of processing* projected as a necessary step to be taken previous to the possibility of constructing an algorithm.

Although Mach's stance seems to be deeply influenced by the British empiricists that began with the concept of mind as a *tabula rasa* (and were thus restricted to the concept of association as explanation of how conceptual thinking arises), he had a far more powerful conceptual tool to add to that of simple association: The theory of evolution of Charles Darwin. Mach was one of the first physicists to take Darwin really seriously and he was greatly motivated to do so, because of the inspiring physiological investigations of Fechner, Bühler, Helmholtz and several

[3]Ernst Mach, *The Analysis of Sensations*. New York, Dover 1959. All subsequent quotes of Mach are taken from this translation unless otherwise identified.

others during his time. Psychology was linked to physiology in these investigations, and physiology to biology and, hence, to evolution. Evolution opens the possibility of gradual development of steps of cognitive processing as part of a specie's genetic inheritance that would add explanatory sophistication to Hume's elementary view of association. Mach was well aware of that when he rejected the notion of *tabula rasa*.

One of the epistemological difficulties of building science directly from sensations as the starting point is their extreme fluidity even in a single individual, as Mach himself frequently pointed out. The discovery of physical laws applying to sensations such as Fechner's quantitative law pertaining to the threshold limits of optical perceptions held out hope for converting into a solid foundation understanding that had previously appeared to be constructed on sand. Obviously, that endeavor would require an enormous amount of work, but for a very energetic researcher like Mach, it enhanced the attraction of the challenge.

Mach's lifelong endeavor to eliminate metaphysics from science, a visceral stance inherited from his father as an educator, was heightened by excessive metaphysical content in the Austrian education of his day. For example, the influence of Aristotle was in conflict with the principles of Newtonian mechanics at a fundamental level, as it was clearly visible to Mach. He was suspicious of any line of investigation that departed from deductions firmly based on the analysis of sensations as was clearly expressed in his introduction to the 4th edition of *The Analysis:*

> The opinion, which is gradually coming to the front, that science ought to be confined to the compendious representation of the actual, necessarily involves as a consequence the elimination of all superfluous assumptions which cannot be controlled by experience, and, above all, of all assumptions that are metaphysical in Kant's sense. If this point of view is kept firmly in mind in that wide field of investigation which includes the physical and the psychical, we obtain, as our first and most obvious step, the conception of the sensations as the common elements of all possible physical and psychical experiences, which merely consist in the different kinds of ways in which these elements are combined, or in their dependence on one another [...] From sensations and their conjunctions arise concepts, whose aim is to lead us by the shortest and easiest way to sensible ideas that agree best with each other, the sensations. Thus all intellection starts from sense perceptions as the most basic attribute of experience. We here have a process for clarifying logical economy, applied to the intellectual transformation of the contents of experience [...] Our genuine mental workers are these sensible pictures or ideas, while concepts are the organizers and overseers that tell the masses of the former where to go and what to do.

The purpose of this paper is not to take sides in the controversy of the relative importance of sensations and their processing relative to algorithmic processing. It would be unfair to judge Mach on the basis of 100 years of the most varied types of investigation subsequent to the date of his decease. It is pertinent to remark, however, that Mach's viewpoint corresponds implicitly to the thrust of two recent areas of investigation. One is the theory of *innate spatial maps*, for which O'Keefe, Moser and Moser received the Nobel Prize in physiology of 2014. The other corresponds to investigations in the development of mental faculties of children from birth and extending through childhood. The modern viewpoint of the origins of concepts was originally developed by Jean Piaget, and was considerably expanded and fine-tuned by later researchers such as Alison Gopnik, Susan Carey and Stanislas Dehaene to name only a few.

Due to such efforts, cognitive psychology has finally become armed with much empirical data that would have been invaluable for the exploration of Mach's psychological interests. Furthermore, neuroscience is bridging an important gap between itself and cognitive psychology by supporting cognitive suppositions with very detailed studies of the neural correlates that appear to underlie specific cognitive functions such as the visualization of spatial relations and symmetry so vital to physics. In cognitive psychology, the first question is *how the multiplicity of perceived signals (corresponding to perpetual input) gets separated into identifiable distinct patterns that stand out in perception and memory*. Very related to this is *how the identification of objects permits locating them in a spatial and temporal frame of reference*. The theory of *innate spatial maps* could provide critical causal insight into that process. Present theory of neuroscience dovetails with the empirical findings of cognitive psychology.

Mach frequently refers to just such identification of objects and their tracking in space and time (aided by memory) as a core defining aspect of human intellectual experience. From the perspective of neuroscience, that requires preprocessing in visual, tactile and auditory cerebral modules. But with respect to putting all this into use in the service of intentionality, the epicenter of coordinating activity has now been identified as the hippocampus, with its direct connections to the executive centers of the prefrontal cortex. The role of intentionality is the critical link that allows Mach to assert the unity of the physical and psychical, just as it is that emphasis what also allows him to deny a fundamental separation between objective and subjective attributes of experience. The hippocampus is the cerebral module that establishes an *allotropic frame of reference* in higher animals or, as Mach would have termed it, the *sensation of space*. An understanding of the detailed mechanisms of its functions confirms a critical aspect of how what is physical becomes united with the psychical in mental activity.

Originally O'Keefe[4] discovered that specific neural assemblies in the hippocampus were activated whenever rats arrived at specific places in their physical environment. Such cells were thus named place cells. That led to the concept of *innate spatial maps*, since the rats automatically updated incoming information in them to complete what was analogous to a *cognitive map*. The map guided their actions as the rats moved about their physical surroundings. Since the maps had no symbols and were analogous to abstract mental images reflecting global configurational relationships, this finding was a direct blow to previous theories such as those of Herb Simon, where propositional content was predominate in an unaltered form without recurring to abstract mental images.

[4]Neil Burgess. "Spatial Cognition and the Brain", in: *Annals of the New York Academy of Sciences* 1124, 2008, 77–97.

What does the above have to do with Mach as an individual? If there was ever a physicist blessed with a gift for creating images using configurational content to add dramatic effect, it had to have been be Ernst Mach. *The Science of Mechanics* contains page after page drawings that brilliantly illustrate the fundamental principles of mechanics so clearly that words are almost unnecessary. Due to his clear and economical gift of exposition using diagrams, his textbooks on physics have been claimed to be among the most popular ones circulating in Europe at the beginning of the twentieth century. Mach himself commented on his proclivity for capturing configurational schemes at a very early age. In his *Leitgedanken* (1919) described how as a child he was able to look into the inner structure of a windmill for grinding grain and immediately grasped and retained an image of the myriad relationships between shafts, gears and flow of forces.

Throughout his career, he demonstrated his special talent for expressing diagrammatically spatial relationships between moving objects and pointing out the corresponding correlations with general mechanical principles. Einstein was another who claimed that he usually based his well-known critical thought experiments on images and that such an approach was more productive than thinking propositionally. Mach, who was among the first to write about thought experiments, would no doubt agree. He cites Leonardo Da Vinci on how to conjure up images for creative thinking by contemplating indistinct weathered patterns on ageing walls which stimulates the imagination to undertake recombination of fragments of patterns. He affirms having used similar methods to stimulate his own creative thinking.

However central to Mach's thinking and his view of the discovery process mental images came to be, there are still several links that must be established before accepting that the concept of *innate spatial maps* is relevant to the development of the concepts of physics.

Edvard Moser asserted that there is the limitation that most investigation of innate spatial maps have been done using electrodes implanted in the brains of free ranging animals. From there to how cognition might function in the human brain could be a big step. Moser and May-Britt Moser have mostly investigated grid cells in the cortex adjacent to the hippocampus where ensembles of neurons respond to directions of salient features in the surroundings. That permits the coordination of landmarks and boundaries with the allotropic aspects of spatial maps.

Through investigations made by implanting electrodes in the brains of humans before surgery to correct for the effects of epilepsy, as well by using magneto-electroencephalogram[5] sensors to detect sequences of dipole activity of pyramidal cell assemblies, there is now more understanding of neuronal space-time processing in the human brain with respect to its modular structure and inter-modular interactions.

[5] Chung-Yeon Lee, Byoung-Tak Zhang, "Effective EEG Connectivity Analysis of Episodic Memory Retrieval", in: *Proceedings of Annual Meeting of the Cognitive Science Society*, 2014, Quebec, 833–838. See also Andrew J. Watrous, Nitin Tandon, Chris Connor, Thomas Pieters, and Arne D. Ekstrom, "Frequency-specific network connectivity increases underlie accurate spatiotemporal memory retrieval", Nature Neuroscience, 16(3), 349–356.

The hippocampus and closely related cortical areas are now considered as multi-functional with respect to the direct mental creation of what could be called objects and their movement in space and time. The neural pattern of connectivity corresponding to the requirements of spatial-temporal processing has been determined to be quite different from the connectivity best adapted to associative processing in other cortical areas. Innate spatial maps and place cells are activated a specialized stage of complementary processing that binds elements together in a holistic framework that sharpens configurational representation. Nevertheless, it has some of the limitations of an index, which limits fine element processing characteristic of binary associations that accumulate over time in long term memory, such as in the parietal and temporal lobes.

Establishing the spatial-temporal images in the hippocampus and entorhinal areas can initially be very rapid. The transfer of stable neuronal connectivity patterns from the hippocampus to long term memory takes much longer, sometimes weeks of recurrent messaging. What is transferred must first be broken down into smaller subgroups of patterns before the subgroups are reduced enough to be suitable for symbolic representation.

Even then the stage is not fully set for propositional processing. Extrapolating from Carey (2009),[6] the final requisite involves the recurrent messaging that takes place over widespread remotely connected areas of the human brain as our capacity for language is trained, slowly bringing it up to an adequate operational level. It is a *procedural process* that according to Carey is achieved *unconsciously*, although the window of opportunity for implementing it is open only until about the fifth year of age. It has to do with the formation of expertise. We are all experts at speaking our own native language. In the case of persons intensively predisposed to perfect their configurational images that at first are very fleeting, spatial concepts and object attributes seem to strengthen and become somewhat accessible to consciousness as input is preprocessed and only gradually consolidated in *long term memory*. Each time a long term memory is activated, feedback to the hippocampal and place cell maps is also activated,[7] whereby the configurational correlates are also strengthened and become more accessible. Through a feedback process, the capability of configurational imagery would appear to become more attuned to the levels required for expression as physical theories.

According to Carey, once the coordination involved in the formation of long term memory is advanced enough to be expressed in linguistic terms, the stage has finally been set for the development of scientific theories. The pattern of configurations in a spatial-temporal framework is normally a necessary prerequisite, but it is not sufficient all by itself. Once the concepts have formed in long term memory,

[6] Susan Carey, *The Origin of Concepts*, Oxford University Press, New York, 2009.

[7] Morris Moscovitch *et al*, "Hippocampal complex contribution to retention and retrieval of recent and remote episodic and semantic memories: Evidence from behavioral and neuroimaging studies of healthy and brain-damaged people", in: *Dynamic cognitive processes*, Springer, Tokyo, 333–380.

Bayesian conditioning of synaptic connections will assure that correlations that are too infrequent or too fine grained to be captured by the coarse pattern responses of the hippocampus will finally take on a sharper more discriminated form that permits penetrating to the level of consciousness in the form of symbolic representation.

The phenomenal ability of chess masters to capture and recall the configurational patterns of pieces on chessboards suggests that with sufficient intensive practice the limits of ordinary long term memory can be complemented by the far more extensive content of the patterns of innate spatial maps, an example of which would possibly be patterns on a chessboard. That is because the map images are updated automatically below the threshold of consciousness, but become strengthened by recurrent effects due to feedback from long term memory to the point of becoming a reliable basis for triggering decisions rapidly, analogous to what happens in the case of rat navigation. Such sensitivity can only be reached by about at least 10,000 h of deliberate practice in the case of chess grandmasters.

Mach himself expressed sensitivity with respect to how intensive practice contributed to firming up visual sensations to the point that they contributed to the formation of diagrammatic representation of physical concepts. If intensive practice and procedural learning is extremely important, the implication is that one must first look further backwards in order to identify the cognitive processing that inspires the creation of new images, instead of simply relying on conventions that still remain vague. He asserts:

> It is natural to suppose that, when mental images occur, the interaction of the organs of the nervous system causes the repetition of organic processes partially identical with those which were determined by the physical stimulus on occasion of the corresponding sensations. Images are normally distinguished from sensations by being less intense, and above all by their instability. The power of replacing the figure with ease and rapidity, is, however, enormously increased by practice[. . .] Where the development of intelligence has reached a high point, such as is presented now in the complex conditions of human life, mental images may frequently absorb the whole of attention, so that events in the neighborhood of the reflecting person are not noticed, and questions addressed to him are not heard; [. . .] Physiological experiment and simple self-observation teach us that such an organ has its own purposive habits, its own peculiar memory, one might almost say its own intelligence.

The process of generating images, corresponding to the exercise of exploiting a special form of intelligence, must then be promoted in science. According to Mach, that would dovetail with how concepts arise as an imperfect process just as evolution itself is an imperfect and ongoing process subject to correction:

> Even towards bare sensations our attitude is not one of mere passivity; for sensations disengage a biological reaction, of which the natural continuation is precisely the adaptation of thought to facts. If this adaptation were immediately and perfectly successful, the process would *ipso facto* come to an end. But since different imperfectly adapted thoughts come into conflict with one another, the biological process continues.

When one reads about current research into the origin of concepts starting right from the most everyday experiences of recently born babies and their development over their first few years, it is striking the compatibility of Mach's epistemology and the perspective of contemporary research being done 100 years later. Some examples are Gopnik's *The Scientist in the Crib*: *What Early Learning Tells Us About the Mind*, Carey's *The Origin of Concepts* and Dehaene's *The Number Sense, How the mind creates Mathematics*. It is clear how their recent investigations are pertinent to Mach's prescient interests expressed in *The Analysis*.

However, there is one salient point where a discrepancy arises. The discrepancy can be analyzed with respect to Mach's concepts of space and matter, how that relates to innate spatial maps and why controversy was inevitable with Einstein, Planck and Boltzmann. If it is accepted that the concept of space arises from everyday experience as Mach believed, it is evident that there is no convincing basis for believing in absolute space or time. No immovable anchor for space or time is evident. That is especially true if the concept of how spatial maps are formed in the hippocampus is accepted. Einstein publically admired Mach for stimulating his thinking leading to the special and general theories of relativity, both of which reject the concept of absolute space and time (for basically the same reasons that Mach had previously argued). Nevertheless, Einstein added that Mach's insistence on restraining inquiry to causal action immediately apparent upon comparing sensations was unreasonably limited. A quote from present day opinion[8] is very specific:

> He [Mach] underestimated the value of pure theoretical speculation in scientific discoveries, especially in physics. There are many important discoveries that clearly could never have been made had theoreticians stuck rigidly to Mach's precept that the role of science is solely to establish directly the immediate connection of phenomena. They include general relativity, Erwin Schrödinger's wave-mechanical formulation of quantum mechanics, and the modern theory of gauge interactions. Many working scientists now accept Karl Raimund Popper's contention that in physics at least significant progress is often made through a bold conjecture that can in no way be justified by direct experience.

How is it that Mach exposed himself so unabashedly to criticisms such as the above? The standard answer is because of an excessive adherence to British Empiricism as it arose during the Enlightenment. However, an additional factor weighs heavily that was only just becoming apparent in about 1900. Physical laws can be very sensitive to scale. In practice very few scientists are competent to theorize over a broad range of scales; in general, they specialize in phenomena corresponding to a specific scale/domain. Nevertheless, the operative structure of the laws of physics changes radically (even for a fixed agglomeration of elementary particles) when there is a change of phase or when the scale of space, energy or velocity exceeds certain limits. The behavior of water changes radically according to whether it is a gas, liquid or solid. Superconductivity, a radical change in physical behavior, only appears when temperature falls below a certain point, even though the elementary particles comprising the superconductive material remain the same.

Mach's preferred scale/domain, within which he created brilliant experiments, was the macroscopic. It could have been no other due to his predominant interest

[8] Donald Borchert. *Encyclopedia of Philosophy*, Thomson Gale, Detroit, 2006.

in the physiology. It corresponds to the sensory mechanisms of living organisms. Not often scientists construct a bridge between different scales, because that usually requires positing new concepts for which there are no experimental or theoretical precedents.

Max Planck strongly resisted the idea of the quantum structure displayed by high temperature blackbody radiation. He tried to justify every possible hypothetical alternative, but finally had to accept that at very high frequencies of electromagnetic radiation the interchange of energy did not correspond to continuous spectra, but to photons whose energy were a discrete multiple of Planck's constant. That was the reason for his acrimonious interchange with Mach. There was no precedent in sensory experience for fragmenting energy into permitted quantum levels because measuring devices had not been previously available operating at the high temperatures corresponding to Planck's experiments. When extensions to the limits of human sensory perceptions were necessary for physical experiments, Mach could be caught off base.

By imagining thought experiments at scales beyond the possibility of human sensory experience, Einstein also broke the mold as when at an early age he imagined himself being translated in parallel with a light ray and asking how the wave undulations would appear to him. When Boltzmann posited his famous theorem H (which then led to his entropy formula), he was building a bridge between the states of discrete collisions between the molecules of an ideal gas and the general equilibrium conditions of the gas as a whole. The former corresponds to a microscopic scale and the latter to a macroscopic one.

The cognitive psychology of Susan Carey alleges that such leaps are possible when the elements of spatial-temporal experience are transferred to areas of long-term memory, and after a while, contradictions become apparent between concepts that build up over time and with additional experience. It is evident from the history of mathematics that novel concepts arise for which there are no precedents. Examples are the invention of negative numbers, imaginary numbers, non-commutative tensor operators, etc. She claims that novelty is possible through recombination of concepts as they tend toward finer degrees of discrimination, and frequently some elements formerly bound together are cast out.

When one surveys the great breakthrough discoveries of science, they are generally related to the use of mathematical algorithmic formalisms that appeared out of the blue. Infinitesimal calculus and Newton's laws of motion, Einstein's relativity linked to mapping between different spatial-temporal frameworks using partial differential geometry and renormalization procedures in high energy physics are examples.

Mach commented on the constant revision that takes place, but seemed to be appreciably less specific with respect to the mechanisms involved that change with scale compared to current research. Threads of great length that are inseparable from mathematical structures prevail in the connections that tie together Mach's fabric of facts.

Current research in neuroscience suggests that innate spatial maps can be involved in the process of discovery because activity in the hippocampus evolved to deal with novelty such as imagining detours when paths become blocked. Evolution put a premium on discovering alternatives when that happens. Executive control of working memory permits manipulating abstract mental images, making changes central to finding a solution. Obviously that extends far beyond the scope of the present paper. Although innate spatial maps are involved, the area of investigation must be broadened. Ample routes for further research are suggested by what is now being learned.

Chapter 11
Mach's Criticism, or a Discourse on the Method

Elena D'Amore

Abstract In this paper, I take Mach's work to be the result of a radical critique of the foundations and forms of knowledge, as well as, as a toolkit for present day basic research. My focus will not be the direct contribution of Mach's work to any particular disciplinary research, but rather the *indirect* benefit and significance for science of two unfaltering attitudes that he was able to jointly apply throughout his life. These are, according to Einstein, an "incorruptible skepticism" and the passionate confidence that any prospect was attainable for experimental scientific research. I will elucidate the features of Mach's *criticism* with an emphasis on its relationship to Kant's philosophy and to Hume's one, focusing on the idea that the only possible foundational discourse is the one on the method.

Ernst Mach's work hasn't been properly acknowledged in historiography. It has no clear place in the history of philosophy, nor in the history of science. Nevertheless, prominent intellectuals and scientists attributed it great worth: not merely relative to its given point in history, but a groundbreaking worth. As a matter of fact, Albert Einstein's short essay,[1] published in 1916 by the "Physikalische Zeitschrift," advocates for the claim that Mach's thought produced a hiatus between the passive acceptance of classical mechanics and the possibility of new ways of seeing physical phenomena. Both in theory and praxis, in the most coherent way, the Austrian physicist had been able to shake that "dogmatic faith" more than anyone else: more than Maxwell, more than Hertz. What he achieved pushed his young reader Einstein to look beyond the then common representations.

The philosopher Immanuel Kant wrote about Hume along similar lines: «I freely admit that the remembrance of David Hume was the very thing that many years ago first interrupted my dogmatic slumber and gave a completely different direction to

[1] Albert Einstein, "E. Mach", in: *Physikalische Zeitschrift*, 17, 1916, pp. 101–104.

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my researches in the field of speculative philosophy.».[2] Two investigations followed these "wake up calls", namely Kant's and Mach's himself. While both had the similar purpose of furthering "the growth of sciences", they concluded with very different results. For Mach – as it had been for Kant – the meaning of a critique lies in opposing dogmas that are acquired by authority. Still, we also acknowledge in Mach's work the sense of *critique* in a radically anti-metaphysical activity, and precisely this second attitude – with its outcomes – made the majority of his peers hostile to him. In contrast, Einstein believed his «incorruptible skepticism and independence» were actually his deepest merit.[3]

11.1 The Nature of Mach's Philosophy of Science

"Empiriocriticism" – the label historians assigned to Mach's work – may well be understood as the carrying on of Kant's project. In fact, a significant part of Mach's life as a scientist was dedicated to matters concerning principles. He investigated the reasons why axioms and general laws had become such. At just the thirty years of age he wrote: «No investigator of nature doubts that under the same circumstances the same always results, or that the effect is completely determined by the cause. It may remain undecided whether the law of causality rests on a powerful induction or has its foundation in the psychical organization».[4] As Kant, Mach too placed his interest beyond the principles' effectiveness. We could write a lot about this issue – the transcendental, or, criticism of Ernst Mach. However, first of all I'm going to investigate the peculiar reasons why he ended up making his choice. In other words, what did he expect from a philosophical discourse on science? Reading Mach, we learn that very concrete requirements, related to his scientific practice, pushed the physicist to go deeper down such a path. Introducing his last significant work, *Knowledge and Error*, Mach stated something about his position as a scientist: «Without in the least being a philosopher [..] the scientist has a strong need to fathom the processes by means of which he obtains and extends his knowledge».[5] This is what, according to Mach himself, he was trying to do in his work.

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[2]Immanuel Kant, *Prolegomena to any future metaphysics: that will be able to come forward as science,* Cambridge: Cambridge University Press 1997, p. 10.

[3]Albert Einstein, "E. Mach", op. cit.

[4]Ernst Mach, "On the definition of mass" (1868), in: Ernst Mach, *History and root of the principle of conservation of energy*, Chicago: Open court 1911, p. 81. See also Ernst Mach, *The science of mechanics: a critical and historical account of its development*, La Salle: Open court 1960, pp. 593–594.

[5]Ernst Mach, *Knowledge and error. Sketches on the psychology of Enquiry*, Dordrecht: Reidel 1976, p. XXXV.

I am trying to argue that Mach developed his own philosophical point of view bearing in mind a practical goal and, moreover, while in search of a critical boundary. We can see the scientist here, before the philosopher.

11.2 Empirio-Criticism

The young Mach studied, taught, and researched in a revolutionary time – tempering the excesses of the Enlightenment, also turning them upside-down. Still a boy, he finds in his father's library Kant's *Prolegomena to any future metaphysics: that will be able to come forward as science,* a reading that strongly impresses upon him the idea that we only get to know empirical phenomena.[6]

During his upbringing and studies, he comes to believe that «not speculation, not insight, but rather bodily sensations are the source of evidence, in whatever field we may inquire».[7] In whatever field we look for knowledge, we are actually allowed to call knowledge an adaptation to phenomena, rooted therefore in the experience. This doesn't imply that all knowledge is raw and unorganized sensory experience, but whoever claims to know without looking for experimental evidence, doesn't really work for science's progress; on the contrary she/he harms it.

Kant told us what had happened to him as he had been investigating «in the field of speculative philosophy»,[8] that was his field of investigation: he had been slumbering. For Mach, on the contrary, the laboratory was "the field". Any new discourse on knowledge should hinge on experience and thus, precisely on sensations.

Consequently, knowledge – and science in particular – can never make itself independent of the building blocks of reality. We only meet "the building block" in actual experiences and beyond language and speculation. As a confirmation of this stance, we can quote Mach himself. Towards the end of his life, he defined his own «epistemological standpoint» as resting «on a study of the physiology of the senses».[9]

[6]Aldo Giorgio Gargani, "La buona austricità di Ernst Mach", in: Ernst Mach, *Conoscenza ed errore: Abbozzi per una psicologia della ricerca*, Torino: Einaudi 1982, p. VIII.

[7]Robert S. Cohen, "Ernst Mach: Physics, perception and phylosophy of science", in: "Synthese", 18, 1968; gathered in Cohen & Seeger, *Ernst Mach: Physicist and philosopher*, Dordrecht: D. Reidel 1970, p. 133.

[8]Immanuel Kant, *Prolegomena to any future metaphysics*, op. cit., p. 10.

[9]Ernst Mach, *History and root*, p. 9 (Preface to the second edition, Vienna: 1909).

11.3 Pragmatism and the Right Place for a Theory

It has been written that Ernst Mach was «eager to criticize what is illusory in science and common sense, and by so doing, better to delineate what is genuinely known».[10] Robert Cohen gives us a strong and coherent picture of him as the physicist as well as the philosopher. Let's start by analyzing his statement: both "in science *and* in common sense" there is something illusory and something genuine.

The status of a valid knowledge is here at stake and we immediately notice that so-called "common sense" is not only mentioned, but also evaluated as a part of the subject. We shouldn't be surprised, as Mach acknowledged in common sense a completely different value from the one Kant accorded to "Meinung",[11] ruling it out from his own account of valid knowledge.

Besides this strong difference, we shouldn't forget the disputes[12] Mach's evaluation of common sense and popular thought caused; since his stance was then in the minority, it distanced him from most of his peers.[13] Science was surely no popular thought for him – by virtue of its reliance on methodology and the careful choice of premises. However, he never saw danger in a non-scientific way of thinking. Both in coarse reasoning and in methodic research, for him, we can acquire knowledge, but we always need to contrast its two kinds: the one acquired in constant relationship with perceptible phenomena, and the pseudo-knowledge springing from ideas encountering other ideas. Basically: according to Mach, science should look for adaptation to the world. Over-speculation does not; rather, it asks the world to adapt and the outcome can only be metaphysical.

"Illusions" are easily due to an over-speculation, Mach claims; it doesn't make any difference whether they stem from imagination or a footloose use of the intellect. In any case, the means by which they should be scrutinized can't be speculative.

We can now better understand Mach's economical concept of science and his dislike of theories. He rejected idle theoretical inquiry, demanding instead that theories be nothing more than tools, and tools among others. As it were for the

[10] Robert S. Cohen, op. cit., ib.

[11] We take Kant's acceptation of "Meinung" for the basic element of common sense, or, common feeling.

[12] See Philipp Frank, "The importance of Ernst Mach's philosophy of science for our times", in Cohen & Seeger, op. cit., pp. 219–234. See also Max Planck, *Die Einheit des physikalischen Weltbildes*, Leipzig: Hirzel 1909, p.36. Mach replied to him in 1910, within a short essay – *Die Leitgedanken meiner naturwissenschaftlichen Erkenntnislehre und ihre Aufnahme durch die Zeitgenossen* – aiming to clarify his epistemology and its background. See "The guiding principles of my scientific theory of knowledge and its reception by my contemporaries", in: S. Toulmin ed., *Physical Reality*, New York: Harper 1970.

[13] See *The science of mechanics*, op. cit., pp. 594–595: «what appears to Husserl as a degradation of scientific thought, the association of it with vulgar or "blind" thinking, seemed to me to be precisely an exaltation of it. It has outgrown the scholar's study, being deeply rooted in the life of humanity and reacting powerfully upon it.».

most famous detective Sherlock Holmes, Sir Conan Doyle's short novel character, so it must be in science. Erwin Hiebert observed, in the English Introduction to *Knowledge and error*, that once an inquirer «begins to twist facts to suit theories» – a sentence selected from Doyle's "A scandal in Bohemia" – she harms the inquiry and science in general.[14] Moreover, Mach wrote: «The object of natural science is the connexion of phenomena; but the theories are like dry leaves which fall away when they have log ceased to be the lungs of the tree of science.».[15]

Still, we have to specify that what's at stake here is the use we make of the tools we have. Choosing which tools to work with is thus for Mach the prerequisite for any conceptual clarification and genealogy. Of course, logic matters, as do theories, but we need them in order to observe and better understand phenomena. This means that they have to *serve* praxis and the work of analysis and that, escaping this bond, they not only lose their role but risk operating as false friends, causing the inquirer to falter, even to slumber and leave the facts behind.

11.4 Hume and Mach: What Science Is

Referring to Hume, Kant also wrote: «everything that we call metaphysics would come down to a mere delusion of an alleged insight of reason into that which has in fact merely been borrowed from experience and from habit has taken on the appearance of necessity». Further, he will judge this idea as «destructive of all pure philosophy» and will commit to preserving philosophy.[16]

Habits and commonsense in the discourse on knowledge are doubtless a leading theme in Mach's work. His contention was that the concepts we have been managing with for a long time and that we ordinarily use to navigate the world, are the ones we better understand. In other words, human beings trust the most familiar concepts and hypotheses.[17] Intimacy – a purely psychological criterion – pervades

[14]Ernst Mach, *Knowledge and error*, op. cit., p. XXII.

[15]Ernst Mach, *History and root*, op. cit., p. 74. See also Philipp Frank, op. cit.

[16]Immanuel Kant, *Critique of Pure Reason*, op. cit., p. 146. See also David Hume, *A Treatise of Human Nature*. Oxford: Clarendon Press 1896, p. 86: «the belief or assent, which always attends the memory and senses, is nothing but the vivacity of those perceptions they present; and that this alone distinguishes them from the imagination. To believe is in this case to feel an immediate impression of the senses, or a repetition of that impression in the memory. 'Tis merely the force and liveliness of the perception, which constitutes the first act of the judgment, and lays the foundation of that reasoning, which we build upon it, when we trace the relation of cause and effect.», pp. 89–90: «The idea of cause and effect is deriv'd from experience, which informs us, that such particular objects, in all past instances, have been constantly conjoin'd with each other: And as an object similar to one of these is suppos'd to be immediately present in its impression, we thence presume on the existence of one similar to its usual attendant.»

[17]See Ernst Mach, *Knowledge and error* op. cit., pp. 128–129: «Which [judgements] are regarded as more authoritative depends of course on how far one is familiar with the field, on one's experience and practice in intellectual thought and on the customay views of the period. [..] In

discourses both on scientific practices and on the constitution of an epistemological background. For instance: «It is the result of a misconception, to believe, as people do at the present time, that mechanical facts are more intelligible than others, and that they can provide the foundation for other physical facts. This belief arises from the fact that [..] we have been on terms of intimacy with mechanical facts for a longer time».[18]

What Hume deemed to be a limit on human knowledge, a hindrance to grant it the status of science, becomes here the only warrant for the actual feasibility of knowing, which is basically a matter of adaptation. Scientists should never hold the idea of science as a "general experience" in high esteem. In fact, we are never responsible for the totality of all possible experiences, but always for *this* single group of experiences.[19]

Mach never stopped believing that the adequacy conditions for any particular knowledge can only be established within practice. However, the scientific experiment can and should be anticipated by clear directions, meant to guide it.

Against Hume's negative conclusion, Mach sets his new foundation of science. It is a "discourse on the method" the one we account for: the only one capable of transversality and of enduring value. Mach's critical work simply aims to be preliminary to the work of every researcher. It spans over psychology, biology, and history; all of the results crossing and turning into tools and rebuilding, without any backing theory, an epistemologically solid ground.

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Newton's time it required much courage to assume action at a distance, even if presented as something still awaiting explanation. Later, success made this approach so common that nobody took offense at it.».

[18] Ernst Mach, *History and root* op. cit., pp. 56–57.

[19] See Ernst Mach, *The science of mechanics*, p. XXIII: «In my fundamental conception of the nature of science as Economy of Thought [..] I non longer stand alone»; and ibid., p. 577: «It is the object of science to replace, or *save*, experiences, by the reproduction and anticipation of facts in thought. Memory is handier than experience, and often answers the same purpose».

Ernst Mach, 1910 "*The guiding principles of my scientific theory of knowledge and its reception by my contemporaries*", in: S. Toulmin ed., Physical Reality, New York: Harper 1970.

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Chapter 12
Mach and Panqualityism

Tomáš Hříbek

Abstract The chapter discusses the rejuvenation of an interest in Mach in the recent metaphysics and philosophy of mind. In the early twentieth century, Mach had been interpreted as a phenomenalist, but phenomenalism fell out of favor in the 1950s. In the later decades, he received praise for his naturalism, but his contributions to metaphysics or philosophy of mind were regarded as misbegotten or irrelevant. With the search for a monistic alternative to both materialism and dualism in the recent philosophy of consciousness, however, Mach attracts a fresh attention. For example, the contemporary philosopher Sam Coleman develops a version of a monistic *metaphysic* called "panqualityism," which resembles Mach's view to a large extent. Like most contemporary monists, however, Coleman works much more closely from Russell's *The Analysis of Matter*, than Mach's *The Analysis of Sensations*. The chapter details the circumstances that have led to the recent rise of monism; the varieties of Russellian monism; Coleman's panqualityism; and the similarities and differerences between panqualityism and Machian monism.

12.1 Introduction

Ernst Mach is enjoying something of a comeback in the contemporary philosophy of mind, or even the general metaphysics. The last time this occurred was shortly after Mach's death, during the 1920s and 1930s, when he was interpreted as a *phenomenalist*, i.e. someone who believed in the possibility of constructing the world out of the data of subjective experience. Rudolf Carnap, among others, believed he could improve upon (what he took to be) Mach's project by employing

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the tools of modern logic that became available in the meantime.[1] As is well known, phenomenalism did not survive the 1950s,[2] and so most of the literature on Mach from the 1970s up to the early 2000s emphasized his contributions to physics and psychology, at the expense of what was often swiftly dismissed as a misbegotten philosophical project.[3] Yet even those who believed, during this period, that Mach's contributions to philosophy were as valuable as those he made to science, did not think those philosophical contributions concerned *metaphysics*. Rather, the author of *The Analysis of Sensations* and *Knowledge and Error* was seen as a progenitor of *naturalism*, i.e. someone who insisted that scientific methods carried over to philosophy.[4] In other words, Mach was viewed as a naturalized epistemologist *avant la lettre*. Mach's name was absent in the metaphysical debates of the past half century in particular due to a near universal dominance of materialism. Especially on the issue of the nature of mental states, materialism and dualism were regarded as two positions that exhausted the alternatives, with dualism in retreat. Since Mach rejected both, he was seen as irrelevant.

Yet things have begun to change in Mach's favor more recently, and I wish to explain and evaluate the character of this change in this chapter. The immediate cause of this development is that the self-confidence of materialists has weakened, while dualists have not recuperated either. This motivates a search for alternatives in the work of long-forgotten philosophical dissenters, including Mach. I shall start by sketching the rationale behind the current debate, which concerns the nature of consciousness (Sect. 12.2). Within this debate, some search for a new kind of monism which resembles Mach's historical position, although most of today's authors work from Russell, rather than Mach. There are several varieties of this

[1] See Rudolf Carnap, *The Logical Structure of the World*. Trans. by R. George. Berkeley, Cal.: University of California Press, 1967 (orig. 1928). A related somewhat later project is Nelson Goodman, *The Structure of Appearance*. Cambridge, MA: Harvard University Press, 1951.

[2] This happened due to a wide acceptance of the criticisms of phenomenalism offered by philosophers such as Chisholm and Austin, among others, during this period. See Roderick Chisholm, *Perceiving: A Philosophical Study*. Ithaca, NY: Cornell University Press, 1957 (especially "Appendix," in which Chisholm explicitly mentions Mach as a target of his criticism); and J. L. Austin, *Sense and Sensibilia*. Oxford: Clarendon Press, 1962.

[3] This approach is exemplified in the texts of John T. Blackmore. It must be acknowledged that Blackmore greatly contributed to the Mach scholarship in the capacity of an editor of several volumes of historical materials as well as contemporary research. See in particular *Ernst Mach: A Deeper Look. Documents and New Perspectives* (Dordrecht: Kluwer, 1992) and J. T. Blackmore/Ryoichi Itagaki/Setsuko Tanaka (eds.). *Ernst Mach's Vienna, 1895–1930: On Phenomenalism as Philosophy of Science* (co-edited with Ryoichi Itagaki and Setsuko Tanaka, Dordrecht: Kluwer, 2001). However, as an interpreter of Mach's philosophy, Blackmore only mechanically contrasted his own favored position, "indirect realism," with Mach's alleged "phenomenalism," of which he claimed that it was refuted by the progress of science.

[4] For a representative of such a charitable approach to Mach in the 1970s and 1980s, see the work of Rudolf Haller, in particular the papers "Grundzüge der Machschen Philosophie" and "Poetische Phantasie und Sparsamkeit – Ernst Mach als Wissenschaftstheoretiker" (in Rudolf Haller/Friedrich Stadler (eds.), *Ernst Mach – Werk und Wirkung*. Vienna: Hölder-Pichler-Tempsky, 1988, pp. 64–86 and 342–355).

Russellian monist view (Sect. 12.3). I'll sketch one particular version which rejects panpsychism in favor of a neutral monist view called panqualityism, which posits qualities as metaphysically basic (Sect. 12.4). Panqualityism is not, however, offered as a reconstruction of Mach's historical view, so it should not be surprising there are differences of doctrine and motivation between the two (Sect. 12.5). Some might interpret these differences as betraying a philosophical naïveté; I prefer to see them as incentives for a critical reflection of our deeply held assumptions (Sect. 12.6).

12.2 Phenomenal Consciousness

The current resurgence of interest in Mach among mainstream philosophers can be traced, I think, to David Chalmers's influential book *The Conscious Mind* (1996). The book is a contribution to the philosophy of consciousness, which is standardly understood as trying to locate consciousness in a purely physical world. Most of those who work on this issue are materialists, and they happen to believe that consciousness is one of the last—if not *the* last—obstacles to materialist reduction. Let us first see how the philosophers of consciousness, including Chalmers, conceive of this phenomenon. A key distinction, which is accepted by many in the field, is between phenomenal and access consciousness, introduced by Ned Block. He defines phenomenal consciousness, or P-consciousness, as follows:

> P-consciousness is experience. P-conscious properties are experiential properties. P-conscious states are experiential states, that is, a state is P-conscious if it has experiential properties. The totality of the experiential properties of a state are 'what it is like' to have it [. . .] we have P-conscious states when we see, hear, smell, taste, and have pains. P-conscious properties include the experiential properties of sensations, feelings, and perceptions, but I would also include thoughts, wants, and emotions.[5]

Block identifies P-consciousness with experience, although he also speaks in terms of certain properties of experience, namely P-properties. They are those that characterize what it is to like to undergo the experience in question.[6] For example, there is something like it is to see a red tomato; this particular experiential property endows the visual experience in question with its distinctive character. In addition to phenomenal consciousness, however, Block distinguishes something which he calls "access-consciousness," or "A-consciousness:"

> A state is A-conscious if it is poised for direct control of thought and action. To add more detail, a representation is A-conscious if it is poised for free use in reasoning and for direct 'rational' control of action and speech [. . .] an A-state is one that consists in having an A-representation.[7]

[5]Ned Block, "On a Confusion about a Function of Consciousness" (1995), repr. in Block, *Consciousness, Function, and Representation*. Cambridge, MA: The MIT Press, 2007, p. 166.

[6]The "what it is like" idiom goes back, of course, to the famous article by Thomas Nagel, "What It Is Like to Be a Bat" (1974), repr. in Nagel, *Mortal Questions*. Oxford: Oxford University Press, 1979, p. 166.

[7]Block, *op. cit.*, p. 170.

Block means that my experiences do not have merely the phenomenal aspect in the above specified sense of there being something like it is to undergo them, but they might also carry a certain information, either about the subject of this experience or about the world. For example, the aforementioned visual experience represents the redness of a tomato. The subject can think about this information, communicate it to others, or use it to adjust her own behavior. Block suggests that experiences usually have both aspects, i.e. P-consciousness and A-consciousness.

Block's distinction is of a key importance because many materialists believe that A-consciousness is susceptible to physicalist reduction, and that it might help with reducing P-consciousness as well. During the last half century, most philosophers accepted a certain division of labor within the philosophy of mind: there is a part which has to do with the representational mind, and then there is another which concerns phenomenality. Over the decades, a majority has come to believe that mental representation can be dealt with in functional and causal terms. This means that the representational mind does not pose any threat to the physicalist worldview. Encouraged by this success, many materialists have, during the last couple of decades, adopted a representational approach to the phenomenal mind as well. Perhaps P-consciousness could be naturalized in terms of A-consciousness, as basically representational, and representation would then be naturalized, in its turn, by means of the familiar functional and causal apparatus, so that phenomenality is ultimately naturalized, after all? Let me just mention one of such representational strategies, which shall play a role in the subsequent discussion (in Sect. 12.3). David Rosenthal has articulated a version of the higher-order theory of consciousness, or HOT, which assumes that the phenomenal character of mental states is actually a matter of their subjectivity. It follows that phenomenality cannot be a property of experience as such; rather, the latter acquires such a character only if it becomes the object of a representation of higher order. For Rosenthal, this higher-order representation assumes the form of a thought. "On the present account," he says, "conscious mental states are mental states that are accompanied by and often cause the occurrence of higher-order thoughts that one is in those mental states."[8] Rosenthal believes that such higher-order thoughts can be given a relational, functionalist account. Surprisingly, he does not think that the *qualitative* character of experience poses any problem for the materialist account—a point raised by one of Rosenthal's critics, to which I shall return in Sect. 12.4.

12.3 Russellian Monisms

However, the plausibility of materialism, including its representationalist variety, has been challenged, most famously by David Chalmers in the aforementioned

[8]David Rosenthal, "Two Concepts of Consciousness" (1986), repr. in Rosenthal, *Consciousness and Mind*. Oxford: Oxford University Press, 2005, p. 29.

book. Chalmers acknowledged that many mental phenomena that we classify as conscious—attention, memory, perception, among others—can be naturalized along the lines suggested by the representationalists, using the functional and causal vocabulary. They present comparatively "easy problems," but there is also a "hard problem" of consciousness which cannot be naturalized in this manner, and this is P-consciousness.[9] Chalmers's key argument assumes a notion of phenomenal consciousness pretty much along the lines defined by Block, and claims that it is conceivable that a conscious person had an exact physical twin who nevertheless lacked P-properties. And if this is conceivable, it follows that P-properties are not identical with physical properties, as required by materialism.[10] This argument led Chalmers to advocate a version of dualism—a naturalistic dualism—but more importantly, for our purposes, he suggested in his book another metaphysical option, different from both materialism and dualism, which has attracted a lot of interest lately. Chalmers spoke of an alternative monism, which was unlike the materialist monism in that it regarded phenomenal or protophenomenal, rather than physical, properties as basic:

> What it finally delivers is a network of intrinsic properties, at least some of which are phenomenal or protophenomenal, and which are related according to certain causal/dynamic laws. These properties "realize" the extrinsic physical properties, and the laws connecting them realize the physical laws. In the extreme case in which all the intrinsic properties are phenomenal, the view might be best seen as a version of idealism. It is an idealism very unlike Berkeley's, however. The world is not supervenient on the mind of an observer, but rather consists in a vast causal network of phenomenal properties underlying the physical laws that science postulates. A less extreme case in which intrinsic properties are protophenomenal, or in which some are neither phenomenal nor protophenomenal, is perhaps best regarded as a version of Russell's neutral monism. The basic properties of the world are neither physical nor phenomenal, but the physical and the phenomenal are constructed out of them. From their intrinsic natures in combination, the phenomenal is constructed; and from their extrinsic relations, the physical is constructed.[11]

Chalmers does not yet mention Mach's name here, but he clearly describes a metaphysic which is akin to the one we find in *The Analysis of Sensations*, with its "vast causal network" of neutral "elements," out of which both physical and mental facts are constructed. Instead of Mach, Chalmers cites Russell, and it is true that most of the subsequent debate about a new monism, which could replace both materialism and dualism, took as its point of departure Russell's *The Analysis of Matter*, rather than Mach's *The Analysis of Sensations*. However, the contemporary Russellians such as Chalmers do not pretend at a resurrection of Russell's historical view, either. Rather, they just take certain insights from Russell in an attempt to build an original alternative to dualism as well as materialism.

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[9] On the easy and hard problems, see David Chalmers, *The Conscious Mind*. Oxford: Oxford University Press, 1996, p. xii, xiii, and also Chalmers, "Facing Up to the Problem of Consciousness" (1995), in Chalmers, *The Character of Consciousness*. Oxford: Oxford University Press, 2010, pp. 3–34.

[10] David Chalmers, *The Conscious Mind*, *op. cit.*, pp. 94–99.

[11] Ibid., p. 155.

Two of these insights are central. First, the so-called *structuralism about physics*:

> physics characterizes physical entities and properties by their relations to one another and to us. For example, a quark is characterized by its relations to other physical entities, and a property such as mass is characterized by an associated dispositional role, such as the tendency to resist acceleration. At the same time, physics says nothing about the intrinsic nature of these entities and properties.[12]

In other words, physics can tell us how a quark and mass behave, but it is silent about what this entity and property are independently of their behavior. Generally speaking, physics can teach us about the nomological and causal role of certain entities or properties, but not about their intrinsic nature.[13] Second, Russell held a certain view about *knowledge* and *perception*, according to which we are directly acquainted with the intrinsic natures of phenomenal properties. Russell calls these directly perceived features of phenomenal properties "percepts."[14] The latter play the role of nodal points that realize the network of relations described by physics. And while few contemporary authors share Russell's notion of perception, they accept the view of intrinsic features of reality inaccessible to physics. Different authors call these intrinsic features variously "quiddities,"[15] "ultimates,"[16] or "inscrutables."[17] However, this basic framework leaves many questions unanswered. For example, what is the nature of those quiddities or ultimates that escape a physical description? Depending on how this question is answered, one can distinguish a whole array of Russellian monist positions.

In the earlier-cited passage, Chalmers suggested at least two such positions. Provided that the intrinsic properties are conceived of as phenomenal, the resulting position is a version of *panpsychism*, which Chalmers defines as follows: "I will understand panpsychism as the thesis that some fundamental physical entities are conscious: that is, that there is something it is like to be a quark or a photon or a member of some other fundamental physical type."[18] If everything instantiates P-properties—if, in other words, every entity, however basic, enjoys experiences—then this kind of panpsychism is really *panexperientialism*. Not everybody, however,

[12]David Chalmers, *The Character of Consciousness*. Oxford: Oxford University Press, 2010, p. 133.

[13]In a late work, Russell summarized his notion of physics thusly: "All that physics gives us is certain equations giving abstract properties of their changes. But as to what it is that changes, and what it changes from and to—as to this, physics is silent." See Bertrand Russell, *My Philosophical Development*. London: Routledge, 1995 (orig. 1959), p. 13.

[14]Russel says that percepts "are the only part of the physical world that we know otherwise than abstractly." See Bertrand Russell, *The Analysis of Matter*. London: Routledge, 1992 (orig. 1927), p. 402.

[15]David Chalmers, "Panpsychism and Panprotopsychism" (2013), in Torin Alter/Yujin Nagasawa (eds.), *Consciousness in the Physical World: Perspectives on Russellian Monism*. Oxford: Oxford University Press, 2015, p. 254.

[16]Galen Strawson, "Real Materialism," in Alter/Nagasawa, *op. cit.*, pp. 161–208.

[17]Barbara Gail Montero, "Russellian Physicalism," in Alter/Nagasawa, *op. cit.*, pp. 209–223.

[18]David Chalmers, "Panpsychism and Panprotopsychism," in Alter/Nagasawa, *op. cit.*, 246–247.

is happy with the view that everything is mental, in the sense that everything has experiences. Those who wish to avoid such a result hold that quiddities are not phenomenal, but rather protophenomenal. Phenomenal properties of our experiences must be aggregates composed of protophenomenal properties. How is such an aggregation accomplished? This is one of the combination problems that Russellian monists must deal with.[19] However, even if we put that one aside, the concept of the protophenomenal itself is problematic, in that it appears inherently unstable. It can be understood in at least two different ways. Either the protophenomenal is a metaphysically neutral—in the sense of neither physical, nor mental—property; or it is a physical property, although inaccessible to the standard physics which recognizes only structural properties. The former view is what Mach and Russell might recognize as *neutral monism*; the latter is *Russellian physicalism*.[20] So there are at least three possible varieties of Russellian monism: neutral monism, physicalism and panpsychism. Every reader of *The Analysis of Sensations* knows that Mach embraced neutral monism (albeit not under this name) and wished to avoid panpsychism, though not necessarily physicalism. It is perhaps not as widely known that there is a contemporary version of this position, which I shall present next, in order to highlight the differences with Mach's view.

12.4 Coleman's Panqualityism

Panpsychism and neutral monism might seem as very different views, since the former regards the mental and the physical as equally fundamental, whereas the latter considers both rather superficial compared to some sort of a third neutral material. The two positions are not so easily distinguished from each other in Russellian monism, though. If the quiddities or ultimates are phenomenal, it can be argued that Russellian monism is not neutral, but rather a version of panpsychism. While some contemporary Russellian monists welcome such an implication,[21] others try to avoid it. Thus, Sam Coleman argues for a form of neutral monism in which the ultimates are qualities.[22] Now, this sounds like the traditional phenomenalism which, as I noted in Sect. 12.1, used to be ascribed to Mach as well, but long ago dismissed as a complete failure. However, Coleman argues that the charge of phenomenalism results from a conflation of qualities with conscious experience. It is

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[19]David Chalmers, "Consciousness and Its Place in Nature," in Chalmers, *The Character of Consciousness*. Oxford: Oxford University Press, 2010, pp. 136–137.

[20]About Russellian physicalism, see Montero, *op. cit*., 216–222.

[21]E.g., Strawson, *op. cit.*

[22]See the most complete exposition of Coleman's view to date in Sam Coleman, "Neuro-Cosmology." In Paul Coates/Sam Coleman (eds.), *Phenomenal Qualities: Sense, Perception, and Consciousness*. Oxford: Oxford University Press, pp. 66–102. See also Sam Coleman, "The Real Combination Problem: Panpsychism, Micro-Subjects, and Emergence." *Erkenntnis* 79.1 (2014), pp. 19–44.

important to distinguish between the two: ultimates instantiate but do not experience qualities. For example, ultimates have the quality of redness, but they do not have the phenomenal property redness.

In order to make the desired distinction between qualities and consciousness, Coleman employs Rosenthal's HOT theory, which was briefly summarized in Sect. 12.2. Recall that, for Rosenthal, consciousness is a matter of awareness, construed as a higher-order thought representing a sensorily qualitative state, e.g. a color. Rosenthal believes that consciousness, having been given this sort of relational account, can be accommodated within the materialist picture. And, argues Rosenthal, so can be qualities. These appeared deviant, from the materialist point of view, only due to their association with consciousness. Once they are separated from it, they can be slotted into the materialist scheme of things as well. Here, however, Coleman diverges from Rosenthal. Qualities cannot be given a standard physicalist treatment, because they are intrinsic, not relational. Due to their irreducible character, qualities must be regarded as ultimate, resulting in the metaphysical picture which might be termed *panqualityism*. The intrinsic-relational distinction comes, of course, from the Russellian structuralist view of physics, according to which physics is blind do the intrinsic nature of things.[23] Hence, for Coleman, the true difficulty for materialism is neither life, as we used to think until Darwin, nor phenomenal consciousness, as many still believe today, but rather qualities:

> Life was problematic, appearing at one time an irreducible property, because consciousness was implicitly mixed in with it. Then it seemed that consciousness was the last bastion against science—but if we make the move of dividing conscious awareness from quality, and attack consciousness relationally, this outpost too will fall. Quality is the truly insurmountable rampart [. . .] Basic matter will have to be qualitative, since we experience qualities.[24]

This is not phenomenalism, because qualities are not my phenomenal properties. Nor it is panpsychism, however, since qualities are not *anyone's* phenomenal properties. As we have just seen, the latter were shown to be composite of a conscious awareness, on the one hand, and qualities, on the other. The intrinsic properties of the world are thus not phenomenal, but qualitative. For Coleman, this amounts to neutral monism: "A position taking qualities as fundamental features of matter, but which makes subjective awareness of qualities a relational (thus reducible) affair, is *neutral monism*."[25] And perhaps somewhat surprisingly—since these qualities are completely devoid of any conscious subjectivity, we could perhaps include them among physical properties, even though this would require a wider construal of physics as admitting quiddities, or ultimates, rather than just

[23]For Coleman's evocation of the Russellian view of physics, see "Neuro-Cosmology," *op. cit.*, p. 85.

[24]*Ibid.*, p. 77.

[25]Coleman, "The Real Combination Problem," *op. cit.*, p. 21 (italics in the original).

the relational properties, as in the standard physics.[26] Accordingly, panqualityism could be interpreted not only as neutral monism, but also a sort of Russellian physicalism.

12.5 Mach's Panqualityism

I believe that Coleman, despite referring to Russell and James more often than to Mach, offers an ambitious metaphysical view that updates the key features of Mach's position.[27] As already noted, Mach held that both mental and physical states were constructed out of the so-called "elements," at least some of which seem to have a qualitative nature.[28] Officially at least, the elements are neither physical, nor mental—they are neutral. In advocating neutral monism, Mach also explicitly rejected panpsychism. At the close of *The Analysis of Sensations*, he says: "Many are the victims that fall a prey to pan-psychism, in the desperate struggle between a monistic conception of the universe and instinctive dualistic prejudices."[29] It thus appears that Mach faced, in the late nineteenth century, a conceptual landscape surprisingly similar to the one described in the works of contemporary philosophers such as Chalmers, Coleman and others. On the one hand, the materialist monism; on the other hand, dualism; and panpsychism as a misbegotten attempt to inject the mental into the physical.

Another prescient aspect of Mach's theory is that it seems to offer an early version of the relational analysis of consciousness of the sort that Coleman recently adopted from Rosenthal. Of course, we do not find anything like a detailed higher-order representation theory in *The Analysis of Sensations*, but there are definite allusions to a functionalist account, according to which consciousness is a matter of organization of elements, or the role some of them play with respect to others. For example, Mach says that

> wherever the reader finds the terms "Sensation," "Sensation-complex," used alongside of or instead of the expressions "element," "complex of elements" it must be borne in mind that it is *only* in the connexion and relation in question, *only* in their functional dependence, that the elements are sensation. In another functional relation they are at the same time physical objects.[30]

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[26]Coleman, "Neuro-Cosmology," *op. cit.*, p. 78.

[27]Chalmers, himself a critic of panqualityism, mentions in passing Mach as one of the pioneers of this theory in David Chalmers, "Panpsychism and Panprotopsychism," *op. cit.*, p. 271.

[28]Mach lists "colors, sounds, temperatures, pressures, spaces, times" as examples of "elements." See Ernst Mach, *The Analysis of Sensations*. New York: Dover, 1959 (orig. 1886), p. 2.

[29]*Ibid.*, p. 362.

[30]*Ibid.*, p. 16 (italics in the original).

Using Coleman's model as a clue, I think we can interpret "elements" as metaphysically neutral qualities, whereas "sensations" are the same elements once they are related as objects of awareness. Perhaps a clearer expression of this view is in a passage in Mach's late work, *Knowledge and Error*:

> Consciousness is not a special mental quality or class of qualities different from physical ones; nor is it a special quality that would have to be added to physical ones to make the unconscious conscious [. . .] Consciousness consists not in a special quality but in a special connection between qualities [. . .] a single sensation is neither conscious nor unconscious: it becomes conscious by being ranged among the experiences of the present.[31]

Thirty years ago, Rudolf Haller was interpreting passages such these as anticipations of the materialism which was the dominant view at the time.[32] With the arrival of Russellian monism, it seems that Mach more or less clearly saw materialism—at least when understood as a view that the standard physics provides a complete description of the world—as a problem, rather than a solution. Having read Coleman, we can interpret Mach as already gesturing toward a view that phenomenal properties appear to pose a deep metaphysical problem only if one's point of departure is the standard materialist picture. Once we disabuse ourselves of this picture and instead adopt qualities as basic, we can explain phenomenality in terms in terms of functional relations among the qualities.

However, this is, of course, a rather anachronistic reading which disregards many important differences between Mach's view and the contemporary panqualityism. To begin with, Mach's reasons for rejecting panpsychism are quite different from those found in the current literature. For example, we saw that Coleman argues that panpsychism is based on a conceptual confusion—that between an instantiation of qualities an experience of qualities. On the contrary, Mach's argument is scientific, rather than purely philosophical. He claims that panpsychism is ruled out as a reasonable scientific hypothesis because it does not advance our knowledge:

> Everything that can have any interest for us must be reached in the course of following out the general task of science. We ask whether animals have sensations, when the assumption of sensations helps us better to understand their behaviour as observed by means of our own senses. The behaviour of a crystal is already completely determined for our senses; and thus to ask whether a crystal has sensations, which would provide us with no further explanation of its behaviour, is a question without any practical or scientific meaning.[33]

In other words, it makes sense to hypothesize about the presence of sensation in particular cases, when such a hypothesis promises an explanatory gain. To entertain a hypothesis that everything has mental properties, however, can be motivated only by an idle metaphysical speculation.

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[31] Ernst Mach, *Knowledge and Error*. New York: Springer, pp. 31–32.

[32] Specifically, Haller claimed that for Mach, the mind-brain identity was a matter of "point of view" (*Betrachtungsweise*). See Rudolf Haller, "Grundzüge der Machschen Philosophie," op. cit., p. 76.

[33] *The Analysis of Sensations*, op. cit., pp. 243–244.

Another difference between Mach and the contemporary discussion concerns the conception of materialism. In the contemporary theories, such as those presented in this chapter, materialism or physicalism is usually understood as a metaphysical view according to which the complete truth about reality can be stated in the language of physics. It is assumed that physics is a developing science, so that its final vocabulary is not yet available.[34] On the contrary, Mach seems to have harnessed materialism to a particular developmental stage of physics, which became obsolete at the close of the nineteenth century. In other words, he was assuming that materialism was a metaphysic of the material substance postulated by the eighteenth-century physicists, and should be dismissed once physics advanced beyond this stage. Few would accept such a narrow notion of materialism today.

Finally, Mach's monism is not Russellian. While he recognizes that physical description is relational, or structural, he nowhere suggests that this should constitute any limitation on the part of physics. Mach's view does resemble Russellian monism to the extent that it also understands science as a matter of relational and functional descriptions. However, Mach does not regard the "elements," among whom these functional relations obtain, as quiddities, or natures, beyond the ken of physics. (In other words, Mach does not recognize either of the two features of Russellian monism that I listed in Sect. 12.3.) Thus, he might perhaps be seen as anticipating those contemporary theories that claim that the structural description of the world is complete.[35]

12.6 Beyond Phenomenal Consciousness

I have tried to explain and evaluate the thesis that Mach originated a metaphysical alternative to dualism as well as the standard materialism—namely, panqualityism. Despite some general agreements, there are however important motivational and doctrinal differences between Mach's view and the contemporary panqualityism. I should like to finish with a reminder of what I take to be the deepest difference. The contemporary authors are ultimately motivated by the "hard problem" of P-consciousness, even though some of them, like Coleman, eventually reveal that phenomenality itself can be naturalized. In contradistinction, Mach simply has no notion of P-consciousness, hence no phenomenal zombies etc. Should

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[34] I am alluding to the current debate between the so-called presentists—who argue that the content of materialism should be based on the present state of physics—and the futurists—who think that materialism must be defined in terms of the complete physics of the future. See Daniel Stoljar, *Physicalism*. London: Routledge, 2010, chap. 5.

[35] Cf. James Ladyman/Don Ross et al., *Every Thing Must Go: Metaphysics Naturalized*. Oxford: Oxford University Press, 2007.

we see this as philosophically naïve? Instead, I wish to suggest that Mach's purely relational account of consciousness should not be viewed as avoiding the "hard problem," but rather as offering us an opportunity to realize that what *many of us today* consider to be inescapable intuitions as to the nature of conscious experiences, might be mere theoretical constructions not shared in earlier times.[36]

[36]However, not everybody in contemporary philosophy believes that we all share some inescapable intuition about the intrinsic nature of phenomenality. Cf., e.g., the many works of Daniel Dennett.

Chapter 13
Can Monism be Neutral?

Germinal Ladmiral

Abstract The paper examines Mach's and Schlick's solution to the mind-body problem. It does not trace their lineage from historically given philosophical schools but tries to draw on the rational reconstruction of the problem within recent philosophy of mind to locate the authors' positions within the logical space of possible solutions to the problem. This suggests that they belong to same class of solutions. Furthermore the main originality of both solution is based on the rejection of the primary/secondary qualities distinction. Nonetheless, Mach and Schlick construe that rejection in different ways: the former identifies the object of perception with the object of physics, the latter distinguishes them and appeals to a causal theory of perception. Either theory has to sacrifice some intuitive, pre-philosophical belief, thus rendering the very idea of a philosophical "one best way", let alone a scientific solution of the problem doubtful.

Keywords Mach · Schlick · Mind-body problem · *Qualia* · Causal theory of perception

13.1 Introduction

Mach's *Analysis of Sensations (*hereafter *Analysis*) and Schlick's *General Theory of Knowledge (*hereafter *GTK)* both deal with the mind-body problem. Actually Mach may be seen as one of the first proponents of a kind of solution that would later come to be known as « neutral monism ». Roughly expressed this view entails that any ontological distinction between the subject matter of physics and the one of psychology should be avoided. What there is to be considered « neutral », neither physical, nor mental, mind and matter being only ways of grouping the neutral stuff the world is made of. Thus, it is argued, the mind-body problem disappears altogether, along other metaphysical worries.

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Schlick shared Mach's will to eliminate all metaphysical obscurities at once and asserted the all-encompassing relevance of empirical knowledge (be it scientific or daily life.) Nonetheless, he devoted one article and two chapters of his GTK to criticise neutral monism, which he called « immanence philosophy ».

In this paper, I would like to assess the common grounds and the divergences between the two, propose a *rationale* for it and sketch a balance sheet of their respective theories. I am not so much concerned More precisely I shall try to locate both authors' solutions within the logical space of possible solutions and assess their underlying reasons. To do so, I shall first borrow the rational reconstruction of the problem proposed by prof. Kirk Ludwig in 2003. According to him the problem consists in the logical incompatibility of four rather appealing propositions that are:

1. Realism. Some things have mental properties. [that is consciousness and/or aboutness.]
2. Conceptual autonomy. Mental properties are not conceptually reducible to non-mental properties, and, consequently, no non-mental proposition entails any mental proposition.
3. Constituent explanatory sufficiency. A complete description of a thing in terms of its basic constituents, their non relational properties, and relations to one another and to other basic constituents of things, similarly described (the constituent description) entails a complete description of it, that is, an account of all of a thing's properties follows from its constituents description.
4. Constituents non mentalism. The basic constituents of things do not have mental properties.

The denying of any of the latter propositions is counter-intuitive. But all four cannot be true since they yield a contradiction. Thus a very broad classification of the solutions to the mind-body problem obtains. The four propositions that are open for rejection determine four classes of solution of the problem. And the particular conception of things an author provides so as to make the rejection appear more natural then determines how his solution differs from others taken from the same class.

We can now compare Schlick's and Mach's solution in a more specific way and ask the following questions:

(1) Did Mach and Schlick advocate a stable or consistent solution?
If so,
(2) Which proposition did they reject?
If they were to reject the same proposition (as will be argued):
(3) What systematic disagreement distinguishes one solution from the other?
(4) Are there cogent reasons to chose one over the other?

I shall first argue that both authors agreed on a the way the problem should be framed, that is as a question regarding the relation between the qualia and the objects referred to in physics (sometimes called the sentience problem). We can summarise it as follows:

– where should we locate the qualia within the physical space? For example, where is the green that we see when we observe a green leaf?
– How can we account for the very happening of qualia within a physical framework?

They also agreed on a monistic solution of the problem, refusing to posit something purely mental that would explain psychical events. But that alone does not necessarily amount to providing a consistent solution to the problem. Furthermore it does not necessarily entail the rejection of (2). For example, subjective idealists à la Berkeley and advocates of a "mind dust" do reject (4) without advocating dualism: the former do not posit some mental substance but either reduce things to bundles of qualia and the latter ascribe sentience to the basic constituents of the world.

A third point, Mach and Schlick agree on is the rejection of the received distinction between primary and secondary qualities. Both authors do deny that shape or position is more basic, more "intrinsic" a feature than say colour or taste. But there is two ways in which the distinction can be abandoned. One can either say that a thing's colour is just as intrinsic to it as its shape or location in space. And then something akin to Mach's position obtains (cf. *Analysis*, I, 4). Or one can say that shapes and positions in space are just as dependant on our perceiving of them as are colours or sounds or other so called secondary qualities. And then something akin to Schlick's position obtains (cf. *GTK*, §27). To put it in a nutshell, Mach's proposal is to consider *qualia* as just as objective as other physical properties whereas Schlick's is to consider perceived shapes and perceived locations as just as subjective as *qualia*. This is the reason why the former firmly rejects "things-in-themselves" and replace them with bundle of (sensible qualities displaying) elements and the latter vindicates things in themselves while insisting that they can be known.

In order to make explicit what each of these solutions amounts to and to sketch a balance sheet of each as a solution to the (restricted) mind-body problem, we shall first examine the arguments in favor of a monistic solution (I), the strictures it imposes on the location and identification problem of the *qualia* (II), Mach's way out (III) and Schlick's way out (IV).

13.2 The Argument for Mind-Body Monism

The rejection of dualism obtains from two epistemological principles both authors agree on, that are the principle of parsimony and the rejection of any *ignorabimus* thesis, a thesis I propose to call "knowledge monism".

Both authors acknowledge some version of the well known "Occam's razor" principle. At first glance that principle can appear both obvious and directly confuting any form of ontological dualism. If entities are not to be admitted unless they enhance our theories' explanatory power and if the positing of two distinct kinds of reality (say mind and matter) do not, then we should refrain from positing them.

But the principle is not as clear as it is well known. Both in vindicating it and saying what it amounts to the two authors disagree. According to Mach (*Analysis*, I, 14) the principle, stated as "principle of economy of thought", is understood as an hereditary traits, sharpen by the very course of evolution. Thus it is a rather pragmatic requisite commanding to go for the "simplest" understanding of the world, that is the one enabling us to most successfully act upon it. Mach states it as a self evident reason for disposing of the Aristotelian substance as something that would remain identical with itself despite sensible changes we do experience and of the Kantian notion of "thing in itself" as an unknowable X that in some way could account for those changes without being identical to them.

Schlick criticised that understanding and vindication of the principle and charged Mach with conflating logical and psychological concepts. In GTK, §13 he claims it to be a purely logical principle, regarding the number of basic (or undefined) concept a system admits of.

Actually, for a theory to be simple (or simpler than an other) can mean at least three things:

– it can admit of the least number of undefined concepts
– it can admit of the least number of unproven propositions (axioms)
– it can enable shorter demonstrations.

Obviously theories handling the same subject matter will be seen as more or less simple depending on the criterion one favours. There might be a fourth criterion, that is how common sensical the basic assumptions of the theory are. But it would only beg the question unless we have a common sensicality criterion that would not rely on some informal notion of simplicity.

But there might be a more cogent reason to adopt monism that both Schlick and Mach advocate. This reason has much to do with the very idea of empiricism and might be called knowledge monism. It is a by default argument: unless there is a proof of it, we have no reason to assume that an allegedly special part of reality should be impossible to know or only open to special, metaphysical enquiries, as opposed to ordinary, empirical ones. Mach advocates it mainly on historical grounds, basing his optimism regarding a scientific psychology on the recent scientific breakthroughs, esp. Darwinian evolution theory (Analysis, I, 4) and proposing the unity of science as a (provisional) goal.

In GTK, Schlick seems to provide a logical reason to hope for an united scientific description of the world in general, and a physicalistic understanding of the psychological process in particular. But if this were to be more than a hope (or a lose inductive conclusion) it would be self defeating. It would indeed amount to claim that all knowledge claims must somehow be empirical (that is open to refutation through observation) but would not itself be so. (Just as a general empiricist principle would be self defeating, as Russell noted in *Human Knowledge*, for it would assert something about world, namely that we cannot say something about unless we have empirical evidence, without empirical evidence.) Hence the position advocated in the 1935 paper devoted to the mind-body problem seems to provide an apt precision of Schlick's view on that point: the very possibility of describing and explaining our mental life in physicalistic terms is itself a fact, "a fortunate circumstance". We can even try to imagine a world where mental events would not bear a regular relation to physical events. It is simply the case that as far as we know they do.

13.3 Two Difficulties with Mind-Body Monism

However the choice of a monistic worldview does have some drawbacks. Actually it raises two puzzling questions regarding the sensible qualities: where should we locate the perceived qualities (location problem)? When are we entitled to speak of one and the same perceived thing (identification problem)? Let us try to reconstruct both problems.

The location problem arises from three intuitive propositions:

(a) The object as we perceive it displays sensible qualities (say a colour).
(b) The corresponding physical object does not have such qualities.
(c) The perceived object is identical with the physical object.

If we admit the principle of indiscernibility of the identicals (as part of the very definition of identity) then a contradiction obtains. Thus we have to reject at least one of those three propositions. As we will see we can reconstruct Mach's position as resulting from the rejection of (b) and Schlick's position as resulting from the rejection of (c).

From the denying of (b) the problem of identification arises:

(non b) The "physical" object does have sensible qualities
Fact 1: Different observers ascribe different sensible qualities to one and the same object
Fact 2: Different observers successfully speak of the same object.

An example might make the problem more vivid. Two people observe one leaf from different places. The first one says that the colour of the leaf is dark green, the second that it is light green. Provided they agree on what light and dark greens are in most contexts, an identification problem arises. Either they must agree that the colour of the leaf is not as objective a propriety of the leaf as say its mass, or they must concede that the dark green leaf and the light green one are not one and the same object.

From the denying of (c) a location or a causation problem arises:

(non c) The physical object is not identical with the perceived object.
(d) Physical objects are all there is in the physical space.
(Fact 3) Perceived objects are perceived to be somewhere.

The proposition (d) results from the very definition of the physical space. To get back to our example, if the physical leaf is not identical with both the perceived dark green leaf and the perceived light green one, then we must ask where these two perceived leaves are to be located in.

With those problems in mind, we can now examine how Mach and Schlick tried to vindicate the rejection of (b) or the rejection of (c) respectively and the rather counter-intuitive consequences either rejection has.

13.4 Mach's Solution

13.4.1 Construed as an Idealism

We can first understand the rejection of (b) in such a way as to imply the rejection of (4) in the aforementionned aporia. Indeed the denying of (b) might be understood as a direct consequence of a stronger claim, that is: the denying of the existence of unperceived objects. Then a berkeleyan idealism obtains: there are only bundle of perceived qualities.

Schlick ascribes that view to Mach and criticizes it for requiring some kind of preestablished harmony to account for the fact of intersubjective agreement about reality (GTK, §26B).

Though this interpretation of Mach is at odd with his many statements that his "elements" are not te be confused with purely mental events. Furthermore, he recognises that he formerly held a monadologic worldview but has now ceased to (Analysis, introduction).

13.4.2 Construed as a Rejection of the Primary/Secondary Qualities Distinction

Which is why I propose to understand it as the rejection of the distinction between primary and secondary qualities. Sensible qualities like colours are no less intrinsic to things than say their mass. Thus those qualities must not be related to some one experiencing them and the "thing" must be understood as a regular series of what we call its aspects or qualities.

In that sense, Mach's solution of the mind-body problem would rather amount to rejecting the proposition (2) of the aporia. Whatever mental concepts are used to describe could also be described resorting to physical concepts only. In an example from Mach himself, the colour of some flower might be a mental event for A who perceives it and a physical one for B who observes A's brain. Mach goes on to say that the relation between the two is a kind of parallelism for each and every change in the perceived flower has a counterpart in the brain (*Analysis*, IV, 3).

13.4.3 Puzzling Consequences of Mach's Solution

Even so construed, Mach's position hardly accounts for the intersubjective agreement we generally reach or the very successes of sciences, which is the core of Schlick's criticism of it.

The very thesis of the objectivity of both perceived and unperceived qualities comes with a very high ontological cost. It commits one to the existence of an infinite set of "potential" qualities that an ordinary thing (say a leaf or a flower) consists in. (GTK, §26,A).

And all those actual or potential series of aspects are yet to be perceived from somewhere, so that we have to either assume the existence of one objective space from where they can all be perceived (which is Russell's solution in *Our Knowledge of the External world,* which is why Schlick praises him for being the most consistent proponent of this way of conceiving things) or to be drawn into an infinite regress of embedded perspectival spaces: the flower is located in the space of A, who is located is the space of B, who must be conceived of as being seen from some position, that in turn must be seen from somewhere etc.

The so called parallelism between the perceived thing and the perceiving subject also relies on a confusion between identity and causality. When B looks at A's brain, what he sees is not the physical grouping of the same "elements" A perceives as a flower. What B perceives is just as mental or just as physical in nature as what A perceives. Some (physical) process brings about the seeing of a flower by A. B can study that process by observing A's brain. But his observations consist in an other (physical) process from the same kind as the one he is investigating. Thus the two events, A seeing a flower and B seeing A's brain, could not be one and the same event perceived from different points of view: they are two distinct events with complicated causal (physical) links between them. (GTK, §32).

13.5 Schlick's Solution

13.5.1 Thing-In-Itself Vindicated

Schlick's own solution consists in an anticritic of the properly (physicalistically) understood thing in itself. Schlick asserts the ontological scope of scientific enquiry and defuses it at the same time. What really exists is simply what the basic hypothesis of best theories at hand implicitly defines as their objects in the same way that mathematical theories implicitly defines mathematical objects through their axioms according to Hilbert (GTK,§7).

Thus the realistic claim that there are perfectly knowable things-in-themselves only results from what we nowadays would call an inference to the best explanation: it would be a miracle if so many things happened in the way our theories tell they will without there being the kind of objects they speak of. So much for the ontologic bearing of empirical sciences.

But those objects can be characterised in different, though demonstrably equivalent ways, depending on the concepts and propositions one chooses to consider as basic. For example, one can either construe the Newtonian dynamic with mass, times and distance or with volume, speed and energy as basic concepts. Either way, we are committed to logically equivalent construals referring to the same reality. And the “entities” we are committed to are actually functional relations. (GTK, §31) Hence the “defused” ontology.

13.5.2 The Rejection of the Primary/Secondary Qualities Distinction

Thus we can understand Schlick’s brand of criticism of the primary/secondary qualities distinction: the so called primary qualities are no more intrinsic to the objective thing our theories refer to than the so called secondary ones. Schlick goes as far as to say that there are as many subjective spaces as there are senses: a visual, a tactile, a haptic space etc. (GTK, §29) And the so called secondary qualities, like colours, are actually located within these perceived spaces so that there is no contradiction in ascribing a colour to the perceived thing and no colour to the underlying physical event: they are not to be located in the same “place”.

How then do we become conscious of the one objective space we come to call “physical”? Through the experience of point coincidence, that is for example through the regular happening of coincidences between a perceived event in different sensible spaces. For example, when I touch the tip of a pen and see it connecting with the tip of my finger at the same time, I experience a coincidence between a visual and a tactile event that has to take place in some underlying, objective space. To put it briefly, the subjective experiences of coincidence is the *ratio cognoscendi* of the inferred, objective (physical) space, which is the *ratio essendi* of the intersensory, intersubjective order of the coincidences. In other words, the positing of physical objects located in one non intuitive physical space is the best explanation of the stable order that our experience displays.

13.5.3 Physicalism or Parallelism?

Thus Schlick seems to advocates a rejection of (2) on physicalistic grounds. When A perceives a flower we can either describe it in psychological terms and speak of the shape or the colour of the flower or in physical terms and describe the string of event that goes from the flower to the brain of A. Of course the term physicalism were still to be coined when Schlick wrote the GTK, but it is still a relevant name for his position since there is no symmetry between the two ways of describing or relating to things. All events in the universe could in principle be described in the physical language whereas only a small subset of them can be described within the psychological one.

Yet there is an ambiguity in Schlick's solution. Sometimes the very mental events (say the seeing of a flower) are said to be identical with physical events (say some brain process). (GTK, §32). Thus Schlick seems to defend what would later be called an "identity theory" or a reductive physicalism. Furthermore, Schlick sketches a causal theory of perception that fits nicely within a physicalistic framework. For example, when he says that perceiving an object is a brain process caused by that object (GTK, §27) or that the object of perception is the object "to which the perceptions relate" (GTK, §33).

But this seems to contradict the affirmation that the perceived qualities are to be located exactly where they are perceived. According to the causal theory of perception the *qualia* should be (physically) located within the brain, which Schlick after Avenarius and Mach strongly denies (GTK, §33).

This hints to an hesitation on behalf of Schlick between denying (2) and equating mental life, or at least here sensations, with particular chains of physical events and denying (4) and advocating some kind of "double aspect" theory which grants mental states (like the perceiving of qualities) an irreducible character. As is case with Mach, the whole architectonic of Schlick's theory of knowledge brings us to favour the physicalist interpretation. But it is interesting that he stumbled on a similar difficulty, giving an appealing solution to the identification problem only at the cost of providing the location problem with a far less appealing one.

13.6 Conclusion

We can now answer the questions we raised. Both Schlick and Mach advocated consistent solutions to the mind-body conundrum, at least understood as the problem of the relation between *qualia* and whatever physical happening explains them. Both authors tend to deny the autonomy of mental concepts and thus try to physicalise them. Both do so by rejecting the classical distinction between primary and secondary qualities.

But the very sense in which they do it differs. By denying the subjectivity of *qualia*, Mach sketches a neutral monism. By denying the objectivity of the perceived spaces, Schlick sketches a physicalistic account of *qualia*.

Both authors sometimes seem reluctant to go all the way down the path they chose though. My hypothesis is that the logical impossibility to solve both the location and identification problem in a way that is intuitive accounts for those ambiguities.

Despite their common ideal of making philosophy scientific, Mach and Schlick gave diverging accounts of the relation between *qualia* and the object of physics, salvaging different parts of our common sensical (though inconsistent) understanding of sentience and its place in nature. That and the difficulties of both solutions should make us less optimistic than they were about there being a "one best way" in philosophy.

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Chapter 14
Intentionality vs. Psychophysical Identity

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Abstract Brentano's empiricism displays striking similarities with Mach's phenomenalism. Both authors hold physical reality to be a "fiction" and reject the traditional view of truth and existence. In this paper, the author seeks to clarify some aspects of the Mach-Brentano debate, with a special focus on the theory of intentionality. First, he links this debate to an earlier one, namely to the debate about the mind-body relation. Secondly, he discusses some of Brentano's objections and construes his intentionalism as an alternative to the psychophysical identity thesis.

At least at first sight, there seem to be essential similarities between the philosophical doctrines of Ernst Mach and Franz Brentano. Both philosophers embraced a radical form of empiricism which quite plausibly deserves the name "phenomenalism". Both defended the view that external reality, viewed as a metaphysical issue, was something of a fiction or illusion. Both thought that empirical science should start by purging itself of all metaphysical assumptions. Just as Mach claims that "all metaphysical elements are to be eliminated as superfluous and as destructive of the economy of science" (Mach 1922: viii/xxviii), so Brentano, in his *Psychology from an Empirical Standpoint*, makes a call for a psychology that is free of the "metaphysical presuppositions" of the traditional theory of the soul (Brentano 1973: 27/18).[1] Yet, in spite of these similarities, Brentano severely criticized a broad range of views that are central to Mach's philosophy.[2]

[1]The second page number always refers to the English translation, if there is one.

[2]The most extensive formulation of that critique can be found in (Brentano 1988). This book, edited by Chisholm and Marek, includes the whole correspondence and an essay on Mach's *Knowledge and Errors* which Brentano dictated in 1905–6. Some letters from Brentano to Mach had been previously published in (Thiele 1968: 294–296) and in (Brentano 1964).

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In this paper I discuss some core aspects of the dispute between the two authors. My starting hypothesis is that this dispute is a manifestation of a larger debate that played a central role in philosophy throughout the nineteenth century. As I will argue, Mach's psychophysical identity thesis as well as Brentano's theory of intentionality are best seen as contributions to the debate about the relationship between the mental and the physical. This is not merely a historical footnote. I think that Brentano's theory of intentionality is *first of all* a contribution to the psychophysical debate and should be regarded as such. For this reason, the Mach-Brentano controversy is key for understanding what is really at stake in Brentano's intentionality theory. For in this controversy Brentano explicitly presents his theory of intentionality as a variety of psychophysical dualism.[3]

14.1 Some Preliminary Remarks

To begin with, let us make some points on notable commonalities between the views of Mach and Brentano.

Franz Brentano's masterpiece, the *Psychology from an Empirical Standpoint* published in 1874, is first and foremost an epistemological treatise. Its aim was to lay the foundations of a scientific, that is, empirical psychology—namely to define what an empirical psychology is or should be and to develop a method for it. As is well known, Brentano defines psychology as the "science of mental phenomena". The reason for this is explained on the opening pages of the first volume of his *Psychology*.

Traditionally, he declares, sciences are defined in reference to what kind of realities or substances they are about. Natural science is defined as the science of physical substances, namely of bodies. Likewise, Aristotle, Leibniz, Spencer, and Lotze define psychology as the science of mental substances, namely of souls (Brentano 1973: 21 ff./14 ff.). Of course, empirical science as such must somehow deal with appearances. On the traditional view, however, appearances are not proper objects of knowledge. The actual objects of empirical science are bodies and souls, and bodies and souls are such that they can be known *through* their appearances in the mind. This is made possible by the fact that appearances stand in some special relation to reality. Physical phenomena are causal effects of bodies; mental phenomena are states or properties of souls. And both physical and mental phenomena must somehow be similar to their causes or substantial bearers.

Brentano rejects this traditional, indirect realist view. In his lecture on phenomenal green held in January 1893 before the Vienna Philosophical Society, he even declares that it has been "refuted by the progress of science" (Brentano 1979: 5).

[3](Albertazzi 2002: 43) provides some hints in this direction.

Phenomena, he claims, *are* the only objects of science. Natural science is not the science of physical reality, but the "science of physical phenomena"; psychology is not the science of the soul, but the "science of mental phenomena". His idea runs as follows:

> But what entitles us to assume that there are such substances? It has been said that such substances are not objects of experience; neither sense perception nor inner experience reveal substances to us. Just as in sense perception we encounter phenomena such as warmth, color and sound, in inner perception we encounter manifestations of thinking, feeling and willing. But we never encounter a being of which these things are properties. Such a being is a fiction to which no reality of any sort corresponds, or whose existence could not possibly be proved, even if it did exist. Obviously, then, it is not an object of science. Hence natural science may not be defined as the science of bodies nor may psychology be defined as the science of the soul. Rather, the former should be thought of simply as the science of physical phenomena, and the latter, analogously, as the science of mental phenomena. There is no such thing as the soul, at least not as far as we are concerned, but psychology can and should exist nonetheless, although, to use Albert Lange's paradoxical expression, it will be a psychology without a soul. (Brentano 1973: 15–16/10–11)[4]

As a matter of fact, Brentano endorsed the project of a "psychology without a soul". At the end of the same section, he most explicitly argues that the modern definition of psychology as the science of mental phenomena is better than the old definition of psychology as the science of the soul, because, among other things, the latter "contains metaphysical presuppositions from which <the former> is free" (Brentano 1973: 27/18).

Remarkably, Brentano here defends a view which closely resembles Ernst Mach's phenomenalism. First, both Mach and Brentano are phenomenalists insofar as they hold that phenomena are the only acceptable objects of science. Secondly, Mach also regards substances as fictions. "The thing and the ego", he claims, "are provisional fictions of the same kind" (*Ding und Ich sind provisorische Fiktionen gleicher Art*) (Mach 1926: 15/9; cf. Brentano 1988: 18). Thirdly, Mach, too, in *Knowledge and Error*, explicitly embraces Lange's idea of a "psychology without a soul" (Mach 1926: 12/8). According to his famous dictum, the ego or soul—Mach uses the two words interchangeably (Mach 1922: 4/5)—is "unsalvageable" (*das Ich ist unrettbar*) (Mach 1922: 20/24). Fourthly and finally, Mach, like Brentano, opts for phenomenalism because the realist option is fraught with unscientific metaphysical presuppositions. As Mach often emphasizes, the purpose behind his

[4] I have slightly modified the English translation because it is manifestly influenced by Oskar Kraus's interpretation, which I think is wrong. Kraus's inability to hear, or willful blindness to, what Brentano actually says in this quote is properly unbelievable. Brentano explicitly says that "neither sense perception nor inner experience reveal substances to us". Yet Kraus maintains that this is not Brentano's own view, and that, for Brentano, "both sensation and inner perception exhibit substances to us". Brentano claims that the "being" (*das Wesen*) "of which <mental phenomena> are properties", so the soul or mental substance, "is a fiction to which no reality of any sort corresponds" (*eine Fiktion, der keinerlei Wirklichkeit entspricht*). Kraus maintains that it is not "the assumption that there is a substance" which is a fiction, but "the assumption that there is an attribute without any subject supporting it" (Brentano 1973: 258/11)!

reductionism is to eliminate "philosophical pseudo-problems" due to ungrounded metaphysical hypotheses (Mach 1922: 22/28; Mach 1926: 12/12; cf. Brentano 1988: 23).[5]

The question I wish to address concerns the relationship between the philosophical programs of Mach and Brentano at the most general level. My view is that these programs, although strikingly similar, are radically opposed in their approach to the psychophysical issue. In my estimation, the difference is between psychophysical monism and dualism. On the one hand, Mach's psychophysical identity thesis asserts a psychophysical monism. On the other hand, as I will suggest, Brentano endorses a form of psychophysical dualism, and this dualism is actually his theory of intentionality itself. In his notes on *Knowledge and Error*, Brentano is very clear on the fact that the most fundamental disagreement between Mach and him is over the psychophysical difference. He claims that "the break with dualism", which he credits to Spinoza, "is full of absurdities", and that Mach's psychophysical identity thesis is actually a "regression to a level below" that of modern psychology and even commonsense (Brentano 1988: 47–48).[6]

14.2 The Psychophysical Identity Thesis

As is well-known, the psychophysical problem was one of the most intensely debated issues in the nineteenth century philosophy. Cartesian metaphysical dualism seemed to be definitively abandoned at that time, and most philosophers embraced substance monism: reality consists of just one type of substance. Metaphysical materialists like Carl Vogt, Jacob Moleschott, and Ernst Haeckel claimed that reality consists only of physical substances, or bodies, or matter. Metaphysical "spiritualists" or "panpsychists", for example Fechner and Lotze, claimed that reality consists only of mental substances, or souls.

However, this is not the most interesting part of the debate. Much more interesting are the discussions on mental and physical *phenomena*. The question is whether it is relevant to distinguish between the two and, if so, what sort of relation they have to each other. This question is crucial if one takes for granted, as many philosophers of the time did, that science must be empirical, that is, deal not with substances, but with phenomena. Science, unlike metaphysics, is not concerned with how the world really is, but with how it appears to be. Lotze and Fechner,

[5]It is true, however, that Brentano, in his 1905–06 dictation on *Knowledge and Error*, attacks this view by pointing out that it leaves no room for philosophy at all (Brentano 1988: 23ff.). This is an interesting aspect of Brentano's critique and one that deserves special attention—but it would take us too far from our main concerns to discuss it here.

[6]In a letter to Husserl dated 26 December 1893, Brentano rather oddly seems to reject both monism and dualism: "If I manage to refute monism, I hope I will then be able to demonstrate the implausibility of dualism as well and to advocate a view that is infinitely different from both" (Husserl 1994: 14–15).

for example, were both metaphysical monists and phenomenological dualists. The former affirms that substances, namely mental substances, are accessible only through intellectual intuition, and that intellectual intuition pertains not to science, but to poetry and religious faith. The scientist, by contrast, confines herself to studying relations between phenomena, especially causal relations between physical phenomena and between mental and physical phenomena. Now, Lotze criticizes materialists for being committed to a phenomenological monism that ignores the qualitative difference between mental and physical phenomena (Seron 2015: 25–26). In spite of his metaphysical spiritualism, Lotze devotes a significant part of his *Medical Psychology* of 1852 to arguing for the irreducibility of the psychophysical difference. Quite unexpectedly, he even goes so far as to defend Descartes against materialists.

Lotze's view is best seen as a metaphysical monism combined with a phenomenological (or scientific) dualism. In short: Lotze states both the substantial identity and the qualitative difference of mental and physical phenomena. Of course, other combinations are possible, but what is important here is that the two issues—the metaphysical and the phenomenological—are independent of each other.

In some respects, Fechner's psychophysical parallelism is very similar to Lotze's conception. Fechner, too, endorses some form of metaphysical spiritualism and claims that mental and physical phenomena form two distinct series. However, his explanations are ambiguous and may be interpreted differently. Fechner claims that mental and physical phenomena are appearances of one and the same being and that they belong to two phenomenologically different types. But he also says that this difference is just a matter of "standpoint" (*Standpunkt der Betrachtung*). By this he means that the only difference between both kinds of phenomena is that mental phenomena are objects of inner experience, while physical phenomena are objects of outer experience (Fechner 1860: 5–6; 1877: 67). For this reason, Lotze criticized him for disregarding the qualitative differences between the mental and the physical and thus falling back, like materialists, into phenomenological monism (Seron 2015: 38).

In a sense, Mach's psychophysical identity thesis represents a further step in the same direction. First, Mach views the metaphysical mind-body problem as a pseudo-problem and, like Brentano, he sweeps it away under the carpet. Secondly, he defends a phenomenological monism according to which there is no constitutive qualitative difference between mental and physical phenomena. There is only one phenomenal world, in which each phenomenon should be viewed as both mental and physical at the same time. The alleged difference between mind and body, claims Mach, actually lies in functional relations between sensations.

Interestingly, Mach explicitly appropriates psychophysical parallelism as a *monist* theory (see Mach 1922: 50 ff./60 ff., 305). Fechner's parallelism, he argues, says that (1) phenomena are either mental or physical, that (2) mental and physical phenomena are distinct facets of one and the same reality, and that (3) mental and physical phenomena are interrelated by relations of functional dependence.[7] Mach

[7] On Mach's debt to Fechner, see also (Mach 1922: xxvii/xxxvi).

rejects the first two theses and endorses the third. First, his version of parallelism holds that each phenomenon is not either mental or physical, but both mental and physical at the same time. This is the psychophysical identity thesis. Secondly, Mach explicitly emphasizes that his theory is not a metaphysical or philosophical theory of how the world really is (Mach 1926: 13/13). He certainly accepts the idea that mental and physical phenomena are aspects of one and the same third, but he denies that this third is an unknowable substance, a thing in itself (Mach 1926: 13/13). In other words: the third must consist of sensation. Thirdly, talk of mental and physical phenomena is just a misleading way of talking about functional relations among sensations. The relation between the mental and the physical is not such that, in order for it to obtain, its terms must be of different natural kinds, mental or physical. Rather, it is the relation itself that makes a sensation mental or physical.

14.3 The Theory of Intentionality as a Phenomenological Dualism

Brentano's philosophy of mind is diametrically opposed to Mach's monism of sensation. Brentano's position, like Mach's, can in some sense be called a "phenomenalism". As said earlier, however, Brentano's phenomenalism is combined with a strong form of phenomenological dualism which as such makes it incompatible with Mach's phenomenological monism. My suggestion in what follows is that Brentano's phenomenological dualism is identical to his theory of intentionality.

At first glance, there may seem to be no unbridgeable difference between Brentano's theory of intentionality and Mach's characterization of the mind-body relation as a relation of functional dependence. After all, Brentano's tenet is that physical phenomena should be viewed as intentional contents, and intentional contents are *dependent* parts of mental acts. Of course, one may object that, in Brentano's view, this dependence relation is one-sided only, while Mach views it as two-sided. But the objection is not really compelling. We could point out that, according to Brentano, the dependence relation between the primary and the secondary object of the mental act is two-sided. The primary object of the mental act is necessarily dependent on its secondary object, and vice versa.

Additionally, Brentano's idea of an intentional in-existence of the object in the mental act may look similar to Avenarius' notion of "introjection", which Mach appropriates for his own account of the distinction between the mental and the physical (Mach 1922: 42–43/51–52). For Mach as well as Brentano, the distinction between the representing subject and the represented object is, so to speak, locative. For Brentano, a represented object is a phenomenon that is intentionally contained within another phenomenon. For Mach, a represented object is a sensation that is enclosed within the spatial boundaries of the representing subject's body (Mach 1926: 5 ff./4 ff.).

So, where is the disagreement? The most prominent difference is that Brentano takes "mental" and "physical" as denoting natural kinds. This is a very general feature of his methodology of philosophy. As he says at the beginning of the second volume of the *Psychology*, "scientific study must have classification and order, and these may not be arbitrary. They ought, as far as possible, to be natural, and they are natural when they correspond to a classification of their subject-matter which is as natural as possible" (Brentano 1925: 3/177). Likewise he claims, some pages further on: "A scientific classification (. . .) must be natural, that is to say, it must unite into a single class objects closely related by nature, and it must separate into different classes objects which are relatively distant by nature." (Brentano 1925: 28/194) Much of the 1874 *Psychology* is devoted to working out a criterion for distinguishing mental from physical phenomena. Mental phenomena differ from the others in virtue of some natural feature, namely the intentional in-existence of an object in them.

For Mach, by contrast, the words "mental" and "physical" do not denote natural kinds. As he declares in *The Analysis of Sensation*, "the boundary-line between the physical and the mental is solely practical and conventional" (Mach 1922: 254/311). Mental and physical phenomena are made out of the same stuff, namely sensations, and it is only their mutual relations that constitute them as physical or mental, things or egos. This is exactly how Carnap puts the matter in Section 164 of the *Aufbau*, where he attacks the intentionalism of Brentano and his followers. It is false, he says, to pretend that the obtaining of an intentional relation depends on the nature of the terms that stand in that relation. Thus, "the intention relation is not a relation of a unique kind which can be found nowhere but between a psychological entity and that which is represented in it" (Carnap 1998: 227).

In marked contrast with this view, Brentano's theory of intentionality is best seen as a form of psychophysical dualism. Like Lotze, Brentano holds that mental and physical phenomena are by nature qualitatively or intrinsically different. Their difference lies in the fact that all mental phenomena, unlike physical phenomena, have an intentional content. This difference is "natural", insofar as it is somehow derived from experience. As Brentano puts it, a classification is "natural" if, and only if, it "proceeds from a study of the objects to be classified and not from an a priori construction" (Brentano 1925: 28/194). The intentional relation—the fact that some phenomena have an intentional content—is not a mere stipulation, it is something that we experience, something that we somehow *discover* or *learn from* inner experience. And this discovery as such does not preclude the possibility that other criteria of the mental will be discovered in the future. As Brentano explains, in the text "Vom Objekt" dating from 1906, the same year as the dictations on *Knowledge and Error*:

> Having an object is a general feature of everything mental, as it appears in our experience. What this means cannot be clarified (*deutlich machen*) without a hint about the experience; this would be impossible just as it is impossible for a blind person to clarify the concept of red, for someone that is never loved or hated to clarify the concepts of love and hatred (. . .). (Brentano 1966: 339)

14.4 Two Objections

We now come to two key objections raised by Brentano to the psychophysical identity thesis—objections which may as well be viewed as arguments in support of phenomenological dualism. These two objections are of a very general character. But for the sake of clarity I will start with a more specific objection which is actually, as I will try to show, a particular case of the second objection. This more specific objection is about concepts. It is presented in the dictations on *Knowledge and Error* and in the 1906 text just quoted.

Mach's theory of concept is expounded in Chapter 8 of *Knowledge and Error* and in Chapter 14 of *The Analysis of Sensation*. It is, basically, a genetic theory. Roughly: the subject associates present or remembered experiences on the basis of similarities, selects such-and-such feature in accordance with her needs (practical, scientific or otherwise), and finally creates a concept which is no more than a sensation "impulse". A concept, says Mach, is "a simple impulse to perform some familiar sensory operation, as the result of which a definite sensational element (the mark of the concept) is obtained" (Mach 1922: 263/322). For example, the concept of red is not a representation. Red in general is not something that can be represented (Mach 1922: 262–263/321–322). It is just an impulse to imagine or remember this or that red thing.

For Brentano, this amounts to denying the *generality* of concepts—or to affirming that there can be no such things as concepts in the traditional sense of the word:

> For Mach, we have only individual sensations and representations, of which all the rest, including concepts, is composed. The first assertion already rules out that there are concepts in the traditional sense of the word. (Brentano 1988: 56; cf. Brentano 1966: 337–338)

Brentano's argument is as follows: Mach takes concepts to be reducible to sensations; now, sensations are by definition individual, and Mach himself undoubtedly agrees with this; therefore, Mach takes concepts to be individual, which contradicts the traditional view of concepts. Since the view that concepts are individual is obviously absurd, the view that concepts are reducible to sensations must be absurd as well.

Brentano plausibly regarded this view as so central to Mach's philosophy as his psychophysical monism. And of course he rejected it as so absurd as psychophysical monism. Additionally, and interestingly, it seems that Brentano considered both views—monism and concept reductionism—to be closely interconnected.[8] And I think he had good reasons for this, which will become apparent later.

Let us now examine the two objections alluded to above. My conviction is that the problem generated by Mach's view of concept is part of a more general problem

[8]See for example (Brentano 1988: 28): "The identification of the act of seeing with colors, of the act of hearing with sounds, of the presentation of a tree with the tree, is false and absurd. Mach has not even given an apparent demonstration of that absurd view; also missing is anything that can be viewed as an apparent demonstration of the fact that a scientific concept is nothing but a compound of sensible presentations, a compound which is of an individual character as are sensations."

which is inherent in psychophysical monism in general, and that Brentano's theory of intentionality precisely aims to overcome this more general problem.

Before proceeding further, it is useful to return to Brentano's theory of intentionality. Phenomena are objects of presentation (*Vorstellung*). In Brentano's sense, a presentation is a direct acquaintance with something that appears, or is given to, the subject. It is the appearance of something in one's mind: "As we use the verb 'to present' (*vorstellen*), 'to be presented' means the same as 'to appear'" (Brentano 1973: 114/81); "We speak of a presentation whenever something appears to us" (Brentano 1925: 34/198). Accordingly, a presentation is not a representation in the contemporary sense of the word, that is, an intentional act or state. Physical phenomena are presented and yet have no intentional content: they are not "intentional" in the contemporary sense. Dermot Moran (2000: 45) rightly stresses that for Brentano a presentation is more like an "idea" in the sense of Locke and Hume, namely a mere phenomenal datum.

Among the subject's presentations, some are perceptions. Perception involves more than mere presentation. A perceived phenomenon not only appears, it must necessarily appear with a character of real, present existence; it is accepted or believed in (*anerkannt*). Brentano calls the phenomena that are perceived "secondary objects", and the phenomena that are not perceived "primary objects". The basic idea of his theory of intentionality is twofold. First, all secondary objects are mental, so mentality is a necessary condition for real existence. Secondly, primary and secondary objects are by nature such that the former are phenomenally contained within the latter. In other words: a primary object is the content of a mental phenomenon—a content which does not exist really but only intentionally, hence a phenomenon which "in-exists" or merely appears within a mental phenomenon that really exists. This is what we contemporary philosophers call "intentionality". As is well-known, Brentano never used the word "intentional" in the contemporary sense of intentional directedness; he rather speaks of the mental act's "relation to a content". This relation to a content is simply a phenomenal relation in virtue of which something that does not exist appears within a mental phenomenon which is innerly perceived and really exists.

What motivations led Brentano to this view? I think he had two more basic reasons or arguments, and that these arguments are precisely those which he uses against Mach's psychophysical identity thesis.

The first argument, which can be found in Chapter 10 of the dictation on *Knowledge and Error*, is about inexistent objects. The idea is that the psychophysical identity thesis makes it impossible to account for representations without object. Indeed, this thesis entails that the represented object and the act of representing it are identical. Thus, if the act of representing an object A exists, then the object A must necessarily exist as well. Therefore, a representation of an object that does not exist is impossible:

> Mach sees no difference between the presentation and the presented object, the act of seeing and the seen object, the act of remembering and what is remembered. Thus, from his point of view, isn't the existence of the presented object as certain as that of the act of presenting it? (. . .) Of course it can be that one waits for something that never happens; but for Mach

> it would not be the case; for, in his view, the act of waiting *is* that which is awaited, and if the act of waiting occurs, then that which is awaited occurs as well. For him, who writes about *Knowledge and Error*, error is simply impossible. (Brentano 1988: 68)

Is Brentano's objection justified? It would for sure hold if Mach had asserted that the represented object and the act of representing it were numerically identical. But this is not what Mach actually says. Mach's actual view is that the two are type-identical. The relation between the two as individuals is not token-identity, but type-identity with functional dependence. The intentional relation is a dependence relation between phenomena of the same type, namely sensations. Nevertheless, there is a looser sense in which Brentano's first objection may be valid, and this brings us to the second objection. If presented or represented objects are sensations, and if one construes Mach's sensations as objects of perception, as Brentano did, then it seems impossible for them not to exist, or not to be accepted as existent. For being perceived involves really existing, or being accepted as really existing. That is why Brentano, in the same chapter, addresses the case of negative judgments. In the case of negative judgments, the presented content is rejected as non-existent. Therefore, it cannot be perceived, it must be represented in another mode than the perceptual.

In my view, one of the most fundamental aims of Brentano's theory of intentionality is to provide a general basis that would ensure the possibility of non-perceptual representations—including conceptual thoughts—within an empiricist framework. This is made possible by the distinction between primary and secondary objects, which is the very core of the theory of intentionality. The secondary object, namely the mental act I presently experience, must be perceived and, as such, really exist. By contrast, the primary object, namely the intentional correlate, is not perceived. It is presented, it appears in the mind, and this appearing has a variety of modes: for example it is remembered, imagined, accepted or rejected, thought, loved or hated, etc.

Plainly, some intentional acts have an object that does not exist. To put it otherwise: not all phenomena really exist. For this to be possible, there have to be presentations that are not perceptions. For perception involves real existence. Therefore, Mach's claim that all phenomena are reducible to sensations is false. Besides the objects of perception—that is, primary objects, the mental phenomena I presently experience—, there must be phenomena that appear without existing, that is, merely "intentional" contents. This is what "intentionality" (in the contemporary sense) is all about: something that does not exist appears within a mental phenomenon that exists.

Given this, it is no surprise that, in the 1906 essay on the object, Brentano's main objection against Mach is that he absurdly tries to eliminate the distinction between primary and secondary objects and the related distinction between direct and oblique modes (Brentano 1966: 337–338). The objection is as follows: Mach grants real existence only to individuals; since concepts, as traditionally conceived, are not individuals, they do not really exist; and they do not even exist in the mind, for the mind is part of what really exists. To this, Brentano objects that being in the mind does not entail really existing:

> When one says that something is in the mind, one does not mean by this that something really *is*, but that there is something that has a presentation of it, or has it as its object. (Brentano 1966: 338)

In short: a concept, like any other intentional content, is something that appears in the mind and does not exist. As opposed to the secondary object, the primary object is something that is presented or thought only in an oblique mode, that is, in a non-referential way or, as Brentano puts it, without being accepted (cf. Brentano 1966: 340).

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Chapter 15
Economical Unification in Philosophy of Science Before and After Ernst Mach

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Abstract This article portrays unification of physics as a central tenet of Ernst Mach's thought, and organizes some of the focal issues in philosophy of science around the process of unification of science. Mach finds a natural place in the history. Newton's *Principia* marked the beginning of the era of mathematical physics, which developed triumphantly in the eighteenth century, until new phenomena were discovered in the nineteenth century whose explanations went over and above Newtonian physics. Also Positivism emerged in the nineteenth century. This was the setting where Mach entered. The notion that a central function of physics is to give mathematical descriptions of perceptions is all over Mach's work, but in Mach's thought mathematics comes together with hypothetical laws of nature and an overall world-view, similarly as in Newtonian physics where mathematics comes together with the laws of motion. Mach's criticism of Newtonian absolute time and space was in line with positivism, and his suggestions about an overall holistic world-view were to function as an intuitive background for the new physics. Thus, as a physicist and a philosopher of physics, Mach should be seen primarily as a unifier, and his famous anti-metaphysics should be seen as derivative from this unificationist project: he did not intend to banish the metaphysical core that he himself proposed, but only metaphysics that is not needed in unified science.

15.1 Introduction

Economical unification is the process of approaching ideal total science which builds on a minimal core of metaphysical postulates that suffices for explaining all phenomena (Fig. 15.1).

Consider the key elements of economical unification in a chain: the progress of science is desirable; unification is progressive as it brings total science closer to the ideal goal, disregarding whether or not the goal is ever actually reached; in order to

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Fig. 15.1 Economical unification as the process of evolution from isolated, heterogeneous and incompatible theories into an ideally unified theory which is the nexus of virtues

efficiently advance the process of unification, the *principle of economy* is needed as an evaluation criterion that favors more unified theories.

This article is organized as follows.

Section 15.2. The structure of theories is opened up and ontological commitments of theories are classified.

Section 15.3. The principle of economy is introduced, formulations of economy are reviewed, and the inseparability of the process of unification and the increase of virtuousness of total science is emphasised.

Section 15.4. Ernst Mach's program of unification of physics and the role of Mach's ideas in contemporary physics are reviewed. The series of reactions which originates from Mach is characterized: the logical positivists' over-propagation of Mach's economy into the verifiability criterion; rejection of the verifiability criterion that resulted into the rise of neo-scholastic metaphysics which is detached from the project of unifying science; the *Principle of Naturalistic Closure* as mean of reuniting philosophical metaphysics with the project of unifying science.

Section 15.5. Economical unification is applied as a point of departure to some focal issues in philosophy of science: *progress of science, underdetermination*, *approximate truth*, and *falsifiability*.

Section 15.6. A summary is given.

15.2 The Structure of Theories

Theory is a fusion of *ontology* and everything that is founded on ontology, including concepts defined in terms of ontology and semantics mapped to ontology (Fig. 15.2). The ontology of a theory consists of *ontological commitments*. All commitments to existence of objects and relations or interactions between them are ontological commitments of the theory.[1] The ontology of a theory is a fusion of *verified* and

[1] Cf. Willard Van Orman Quine, "Ontology and ideology", in: *Philosophical Studies* 2, 1, 1951, pp. 11–5.

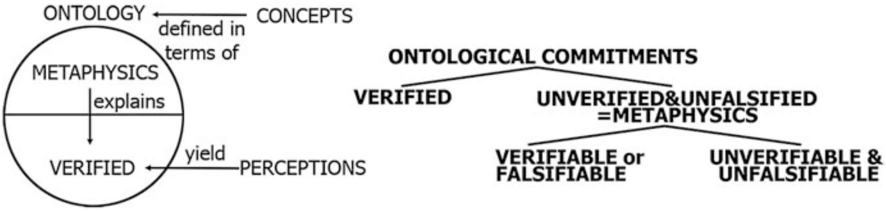

Fig. 15.2 Structure of theories and classification of ontological commitments

unverified commitments. Perception yields verified commitments (or beliefs) in the existence of objects such as the Moon, the Sun and the Earth. These are verified commitments of theories of the Solar System. E.g. the concept *one year* may be defined in terms of ontology of a theory of the Solar System, as the period during which the Earth orbits once around the Sun.

Beliefs yielded by perception are not involved with *interpretation* in any significant sense, whereas *metaphysical* commitments especially *are* interpretations, explanations and generalisations induced from the verified commitments and answers to questions that result from them. Abbreviating 'verified commitments' as 'perceptions' allows saying that metaphysics explains perceptions and saves the phenomena.

The unverifiable & unfalsifiable metaphysical commitments are not verifiable nor falsifiable by perception even in principle. Such commitments function as eventual explanations and starting points in building theories. The verifiable-or-falsifiable metaphysical commitments are currently unverified and unfalsified, but are either verifiable or falsifiable. For instance, before atoms and the planet Neptune were verified to exist, the commitments to their existence were metaphysical. Once Neptune and atoms were verified to exist, the commitments to their existence ceased to be metaphysical.[2]

15.3 The Principle of Economy as an Evaluation Criterion

The principle of economy evaluates (i) evidentiality and (ii) metaphysical weight of competing theories in predicting and explaining the same phenomena, perceptions

[2]For comparison, Michael Heidelberger (lecture on 17.6.2016, *Ernst Mach Centenary Conference*, Vienna) maintained that according to Gustav Fechner (Über die Physikalische und Philosophische Atomenlehre, Leipzig: Hermann Mendelssohn 1855), physics involves four kinds of metaphysics. (1) Inference to the *best explanation of phenomena*: theoretical entities explaining the phenomena are not given in experience (yet they are of an experiential form). (2) Inference to *possible appearances*: they are not given in actual experience. (3) *Inductive metaphysics*: philosophical 'completion' of physical theories. (4) *Speculative metaphysics*: to assume theoretical entities of no experiential form. (1) and (3) seem to overlap.

or empirical data D. Economy favors the most evidential theory, i.e., the theory with the most accurate predictions and the deepest explanations.[3] Of two theories that are equally evidential with respect to D, economy favors the metaphysically simplest.[4] Condition (i) guarantees that economy does not favor over-simplification, whereas condition (ii) guarantees that economy does not favor unnecessary complexity. Formulations of economy are reviewed in a chronological order.

Aristotle sought for the simplest set of core postulates:

> When the objects of an inquiry, in any department, have principles, conditions, or elements, it is through acquaintance with these that knowledge, that is to say scientific knowledge, is attained. For we do not think that we know a thing until we are acquainted with its primary conditions or first principles, and have carried our analysis as far as its simplest elements.
> *Physics,* bk. 1, ch. 1

Thomas Aquinas and William of Ockham advice us to avoid violations of economy:

> If a thing can be done adequately by means of one, it is superfluous to do it by means of several.[5]
> For nothing ought to be posited without a reason given ...[6]

Isaac Newton states that violations of economy are to be avoided, and that a theory ought not be replaced until a more economical theory is available:

> We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances. ... In experimental philosophy we are to look upon propositions inferred by general induction from phenomena as accurately or very nearly true, notwithstanding any contrary hypotheses that may be imagined, till such time as other phenomena occur by which they may either be made more accurate or liable to exceptions.[7]

J.B.S Haldane:

> In scientific thought we adopt the simplest theory which will explain all the facts under consideration and enable us to predict new facts of the same kind.[8]

[3]Causal depth of an explanation denotes accuracy or the level of detail in which it characterizes phenomena, and the degree of variability in the phenomena it can manage. Cf. Michael Keas, "*Systematizing the theoretical virtues*", in: *Synthese*, 195, 6, 2018, pp. 2761–2793.

[4]Metaphysical weight of a theory is determined by the number of different types of metaphysical entities and quantities of each type. Both need to be counted, for one can compensate the other. Cf. Daniel Nolan, "*Quantitative parsimony*", in: *British Journal for the Philosophy of Science* 48, 3, 1997.

[5]Thomas Aquinas, *Basic Writings of St. Thomas Aquinas*, vol. 2. Anton C. Pegis (Ed.). New York: Random House 1945, p. 129.

[6]Girard Etzkom and Francis Kelly (Eds.), *Opera Theologica*, vol. 4. New York: St. Bonaventure University 1979, p. 290.

[7]Isaac Newton, *Mathematical Principles of Natural Philosophy*. 3rd ed. Translated into English by Andrew Motte. New York: Daniel Adee 1846, bk. 3, Rules I and III.

[8]J.B.S Haldane, *Science and Theology as Art-Forms*, 1927. As quoted in p. 105, James W. McAllister, *Beauty & Revolution in Science*. Ithaca and London: Cornell University Press 1996.

Einstein:

> It can scarcely be denied that the supreme goal of all theory is to make the irreducible basic elements as simple and as few as possible without having to surrender the adequate representation of a single datum of experience.[9]

In Eino Kaila's[10] formula for *relative simplicity* of theory *T,*

$$\mathrm{RS}\,(\mathrm{T},\mathrm{e}) = \frac{\mathrm{syst}\,(\mathrm{T},\mathrm{e})}{\mathrm{K}\,(\mathrm{T})}$$

syst(T,e) is the number of empirical propositions that are derivable from T based on empirical evidence e, and K(T) is the number of logically independent assumptions of T[11]: "a theory has high relative simplicity, if it explains a multitude of empirical data by means of a few independent assumptions."[12] When *independent assumptions* are translated as *metaphysical commitments*, relative simplicity is very close to economy: given two theories which explain the same phenomena, the metaphysically simpler has greater relative simplicity.

Mario Bunge:

> conceptual entities should not be multiplied *in vain* ... but they should be welcomed whenever they lead either to a deeper understanding of reality or to a syntactical simplification of theories.[13]

Michael Friedman's[14] formulation of unifying power is very similar to Kaila's relative simplicity:

> Friedman's motivational argument suggests a way of working out the notion of unification: characterize E(K) as the set of arguments that achieves the best tradeoff between minimizing the number of premises used and maximising the number of conclusions obtained.[15]

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[9]Albert Einstein, "On the method of theoretical physics", p. 165, in: *Philosophy of Science*, 1, 2, 1934, pp. 163–169. Originally delivered as The Herbert Spencer Lecture at Oxford, 10 June 1933.

[10]Eino Kaila, *Human Knowledge: A Classic Statement of Logical Empiricism*. Translated from the Finnish 1939 version by Anssi Korhonen. Juha Manninen, Ilkka Niiniluoto and George A. Reisch (Eds.). Chicago: Open Court 2014, pp. 77–83.

[11]This formulation in Ilkka Niiniluoto, "Descriptive and Inductive Simplicity", pp. 158–9, in W. Salmon and G. Wolters (Eds.), *Logic, Language, and the Structure of Theories*, *Proceedings of the Carnap-Reichenbach Centennial, University of Konstanz*, 21.-24. May 1991. Pittsburgh: University of Pittsburgh Press/Universitätsverlag Konstanz, 1994, pp. 147–70.

[12]Ilkka Niiniluoto, "Evaluation of Theories", p. 190, in: Theo Kuipers (Ed.) *Handbook of the Philosophy of Science: General Philosophy of Science – Focal Issues*. Amsterdam: Elsevier 2007, pp. 175–217.

[13]Mario Bunge, *The Myth of Simplicity*. Englewood Cliffs: Prentice-Hall 1963, p. 75.

[14]Michael Friedman, "Explanation and scientific understanding", p. 11, in: *Journal of Philosophy*, 71, 1, 1974, pp. 5–19.

[15]Philip Kitcher, *Explanatory Unification and the Causal Structure of the World*, p. 431, in: Philip Kitcher and Wesley Salmon (Eds.) *Scientific Explanation*. Minneapolis: University of Minnesota Press 1989, pp. 410–505.

There is a small step from economy as a criterion that evaluates evidentiality and metaphysical simplicity, into a criterion that evaluates virtuousness in general. For, most of the typically mentioned virtues are versions of economy, components of economy (evidentiality and metaphysical weight), implicit in a component of economy, or at least partially derivative from a theory's degree of economy. It is illustrated how the virtues in the following list can be organized around economy: *unifying power, empirical sufficiency, comprehensiveness, metaphysical simplicity, lack of ad hoc features, coherence*, *consilience* and *understandability*.[16]

Consider first the relation of economy and unifying power. A theory with a great unifying power explains much in terms of a small set of postulates. Such theory is also highly economical, for it explains a great deal of data D in terms of a small sum of metaphysics M. Moreover, economy of theory T with respect to data D can be expressed as the fraction of E_D/M_D of its evidentiality E_D and the sum of metaphysics M_D that T applies in explaining D. It appears that there is not much difference in relative simplicity, unifying power and economy. However, economy and unifying power are not the same concept, for economy is open-ended about the data D to be explained: when measuring unifying power of theory T, D denotes all data that T explains in terms of all its postulates; when measuring economy of T, D may in principle denote anything from a single phenomenon to all data that T explains, i.e., T's degree of economy is determined based on its evidentiality with respect to the *selected* data D, and the metaphysics it applies in its predictions and explanations of the selected data D. However, when we evaluate theories with respect to all data they explain, economy and unifying power are interchangeable.

Second, empirical sufficiency and comprehensiveness are implicit in evidentiality, which is a component of economy. Also consilience can be seen implicit in evidentiality, for independent points of view, new hypotheses and observations conform to a consilient theory.[17] Whenever such successful development takes place, evidentiality of T increases, and when its evidentiality increases while its metaphysical weight stays constant, its degree of economy increases. Further, the central components of high coherence are consistency and strong inferential-explanatory relations.[18] Consistency (being non-contradictory) is implicit in evidentiality, for an inconsistent prediction or explanation is invalid; or at any rate, a consistent theory is more evidential than an otherwise equal inconsistent theory.

Third, metaphysical simplicity and the lack of ad hoc features are implicit in the criterion for metaphysical weight, which is a component of economy. Of two otherwise equal theories, economy favors the metaphysically simpler. Metaphysical simplicity and the lack of ad hoc features walk hand in hand. For, a unified theory

[16]These virtues are listed in the following works. Stathis Psillos, *Scientific Realism: How Science Tracks Truth*. London and New York: Routledge 1999, p. 171. Anjan Chakravartty, op. cit. Daniel Nolan, "The A Posteriori Armchair", p. 224, in: *Australasian Journal of Philosophy*, 93, 2, 2015, pp. 211–31.

[17]William Whewell, *Novum Organon Renovatum*. London: John W. Parker 1858, pp. 83–96.

[18]Adolfas Mackonis, "Inference to the best explanation, coherence and other explanatory virtues", in: *Synthese*, 190, 6, 2013, pp. 975–995.

incorporates a small sum of metaphysics that suffices in explaining a great deal of data or different scales of phenomena, whereas a disunified theory requires metaphysical ad hoc parameters for different scales of phenomena, which increase its metaphysical weight M and proportionally decrease its economy E/M. Thereby, a theory with lots of parameters is uneconomical with respect to an otherwise equal theory with less parameters. Further, strong inferential-explanatory relations walk hand in hand with great economy. Mackonis[19] opens up the inferential-explanatory relations: "an explanatory hypothesis would cohere with background knowledge if it explains the background knowledge or if the background knowledge explains the explanatory hypothesis." When 'explanatory hypothesis' is considered as theory T, and 'background knowledge' as a collection of theories C against which the coherence of T is evaluated, the inferential-explanatory relations appear as reductive relations, which increase economy of T or C: if T reduces/explains the theories in C, the metaphysical weight of T does not increase, but its evidentiality increases by the evidentiality of C; if C reduces/explains T, the metaphysical weight of C does not increase, but its evidentiality increases by the evidentiality of T. Economy of total science increases in both cases.

Fourth, understandability of a theory is at least partially derivative from its economy. Consistency is implicit in evidentiality, and evidentiality is a component of economy; consistency is a prerequisite for understandability, whereas an inconsistent theory cannot be genuinely understood. Understandability and comprehensiveness are interrelated: a comprehensive theory does not leave central aspects of nature unexplained, and as these are explained these are also understood. It is easier to understand a minimal sum of interrelated commitments that explain all scales than to understand several isolated theories individually, and which in any case fail to catch the unified picture of reality: "A unified picture of nature provides more and deeper understanding than does a view of nature that represents it as a disunified aggregate of isolated and disconnected facts."[20]

15.4 From Mach to the Present

Ernst Mach is best seen as a unifier of science, whose work was in line with general positivism or empiricism, which was in turn natural continuation of the eighteenth century *Age of Enlightenment* where the common world-view was no longer given by the church but by science, and where unnecessary mysticism was to be banished from science. He coined in the term *the principle of economy of thought* and emphasised its importance in several works. For Mach the task of science is to give an optimally economically unified description of nature:

[19] Adolfas Mackonis, op. cit., p. 983.

[20] Jeffrey Poland, *Physicalism: The Philosophical Foundations*. Oxford: Clarendon Press 1994, p. 29.

> The goal which it has set itself is the simplest and most economical abstract expression of facts.[21]
>
> . . . any stock of knowledge worthy of the name is unattainable except by the greatest mental economy. Science itself, therefore, may be regarded as a minimal problem, consisting of the completest possible presentment.[22]
>
> . . . every *metaphysical* and every one-sided *mechanical* view of physics were kept away, and an arrangement, according to the principle of economy of thought, of facts—of what is ascertained by the senses—was recommended.[23]

Seeing Mach as a unifier of science helps to understand that by *keeping metaphysics away*, Mach rejects only that metaphysics which is not needed in unifying science and which is thus unnecessary and uneconomical.[24] Although Mach famously stated “where neither confirmation nor refutation is possible, science is not concerned”,[25] he obviously did not reject those irrefutable metaphysical principles that he himself proposed as the center of unified science. Mach may have considered his suggestions verifiable, as these can be used as basic postulates in theories which give verifiable predictions.

Mach[26] explicitly stated that he is not a solipsist, i.e., he was an ontological realist. However, Mach concentrated heavily on psychology and on the perceiver’s sensations, and he can be easily misinterpreted as an extreme idealist when looking at passages such as: “Nature is composed of sensations as its elements.”[27]

Mach aimed at a non-mechanistic or holistic description of nature, where phenomena and the conveying of causal influences are not explained in terms of movement of particles, and where “investigation of the dependence of phenomena on one another was ... the aim of natural science.” CITE Ernst Mach, History and Root of the Principle of the Conservation of Energy, op. cit, p. 9. The search for a non-mechanistic explanation is a natural reason behind his rejection of the atomic hypothesis.[28]

Mach suggested a shift away from Newtonian absolute space and time that are independent of objects *in* space and where objects are thought to move with respect

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[21] Ernst Mach, *The Economical Nature of Physical Inquiry*. In *Popular Scientific Lectures*, 5th ed., pp. 186–213. Translated by T.J. McCormack. La Salle: Open Court 1943, p. 207.

[22] Ernst Mach, *The Science of Mechanics: a Critical and Historical Account of its Development*. 4th ed. Translated by T.J. McCormack. Chicago and London: The Open Court Publishing Co. 1919, p. 491.

[23] Ernst Mach, *History and Root of the Principle of the Conservation of Energy*. 2nd ed.Translated by Philip Jourdain. Chicago: The Open Court Publishing Co. 1911, p. 9.

[24] I thank Karl and Hayo Siemsen for guiding me into this interpretation.

[25] Ernst Mach, *The Science of Mechanics*. *op. cit*, p. 490.

[26] Ernst Mach, “The Guiding Principles of My Scientific Theory of Knowledge and Its Reception by My Contemporaries”, p. 39, in: Stephen Toulmin (Ed.), *Physical Reality*. New York: Harper Torchbooks 1970, pp. 28–43. Ernst Mach, *The Analysis of Sensations and the Relation of the Physical to the Psychical*. Translated by C. M. Williams. La Salle: Open Court 1984, pp. 361–2.

[27] Ernst Mach, *The Science of Mechanics*. *op. cit.,* p. 482.

[28] Ernst Mach, *History and Root of the Principle of the Conservation of Energy*, *op. cit,* p. 9. S.G. Brush, “Mach and Atomism”, in: Synthese, 18, 2, 1968, pp. 192–215. John Blackmore, “An Historical Note on Ernst Mach”, in: *British Journal for the Philosophy of Science*, 36, 3, 1985, pp. 299–305.

to the absolute space.[29] Mach sided with the Leibnizean[30] definition where the change of time is defined as the change of objects in space. The rejection of absolute space is congenial with Mach's view of the Universe as a total gravitational system, where the principle "that links inertia of mass to the total mass in space"[31] has become to be called *Mach's Principle*. The basic idea is that the movement of a mass object is relative to and affected by the rest of the mass in space, i.e., there is no 'absolutely free movement' that is not affected by the rest of the Universe. Mach's accreditation of the conservation law of energy[32] is congenial with Mach's Principle and the rejection of absolute space, as the conservation of energy makes sense in a Universe as a total gravitational system whose all parts interact.

Contemporary standard physics is very far from Mach's suggestions about scientific metaphysics and also from his ideal of economical unification. To start with, it is well know that Relativistic physics and quantum mechanics build on different postulates, i.e., they remain disunified. And directly against Mach's ideas about a non-mechanistic description of nature, standard physics is mechanistic, i.e., influences are thought to be conveyed by force-carrying particles.

Most of Mach's central suggestions contradict Relativistic physics.[33] First, absolute simultaneity and instantaneous causal interactions are implicit in Mach's holistic conception of the Universe, whereas Relativistic physics especially violates absolute simultaneity and the velocity of light is the speed limit for causal interactions. Second, conservation laws are the primary laws e.g. in particle physics and concerning planetary systems, but the conservation law makes no sense in the Relativity-based standard model of cosmology which has been parametrised e.g. by *dark energy*. Third, Mach's Principle is practically rejected in the General Theory of Relativity.[34]

In contrast to standard physics, Mach's suggestions are in the center of Tuomo Suntola's *Dynamic Universe*[35] model, which postulates the conservation law of energy in spherically closed space, commits to absolute simultaneity and non-mechanistic causal influences, shifts from force into energy as the basic quantity,

[29]Ernst Mach, *The Science of Mechanics*. *op. cit.,* e.g. pp. 229, 542–3.

[30]See Leibniz's Letters to Clarke III.4. and IV.41.

[31]Tuomo Suntola, *The Short History of Science — or the long path to the union of metaphysics and science*. Espoo: Physics Foundations Society 2012, p. 267.

[32]Ernst Mach, *History and Root of the Principle of the Conservation of Energy, op. cit.*

[33]Mach had doubts about the Theory of Relativity: "Will it prove to be more than a transitory inspiration in the history of science?" Ernst Mach, *The Principles of Physical Optics: an Historical and Philosophical Treatment.* Mineola, New York: Dover Publications, 2013, p.viii. Originally published: London: Methuen & co., 1926.

[34]References that GR does not implement Mach's Principle. D. W. Sciama, "On the origin of inertia", in *Monthly Notices of the Royal Astronomical Society*, 113, 1953, pp. 34–42. M. Reinhardt, "Mach's principle — A critical review", in *Zeitschritte fur Naturforschung A*, 28, 1973, pp. 529–537. D. J. Raine, "Mach's principle and space-time structure", in *Reports on Progress in Physics*, 44, 1981, pp. 1151–1195.

[35]Tuomo Suntola, *The Dynamic Universe: Toward a Unified Picture of Physical Reality*, 4th ed. Espoo: Physics Foundations Society; Helsinki: The Finnish Society for Natural Philosophy. 2018

and produces a quantitative expression of Mach's Principle as the work that local motion in space does against the gravitation due to space as a whole.

Mach was the biggest influence behind the anti-metaphysics of the Vienna Circle in the 1920s and 1930s.[36] Their *verifiability criterion*, where only verifiable theories are scientific, renders all unverifiable metaphysics unscientific. The verifiability criterion can be seen as an over-propagation and mis-interpretation of Mach who did not aim to eliminate metaphysics completely. The high point of the positivist movement was perhaps in the 1950s,[37] after which the verifiability criterion was rejected.

When philosophers started to openly contemplate about metaphysics again in the 60s and 70s, economy had very little importance, which can be seen as an overpropagated counter reaction to the logical positivists' anti-metaphysics. Although economy was dropped, the logical positivists' emphasis on language and logic was sustained: analytical metaphysics as an economy-free investigation of cosmetic issues was born.

Ross et al.[38] characterize the transition from positivism into *neo-scholastic* metaphysics, which has very little to do with unification of science, which of course should be the primary task of metaphysics. They (*ibid*, p. 30) present the *Principle of Naturalistic Closure* (PNC) as a guideline of reuniting philosophical metaphysics with empirical science:

> Any new metaphysical claim that is to be taken seriously should be motivated by, and only by, the service it would perform, if true, in showing how two or more specific scientific hypotheses jointly explain more than the sum of what is explained by the two hypotheses taken separately, where a 'scientific hypothesis' is understood as an hypothesis that is taken seriously by institutionally bona fide current science.

Economy is implicit as PNC accepts only those new hypotheses which explain more than previous hypotheses separately, and which thus yield relatively simpler theories. As PNC accepts only hypotheses taken seriously by institutional science, PNC functions solely *within* the current paradigms. This would naturally prevent all theory shifts.[39] This exaggeration can be removed by transforming 'institutionally bona fide current science' into 'institutional science or science that is more economical than institutional science'.

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[36] Cf. Thomas Uebel, "Vienna circle", in: Edward N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy*. Stanford: Stanford University 2015.

[37] Atocha Aliseda and Donald Gilles, "Logical, Historical, and Computational Approaches", p. 436, in: Theo Kuipers (Ed.) *General Philosophy of Science: Focal Issues*. Amsterdam, Oxford: Elsevier 2007, pp. 431–514.

[38] Don Ross, James Ladyman and David Spurrett, "Defence of Scientism", pp. 9–10, in: James Ladyman, Don Ross, David Spurrett and John Collier (Eds.), *Every Thing Must Go: Metaphysics Naturalized*. New York: Oxford University Press 2007, pp. 1–65.

[39] Cf. Andrew Melnyk, "Can Metaphysics Be Naturalized? And If So, How?", p. 94, in: Don Ross, James Ladyman and Harold Kincaid (Eds.), *Scientific Metaphysics*. Oxford: Oxford University Press 2013, pp. 79–95.

15.5 Focal Issues Organized Around Economical Unification

The process of economical unification and the principle of economy function together as a unifying point of departure to some of the focal issues in philosophy of science: *progress of science, underdetermination*, *approximate truth*, and *falsifiability* or *demarcation* in general.

Consider first how economical unification brings together ways in which science leaps forward. Start with Kuhnian[40] paradigm shifts, where the metaphysical weight of theory T increases along with the increase of empirical data, as T incorporates new ad hoc parameters in explaining new data. Such development is undesirable, and eventually T is replaced by a new theory T' which explains by its basic structure all phenomena that T explains with the aid of its parameters. As T' comes without the parameters of T, T' is more economical than T. Also Nagelian[41] reductions where a secondary science is derived from a primary science are steps toward more unified science. For, when secondary science is reduced to primary science, the primary science incorporates evidentiality of the secondary science, while the metaphysical weight of total science decreases, as the extra commitments of the secondary science can be dropped. Also partial unifications increase economy of total science: a common postulate is discovered for previously isolated theories, but the theories have non-overlapping postulates even after this.[42]

Second, the choice between equally evidential theories is *evidentially underdetermined*. Their metaphysical simplicities may be evaluated in such cases, i.e., economy overcomes the challenge of underdetermination. Were the choice between two theories underdetermined also with respect to metaphysical simplicity and all related virtues, we would be dealing with a problem of a more advanced age.

Third, economy incorporates Popper's[43] demarcation criterion, where a scientific theory must be *falsifiable* by empirical data. Against Popper's criterion, when the predictions of theory T do not match new data, T can be saved from falsification by introducing new metaphysical parameters. In such process, T's evidentiality increases as it explains new data, but the increase of its evidentiality is counterbalanced by the increase of its metaphysics. Therefore, economy or relative simplicity of T stays approximately constant. In contrast, a consilient theory explains new data by its basic structure, and in effect its relative simplicity increases. This example reminds that unless metaphysical weight counts in theory evaluation, scientific metaphysics can practically flow free. Further, economy functions as an advanced

[40] Thomas Kuhn, *The Structure of Scientific Revolutions*. 2nd ed. Chicago: University of Chicago Press 1970.

[41] Ernst Nagel, *The Structure of Science. Problems in the Logic of Explanation*. New York: Harcourt, Brace & World Inc. 1961.

[42] Psillos considers the atomic hypothesis as such postulate, for it functions as a bridge between "the kinetic theory of gases and the molecular theory of the chemical elements, and gains support from both." Stathis Psillos, op. cit., p. 173.

[43] Karl Popper, *The Logic of Scientific Discovery*. London: Hutchinson & Co. 1959.

demarcation criterion. It is not asked whether a theory is scientific or not, but it is asked which of two theories is more economical: the more economical, the more scientific.

Fourth, Kuhnian paradigm shifts raise the challenge of *pessimistic induction*: if "theories at any given time will ultimately be replaced and regarded as false from some future perspective" then "current theories are also false."[44] As pessimistic induction renders theories false, it raises the challenge of defining the concept *approximately true* or *truthlike*. The two broad strategies of defining approximate truth are the formal and informal strategy. The formal strategy can be characterized in terms of the *similarity approach* where "the truthlikeness of the statement *h* depends on the similarities between the states of affairs allowed by *h* and the true state of the world."[45] The basic idea is that the more accurate predictions, the closer to truth is the theory. The similarity approach thus leaves metaphysical commitments of theories totally intact, and faces the challenges of underdetermination and falsifiability. As the informal strategy to truthlikeness is the evaluation of simplicity and other virtues, it is seen that economy fuses together the formal and informal strategies.

15.6 Conclusions

The preference for unified explanations and the related preference for metaphysical simplicity have been implicit in scientific and philosophical thought since antiquity. These ideas were conveyed to the twentieth century philosophy of science through Ernst Mach. However, although some contemporary philosophers of science take economical unification seriously, it has not been placed in the *center* of philosophy of science where it could function as the unifying nexus. In overall, development of detailed topics is more characteristic to the twentieth and twenty-first century philosophy of science, than the goal toward unified solutions.

We can find reasons for the present state from the historical oscillation of economy in philosophical thought. The logical positivists mis-interpreted Mach's economy and over-propagated it into the verifiability criterion. The verifiability criterion was rejected, but the ghost of verifiability may still prevent many philosophers from seeing economy in the correct light. On the other hand, after its oscillation, the settling of economy into an equilibrium takes time. We can search for a reason also from contemporary physics. Standard physics is disunified and highly parametrised, and the vast majority of physicists concentrate on developing mathematical descriptions of perceptions in the context of the postulates of standard physics, not on developing a system of unified physics. Perhaps many philosophers of science are satisfied with how the picture of disunified science matches contemporary science?

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[44] Anjan Chakravartty, "Scientific Realism", in: Edward N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy*. Stanford: Stanford University 2015.

[45] Ilkka Niiniluoto, *Truthlikeness*. Dordrecht: D. Reidel Publishing Company 1987, p.xii.

It is crucial here to distinguish between *how science is* and *how science should be*. Philosophers of science should not bury the goal toward unified science because science is currently disunified. Were unified science accepted as the overall goal, the process of economical unification could be openly placed in the center of philosophy of science. Such philosophy of science would certainly look more like Ernst Mach.

Chapter 16
Talking Past Each Other: Mach and Husserl on Thought Economy

Iulian D. Toader

Abstract This paper revisits the debate between Mach and Husserl on thought economy and argues that, to a considerable extent, they talked past each other, insofar as the latter rejected thought economy as a principle of theoretical rationality, whereas the former conceived of it as a principle of practical rationality. This is further supported by their correspondingly different readings of the so-called principle of the permanence of forms.

In a letter to Mach from June 18, 1901, right after the publication of a new edition of *The Science of Mechanics*, Husserl claimed that his analysis of pure logic in the *Logical Investigations* neither should, nor could be taken to invalidate or make obsolete Mach's methodological views on science, especially his doctrine of thought economy.[1] This claim contrasted rather sharply with Husserl's published remarks on this doctrine, as we will see, and it raises a question about his actual understanding of Mach's views. The doctrine of thought economy had been introduced in the 1882 paper "On the economical nature of physical inquiry" and then expanded upon in "The economy of science" – chapter IV, section 4 of *The Science of Mechanics*, published in 1883. Husserl reacted to it in 1900, in his "Logic and the principle of the economy of thought" – chapter 9 in the *Prolegomena to Pure Logic*, the first volume of his *Logical Investigations*. Mach responded directly in Appendix XXVII of *The Science of Mechanics*, the 1901 edition, which triggered Husserl's letter, and then again indirectly in *Knowledge and Error*, published in 1905.

[1] See "Ein Brief Edmund Husserls an Ernst Mach", edited in 1965 by Joachim Thiele, *Zeitschrift fuer philosophische Forschung*, 19, 134–138.

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In this note, I revisit this debate and argue that, to a considerable extent, Mach and Husserl talked past each other, insofar as the latter rejected thought economy as a principle of *theoretical* rationality, whereas the former conceived of it as a principle of *practical* rationality. My argument is further supported, as I will show, by their correspondingly different readings of the so-called principle of the permanence of forms, explicitly formulated by the Cambridge algebraist George Peacock in the first half of the nineteenth Century, and later propagated by the German mathematician Hermann Hankel.

According to Mach's methodological views on science, let us briefly recall, thought economy is, on the one hand, an ideal of science, and on the other hand, an adequate description of (at least part of) science. This was emphasized by Mach, himself, in the 1882 paper: "The goal which [science] has set itself is the simplest and most economical conceptual expression of facts. [. . .] The greatest perfection of mental economy is attained in that science which has reached the highest formal development, and which is widely employed in physical inquiry, namely, in mathematics." He further specifically indicated abstraction, idealization, and symbolization as thought economical methods in mathematics: "The use of the signs of algebra and analysis, which are merely symbols of operations to be performed, stems from the observation that one can disburden the mind and spare it for more important and more difficult functions by transferring a part of the mechanically repetitive operations to the hand." But in fact, Mach referred to anything that goes beyond the flux of unrepeatable experiences as thought economical. Most famously, perhaps, in chapter IV of the 1883 book, he noted with respect to mathematical methods: "Even a total disburdening of the mind can be effected in mathematical operations, for operations of counting hitherto performed are symbolised by mechanical operation with signs, and our brain energy, instead of being wasted on the repetition of old operations, is spared for more important tasks.[2]

In his discussion of Mach's doctrine of thought economy, in the *Logical Investigations*, Husserl agreed that this provides an adequate description of some scientific methods, e.g., symbolization in mathematics: "Mathematical disciplines [. . .] overcome the defects of our mental constitution, and permit an indirect achievement by way of symbolic processes from which the intuitive element, as well as all true understanding and inner evidence are absent. [They] have the character of devices which economize thought. They arise [. . .] out of certain natural processes of thought-economy. [. . .] Such methods can be used without insight, so to say mechanically." However, Husserl strongly emphasized that this does not mean that these methods *should* be used in this manner. One reason for this was that, according to him, thought economy does not provide an adequate epistemic ideal for science, since no such ideal could admit of a merely psychological

[2]For a recent discussion of Mach's doctrine of thought economy, see Eric Banks' book *Ernst Mach's World Elements: A Study in Natural Philosophy*, esp. chapter 8, and his article "The Philosophical Roots of Ernst Mach's Economy of Thought", *Synthese*, 139, 23–53.

grounding. More generally, one cannot derive an adequate epistemic ideal for science from a description of scientific practice, as Mach had allegedly done with thought economy. Another reason was that Husserl saw thought economy as an obstacle to verificationism – the epistemic theory of truth developed in the *Logical Investigations*.[3]

As an adequate epistemic ideal for science, Husserl proposed the ideal of maximum rationality – the supreme goal of all rational sciences: "If all matters of fact obey laws, there must be some minimum set of laws, of the highest generality and maximum deductive independence, from which all other laws can, by mere deduction, be derived. These 'basic laws' are, accordingly, laws of supreme coverage and efficacy, whose knowledge yields the absolute maximum of insight in some field, which permits the explanation of all that is in any way explicable in that field." It is the verificationist element constitutive of this ideal, i.e., the claim that a maximally rational science requires maximum insight, that Husserl believed collided with thought economy. This is because he took thought economy to require minimization of insight and, thus, to go against verificationism. However, as an argument against Mach, this is puzzling, because as we will see below Mach also endorsed verificationism.

Lest one considered that one could found the ideal of maximum rationality on thought economy, Husserl further argued that this would be rather absurd: "The thought-economist turns the *ideal* tendency of logical thinking towards rationality into a *real* tendency of actual thinking. ... [But] our actual thinking does not in fact conform to its ideals – as if ideals were some sort of natural forces." And he continued: "The ideal validity of this norm [of maximum rationality] is *presupposed* by all meaningful *talk* of an economy of thinking; it is not therefore a possible explanatory outcome of a theory of such economy. We *measure* our empirical by our ideal thinking, and we then say that the former to some extent runs as if guided by insight into these ideal principles." On Husserl's view, one must distinguish between "blind," thought-economical reasoning in science and the logical thinking of pure logic, the latter being the quintessential expression of the ideal of maximum rationality and fundamentally prior to all thought economy.

In his response, Mach first noted that Husserl's "animadversions on my theory of mental economy ... are in part answered in my reply to Petzoldt" in the 1896 *Principles of the Theory of Heat*. Petzoldt's earlier criticism, as quoted by Mach, had attempted to reduce the importance of thought economy for understanding science, while relegating it to other principles: "Not maxima, minima and [thought] economy, but uniqueness and stability are brought into relief by those aspects of reality which must stand in the foreground of our interest." To this Mach replied that "Economy cannot be predicated of physical processes, since there is no choice

[3]For the historical context of Husserl's verificationism, see Kevin Mulligan's article "Brentano's Knowledge, Austrian Verificationisms, and Epistemic Accounts of Truth and Value", *The Monist*, 100, 88–105. See also my *Objectivity Sans Intelligibility: Hermann Weyl's Symbolic Constructivism*, PhD diss., University of Notre Dame, esp. chapter 2.

between the actual happening and another. For this very reason I have not used the notion of economy in any way in this domain." Basically, he says that, in relation to science, he spoke of mental, not physical, economy. So he thought that Petzoldt was somewhat confused.

Mach might not have thought that Husserl, too, was confused, but he did think that Husserl was rather audacious, and noted with frenzy in the 1901 Appendix: "I am perfectly able to distinguish between psychological and logical questions." Most certainly, he did not appreciate Husserl's "temerity" to say that he couldn't make the distinction between "blind," thought-economical reasoning and logical thinking. For what is worth, Mach insisted that even a maximally rational science should deploy thought economical methods: "Even if the logical analysis of all the sciences were complete, the biologico-psychological investigation of their development would continue to remain a necessity for me... Thought economy is [...] a very clear logical ideal which retains its value even after logical analysis has been completed." The claim here is that the ideal of thought economy does not go against the ideal of maximum rationality. In particular, even if verificationism were satisfied, thought economy would still be a requirement: "The systematic form of a science can be deduced from the same principles in many different manners, but some one of these deductions will answer to the principle of economy better than the rest. [...] What appears to Husserl as a degradation of scientific thought, the association of it with vulgar or 'blind' (?) thinking, seemed to me to be precisely an exaltation of it." Mach's suggestion here is that even if a minimal set of most general laws in a given domain provided maximum insight in that domain, this may be obtained on various deductive routes, some more economical than others.

Furthermore, in his 1905 book, Mach strongly endorsed the verificationist doctrine that genuine scientific knowledge and understanding requires the possibility to verify that there is something real and intuitive corresponding to symbols and concepts: "Thought does not proceed in empty forms, but according to a vividly presented content, either directly or through concepts. [...] Empty logical formulae cannot replace a knowledge of the facts. Nevertheless, a look at algebra and mathematical symbolism in general shows that attention to thought as such and the symbolic representation of the abstract forms of intellectual operations are by no means devoid of all merit. Anyone who could not carry out these operations without such help would however gain no profit from these methods." This indicates that thought economical methods are practically, although not theoretically, necessary. Scientists should be capable of dispensing with them, however advantageous they may be otherwise. So Mach warned against the unverifiable use of symbolic reasoning: "Symbolic representation has likewise the disadvantage that the object represented is very easily lost sight of, and that operations are continued with the symbols to which frequently no object whatever corresponds. [...] Are we not subject here to an illusion, in that we operate with symbols to which perhaps nothing real corresponds, or at least nothing intuitive, by means of which we can verify and rectify our concepts?" If one were unaware of this illusion, Mach implied, one might wrongly think that atomistic physics is science, rather than metaphysics.

Mach had expressed similar verificationist ideas already in the 1882 paper: "One must say that there is no scientific result that in principle could not have been found without any [thought economical] methods." In other words, thought economical methods are profitable only if they are in principle dispensable. Also, with regard to the scientific character of atomistic physics, Mach had noted in his 1897 book, *The Analysis of Sensations*: "The [hypothetical atoms and molecules of physics and chemistry] remain economical ways of symbolizing experience. But we have as little right to expect from them, as from the symbols of algebra, more than we have put into them, and certainly not more enlightenment and revelation than from experience itself. We are on our guard now, even in the province of physics, against overestimating the value of our symbols."

All this textual evidence, then, indicates that Mach considered thought economy to be a principle of practical rationality, whereas Husserl understood thought economy, and rejected it, as a principle of theoretical rationality. This explains why he believed that thought economy could be in conflict with the ideal of maximum rationality. Furthermore, if this is true, and I think there is good reason to believe it is, then Mach and Husserl really talked past each other in this debate.

Interestingly, however, in his letter to Mach, which I mentioned at the outset, Husserl denied that he actually reacted to Mach's views, and claimed that his criticism was rather directed against the school of Avenarius and especially against Cornelius. Husserl added that he did not think that his analysis of pure logic should, or even could, invalidate or make obsolete Mach's views on science. Moreover, Husserl highly deferentially emphasized the extraordinary fruitfulness of these views for the methodology of science, and then added that Mach's name came up in his critical remarks merely because Cornelius had referred to him (though not always with justification) in his own discussion of thought economy. The letter remains silent, though, on why Husserl thought that his critical remarks should not, and could not, despite all appearances, be seen as extending to Mach's doctrine of thought economy. There is no hint that Husserl actually realized that, for Mach, thought economy was a principle of practical, rather than theoretical, rationality. In any case, it's hard to imagine how such a letter could have eased Mach's unhappiness with the remarks in the *Logical Investigations*.

The view suggested here is, I believe, indirectly supported by Mach's and Husserl's correspondingly different readings of the principle of the permanence of forms (henceforth, PPF). As I show in the balance of this note, Husserl rejected the PPF as a principle of theoretical rationality, for the reason that it unjustifiably assumes an inference from consistency to truth, while on Mach's view, permanence, of which Hankel's permanence of forms is just a special case, is a thought-economical principle of practical rationality, just like consistency. Husserl first considered the PPF for a public *Disputatio* at the University of Halle, in 1887, with the occasion of his Habilitation, and then in his *Doppelvortrag* at the Mathematical Society of Goettingen, in 1901. For Mach's views on permanence, I will refer again to his 1905 book, *Knowledge and Error*, but also to Musil's 1908 doctoral dissertation.

Since there is no space here for a detailed discussion of the historical and conceptual significance of this principle, let us just note that Peacock formulated the PPF in his 1833 *Report on the recent progress and present state of certain branches of analysis* as follows: "Whatever form is algebraically equivalent to another when expressed in general symbols, must continue to be equivalent, whatever those symbols denote." In particular, it must continue to be equivalent when the symbols specifically denote numbers, as they do in arithmetical algebra. The converse states that "Whatever equivalent form is discoverable in arithmetical algebra considered as the science of suggestion, when the symbols are general in their form, though specific in their value, will continue to be an equivalent form when the symbols are general in their nature as well as in their form." Thus, for example, if m, n and a denote integers, then ma + na is equivalent to (m + n)a in arithmetical algebra. This is true in virtue of the previously given definitions of basic operations. As Peacock put it, an arithmetical equivalence like ma + na = (m + n)a has a "necessary" existence. The PPF demands that ma + na remains equivalent to (m + n)a in symbolic algebra as well, where m, n and a may denote anything whatsoever. An algebraic equivalence has, however, only a "conventional" existence. For it cannot be true in virtue of the definitions of basic operations, since no such definitions are previously given. The meaning of the basic operations is only determined by algebraic rules like ma + na = (m + n)a.

In advocating the PPF as "the real foundation of all the rules of symbolic algebra," one of Peacock's main concerns was the applicability of symbolic algebra. He pointed out that algebraic rules are sufficient for deducing equivalent forms, but argued that symbolic algebra would be a science of mere symbols if it amounted to a set of arbitrary rules having a conventional existence but admitting no applications. To ensure that this was not the case, Peacock adopted arithmetical algebra as "a science of suggestion," i.e., he required that all algebraic equivalences allow an arithmetical interpretation. Another concern was the generality of the PPF, which seems to further require that all equivalences in arithmetical algebra should be transferable to symbolic algebra. As Peacock was well aware of, however, some arithmetical equivalences are essentially connected to the specific value of some of their symbols, and so they are not transferable. Such are, for example, Euler's inexplicable functions. In this case, arithmetical equivalences are only hypothetically transferable in the sense that their transferable forms have only a "hypothetical" existence and degenerate into the actual forms of the inexplicable functions for some specific values of its symbols.

It is doubtful that Peacock considered this maneuver completely satisfactory. For he clearly recommended extreme caution when applying the PPF. But what is important for my discussion in this note is that he seems to have conceived of it as a principle of theoretical rationality, just like logical consistency. What I mean by this is that, as I understand Peacock's position, he seems to have thought that the PPF was indispensable to the development of symbolic algebra as a genuine science. He considered the PPF as the "proper guide" that "must guide us" in the development of symbolic algebra. Peacock implied that without taking the PPF as our guide, we might end up with a set of merely arbitrary symbolic rules with no application whatsoever. That, according to him, would hardly be deserving of the name of science.

A similar conception of the PPF was later defended by Hermann Hankel in his 1867 book, *Vorlesungen ueber die complexen Zahlen und ihre Functionen*. His proposal and development of a purely formal mathematics, completely disconnected from intuition and constrained only by the conditions of logical consistency and mutual independence of its rules, was to be similarly guarded against potential meaninglessness. This required stipulating that the formal rules for operations with objects of thought admit the actual rules for operations with objects of intuition (e.g., the rules of universal arithmetic) as subordinate. This provision was meant to ensure that the results in formal mathematics would have an interpretation and applicability. In Hankel's own words, the PPF was given the following formulation: "If two forms expressed in the general signs of universal arithmetic are equal to one another, they should remain equal even if the signs cease to denote simple quantities and the operations thereby take on a different content as well." This corresponds to the converse of Peacock's formulation of the principle. Just like Peacock, Hankel conceived of the PPF as an indispensable guide for the development of formal mathematics. He also warned against its incautious general application. For example, in developing the formal theory of complex numbers, he determined its rules via the PPF, but duly noted that not all rules that are valid for real numbers are transferable. $a^2 > 0$, for instance, loses its meaning for complex numbers.

Meanwhile, others unequivocally denied the validity of the PPF. For instance, Russell famously did so in his 1903 book, *The Principles of Mathematics*: "The principle of the Permanence of Form [. . .] must be regarded as simply a mistake: other operations than arithmetical addition may have some or all of its formal properties, but operations can easily be suggested which lack some or all of these properties." Russell denied that one can develop symbolic algebra only if guided by the PPF. He rejected both its indispensability and its generality, though as we have suggested above, both Peacock and Hankel had recommended caution with respect to the latter. Somewhat later than Russell, in 1910, Peano also expressed skepticism about the PPF in his *Foundations of Analysis*: "This principle of permanence reached its apogee with Schubert, who, in the *Encyclopaedie der mathematischen Wissenschaften*, affirmed that one must 'prove that for numbers in the broad sense, the same theorems hold as for numbers in the narrow sense.' Now, if all the propositions which are valid for the entities of one category are valid also for those of a second, then the two categories are identical. Hence – if this could be proved – the fractional numbers are integers! In the French edition of the *Encyclopaedie* these things are put to rights. There it says that one must be 'guided by a concern for keeping the formal laws as much as possible.' Thus, the principle of permanence acquires the value of a principle, not of logic, but of practice, and it is of the greatest importance in the selection of notation." While rejecting the PPF, whether with good reason or not, Peano clearly endorsed it as a principle of practical rationality. Indeed, he conceived of the PPF as a thought-economical principle, in Mach's sense: "The principle of permanence [is] a particular case of what Mach called the principle of economy of thought."

Coming back to the debate between Mach and Husserl, let us recall that one of the several theses that Husserl set out to defend in Halle, in 1887, was the following: "Hankel's 'Principle of the permanence of formal laws' in arithmetic is neither a 'metaphysical' nor a '*hodegetische*' [i.e., methodological] principle." We don't know whether he did actually speak about this, or in case he did, what his argument looked like. But we do know his critical remarks in the 1901 *Doppelvortrag* in Goettingen. There he said the following: "We rise, according to the principle of permanence, above the particular domain, pass over into the sphere of the formal, and there can freely operate with [signs like] $\sqrt{-1}$. Now the algorithm of the formal operation is indeed broader than the algorithm of the narrower operations. But if the formal arithmetic is internally consistent, then the broader operating can exhibit no contradiction with the narrower. Therefore, what I have formally deduced in such a way that it contains only signs of the narrower domain must also be true for the narrower domain." The view that Husserl ascribed here to mathematicians who adopt the PPF is that consistent extensions of arithmetic can prove arithmetical truths. But he denied that this inference from consistency to truth is justified. For he saw here yet another tension with verificationism, which was made evident by the fact that that formal proofs, i.e., proofs of formal arithmetic, are "symbolic," "blind," or "mechanical."

As we have seen above, Mach's own verificationism comprised the requirement that there be something real and intuitive corresponding to symbols and concepts. So it seems fair to say that Mach would have agreed with Husserl that the PPF, conceived of as a principle of theoretical rationality, is to be rejected. But Mach never thought of the PPF as a principle of theoretical rationality. Rather, he took it to be a principle of practical rationality. On his view, as expressed in the 1905 book, *Knowledge and Error*, permanence of forms, just like logical consistency, is not indispensable to the development of a scientific theory; both permanence and consistency are merely thought-economical principles: "In the service of life, thoughts adapt to each other and to facts, and if the thinking process has become sufficiently strong, disagreement between thoughts is in itself disturbing, so that one will try to solve the conflict if only to remove intellectual unease ... The mutual adaptation of thoughts is not exhausted in the removal of contradictions: whatever divides attention or burdens the memory by excessive variety, is felt as uncomfortable, even when there are no contradictions left. The mind feels relieved whenever the new and unknown is recognized as a combination of the known, or the seemingly different is revealed as the same, or the number of sufficient leading ideas is reduced and they are arranged according to the principles of permanence and sufficient differentiation." As particular cases of a general principle of permanence, Mach spoke about the permanence of ideas, of relations, as well as of the permanence of basic laws and equations. This was emphasized also by

Musil, in 1908, in his doctoral dissertation on Mach: "It is in [. . .] constant laws and equations [. . .] that thought seeks to grasp those ideas which can be held on to permanently whatever individual changes may occur."

To conclude, then, in light of what has been said in this brief note, one can maintain with confidence that Husserl was not only "audacious," but also rather confused about Mach's doctrine of thought economy. For whereas the latter defended thought economy as a principle of practical rationality, the former rejected it as a principle of theoretical rationality. This indicates that they really talked past each other in the debate on thought economy. This conclusion is further supported by Mach's and Husserl's correspondingly different interpretations of Hankel's permanence of forms. For to endorse the PPF as a principle of practical rationality, like Mach and Peano did, is to uphold certain goals like convenience of notation and thought economy. To deny its validity and indispensability for the development of a genuinely scientific theory, like Husserl and Russell did, is to reject the PPF as a principle of theoretical rationality.[4]

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Part III
On Mach's Impact and Influence

Chapter 17
Appraisal and Influence of Mach's Works in South America

Critical Remarks on the Cases of J. E. Blanco and Hans A. Lindemann in the First Half of Twentieth Century and the Contemporary Account of Gonzalo Munévar

Eduardo Bermúdez Barrera, David Dahmen, René J. Campis, and Ronald Villa

Abstract Perhaps the first approach in South America to the work of Mach of which we have knowledge is the study (1911) on the *Analyse der Empfindungen* made by Colombian philosopher Julio Enrique Blanco (1890–1986) in Barranquilla, which was derived from his interest in the explanation of living phenomena in general and the psychophysical problem in particular. Despite the difficulty in tracing the path of the work of Mach on South American soil, another point of contact was identified through the influence exerted by Hans A. Lindemann in Buenos Aires, who attended the *Schlick Circle* on a regular basis. His works, which were reviewed in some journals, offer us the chance to start giving an account of the conceptual lineage of Machian root in South American territories. This work aims to constitute a contribution in that sense. Machian ideas were spread more recently due to the Mach-Einstein connection. Gonzalo Munévar represents a remarkable exception to this pattern due to his account of Machian ideas related to the theory of knowledge and evolution and his relationship with Feyerabend and Hempel.

Keywords Ernst Mach · South America · Julio E. Blanco · Hans A. Lindemann · Revista Voces · Revista Minerva

17.1 Julio Enrique Blanco and *The Analysis of Sensations*

Julio Enrique Blanco (1890–1986) is one of the most important philosophers of Colombia in the first half of the twentieth century. For instance, he is one of

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Table 17.1 Sections of the Autobiographical Notebook #5 related to Mach, the Analysis of Sensations and related topics. (Blanco's Archive)

#	Title
07.	From Kant and Hering to Mach and Loeb
14.	Mind and body
15.	Physiological and neurological psychology
16.	The *Analysis of Sensations* according to Mach
17.	Concepts of Mechanics, Physics, Chemistry, Biology and Psychology that are predominant in *Die Analyse der Empfindungen*
18.	Space according to Mach
19.	Critical consideration on the concept of space according to Mach
20.	Complementary comments to the above mentioned
21.	The concept of time according to Mach
22.	Brief critical appreciation of the concept of time in Mach
23.	Relation between time and attention and general critique of Mach
23[a]	Transition to the consideration of the dynamics of living phenomena
24.	The dynamics of living phenomena
25.	Radiant energy, Space and Time according to Loeb

the few Latin American thinkers who could give an account of current European philosophy in the first half of the twentieth century given his readings of German, English and French updated writings on science (especially biology and physiology) and philosophy (See Blanco 1917, 1920). This is to be compared to the fact that Colombian mainstream philosophy was still Neotomism even by the 1940's, whereas Blanco constructed his thought rejecting the subordination of philosophy to catholic theology.

In 1911, the young philosopher devoted over 60 pages in his Autobiographical notebooks to his studies on *Die Analyse der Empfindungen* (Jena, Fischer, 1906, 6th edition) and related issues such as the psychophysical problem and the dynamic of living phenomena (Table 17.1).

When Blanco [JEB] wrote his lengthy comments to the *Analyse der Empfindungen* he was imbued in the neokantian environment of late nineteenth and early twentieth centuries; his critical reading was already biased towards a certain kind of Neokantism. However, it is clearly seen that he had certain doubts regarding this inclination: "I've come to ask myself if I'm not getting lost by devoting myself with so much endeavor almost exclusively to the works of metaphysical speculation." As early as 1907, Blanco was already interested in the explanation of living phenomena. He started upon the study of the works of authors such as Darwin, Haeckel, Loeb Hertwig and Hering. It is by the study of Hering that Blanco came to be interested in the works of Ernst Mach:

> My previous translations have indeed especially lead me now to the study of two scientific books that I just received. One of them is Mach's *Die Analyse der Empfindungen* and the other is one of Jacques Loeb. *Dynamik der Lebenserscheinungen*. But I also have added to the latter *Comparative Physiology of the Brain and Comparative Psychology*, also from

> Loeb. With these studies there's a revival of the passion for the study of biological and psychological problems that I now intend to delve. (JEB's unpublished Autobiographical Notebooks, #5, 1911)

The first section of his Notebook #5 is devoted to explain some details behind the translations he made of Kant's *De mundi sensibilis atque intelligibilis forma et principiis* (from Latin) and the *Prolegomena* as well as his translation of Ewald Hering's *Über das Gedächtnis als eine allgemeine Funktion der organisierten Materie* (both from the German original versions). The next four sections are dedicated to discuss the concepts of imagination, the receptivity of senses and intelligence in Kant.

The 6th section of that Notebook verses on the relation between Kant and Hering, where Blanco states that both authors attempted to explain the constitution of mental states that operate in cognitive functions. According to Blanco, the intermediary between the sensory apparatus and the intellect is imagination in the case of Kant, whereas it is memory for Hering.

The young philosopher Blanco dwelled between teleology and causality. In the Helmholtz-Hering controversy he favored nativism over empiricism. This can throw some light on why he later in 1917 attempted to explain the relation between the Psychical and the Physical in his *De la causalidad biológica* by appealing to a sort of special causality that would only apply to biological domain. This is also an attempt to remain consistent with his post-Kantian framework while attending to the Machian objections to the concept of teleology. By the time of the publication of the *Revista Voces* (1917–1920) we could find evidence of new mentions to Mach and other authors of scientific philosophy made by JEB and Enrique Restrepo, another Colombian thinker interested in the philosophy of science at the dawn of the twentieth century. These facts are understood from the shared interest (of Blanco and his fellow debater Restrepo) in the explanation of the phenomena of life in general – as stated by the frequent mentions in the articles published in the *Voces* magazine of authors such as Jacques Loeb, Ewald Hering, Wilhelm Wundt, Ernst Haeckel and of their works– and the psychophysical problem in particular (cfr. Blanco 1917a, 1917b, 1917c and Restrepo 1917). In *De Herbart a hoy* (1918), Blanco continues dealing with the psychophysical problem and causality by explaining the origins of scientific psychology from Herbart to the times of Mach and Wundt.

Going back to Blanco's study of *Die Analyse*, he devotes a fair amount of pages to explain the Machian account of space and time (sections 16–22 of his Notebook #5) and concludes in section 23 that Mach was wrong in assuming the sensation of time being produced by "tropisms of the organisms as a result of mere chemical affinities or physical attractions". Being rooted in the post-Kantian framework and lacking a proper training in biology, it is easy to understand why Blanco would assume that the sensation of time and space and the focus of attention are a faculty of *Pure Intelligence* rather than being the product of physiological processes as stated by Mach: instead of following the developments of physiological research, Blanco found in the shortcomings of physically oriented explanations of global mental faculties a reason to stick to the concepts such as *Pure Reason* so as to develop his own concept of *Pure Intelligence* (which he referred to as “in-tele-agency”, to remind us of his etymological interpretation of the concept). Upon this very last concept, Blanco then proceeded to construct his own metaphysical system in a post-Kantian key, which was the endeavor of the rest of his life.

Blanco travelled to New York in 1907 and 1914, an issue that helped him to gain up to date literature in philosophy and science. Given the fact that during the first half of twentieth century Colombia did not have a robust system of universities and the lack of a long modern tradition that would provide the supplies to feed philosophical and scientific discussion, it was only natural that Blanco derived in conceptions strongly aligned towards speculative metaphysics as he effectively did.

17.2 Hans Lindemann, Ernst Mach and *El Círculo de Viena y la filosofía científica*[1]

Lindemann was born in Güstrow (Germany) in 1882 in a family of mathematicians and scientists that initially was more interested in arts than in science and philosophy, but subsequently got interested in them as he recalls in Lindemann (1944): “Material circumstances stronger than myself were what lead me first to the pragmatics in life, then to arts and philosophy and finally to science, logic and exact disciplines”. Although born in Germany, Lindemann exerted a great influence in terms of the in diffusion and discussion of the ideas related to Mach and Vienna Circle in South America.

This quote is taken from *El círculo de viena y la filosofía científica*, an article he published in *Revista Minerva* –an Argentinean philosophical magazine (1944–1945) founded by young physicist and philosopher Mario Bunge–. Lindemann gives an account of the Vienna Circle and the first Wittgenstein. Bunge became subsequently more known, while some circumstances related to Lindemann, his work and life have remained almost unknown until present days. But if we follow what he tells about himself in the above mentioned article, just as Blanco, he admits being influenced by Kant:

> My philosophical speculations started under the influence of Kant and neo-Kantians, without accepting that doctrine at all, but not knowing how to escape from it because of a lack of orientation in a purely commercial environment like Buenos Aires during the period 1912/27.

After moving to Berlin in 1927, then he went to Vienna to study philosophy where he attended Schlick’s seminar in 1929–1930 (Cfr. Lindemann 1944, p. 146. Also Stadler 2001, p. 235). There they discussed Russell’s *Analysis of matter* and modern physics (the theory of relativity and quantum physics) as well as the

[1] This section contains large quotes of Campis and Bermúdez (2006) which were slightly modified. In that text, Lindemann was identified as Austrian-Argentinean, but research has lead us to identify him with no doubt as German.

foundations of mathematics. This coincides in time with the meetings of Schlick, Waismann and Wittgenstein. Having read in Buenos Aires the works of Poincaré – another coincidence with Blanco–, whose ideas he thought to be continued by the philosophy of the Vienna Circle, he soon found that "the only way out of the abysm of school philosophy was to apply the method of science to philosophy as well". This last assertion of Lindemann coincides with Smith (1994) regarding the role of Franz Brentano in Austrian philosophy, which held that "the true method of philosophy is none other than that of the natural sciences". Lindemann's account of the Vienna Circle and its antecedents shares also some lines with Stadler (1994), though the works of Smith and Stadler are more complete and profound studies. Therefore, Lindemann turns into a significant antecedent in the studies on the influence of both Mach and the Vienna Circle.

Lindemann (1944) states:

> There is no doubt that the most decisive influence on the formation of the Vienna Circle was exerted by Ernst Mach, who had since the beginning the clear and decided vision of gaining the unity of science through severe criticism of its fundamental concepts and eliminating any metaphysical concept. Instead of attempting to unify the different empirical sciences by means of *ad hoc* constructed metaphysics and epistemology that would change in each era because it was a metaphysical hypothesis, that is, without enough empirical foundations that guarantee its lasting.

He also correctly identifies that Mach positivism "against the abuses of metaphysical concepts has determined to a high degree the attitude" of the Circle. Lindemann also goes further on to identify three points in which he thought Mach was wrong:

First: Mach did not value sufficiently enough the function of logic and mathematics in science. Second: he combatted the atomistic theory in physics as being a fiction; that was his biggest mistake. Third: there was a certain vagueness in the affirmations of Mach in that physics only makes judgments on the impressions of the senses.

Lindemann continues by affirming that Mach was wrongly identified as an undercover idealist by Lenin and a strict mechanicist. He also refers to 1910 as the approximate year in which the work of Mach exerted its maximum of influence in Vienna, when "The errors of Mach were seen, but at the same time the importance of his general position was acknowledged. Therefore, there was an attempt to reconstruct his ideas in the most modern, possible way."

Rather than continuing building upon the philosophy of Ernst Mach or the Circle, Lindemann continued his philosophical work in South America (Valparaíso, Santiago de Chile and Buenos Aires) in the vein of the Vienna Circle, concentrating on a direction that put value on psychology, the future of social science and trying to popularize such ideas by means of divulgative texts and conferences (for instance, *La influencia de la investigación científica en la filosofía*, a conference held on June 6th, 1944 and published in Buenos Aires in 1945). It is worth mentioning that some of his works were reviewed by Quine and other authors in international journals. Also two of his books in the form of dialogues, *Pláticas filosóficas entre un sabio,* *un poeta y un filósofo* (Philosohphical converstions between a wise man, a poet and a philosopher, Santiago de Chile, 1940) and *Lenguaje y filosofía; el lenguaje: foco central de la discusión filosófica moderna* (Language and philosophy; Language as the central focus of modern philosophical discussion, 1946). The life and works of Lindemann is subject of ongoing research currently.

17.3 Mach and Munévar or The Connection Between Evolution and the Nature of Scientific Knowledge

> Realizing that philosophical positions contain assumptions about the world he criticizes the separation of science and philosophy. [. . .] The epistemology that emerges is elucidated with the help of examples, compared with familiar views such as those of Mach, Spencer, Popper, Kuhn, Lakatos and Toulmin. Paul Feyerabend on Munévar (1983).

Academic philosophical circles in South America were more familiar with Mach as an antecedent of the theories of Einstein. However, there is a connection with Mach that is closer to biological epistemology and an evolutionary perspective in philosophy. Gonzalo Munévar, former disciple of Paul Feyerabend and Carl Hempel, belongs in this line of research, which has come to be consistent with current cognitive neuroscience and evolutionary psychology. The chief interest of Munévar is not that of explaining the meaning or relevance of Mach for the theories of Einstein. Both his *Radical Knowledge* (1981) –references will be to the expanded Spanish version, *Conocimiento Radical* (2003)– and *Evolution and the Naked Truth* (1998) –Spanish version: *La Evolución y la Verdad Desnuda* (2008)– refer amply to Mach and his evolutionary stance for the explanation of cognition and scientific knowledge.

Munévar (2003) regards Mach as the one thinker who probably offered the best arguments in favor of an evolutionary epistemology in the IX Century, and his views on the subject as more insightful than those of XX Centuy thinkers as famous as Popper and Toulmin. Indeed Munévar sees some important continuity not only between Mach and Lorenz, but even between Mach and himself, although some aspects of Machian epistemology are not sustainable due to biological considerations.

According to Munévar, most IX Century evolutionary epistemologists, particularly Spencer, the human mind was the result of a natural evolution whose final stage displayed neo-Kantian categories: Newtonian, Euclidean, etc. Mach was a devastating critic of Newtonian physics but agreed that the structure of the human mind was Euclidian:

> Seldom have thinkers become so absorbed in revery, or so far estranged from reality, as to imagine for our space a number of dimensions *exceeding the three of the given space of sense*, or to conceive of representing that space by any geometry that departs appreciably from the Euclidean. Gauss, Lobachevski, Bolyai, and Riemann were perfectly clear on this point, and cannot certainly be held responsible for the grotesque fictions which were subsequently constructed in this domain. Mach (1943).

But how committed was Mach to the notion that our mental evolution was complete and unchanging? For Mach our mental structure was largely the result of a process of adaptation. As he says, "It is not to be denied that many forms of thought were not originally acquired by the individual but were antecedently formed, or rather prepared for in the development of the species..." (Mach (1943)). As the result of evolution, "the structure of the world becomes the structure of the mind." Nevertheless, for Mach this process is not complete, as he shows when he expresses his approval of C.E. von Baer for discussing

> The narrowness of the view which regards an animal in its existing state as finished and complete, instead of conceiving it as a phase in the series of evolutionary forms and regarding the species itself as a phase of the development of the animal world in general. Mach (1943).

Back to the structure of the mind and its processes, Mach referred to the concept of plasticity in one of his *Popular Scientific Lectures*, namely in "On transformation and adaptation in scientific thought":

At first sight an apparent contradiction arises from the admission of both heredity and adaptation; and it is undoubtedly true that a strong disposition to heredity precludes great capability of adaptation. But imagine the organism to be a plastic mass which retains the form transmitted to it by former influences until new influences modify it; the one property of plasticity will then represent capability of adaptation as well as power of heredity.

In the vein of Mach, Munévar (2003) also considers that the functions and structures of the mind are liable of change, growth and further development in terms of the species as well as of the individual:

Just as the human being develops according to a certain mold, and attains a certain biological equilibrium, both of which are the results of a long evolutionary process, the human mind develops from infancy to maturity according to a certain mold and then settles into a more or less permanent functional structure, both of which are also the results of a long evolutionary process.

It seems to Munévar that Mach's view held great promise as a way to understand the evolution of our basic cognitive mechanisms, but what about Mach's understanding of the evolution of science, an area where Popper and Toulmin vehemently disagreed him? For Mach, "the extension of our sphere of experience always involves a transformation of our ideas," and, moreover, that sphere is "constantly widening". This suggested to Toulmin and others that Mach thought that the development of our scientific ideas was also the result of natural evolution, and that was clearly wrong since the structure of our brains could not have changed as quickly as our scientific ideas have in the last few centuries. Both Popper and Toulmin thus emphasized that scientists do not judge the worth of scientific theories by their adaptive value. Popper and Toulmin are evolutionary epistemologists only in the sense that they see some analogies between the history of science and the evolution of species.

As Munévar reminds us, however, for Piaget intelligence is not only the result of evolutionary adaptation but also an instrument of adaptation. That is, intelligence allows individuals to adapt to their environments. Furthermore, science is a social extension of intelligence. In this sense, Munévar has argued in his books and many papers, science is a (social) instrument for adapting to the universe. And, of course, Popper and Toulmin may well be correct in saying that scientists are motivated by the search for truth or by their curiosity. But these motivations do not sever the connection between science and adaptation. As Konrad Lorenz made it very clear, curiosity has adaptive value for animals such as rats and ravens, and humans as well, all of which Lorenz calls "specialists in non-specialization," for it allows them not only to come to grasp their new environments better but to develop the skills they will need to adapt better to them. Thus, curiosity permits them to explore and survive in a great range of environments.

Additionally, as modern science developed artificial extensions to inherited sensory systems such as radio telescopes and long-range communication, the ecological niche of mankind also grew. Since the mind involves the interaction between inherited proclivities and a changing environment, the accelerated development of scientific knowledge is compatible with a direct evolutionary epistemology based on the perspectives of Mach and Munévar.

Science, a social activity prompted by curiosity, may thus allow us to explore and survive in the universe in a grand scale. Perhaps Mach did not express the point very clearly, but he did anticipate the more sophisticated versions of evolutionary epistemology that were developed in the twentieth Century.

Perhaps it is important to mention that in the new context the line of thought that was consolidated by Konrad Lorenz and was continued by authors such as Rupert Riedl, Gerhard Vollmer and Franz Wuketits among others, starts with the study of the evolution of cognition and saves scientific knowledge for later. It is remarkable how Riedl (coming from the empirical context of biological sciences to epistemology), and Munévar (coming from an educational context within philosophy of science to an empirical one), do coincide in their appreciations on how thought and mind were shaped by evolution rather than our perceptual apparatuses being a reflection of nature's ultimate order.

As Munévar puts it, it is possible to limit ourselves to trace the evolution of the structure of mind (evolutionary psychology), and leave the problem of science for later. "Indeed, such a task may be of great value to epistemology. This has in fact been the approach taken by Konrad Lorenz". Following Munévar in the discussion of the nature of the categories of our conceptual processes, Mach was ambiguous; although having praised Riemann's non-Euclidean geometry, he refused to believe that these categories could correspond to a non-Euclidean structure of mind (though he conceived that structure to be a product of adaptation). By relating only that what is conceivable only with what fits within that Euclidean structure, what cannot be conceivable in such terms is not an acceptable alternative. Thus, the structure of mind, however, reflects the world only approximatively.

17.4 Final Remarks

Our purpose here was to present three instances in which the philosophical ideas of Ernst Mach were discussed and reviewed on American soil. The subject of the contribution was neither the history of science, nor the history of philosophy, but on the history of the philosophy of science in South America, particularly, on the influence of Ernst Mach. The case of Blanco offers us the chance to see the difficulties that scientifically oriented philosophy faced in Colombia in the first half of the twentieth Century; the works of Lindemann published in Argentina (1945–1959) reaffirms what Campis and Bermúdez (2006) and Stadler (2014) consider as a case of early intercontinental dialogue in philosophy. Last, but not least, the case of Munévar reassesses the role of the evolutionary thought of Mach and puts it in a more recent context. Far from being a case of mere historical interest, the evolutionary thought of Mach proves to be a source of inspiration for contemporary researchers beyond the context of physicalism and his role in the development of the new physics.

Chapter 18
Ernst Mach in Prague and the Dawn of Gas Dynamics

Rudolf Dvořák

Abstract Ernst Mach came to Prague in 1867 to become Professor of Experimental Physics and Director of the Institute of Physics of the Carlo-Ferdinand University. He spent in Prague 28 years before leaving for Vienna in 1895 to become Professor of Natural Philosophy at the University of Vienna. Besides teaching duties during the first years in Prague, he resumed his former research in physiology of sensations and experimentally proved the Doppler effect. With his students he carried out a systematic investigation into propagation and interaction of acoustic waves. As an empirio-critical philosopher Mach subjected to critique Newton´s mechanics in a book on mechanics which strongly influenced Einstein. However, most important was his contribution to the science of gas dynamics: he was the first to visualize successfully the high-speed flow phenomena and to unveil the secrets of shock waves – the most typical and important phenomenon of high speed aerodynamics.

It would be hardly possible today to find a person who has never heard about supersonic flight or who has never come across the word *"Mach number*". Where has this phrase come from?

Ernst Mach was, no doubt, one of the greatest scientists of the second half of the nineteenth century. He was and still is the epitome of a talented physicist and empirio-critical philosopher. His 28-year period in Prague was a period of his life most fertile in ideas, and, at the same time most fruitful for the development of the science of gas dynamics: he was the first to visualize successfully the high-speed flow phenomena and to unveil the mystery and secrets of shock waves – the most typical and important phenomenon of high speed aerodynamics (see Dvořák 2002, 2005).

Mach studied physics in Vienna and in 1860 was awarded a doctorate in philosophy after submitting a dissertation "On Electrical Discharge and Induction". His intellectual world, however, extended far beyond physics, and the period

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between 1867 and 1860, i.e., before coming to Prague, was a period of searching for his own scientific identity. He started to give lectures on physics and physiological physics to medical students, studied psychology and physiology of sensations, and published several completely original papers on physiology. He even lectured on musical theory and participated in sessions on music, drawing, and poetry. He was offered the Chair of Physiology, at the University of Salzburg, but, instead, decided to accept the Chair of Mathematics, and, later, of Physics at the University of Graz. Though he met his future wife there, Graz did not satisfy his expectations. He regarded it too provincial, and so – at the age of 29 – after an unsuccessful attempt to obtain a professorship at the Prague Polytechnic, in 1867 he accepted the offer from the Carlo-Ferdinand University in Prague to become Professor of Experimental Physics, and, at the same time, also Director of the Institute of Physics at this University.

In the middle of the nineteenth century lecturing in physics at the University in Prague was oriented mainly towards the demands of future grammar school teachers of physics, medical doctors, and pharmacists, i.e. rather towards general physics and experimental physics. At that time courses in theoretical physics and mechanics were given by professors of mathematics. The lecture halls were in the Carolinum and the Clementinum – precincts of the University. Mach and his family were accommodated in close neighbourhood of the University, in the Old Town Square, and later in the Fruit Market Square (Ovocný trh), directly in the building of the Institute of Physics.

Both positions he held gave him the right and chance to modify syllabi of his lectures, to upgrade their contents, as well as to introduce new seminars, like Discourses on Contemporary Physics, Instructions for Individual Work in Physics, and Experimental Physics on a Scientific Basis. He was successful in acquiring an extremely skilful mechanician, František Hájek, with whom he designed and even produced many instruments and demonstration devices (by his own hands - do not forget that as a boy he was trained to be a cabinet maker!). Many of these instruments were used at universities and grammar schools all over the Austro-Hungarian Monarchy for almost a century. Mach´s lectures and seminars very soon gained excellent reputation for their clarity and attractivity not only among students, but even among the general public (Úlehla 1988; Dvořák 2005). Many of the classroom experiments were conducted by Mach himself. The Institute of Physics grew in fame, soon gained full-time assistants, and was able to provide open positions for doctoral students. During the 28 years of Mach´s Prague period 17 doctoral students in all submitted their theses under Mach´s supervision. Later many of them were appointed university professors, and one of them, Vincenc Strouhal (1850–1922), succeeded Mach in the Chair of Experimental Physics at the Carlo-Ferdinand (since 1920 Charles) University in Prague. Out of the same group of students, or later assistants, Vincenc Dvořák (1848–1922) became Professor of Physics in Zagreb and Gustav Gruss (1854–1922) became Professor of Astronomy in Prague.

In 1873 Mach was elected Dean of the Faculty of Natural Sciences, and in 1879 Rector of the Carlo-Ferdinand University. Thanks to his efforts and activities, the Institute of Physics acquired a new building in Viničná Street, to which Mach transferred with the whole family. Till the end of WW2 this building housed the German part of the University, and it was here that Albert Einstein gave his lectures and started his work on the general theory of relativity, and that Philip Frank later became Professor.

In the same year when Mach arrived in Prague, the Habsburg Austrian Monarchy became a dual Austro-Hungarian Monarchy, in which Hungary was granted the status of an equal partner to Austria. This had a strong impact on the patriotic fervour in the historic Czech Lands (Lands of the Bohemian Crown) which had the feeling of having been left aside. Until this act The Czech- speaking population and the German-speaking population had been living side by side as equal members of the same Monarchy. Mach was a typical example. Born in a German speaking family with Czech ancestry, he attended the Piaristic Gymnasium in Kroměříž (Kremsier), where the curriculum included also Czech, and the German-speaking university in Vienna; he married an Austrian and spoke German at home, he lectured in German, however, he did not mind speaking Czech with his students and assistants. In his application for the university post in Prague he even offered lecturing in Czech. Personally, he disliked any forms of nationalism and exaggerated patrotism.

At the time Mach was elected Rector of the University, the Czech national revival movement culminated. Heated and protracted disputes of a part of Czech patriotic intellectuals over the language of instruction at the University were inspired by the engineering school in Prague, where lectures were already offered both in Czech and German, and in 1869 the school split into the Czech and German autonomous branches. They also demanded that the University should follow this model. Charles University was established in 1348 by Charles IV, as a university for Czech and other central European students; but, after merging with the Jesuits College in 1654, it became a German speaking Carlo-Ferdinand University. Mach, as Rector of the University, strongly opposed fanatical patriotism of those days and did not support this model. He did not want to see two poor universities instead of one not very wealthy university. Nevertheless, in February 1882, by an Imperial Decree, the University in Prague did split into two parts enjoying equal rights – the Czech Carlo-Ferdinand University and the German Carlo-Ferdinand University. After the "lost battle" Mach opted for the German University and became also its first Rector. His lectures, however, were attended – as much as in the past – by many Czech students.

Despite all the problems mentioned above, the Prague period was the most rewarding period of Mach´s life. Remarkable is not only the scope of his interests in so many fields of science, but namely the real originality of his ideas and their persisting value.

In the first years of this period Mach returned to the Doppler principle, the problem which had been his main preoccupation already in Vienna. In Prague he realized two experiments to demonstrate the so called Doppler effect not only to physicists but even to the general public[1]. In addition, he was completely engrossed

[1]E.Mach: *Neue Versuche zur Prüfung der Doppler´schen Theorie der Ton- und Farbenänderung durch Bewegung,* Sitzungsberichte AW Wien (Math.-Naturwiss.C., IIa, Bd.77, Jg.1878

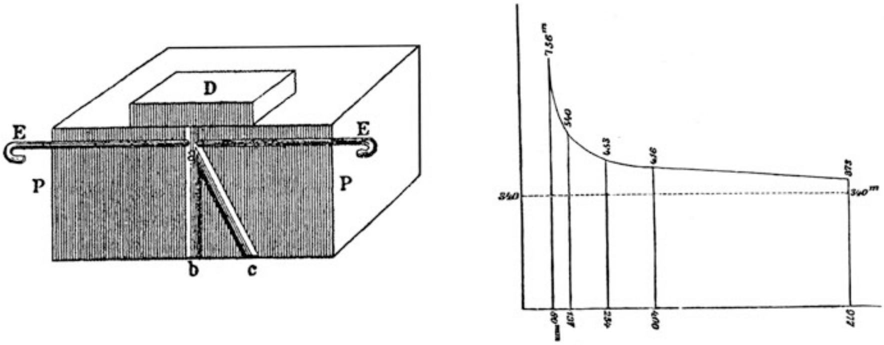


Fig. 18.1 A wooden block with two channels of different length for measuring travel times of a compression wave generated by a spark between two electrodes E-E. The distance-dependent speed of the wavefront is in the neighbouring picture. (E.Mach., J.Sommer:*Über die Fortpflanzungsgeschwindigkeit von Explosionsschallwellen*, Sitzunsber.AW Wien, Bd.75, 1877; E.Mach, O.Tumlirz, C.Kögler:. *Über die Fortpflanzungsgeschwindigkeit der Funkenwellen,* Sitzunsber.AW Wien, Bd.77, 1878)

in systematically studying propagation and interaction of acoustic waves and the speed of sound. One of his findings was really momentous – he proved that the character of the propagating wave of finite amplitude depends on the wave intensity and that its front part becomes gradually steeper to become a shock wave (see, e.g., Fig. 18.1). This was a completely new piece of knowledge. Nobody had observed and seen a shock wave ever before, though it had already been mathematically predicted by Bernhard Riemann in 1860. However, Mach discovered some incorrect thermodynamic assumptions in Riemann´s paper, and asked his assistant Otto Tumlirz to revise and rederive the theory using new assumptions. This was a real turning point in Mach´s research: from this point up, shock waves became the main object of his investigations for the rest of his Prague period.

In his experiments with propagating acoustic waves and weak shock waves Mach investigated and analysed their various interactions. He discovered an irregular reflection occurring either at excessively large turning angles or at excessively low initial velocity, referred to today as *Mach reflection,* or *Mach stem* (see, e.g., Fig. 18.2) (Reichenbach 1983; Dvořák 2005).

It was Mach´s inseparable interest in gas dynamics and his empiriocritical philosophy that brought him to flow visualization. This has become an excellent example of his methodology, of a concentrated effort to grasp and understand the physical phenomena observed, as well as of a great inventiveness and skill in experimental work.

In his first experiments Mach used Karol Antolik´s method of 1873 to visualize acoustic waves generated by electric discharges by their traces on a sooted glass plate. Soon he found a more appropriate method in the device built by Augustin Toepler in 1864 to visualize fields of different indices of refraction in glass, and developed this device into an instrument suitable for optical measurements in aerodynamics, see Fig. 18.2).

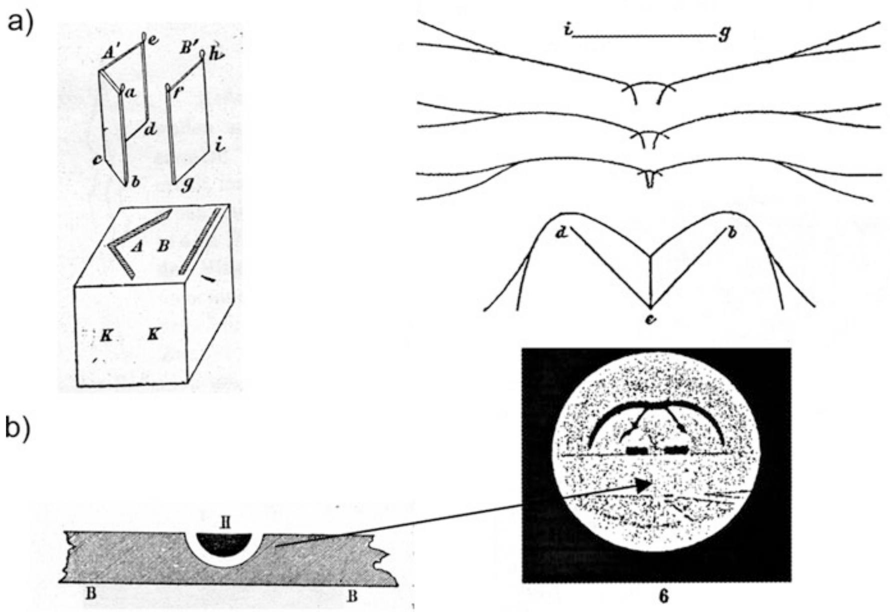


Fig. 18.2 (**a**) underneath a wooden block with inserted electrodes was a sooted plate; traces of the blast waves generated by these electrodes at different times are in the neighbouring picture. The weak wave fronts at their intersection point develop a bridge-wave, called today *Mach stem*. (1878), (E.Mach: *Über den Verlauf der Funkenwellen in der Ebene und im Raume,*Sitzunsber.AW Wien, Bd.77, 1878, 819-838) (**b**) in an experiment from1889 the two reflecting waves generated by explosion in a semicircular open channel are again forming a Mach stem, visualized in this case by the Toepler schlieren method. (E.Mach, L.Mach: *Über die Interferenz der Schallwellen von grosser Excursion,* Sitzunsber.AW Wien, Bd.98, 1889, 1333-1337)

As early as 1876, Mach and W.Rosický, his assistant, made an attempt to use an interferometer, and 2 years later Mach and J.v.Weltrubský used the Jamin interferometer for the first quantitative optical measurements of aerodynamic phenomena ever made (Fig. 18.3) (Reichenbach 1983; Dvořák 2005).

Mach was aware that to obtain high resolution in the visualized pictures, it is necessary to work with very short exposure times (about 0.8 .10^{-6} s) attainable only by using an electric spark as a light source, perfectly triggered to the right moment. Together with G.Gruss Mach developed various sophisticated delay circuits (Figs.18.4 and 18.5) required for producing the exact time delay between a spark used as a wave generator and a discharge used as a light source. As capacitors they used Leyden jars.

In 1881 Mach received a strong new impetus for his gas dynamic research in a lecture by Melsens, a Belgian ballistician, describing in a doubtful way effects of projectiles striking a human body. Mach felt a strong desire to visualize the described gas dynamic phenomena and immediately started experiments with bullets shot from a pistol. However, their velocity was too low for the supersonic

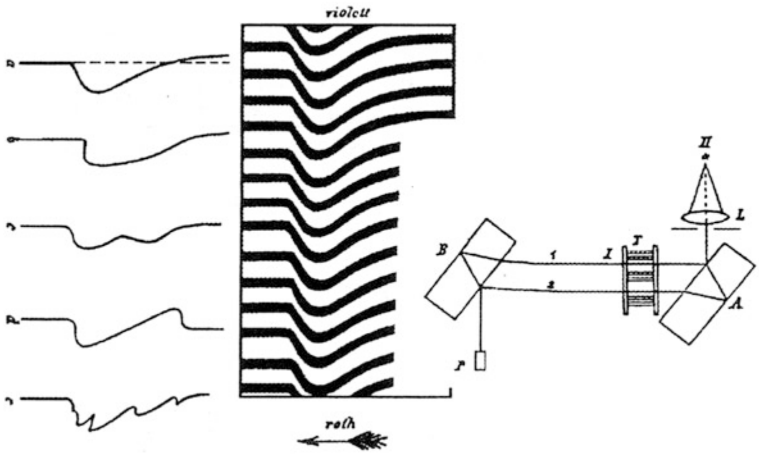


Fig. 18.3 Shock wave structure and density profiles obtained by the Jamin interferometer. (E.Mach, J.v.Weltrubský: *Über die Formen der Funkenwellen,* Sitzunsber.AW Wien, Bd.78, 1879, 551-560)

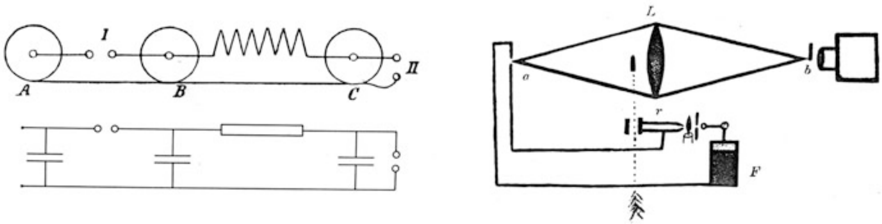


Fig. 18.4 A simple delay circuit according to Mach and Gruss (1878) (below in modern symbols), and a quitesophisticated delay circuit from the ballistic measurements (1897). The bullet flying along the open endof tube *r* generates in it a pressure wave which diverts the flame of a candle at the other end. The ionized gas of the candle flame triggers electrically the discharge of the Leyden jar. By changing the length of tube *r*, triggering of the light source can be controlled. (E.Mach, G.Grus: *Optische Untersuchung der Funkenwellen,* Sitzunsber.AW Wien, Bd.78, 1879, 467-480, E.Mach: *Über Erscheinungen an fliegenden Projektilen* (Vortrag im Wiener Verein zur Verbreitung naturwissenschaftlicher Kenntnisse, In: Populärwiss. Vorlesungen, 5.Auflage, Leipzig, 1923, 356-383)

phenomena to develop. Experiments with a more powerful gun were resumed only after Mach had transferred to the German university. Together with a new team and in close cooperation with Professor Salcher from the Naval Academy in Fiume, Mach made them with great enthusiasm at two professional shooting ranges, namely in Pola and in Meppen. I will mention here only experiments with a bullet 11mm in diameter flying at supersonic velocity 440 ms^{-1}. Mach reported on the results as early as June 10, 1886, in a preliminary note to the Academy of Sciences in Vienna. In his note he could display - for the first time - a picture of an object flying at supersonic velocity with a shock wave in front of it. On April 21, 1887, Mach

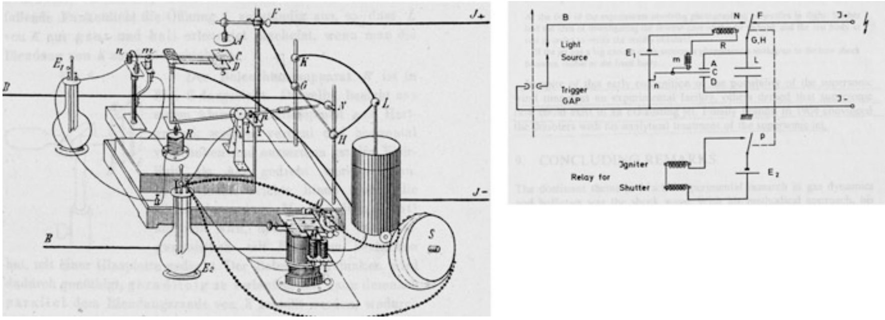
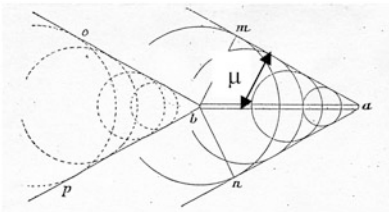


Fig. 18.5 Experimental set used in 1889 by Mach and Salcher in their ballistic tests, together with a simplified diagram of the trigger and delay circuit. (E.Mach, P.Salcher: *Über die in Pola und Meppen angestellten ballistisch-photographische Versuche,* Sitzunsber.AW Wien, Bd.98, 1889, 41-50; E.Mach, L.Mach: *Weitere ballistisch-photographische Versuche,* Sitzunsber.AW Wien, Bd.98, 1889, 1310-1327)



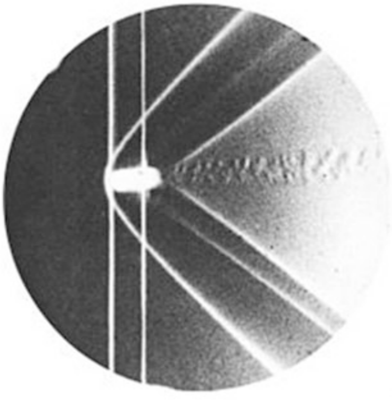
Mach number U / c

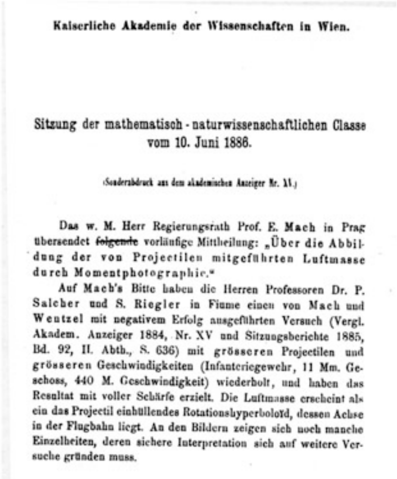
Mach angle $\sin \mu = c / U = 1 / M$

Fig. 18.6 Fig. 18.2 from the Mach and Salcher´s 1887 paper mentioned in the text, in which the Mach number and the Mach angle were introduced for the first time. *a-m* is a Mach wave generated by a moving body *a* with avelocity U greater than the speed of sound c

and Salcher published a full account of the experiment and its results in a paper entitled *"Photographische Fixirung der durch Projectile in der Luft eingeleiteten Vorgänge"*. Not only was this the first visual presentation of a real shock wave, but, in fact, up to that date nobody had ever seen and nobody had ever heard of the existence of a front shock wave and the whole shock wave pattern typical of a supersonic flow past a body. And, actually, in the same paper, they described the so called *Mach wave* and *Mach angle* of the front shock wave asymptote. They also introduced a new parameter U/c (flight velocity to the velocity of sound), later referred to by Jacob Ackeret as the *Mach number* (Fig. 18.6). The fundamental value of this pioneering paper is in making it the real beginning of supersonic aerodynamics as a new field of science.

Thanks to Mach´s experience and good theoretical background, the schlieren pictures enabled him to discover the wave drag of bodies moving at supersonic velocities. He stated correctly and gave a convincing evidence that the bullet drag consists of drag due to wave production, due to vortices in the wake, and due to skin friction. We only have to admire Mach´s analysis of the limited experimental results, of pictures 5 mm in diameter which, nevertheless, provided so many new and important data (Fig. 18.7).





Kaiserliche Akademie der Wissenschaften in Wien.

Sitzung der mathematisch-naturwissenschaftlichen Classe vom 10. Juni 1886.

(Sonderabdruck aus dem akademischen Anzeiger Nr. XV.)

Das w. M. Herr Regierungsrath Prof. E. Mach in Prag übersendet ~~folgende~~ vorläufige Mittheilung: „Über die Abbildung der von Projectilen mitgeführten Luftmasse durch Momentphotographie."

Auf Mach's Bitte haben die Herren Professoren Dr. P. Salcher und S. Riegler in Fiume einen von Mach und Wentzel mit negativem Erfolg ausgeführten Versuch (Vergl. Akadem. Anzeiger 1884, Nr. XV und Sitzungsberichte 1885, Bd. 92, II. Abth., S. 636) mit grösseren Projectilen und grösseren Geschwindigkeiten (Infanteriegewehr, 11 Mm. Geschoss, 440 M. Geschwindigkeit) wiederholt, und haben das Resultat mit voller Schärfe erzielt. Die Luftmasse erscheint als ein das Projectil einhüllendes Rotationshyperboloïd, dessen Achse in der Flugbahn liegt. An den Bildern zeigen sich noch manche Einzelheiten, deren sichere Interpretation sich auf weitere Versuche gründen muss.

Fig. 18.7 The first visual presentation ever published of front and exit shock waves on a projectile flying at supersonic velocity. The diameter of the picture as presented in Mach´s original paper was 5 mm

To complete the account of Mach´s Prague period, it is necessary to mention his publications: about 20 papers on physiology of sensory organs completed in this period; about the same number of original contributions devoted to acoustics and physical optics, dealing mainly with interference and diffraction phenomena, refraction of light and passage of light through different media. The experimental methods he developed and perfected in stroboscopy and photography were summarized in his book *Optisch-akustische Versuche* (1873).

Out of the 10 books he published in this period mention should be made of the *Die Geschichte und die Wurzel des Satzes von Erhaltung der Arbeit* (1872), and of his crucial work on mechanics with his critique of Newton´s mechanics *Die Mechanik in ihrer Entwicklung: Historisch-kritisch dargestellt* (1883), a book which has strongly influenced Albert Einstein and many other physicists since. It is an account in which the foundations of mechanics are analysed and subjected to a critique by an empirio-critical philosopher.

In the other two fundamental books *Die Analyse der Empfindungen und das Verhältnis des Psychischen zum Phys*ischen (1886), *Grundlinien der Lehre von der Analyse der Empfindungen* (1875), philosophy had already dominated.

Towards the end of the nineteenth century Mach had already been a famous and distinguished physicist and had enjoyed the fame of a brilliant lecturer. Moreover, his historico-empirio-critical approach to mechanics and thermodynamics was being step by step appreciated even by theoretical physicists who developed their theories on these fundamental investigations. At the same time he had already been well known as a respected philosopher, and, we have to admit that Vienna had - much earlier and in a more praiseworthy way than Prague - appreciated his achievements;

and so, in 1895 the Chair of the History and Philosophy of Inductive Sciences was created for him at the University of Vienna, which he accepted. However, this was the end of his further direct involvement in physics.

While reviewing all the merits of Ernst Mach and his admirable contributions to physics, physiology, philosophy, and the art of teaching, we should not forget his personality traits: his modesty and humanity, perseverance, restraint in behaviour, well thought-out and prudent approach to anything he did, as well as mastership in conveying his ideas and passing knowledge to everybody.

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Chapter 19
Ernst Mach and Johannes Kessel in Prague 1871–1874

Rüdiger Hoffmann and Lutz-Peter Löbe

Abstract Among the numerous activities of the younger Ernst Mach in the development of psychophysics, there is a period of cooperation with the German otologist Johannes Kessel (1839–1907) in Prague from 1871 to 1874, which was not investigated in detail before. This cooperation was important because a number of essential findings in the psychophysics of hearing were published by both authors. Preparing a biography of Kessel, we collected new material about his cooperation with Mach from hitherto unpublished letters, archive material, and from Mach's unpublished diaries from the corresponding years. This paper describes the previous activities of Mach in psychophysics of hearing including the development of the required methods, the grant from the Vienna Academy for the investigation of the sound conduction in the human hearing organ through the middle ear and especially through the ossicles, the curriculum vitae of Kessel before he came to Prague, the contents and the results of the common research in Prague, and the influence of this period on the further development of Mach and Kessel.

19.1 Introduction

The importance of Ernst Mach in the development of psychophysics is well known. His work in optics, acoustics, and the sensation of equilibrium is mainly concentrated to his early years in Vienna, Graz, and Prague. Among his numerous activities, there is a period of cooperation with the German otologist Johannes Kessel (1839–1907) in Prague from 1871 to 1874. This cooperation is of importance

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because a number of essential findings in the psychophysics of hearing were published by both authors. However, their cooperation has not been investigated in detail before. There are only few publications about Mach's physiological work in Prague,[1] and his cooperation with Kessel is evaluated (if at all) only on their three common publications.

When we prepared a monography[2] about the life and work of Johannes Kessel, we found new material about his cooperation with Mach from hitherto unpublished letters and archive material, as well as from Mach's diaries from the corresponding years. This paper gives an overview of our findings and underlines the impact of the cooperation of Mach and Kessel on the development of the otology and the psychophysics of hearing.

19.2 Ernst Mach and the Psychophysics of Hearing Before Prague

19.2.1 First Activities in Psychophysics of Hearing in Vienna

Mach started his psychophysical work with lectures influenced by the most recent works of G. Th. Fechner ("Elements of Psychophysics", 1860) and H. Helmholtz ("Theory of the Sensation of Sound", 1863) in Vienna 1863/64. He came in contact with the famous physiologists Ernst Brücke and Carl Ludwig who worked in Vienna at the time. Mach recognized that the theory of hearing offered numerous unsolved problems[3]: "While the knowledge on the structure and the function of the eye has developed to a rather important clearness, while at the same time the ophthalmology reached a level which could nearly not be foreseen by the previous century, [. . .] the theory of the ear lies still in a partial darkness, which is at the same time mysterious as well attractive for the researcher." He published his first paper in this field in 1863.[4]

[1] Dieter Hoffmann; Hubert Laitko (eds.): *Ernst Mach, Studien und Dokumente zu Leben und Werk*. Berlin: Dt. Verl der Wissensch. 1991; John T. Blackmore et al.: *Ernst Mach's Prague 1867–1896 as a Human Adventure*. Sentinel Open Press 2010.

[2] Rüdiger Hoffmann; Lutz-Peter Löbe; Wieland Pfeiffer: *„Ich holte meine Prager Schriften." Leben und Werk des Otologen Johannes Kessel (1839–1907)*. Dresden: TUDpress 2015 (Studientexte zur Sprachkommunikation; 80).

[3] Ernst Mach: *Zwei populäre Vorlesungen über musikalische Akustik*. Graz: Leuschner & Lubensky 1865, pp. 5–6.

[4] Ernst Mach: *Zur Theorie des Gehörorgans*. Sitzungsber. d. math.-naturwiss. Classe der Kaiserl. Akademie d. Wissensch., vol. 48, II. Abt., 1863, pp. 283–300.

19.2.2 Sphygmograph and Kymographion

It is also important that Mach contributed significantly to the development of the kymographion. In 1860, the renowned French researcher E. J. Marey developed his version of a sphygmograph (a kymographion for recording blood pressure). It is highly probable that he visited the laboratory of C. Ludwig in Vienna before. Ludwig had applied the old principle of recording on a revolving drum to blood pressure measurement and thus invented the kymographion as early as 1847. Mach investigated the sphygmograph in 1862/63 and published three papers on it. He acknowledges in his autobiography, that he was directed from the theory of the kymographion to the theory of the hearing organ. In his abovementioned paper from 1863, he claimed: “The ear is also a kymographion. It records the sound waves in the liquid of the labyrinth, where they are recorded by the auditory nerve.” He announced the investigation of anatomic dissections of the ear as well as the construction of artificial ear models. For the first task, he wanted to study the movement of the elements of the ear in cooperation with A. Politzer, who was an outside lecturer for otology in Vienna since 1861. Politzer (1835–1920), a scholar of Ludwig, was one of the most important people in the development of the otology.

19.2.3 The Grant of the Imperial Academy of Sciences

In exactly the same year, the professors Ludwig and Brücke proposed to the Imperial Academy of Sciences in Vienna on December 10th, to support the work of Ernst Mach on the ear. The academy awarded a 500 fl. grant on December 31, 1863, with the purpose, “to perform a state-of-the-art investigation of the sound conduction in the human hearing organ through the middle ear and especially the ossicles” and to publish the results in the proceedings of the academy.[5]

19.2.4 Graz and the Prerequisites in Stroboscopy

Mach gratefully accepted the grant on January 6th, 1864, however he moved to the Graz University later that year and remained there until 1867. Although he published a number of papers on some problems of hearing there, the conditions were not sufficient for complicated experiments. The investigation of the sound conduction in the ear had to wait until Mach was appointed Professor of Experimental Physics at the University of Prague.

[5]Archive of the Austrian Academy of Sciences, Vienna, files no. 1109/1863 and 17/1864. These documents are reprinted in Hoffmann/Löbe/Pfeiffer (2015), *loc. cit.*, appendix A.

Meanwhile, Mach worked (among other tasks) on the improvement and new applications of the stroboscopy. The stroboscope has several inventors in several countries, but it was patented by Simon Stampfer (a professor of mathematics in Vienna) in 1833. Based on experiments by Plateau and Doppler, Mach improved the stroboscopic measurement methods for the observation of vibrations significantly until 1870. He proposed the "stroboscopic self-control" to prevent synchronization problems.[6] This was an essential prerequisite for starting the pending investigation of the middle ear.

Obviously, Politzer was no longer available for the cooperation, and therefore Mach had to look for another expert in otology, who could play the anatomic part of the project. We do not know how Mach came in contact with Kessel, but he arrived at Prague as a postdoc in the beginning of 1871.

19.3 Johannes Kessel Before Prague

19.3.1 Education and Studies

The physician Johannes Kessel (Fig. 19.1) was only 1 year younger than Mach, but he was still in his postdoctoral phase. His father was a wealthy winegrower in Germany, which allowed Kessel to spend much time on his studies.

Kessel was born in Selzen, which was part of the Grand Duchy Hesse, in 1839. After graduation from high school in the residence Darmstadt, he studied medicine at the universities of Gießen and Würzburg starting in 1857 and received his doctorate in 1866. The supervisor of his thesis was the important Gießen surgeon Adolph Wernher (1808–1883), who was also interested in the surgery of the ear. His teacher in Würzburg was Anton von Tröltsch (1829–1890), who is known as the "father of otology". Würzburg was furthermore the place where Corti had revealed the structure of the inner ear (the cochlea) in 1850/51. In 1864, von Tröltsch founded the first journal on otology, the "Archive of Otology", which is still the most influential journal to this day, and Kessel published his first journal paper in said periodical in 1867. H. Schwartze (Halle) and A. Politzer (Vienna) served as co-editors of the "Archive"; the latter possibly influenced Kessel to continue his postdoc phase in Vienna.

19.3.2 The Postdoctoral Phase in Vienna

Kessel turned to Vienna no later than spring 1869 like many young scientists, who wanted to improve their knowledge at the famous Medical Faculty, where the "second Vienna medical school" flourished. Kessel worked as a guest scientist at

[6]Ernst Mach: *Weitere Mittheilung über die Beobachtung von Schwingungen*. Anzeiger der Kaiserl. Akademie d. Wissensch., Math.-Naturwiss. Klasse, vol. 7, 1870, p. 43–44.

Fig. 19.1 Portrait photograph of Johannes Kessel from his years in Graz (1875–1886). (By courtesy of Josephinum, Collections and History of Medicine, MedUni Vienna)

the Institute for Experimental Pathology, which was directed by Salomon Stricker (1834–1898), a scholar of Brücke. There he carried out new histological studies of the ear, which were summarized as a part of Stricker's "Manual of Human and Comparative Histology" in 1871 (English translation 1873). This also served as the habilitation thesis of Kessel in 1875. In 1879, Politzer, who was already an influential Clinical Director, acknowledged Kessel's histological work, stating that it included "a big number of newly detected anatomical details of the hearing organ".[7] Kessel was thus coined an expert in the anatomy of the ear, when Mach and he started the common work in Prague.

[7] Adam Politzer, report about Kessel for the University of Graz, 1879, cited in: Gertrud Stelzig: *Johannes Kessel – Vater der Stapes- und funktionellen Mittelohrchirurgie*. Ztschr. f. Laryngologie, Rhinologie, Otologie u. ihre Grenzgebiete, vol. 49, no. 9, 1970, pp. 551–564.

19.4 The Common Work in Prague

19.4.1 Sources

The most essential source of information on the work of Mach and Kessel in hearing acoustics and otology is, of course, their own publications. We counted 22 titles by Mach on the ear and acoustic measurement methods and 17 titles by Kessel until the end of their cooperation in 1875, as well as the three common papers, which we are concentrating on. Apart from several material at different places, these printed sources are mainly complemented by two convolutes.

The first one is established by thus far unpublished letters by Mach (6 letters, 1872–74) and Kessel (9 letters, 1873–76) to the editor of the "Archive of Otology",[8] who was Hermann Schwartze since the start of the "New Series" in 1873. Starting that year, Mach was a member of the editorial board of the "Archive", obviously by a proposal of von Tröltsch. In the first of his letters (October 30, 1872), he not only accepts his membership to the board, but also announces a common paper with Kessel.

The second one is formed by a collection of diaries of Ernst Mach, which are preserved in the Deutsches Museum in Munich. There are five diaries which cover the period of our interest.[9]

Mach‘s stroboscopic technology was ready to use, when Kessel joined his laboratory. Mach and Kessel published a short notice, that they started the investigation of the ear using this technology[10]: "Since February 1871, we are investigating the movements of the hearing organ by a method, which can be characterized as stroboscopic self-control and which was mainly described by one of us earlier."

It should be obvious, that this was a cooperation with equal rights, because Mach was the specialist in (stroboscopic) measurement, while Kessel played this role in anatomy. If there is some doubt, it can be dissolved by a text block, which Mach recorded for later usage in the third of the abovementioned diaries: "K. performed the anatomical investigation and the preparation of the dissections, M. produced the physical apparatuses, and the experiments were performed jointly."

The outer conditions for the cooperation in Prague are known.[11] The "Physical Cabinet" (originally in the Clementinum building) was located in the "Bouquoi House" (between Ovocný trh and Celetná) since 1859. Ernst Mach worked there since he was appointed Chair for Experimental Physics in 1867, and this is also the location where the cooperation took place.

[8] These letters are now reprinted in Hoffmann/Löbe/Pfeiffer (2015), *loc. cit.*, appendix B.

[9] Archive of the Deutsches Museum, Munich, estate of Ernst Mach, signatures NL 174/505 to 509.

[10] Ernst Mach; Johannes Kessel: *Vorläufige Mittheilung*. Centralblatt für die medicinischen Wissenschaften, vol. 9, no. 38, 1871, p. 593.

[11] Dieter Hoffmann: *Ernst Mach in Prag*. In Hoffmann/Laitko (1991), *loc. cit.*, pp. 141–178.

Kessel's private address was: Breite Gasse (now Jungmannová) 32.[12] We do not know much about his personal life in Prague, apart from his contacts to the family of the architect Johann (Hans) Pichler (1837–1908), where he met his prospective wife Marie Moritsch (1856–1945).

The cooperation of Mach and Kessel may be subdivided into three phases:

19.4.2 Phase 1 (1871/72)

In the first 2 years, Mach and Kessel developed common activities with high intensity, which were summarized in two papers for the Proceedings of the Vienna Academy,[13] and were also reprinted in the "Archive of Otology". The progress can be tracked by numerous entries in Mach's diaries, which also include an inserted measuring protocol in Kessel's handwriting. The research work, which was really a pioneering one, included experiments and measurements with dissections from lifeless ears as well as with living ears.

The function of the tympanic cavity was explored by means of anatomic dissections. To study the movement of the ossicles, they were excited by sound from a pipe, and the movement of gold particles, which were attached at the ossicles, was observed by a standard microscope.

A central question of that time was the influence of the muscles of the middle ear on the transfer of sound.[14] In experiments, the musculus tensor tympani and the musculus stapedius were stressed by weights. It was shown that the sensibility of the ear was lowered by stressing the tensor tympani only at low frequencies.

The movement of the eardrum was demonstrated by observing a gold point, which was attached on its surface, by means of a vibration microscope from the Lissajous type. The influence of the tensor tympani only at low frequencies was confirmed by impressive Lissajous figures.

The investigations with the living ear required an innovative technology. The authors developed a special "ear microscope" or "ear mirror", which allowed the observation of the eardrum with simultaneous supply with sound from a pipe and light, which also could be pulsed for stroboscopic observation. Apart from this microscope, they also developed a tool for experiments with the Eustachian tube at changing air pressure.

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[12] Praha, Narodní Archiv, notice from April 18, 2008.

[13] Ernst Mach; Johannes Kessel: *Die Function der Trommelhöhle und der Tuba Eustachii.* Sitzungsber. d. math.-naturwiss. Classe der Kaiserl. Akademie d. Wissensch., vol. 66, III. Abt., 1872, pp. 329–336. — Ernst Mach; Johannes Kessel: *Versuche über die Accomodation des Ohres*. Sitzungsber. d. math.-naturwiss. Classe der Kaiserl. Akademie d. Wissensch., vol. 66, III. Abt., 1872, pp. 337–343.

[14] Mach and Kessel supposed, that the Musculus tensor tympany would act as an accommodation organ. Mach recognized soon, that there was no evidence for this, but Kessel believed this as long he lived and propagated the tenotomy of the tensor tympani as a suited surgical procedure.

The stroboscopic method was not really applied to the ear; the observation of the eardrum was performed with gold points only. However, Mach used the experiments for improving the stroboscopic measurement of the pitch of the sound of a siren and published the results in a separate paper.[15]

19.4.3 Phase 2 (1873)

In 1872/73, Mach served as Dean of the Philosophic Faculty and was more and more in the focus of public interest. This might be the main reason why the cooperation of Kessel and him became looser, which is visible in independent publications in 1873. Nevertheless, these single-author papers are more related to each other than it seems at a first glance.

Kessel's continuing interest was directed to the anatomy and function of the eardrum and the attached muscles. He finished a paper in July 1873,[16] where he described further experiments with anatomic dissections, where he used stroboscopic methods with the "ear mirror" for the first time. The experiments confirmed, that the movement of the parts of the middle ear and the influence of the muscles could be observed nicely in this way, but revealed also some drawbacks of the method. At first, the method is restricted to sound frequencies which are multiples of the frequency of the stroboscopic lightening. Secondly, the latter was in that time, when electric light was not available, dependent on the sunshine. In one of the abovementioned letters to Schwartze (April 6, 1873), Mach reports a good progress of the experiments and adds the remark: "We still need some beauty sunny days for control experiments."

Kessel also recognized the main reason for the lack of applicability of the stroboscopic method at the investigation of the living ear. To see the movements of the eardrum correctly, he needed sound pressures above 760 Pa, which are far above the pain threshold of the ear.[17] As an alternative measuring method for living humans, he proposed to glue a small mirror at the eardrum and to observe the reflected light. This is remarkable, because even this method was applied by

[15]Ernst Mach: *Über die stroboskopische Bestimmung der Tonhöhe*. Sitzungsber. d. math.-naturwiss. Classe der Kaiserl. Akademie d. Wissensch., vol. 66, II. Abt., 187), pp. 267–274.

[16]Johannes Kessel: *Über den Einfluss der Binnenmuskeln der Paukenhöhle auf die Bewegungen und Schwingungen des Trommelfells am todten Ohre*. Archiv für Ohrenheilkunde, vol. 8, no. 1, 1873/74, pp. 80–92.

[17]Stroboscopic images of vibrations of the living ear were produced for the first time by the Berlin otologist August Lucae (1835–1911); cf. *Das Oto-Stroboskop und seine physiologische diagnostische Bedeutung.* Archiv für Ohrenheilkunde, vol. 53, 1901, pp. 39–51.

W. Köhler (1887–1967) in his doctoral thesis from 1909.[18] This date shows how long the results of Kessel and Mach determined the state of the art. Later on, Köhler was very popular as a researcher in the behavior of chimpanzees.

Mach also included some remarks on the experiments on the ear with Kessel in his monography[19] on "optical-acoustic experiments" in the same year. There he announced a separate publication on it. We know the outline of this planned publication from one of his diaries (which begins at April 12, 1873), but the project was not completed in the announced way.

After finishing the publication on the eardrum, Kessel, who was really a *medical* doctor, concentrated on the interpretation of the findings with respect to the diagnostics of otologic diseases. This resulted in his first conference paper,[20] which he presented at the assembly of the renowned "Society of Natural Scientists and Physicians" in Wiesbaden in September 1873. We know from his letters that he used this travel to visit his home village Selzen, which is situated in Hesse nearby, and returned to Prague not before the middle of November.

Although occupied by many duties, Mach published 11 scientific works on very different topics in 1873, among them the first part of his famous series on the sensation of equilibrium.[21] This has a small prehistory: On October 26, 1871, Mach and Kessel had a common appearance in the Prague society of natural history "Lotos". While Mach reported about the beginning work of the geometry of the middle ear, Kessel introduced the state of the art of interpretation of the semicircular canals of the inner ear, which were argued to be the organ of equilibrium.[22] By the way, Kessel was not convinced about this interpretation all his life.

Mach profited from the experimental assistance with dissections of the ear by Kessel, when he developed his theory of the semicircular canals in 1873. However, the "bloodless" experiments on the sensation of equilibrium and movement with test persons were certainly performed without Kessel. Following a remark in his autobiography,[23] Mach had the feeling to have satisfied the expectations now, which had been posed by the grant of the Vienna Academy in 1863.

[18] Wolfgang Köhler: *Akustische Untersuchungen*. Zeitschr. f. Psychologie, vol. 54, 1910, pp. 241–289.

[19] Ernst Mach: *Optisch-Akustische Versuche. Die spectrale und stroboskopische Untersuchung tönender Körper*. Prag: Calve 1873.

[20] Johannes Kessel: *Über die diagnostische Verwerthung gewisser Befunde am Trommelfell und der Paukenhöhle*. Tageblatt der 46. Versammlung deutscher Naturforscher und Ärzte in Wiesbaden vom 18. bis 24. September 1873, pp. 39, 172–173. — Extended version in: Archiv für Ohrenheilkunde, vol. 8, no. 2, 1873/74, pp. 231–236.

[21] Ernst Mach: *Physikalische Versuche über den Gleichgewichtssinn des Menschen*. Sitzungsber. d. math.-naturwiss. Classe der Kaiserl. Akademie d. Wissensch., vol. 68, III. Abt., 1873, pp. 124–140.

[22] Ernst Mach: *Methode die einzelnen Theile des Gehörorgans richtig graphisch darzustellen*. Johannes Kessel: *Über die Bedeutung der halbzirkelförmigen Canäle des Ohrlabyrinthes*. Lotos – Zeitschrift für Naturwissenschaften, vol. 21, no. 11, 1871, p. 198.

[23] Ernst Mach: *Selbstbiographie (1913)*. In: Hoffmann/Laitko (1991), *loc. cit*., pp. 428–441, here especially p. 435.

19.4.4 Phase 3 (1874)

Mach, as a physicist, had to have big interest in describing the function of the ear not only qualitatively, but also with exact geometric measurements. This was a continuous task throughout the whole period with Kessel, and both wrote a summarizing paper on it in the final year of their cooperation.[24] The essential content was predicted as early as 1871, when Mach explained the project in the abovementioned session of the society "Lotos"[25]:

> The position of the most important parts of the hearing organ was determined, bringing them in relation to three suited Cartesian coordinate planes, which can be easily anatomically determined in the head. Correspondingly, two orthogonal projections of the hearing organ were plotted following the rules of the descriptive geometry.

Due to a surprising find in one of the diaries of Mach, we know that he and Kessel prepared a pre-printed measuring sheet, showing the projection of the ossicles in two planes, which could be used as form for recording their measuring results (Fig. 19.2). We found such a sheet for the left ear (there were certainly forms for the right ear, too) which was used at October 22, 1871.

The value of the common paper is the summarizing presentation of real measurements[26] at the end of a working period of 3 years. It was presented to the Vienna Academy on April 23, 1874. Its content is complemented by some new stroboscopic analyses of the mechanics of the middle ear.

In that year, Mach additionally wrote a smaller article about the outer ear (his only original work for the "Archive of Otology") and two longer papers, which continued his work in the sensation of equilibrium and movement. In August 1874, he finished a summarizing monography about this topic, which appeared in the following year.[27]

Kessel published nothing else in 1874, because he took care for his personal future. He wanted to move to the Graz University as an outside lecturer of otology. As already mentioned, he used his contribution for Stricker's handbook as his habilitation thesis. Because he was a German citizen, he had to "nostrify" in Austria beforehand, which meant the naturalization as well as the approval of his academic

[24]Ernst Mach; Johannes Kessel: *Beiträge zur Topographie und Mechanik des Mittelohres.* Sitzungsber. d. math.-naturwiss. Classe der Kaiserl. Akademie d. Wissensch., vol. 69, III. Abt., 1874, pp. 221–243.

[25]Ernst Mach, Lotos, *loc. cit.*

[26]The measurements include some results on the semicircular canals, which supports the opinion that Mach's work on the equilibrium profited from the investigations.

[27]Ernst Mach: *Grundlinien der Lehre von den Bewegungsempfindungen*. Leipzig: Engelmann 1875.

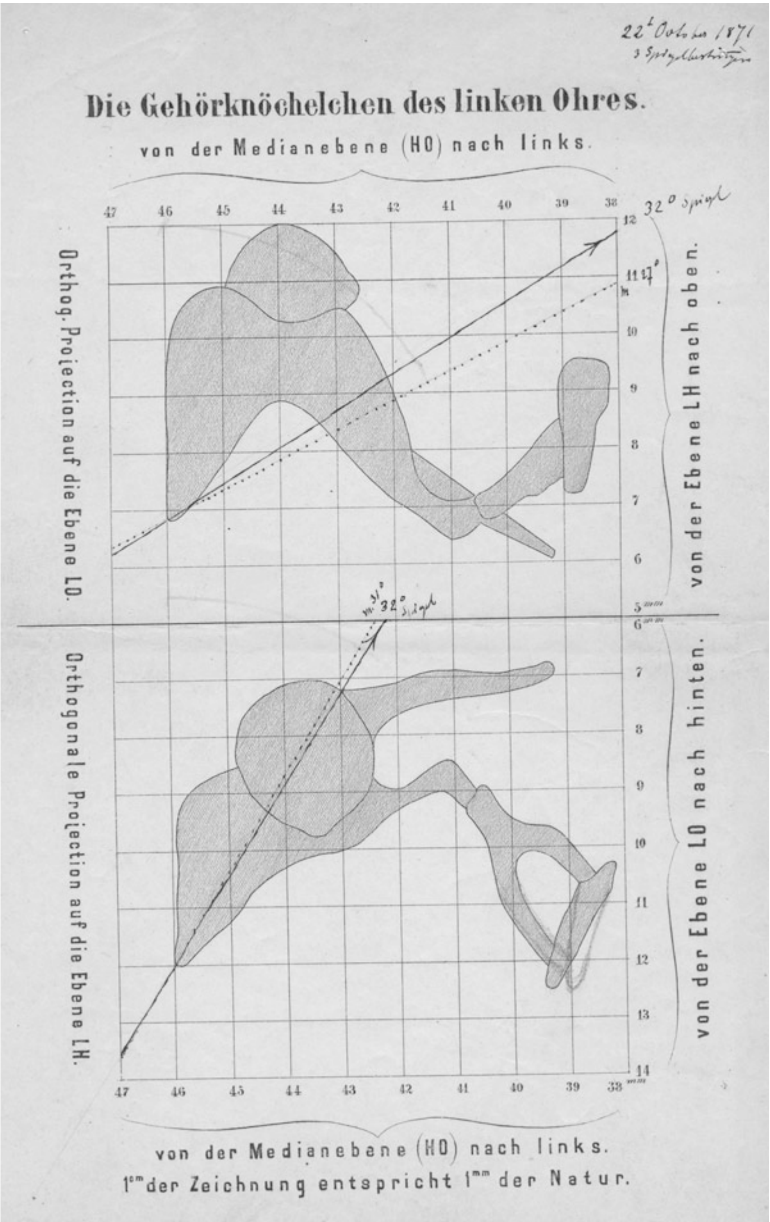

Fig. 19.2 Pre-printed measuring sheet with entries in handwriting, probably by Johannes Kessel. Insert found in Mach's diary NL 174/506 in the Archive of the Deutsches Museum. (Photograph by courtesy of Deutsches Museum München)

degrees. Mach supported the plans of Kessel utilizing his contacts to Alexander Rollett (1834–1903, a physiologist and scholar of Ernst Brücke), who was the Dean of the Medical Faculty in Graz at that time.[28]

19.5 The Further Work of Johannes Kessel

Kessel was appointed outside lecturer of otology at the University of Graz on April 9, 1875. There he maintained his “Ambulatorium for otology” successfully for one decade. His most successful period was in the first years of the time in Graz, where he became a founder and pioneer of the surgery of the middle ear. In detail, he performed the first mobilization of the stapes in 1875, followed by further new procedures in the surgery of the middle ear which may be characterized as steps towards tympanoplasty. In 1877, he carried out first extraction of the stapes. Kessel reported 16 cases of mobilization of the stapes in 1879.[29]

Surgery of the middle ear was a delicate problem due to the small geometry and the close proximity to other, highly sensitive organs. It required excellent knowledge about function and structure of the hearing organ and much experience, which Kessel hat at his disposal due to his time in Vienna and especially with Mach in Prague.[30] That was clear to him, and he referred on his time in Prague in several papers and letters, mentioning experiments with animals since 1871 and more than 1000 dissections. Kessel explicitly stressed the importance of his Prague years in a letter to his mother-in-law from 1876[31]: “I took my Prague publications, included newer experiences, and got finally convinced [. . .], that the operation should be performed in this case.”

On May 15, 1886, the Jena University appointed Kessel as an extraordinary professor for otology as the successor of F. E. Weber-Liel. There he opened an outpatient department for otology, which was expanded into a separate clinic for otology in 1890. Ten years later, he achieved a further extension of the otologic clinic in a separate building. He was one of the founders of the “German Otologic Society”. He got additional responsibility for the pupils of the School for Deaf

[28] W. Höflechner; I. M. Wagner (eds.): *Alexander Rollett – Seine Welt in Briefen 1844–1903*. Graz: Akadem. Druck- u. Verlagsanst. 2012. Cf. especially the letter L.743.

[29] Johannes Kessel: *Über das Ausschneiden des Trommelfelles und Mobilisiren des Steigbügels*. Oesterreichische Aerztliche Vereinszeitung, vol. 3, no. 24, 1879, pp. 203–205.

[30] In the French literature, the influence of Mach was estimated as big, that the first stapes mobilization was attributed to him, which is definitely wrong; cf. André A. Sultan: *Histoire de l’otologie*. Acta Oto-Rhino-Laryngologica Belgica, vol. 35, supplement II – V, pp. 1141–1398, here especially p. 1348. The error was adopted recently by Rince A. Tange: *The history of otosclerosis treatment*. Amsterdam: Kugler 2014, p. 6.

[31] Johannes Kessel, *Letter to Sidonie Moritsch*, February 10, 1876, reprinted in: Hoffmann/Löbe/Pfeiffer, *loc. cit*., pp. 200–202.

and Blind, Weimar. Therefore he contributed not only to the progress of otology, but also to the care for hard-hearing people and the development of rehabilitation engineering. He died in Jena at September 22, 1907.

19.6 Further Traces in the Work of Ernst Mach

With the end of the cooperation of Mach and Kessel, Mach finished his active work in the psychophysics of hearing (apart from one single paper on the analysis of the sensation of tones, one decade later). His scientific interest was now directed to other problems. In 1879/80, a new building for the Institute of Physics (and others) was completed in the Viničná in Prague, which allowed Mach to perform new, extensive physical experiments.

Nevertheless, Mach remained to be a member of the board of the "Archive of Otology" until 1903. In his biographical notes, he mentions the work with Kessel mainly as an application of the stroboscopic methods.[32]

19.7 Conclusion

The importance of their work is that Mach and Kessel did the most influential investigations of functionality, geometry, and mechanics of the middle ear after Helmholtz. They utilized the available technology in a perfect way. Refined results were not obtained before the twentieth century, when improved laboratory equipment was available. Since the appearing of Hermann's "Handbook of Physiology" in 1880,[33] the papers from Mach and Kessel are cited in the literature on the psychophysics of hearing again and again, and this still continues.

We have shown that both scientists took profit from this cooperation in their individual further works. Nevertheless, there is no evidence on further scientific or personal mutual contacts between Mach and Kessel.

[32] Ernst Mach, *Selbstbiographie (1913)*, *loc. cit.*, p. 436.

[33] Victor Hensen: *Physiologie des Gehörs*. In: Ludimar Hermann (ed.): *Handbuch der Physiologie*, vol 3. Leipzig: Vogel 1880, pp. 1–142.

Chapter 20
The "Mach Argument" and its Use by Vladimir Fock to Criticize Einstein in the Soviet Union

Jean-Philippe Martinez

Abstract Following Lenin's critique of Mach in *Materialism and Empiriocriticism*, the name of the Austrian philosopher was often used in the Soviet Union to discredit philosophical positions, theories, or individuals, because of the assumed influence he had on them. This is what we define as the "Mach argument", a matter of rhetoric that usually did not require any additional explanations and suited the political discourse required by the Soviet regime. This chapter aims to study its use by the Soviet physicist Vladimir Fock, to better understand the modalities of his scientific discourse. It highlights the complex situation he faced, as his need to defend modern theories of physics against unjustified ideological attacks in the Soviet Union was in some way at odds with his own belief that their interpretations needed revision. In response, Fock elaborated a strategy that required a form of politicization of his professional culture. Nevertheless, we argue that the scientist showed a great capacity for adaptation as it did not mean in any way an abandonment of his traditional scientific values and principles.

Keywords Vladimir Fock · Ernst Mach · Soviet Union · Scientific discourse · General relativity

In 1909, Lenin published *Materialism and Empiriocriticism,*[1] a book devoted to physics and the problems of interpretation. It was in part a reaction to the attempt of Alexander Bogdanov to combine Marxism with Ernst Mach's empiriocriticism.

The present chapter stems from PhD research on Vladimir Fock defended in 2017 at the University Paris Diderot.

[1] Vladimir I. Lenin, *Materializm i Empiriokrititsizm,* Moscow: Zveno 1909.

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The doctrines and positions upheld in the book, most notably against Mach, were taken at face value by Lenin's later followers. Lenin became a reference in the Soviet Union regarding philosophical questions in physics. Thus, during periods of strong ideological pressure, theories and physicists were often attacked for their supposed "idealism" or "positivism", but also "Machism". In many cases, because of the negative connotation of these words, no further explanations were needed, they were only a matter of rhetoric that suited the political discourse required by the Soviet regime. The name of Mach was used to discredit philosophical positions, theories or individuals, because of the assumed influence the Austrian philosopher had on them. This is what we define as the "Mach argument".

The present work wishes to investigate the use of the "Mach argument" by the physicist Vladimir Fock (1898–1974), to better understand the modalities of his scientific discourse. Nowadays Fock is a familiar name to many physicists, especially those busy with quantum theory. The Fock space used to describe quantum states in situations where the number of particles is not fixed, or the Hartree-Fock method of approximation for the determination of the wave function in many-body problems, are recognized as fundamental contributions to quantum physics. Those interested in relativity theory will instead remember his contributions to the motion problem in General Relativity, and possibly his unorthodox views on its interpretation. On this occasion, he criticized Albert Einstein and used the "Mach argument".

Section 20.1 of the present work briefly introduces Fock's interpretation of General Relativity, while Sect. 20.2 investigates the scientific roots of his use of the "Mach argument". Section 20.3 questions the place of the "Mach argument" in the context of the Soviet Union, and helps us then to question the different dimensions of its use by Fock (Sect. 20.4).

20.1 The Unorthodox Interpretation of General Relativity by Vladimir Fock

While still a student,[2] Fock was introduced to relativity theory by his senior colleagues Friedmann and Frederiks at Leningrad University at the beginning of the 1920s.[3] However, it was only at the end of the 1930s, after years of scientific activity devoted to quantum theory that he turned again to relativity problems, and

[2]Fock started University in 1916 at the Faculty of Physics and Mathematics. Graduated in 1922, he made all his career at Leningrad University, where he became full Professor in 1932.

[3]Regarding Fock and relativity, see the very informative paper by Gennady Gorelik, "Vladimir Fock: Philosophy of Gravity and Gravity of Philosophy", in: John Earman, Michael Janssen, John D. Norton (Eds.), *The attraction of gravitation: new studies in the history of general relativity*, Boston: Birkhäuser 1993, pp. 308–331.

obtained important results concerning the problem of motion in General Relativity.[4] At that time Fock also developed a very personal point of view on what Einstein's theory really was (and was not). This led him to deliver a sweeping criticism of Einstein's own understanding of General Relativity. In spite of the skepticism of his colleagues both in the East and West, he defended his unorthodox interpretation of the theory until the end.

The main point of Fock's criticism is that General Relativity is actually not "general" at all: the general principle of relativity not only is not a generalization of the special (1905) one, but has rather to be considered as a restriction of the latter. In his reasoning Fock relied on fundamental differences between the two theories, and more particularly regarding the approach of space and time. His conception opposed the "homogeneous" space-time of Minkowski (Special Relativity) with the "inhomogeneous" one of Einstein (General Relativity). The homogeneity of the former is physically characterized by the absence of privileged points in space and time, of privileged directions as well as of privileged inertial frames. This is expressed mathematically by the Lorentz group being the invariance group of the pseudo-euclidean Minkowski metric. This is an example of a more general situation where space-time admits a transformation group, a situation which requires that its curvature must be constant. Nevertheless, the theory of universal gravitation was based by Einstein on the idea of abandoning the uniformity of space as a whole. Thus, in such an inhomogeneous space-time with a varying curvature, there is no transformation group as in Minkowski spacetime.

For Fock, the appraisal of "relativity" was naturally connected with uniformity of space and time. Indeed, the possibility to speak of relativity of position (invariance under translations), direction (rotations) and of absence of privileged observation frames (Lorentz boosts) is guaranteed by the Lorentz invariance. In the inhomogeneous case, there is no way to speak of relativity since the Lorentz invariance is lost: "in the theory of nonuniform space-time, there is no principle of relativity [. . .] If one uses the word relativity consistently, then the general principle of relativity is nonsensical."[5] Consequently, relativity is restricted in the theory of General Relativity, but also, the requirement of general covariance is not crucial to the theory as neither is the principle of equivalence. Despite the heuristic value in the discovery of General Relativity that Fock granted to the latter, he did not consider it instrumental to the physical meaning of it. In conclusion, for the Soviet physicist, the "Einstein's theory", was a mere, albeit very successful and impressive, theory

[4]Vladimir A. Fock, "Sur le mouvement des masses finies d'après la théorie de gravitation einsteinienne", in: *Journal of Physics* (Moscow), 1/2, 1939, pp. 81–116.

[5]Vladimir A. Fock, "Three Lectures on Relativity Theory", in: *Review of Modern Physics*, 29, 1957, p.326 (325–333).

of gravitation. As he used to say "the physical relativity can not be general and the general relativity can not be physical" ("*la relativité physique ne peut être générale et la relativité générale ne peut être physique*").[6]

20.2 Fock and the "Mach Argument"

All this explains why Fock did not hesitate in the 1950s to attack directly Einstein's views.[7] One of the most peculiar expressions of his criticism of Einstein was an article published in the *Pravda* in 1956 untitled "Half a Century of a Great Discovery. On Albert Einstein's Theory of Relativity".[8] This article, prepared a few months after Einstein's death, has an ambivalent tone. Indeed, Fock highlighted the successes of the theory of relativity, but he was as well promoting his own interpretation and criticizing Einstein's deep misunderstanding of the real signification of General Relativity. Among the considerations developed by Fock, we find a special attention to Einstein's philosophical views, and in that frame, a reference to the influence Mach had on him.[9] As Fock considered that influence negative, he simply made use of the "Mach argument".

Nevertheless, it is necessary to underline that Fock's use of the "Mach argument" aimed at Einstein in the frame of General Relativity was restricted to a very short period. Indeed, its first use occurred in 1953, and its last one in 1956. That time period will be put back into context in the next sections. However, we want first to focus on the form and the scientific meaning of the "Mach argument" in Fock's discourse. During these 4 years Fock published nineteen original[10] articles. Twelve discussed General Relativity. But most interesting is that, with only one

[6] Vladimir A. Fock, "Les principes physiques de la théorie de la gravitation d'Einstein", in: *Annales de l'I.H.P., section A*, 5/3, 1966, p.212 (205–215).

[7] Fock's conception of Einstein's theory definitely requires a more detailed account. The interested reader is referred to the paper of Gorelik, "Vladimir Fock: Philosophy of Gravity and Gravity of Philosophy", *op.cit.*

[8] Vladimir A. Fock, "Polveka velikogo otkrytiya. O teorii otnositel'nosti Al'berta Eynshteyna", in: *Pravda*, 106, April 15, 1956.

[9] The present article does not intend to question that influence. It has been already well developed in the literature, and must be considered as an established fact. See, among others, Vladimir Vizgin, "The Role Played by Mach's Ideas in the Genesis of the General Theory of Relativity", in: Yuri Balashov/Vladimir Vizgin (Eds.), *Einstein Studies in Russia*, Boston: Birkhäuser 2002, pp. 45–89, or John Stachel, "Einstein and the Rigidly Rotating Disc.", in: *General Relativity and Gravitation*, 1, 1979, pp. 30–45. Einstein himself recognized the role played by Mach in the development of his ideas concerning General Relativity. See, for instance, his autobiographical notes: Albert Einstein, *Autobiographical notes: A Centennial edition*, Schilpp P. A. (trans. and ed.), La Salle, Illinois: Open Court 1979.

[10] Slightly revised versions of former articles, and translations, have been excluded.

exception,[11] every time Fock mentioned Einstein as an individual,[12] he used the "Mach argument" to discredit him. It happened six times.

The diversity of the documents where Fock used the "Mach argument" is also a striking point to every commentator. It goes from Fock's monography on General Relativity, a purely scientific journal, *Uspekhi Fizisheskikh Nauk*, a popular scientific journal, *Priroda*, a philosophical journal, *Voprossy Filosofii*, to a newspaper, *Pravda*. In other terms, we find a book,[13] two technical articles where Fock exposed his views on General Relativity,[14] one review of Einstein's autobiographical notes,[15] a political article denouncing the "ignorant criticism" of Soviet philosophers,[16] and a newspaper article.[17] Fock just suddenly systematized the "Mach argument" any time it was possible.

Depending on the publications, Fock presented the "Mach argument" in different ways. This could be purely rhetorical: "Concerning the philosophical views of Einstein, all his life he was influenced by the idealist philosophy of Mach"[18]; or part of a more developed argumentation:

> On the question of privileged systems of coordinates Einstein, the founder of gravitational theory, maintained a point of view opposite to ours, denying their existence in all cases. This is connected with his aforementioned preference for the local method of discussing properties of space (which method is the basis of Riemannian geometry) and his underestimation of the importance of considering space as a whole. Undoubtedly the philosophical attitude of Einstein, influenced throughout his life by the ideas of Mach, played its part in this.[19]

Considerations on space, or space-time, were actually in General Relativity the key point of Fock's rejection of Mach's ideas. Fock defended an absolute conception

[11]That exception can be easily justified. It is the article "Relativity Theory" of the *Great Soviet Encyclopedia* (Vladimir A. Fock, "Otnositel'nosti teoriya", in: Vvedenskiy B. A., *Bol'shaya sovetskaya entsiklopediya*, 31, 1956, pp. 405–411). Fock wrote the technical part. But even if he decided there to discuss Einstein's interpretation he could not go further in a philosophical criticism as a second article by Aleksandr D. Aleksandrov was devoted to the "epistemological value" of the theory (Aleksander D. Aleksandrov, "Otnositel'nosti teoriya (teoretiko- poznavatel'noye znacheniye)", in: Vvedenskiy B. A., *Bol'shaya sovetskaya entsiklopediya*, 31, 1955, pp. 411–416).

[12]The other documents dealing with General Relativity were simply summaries of technical points presented during conferences and articles criticizing another Soviet physicist, F. I. Frankl.

[13]Vladimir A. Fock, *Teoriya prostranstva, vremeni i tyagoteniya*, Moscou: Gostekhizdat 1955.

[14]Vladimir A. Fock, "Ponyatiya odnorodnosti, kovariantnosti i otnositel'nosti v teorii prostranstva i vremeni.", in: *Voprosy filosofii*, 4, 1955, pp. 131–135; Vladimir A. Fock, "Sovremennaya teoriya prostranstva i vremeni.", in: *Priroda*, 12, 1953, pp. 13–26.

[15]Vladimir A. Fock, "Zamechaniya k tvorcheskoy avtobiografii Al'berta Eynshteyna.", *Uspekhi fizicheskikh nauk*, 59/1, 1956, pp. 107–117.

[16]Vladimir A. Fock, "Protiv nevezhestvennoy kritiki sovremennykh fizicheskikh teoriy", *Voprosy filosofii*, 1, 1953, pp. 168–174.

[17]Fock, "Polveka velikogo otkrytiya. O teorii otnositel'nosti Al'berta Eynshteyna", *op.cit.*

[18]*Ibid*.

[19]Vladimir A. Fock, *The theory of space, time, and gravitation*, 2nd rev. ed., translated from the Russian by N. Kemmer, New York: Macmillan 1964, p.4.

of space which differed from Newton's one. The Briton considered the absolute space as an active part of all mechanical processes which was not subjected to the influence of masses and their movements.[20] For Fock:

> the idea of absolute space as an active part of mechanical processes could be saved if we understand absolute space as any space that has his own objective properties (for example, a specific metric), even if these properties are subjected to the influence of masses and their movements.[21]

Fock considered that the idea of a space-time with objective properties in General Relativity could be extended to the notion of acceleration. In this case, he sometimes referred to his teacher, Friedmann, who cited Lomonosov: "Who has seen among chefs, such a simpleton that he would turn the fireplace around the roast" ("*Qui verrait un sot de cuisinier qui tournerait le foyer autour du rôti*").[22] All of this definitely guided Fock concerning the principle of equivalence, and his considerations on the privileged frames of reference.

On the contrary, Mach had a reverse attitude toward what we can call the "geometrical absolutism".[23] Thanks to the abandoning of absolutism the Austrian philosopher could elaborate his so-called Mach principle. Combined with the discussions on the Newton's bucket, and generally the criticism of classical mechanics, all of this had a great effect on Einstein.[24] Then, Fock considered that:

> Einstein tries to introduce a conception of time based on the subjective sensations of duration and sequence of events, which then arithmetize itself thanks to the help of clocks. Similarly, the concept of space is introduced (or "explained") based on the sensations of the observer conducting measurements with the help of overlay solids. Arguments of that type, in the spirit of positivist philosophy, in the spirit of Mach and Poincaré, not only are not necessary to justify the theory of relativity, but are also directly an obstacle of a correct understanding of that theory.[25]

This quote makes clear that Fock's use of the "Mach argument" was mainly aimed at Mach's influence on Einstein regarding his rejection of objective space, time and acceleration. Moreover, Einstein wanted to pursue a relativistic program similar to the one followed that Mach.[26] In his progress towards General Relativity he was highly motivated by the desire to widen the allowed classes of reference systems

[20] It has to be underlined that while Newton was guided by religious convictions in building his absolute conception of space and time, Fock was an atheist who rejected any arguments of that type. In his approach to General Relativity, he put the emphasis on the necessity for physical content in scientific explanations and was working in a materialist perspective.

[21] Fock, "Zamechaniya k tvorcheskoy avtobiografii Al'berta Eynshteyna.", *op.cit*, p.110.

[22] See Vladimir A. Fock, "Les systèmes de Ptolémée et de Copernic à la lumière de la théorie Générale de la relativité", in: *Questions* philosophiques, 1, 1952, p.150 (147–154).

[23] About Mach and the "geometrical absolutism", see Vizgin, "The Role Played by Mach's Ideas in the Genesis of the General Theory of Relativity", *op.cit.*, pp. 50–52.

[24] *Ibid.*, pp. 54–58.

[25] Fock, "Sovremennaya teoriya prostranstva i vremeni.", *op.cit.*, p.26.

[26] See Vizgin V., "The Role Played by Mach's Ideas in the Genesis of the General Theory of Relativity", *op.cit.*, pp. 65–70.

in comparison with Special Relativity. In that direction, he considered his principle of equivalence as central because, like Mach, he wanted to keep in his theory the “relativity of inertia” (Mach principle). For Fock, Einstein made there his worst mistake. He considered that in order to construct a theory of gravitation and to apply it to physical problems, it is insufficient to study space and time only locally. Or the principle of equivalence came from a local description, and nothing allows scientists to consider that in the universe regarded as a whole, it could be applied everywhere.

20.3 Rhetoric in the Soviet Union

We just made clear that Fock’s use of the “Mach argument” had deep roots in scientific conceptions of the Austrian philosopher which highly influenced Einstein’s approach of General Relativity. However, another element needs to be taken into account, since at the beginning of the 1930s Fock had become a supporter of dialectical materialism and claimed that this had direct effects on his contemporary understanding of General Relativity. The introduction of Fock’s monograph on the theory of gravitation makes this very clear:

> The philosophical side of my views on the theory of space, time and gravitation was formed under the influence of the philosophy of dialectical materialism. [. . .] The teaching of dialectical materialism [. . .] helped me also to understand correctly, and to interpret, the new results obtained by me.[27]

Given that new element, the “Mach argument” could take a new sense in Fock’s rejection of Einstein’s understanding of General Relativity. Indeed, as we briefly mentioned in introduction, with respect to Lenin’s writings and the Soviet ideological line it had also a particular significance. Then, it seems necessary to reconsider Fock’s argumentation in its context.

Nikolai Krementsov published in 1997 a very powerful book entitled *Stalinist Science*[28] where he took into consideration some aspects often forgotten as the role of rituals and rhetoric. In particular, he focused on three components: the language, the public behavior and the criticism. Then, Krementsov established that the professional culture of the scientific community perfectly reflected the symbiosis between the State and the scientists, as they adopted the rhetoric, etiquettes and critical style of the state bureaucracy.[29] While the authorities tried to impose a unique ideological line and to keep control on the scientific community, scientists were in return engaged in a struggle to pursue their career objectives or to legitimate their scientific interests. The concept of “Stalinist science” can actually be applied to a period which finds its roots in the system established during the 1920s and which continued after Stalin’s death. Indeed, even if with Khrushchev and the

[27] Fock, *The theory of space, time, and gravitation, op.cit.*, p.8.

[28] Nikolai Krementsov, *Stalinist Science*, Princeton: Princeton University Press 1997.

[29] *Ibid.,* p.6.

De-Stalinization some of its characteristics gradually dissipated, in no way was 1953 a complete rupture. Moreover, World War II could be considered as a break in the process of Stalinization. So, we can distinguish two main periods for our development: the 1930s as a result of the "Great Turn", and the Cold War with the *Zhdanovshchina* at its threshold.

1929 was a turning point for the Soviet society. With the "Great Turn", rapid industrialization and collectivization of agriculture were accompanied by the establishment of a definitive single ideological line (dialectical materialism). It marked the beginning of a specific cultural policy which had a great impact on science. A strict control by the communist Party led to the politicization of the Soviet professional culture, which adopted the lexicon and the polemic style of the authorities. Political campaigns were launched against the "Menshevik idealism" or against the "servility to the West". The role of rhetoric was reinforced as the scientific community wanted to demonstrate its conformity with the ideological line of the Party, its policies, and then to justify its work. Scientists generalized the use of words such as "practical" or "Marxist" but also invented a new rhetorical tool, "the founder father", to defend an acceptable origin of their work. The scientific traditional criticism also extended itself toward a "social" criticism, to denounce or expose scientific deviations and perversions. It was directly inspired by the polemic and critical style of Marx or Lenin. Thus, the scientific content of criticized research lost its importance in the scientific discourse and was replace by individual attacks and philosophical criticism. In short, scientists' adaptation "politicized the scientific discourse and polarized the community into opposing camps – 'us' and 'them'".[30]

The *Zhdanovshchina,* as a Soviet cultural doctrine developed by Central Committee secretary Andrei Zhdanov in 1946 was a confirmation of that tendency, and its formulation on a more official level after the war. Zdhanov proposed that the world be divided into two camps: the "imperialistic", headed by the United States; and "democratic", headed by the Soviet Union. He especially revived the process engaged in the 1930s regarding a unique ideological line, and began the most intense ideological campaign in the history of Soviet scholarship. Of course, the aim was to re-establish after the war the ideological primacy and the authority of the Communist Party. In *Stalin's Great Science,* Alexei Kojevnikov put forward that this period was rhythmed by different ritualistic performances, or cultural games, as *diskussia* (disputation) and *kritika i samokritika* (criticism and self-criticism).[31] Usually played within the Party structures, they spread to the scientific community, leading to a more generalized and virulent practice of criticism. In the words of Krementsov, criticism reaffirmed "the primacy of political and ideological values

[30] *Ibid.*, p.53. For more on the "Politicization of Professional Culture" during the 1930s see pp. 45–53.

[31] Alexei B. Kojevnikov, *Stalin's Great Science: The Times and Adventures of Soviet Physicists,* London: Imperial College Press 2004, pp. 197–203.

over traditional scientific values.”[32] About rhetoric there was a particular attention to the “patriotic” language, leading to a complete distinction of “soviet” science and “western” science. A special kind of name-calling made its apparitions, the scientific names being transformed in different “isms” thus defining completely an ideological position. Using the name of an enemy allowed to denounce the sterility, servility or idealism or the opponents.

Concerning physics, as mentioned in introduction, Lenin became one of the main references, and his opposition to Mach in *Materialism and Empiriocriticism* was widely spread in every branch of the subject. While Lenin argued that human perceptions correctly and accurately reflect the objective external world, in Mach’s philosophy, the scientific laws, somewhat idealized, had more to do with describing sensations than with reality as it exists beyond sensations. Then, attacks for “idealism”, “positivism” or “Machism” were generalized, whatever was the real physical content of the problem discussed. Rhetorical elements like the “Mach argument” were widely used by Soviet philosophers to deny the validity of the modern theories. Moreover, scientists themselves began to use them. For instance, in quantum mechanics, while the crucial question of observation was widely discussed by the scientific community, in the Soviet Union, for being close to Bohr, Fock himself was simply accused in 1937 by the physicist K. V. Nikol’skiy to be an “idealist” influenced by Mach.[33]

20.4 The “Mach Argument” in Defense of General Relativity?

As a consequence of that peculiar atmosphere, many attacks aimed at relativity in the Soviet Union were of rather poor intellectual content. Most often they came from incompetent people with a shallow if not wrong understanding of the theory. The division in two camps guided to frequent criticisms directed against western specialists of General Relativity, Arthur Eddington, James Jeans or Philipp Frank to quote a few. Einstein’s views were generally criticized for the influence exerted on him by Mach’s philosophy. But more critical, the question of the existence of a world independent of our sensations, led to flatly condemned relativities of length, time or simultaneity, simply because of their postulated incompatibility with the objective materiality of the world. Thus, inevitably, some commentators called for a complete rejection of the theory.[34]

[32] Krementsov, *Stalinist Science*, *op. cit.*, p.222. More on “‘Politically Correct’ Science” and the *Zhdanovshchina* on pp. 215–225.

[33] Konstantin V. Nikol’skiy., “Otvet V. A. Foku”, in: *Uspekhi Fizicheskikh Nauk*, 17/4, 1937, p.555 (554–560).

[34] More on the reception of Einstein’s ideas in the Soviet Union in Alexander S. Vucinich, *Einstein and Soviet Ideology*, Stanford: Stanford University Press 2001. See also Kojevnikov’s review

Can we simply add Fock to this disastrous balance sheet because of his endorsement of dialectical materialism and his use of the "Mach argument"? The answer is no. Not only because as showed before, Fock's criticism of Mach's influence on Einstein was developed on a scientific basis, but also because as surprising as it can be, Fock revealed to be in the Soviet Union one of the main defender of Einstein's theory. Indeed, Fock fully accepted Special Relativity, and despite his criticism of the philosophical implications of General Relativity, he also largely promoted its mathematical core and main principles:

> As a conclusion, we would like to underline that our critical remarks do not touch the basic equations of the theory of gravitation, and generally the essence of that theory, that without any doubts is a great realization of human genius.[35]

Each of his articles were occasions to be very laudatory toward what he retained of the theory, as a theory of gravitation.

Fock's ambition at the beginning of the 1950s was not only to diffuse his own conception of General Relativity, but also to defend the theory against undue philosophical offensives. In 1952, a book edited by the philosopher Aleksandr A. Maksimov and published by the Academy of Sciences, particularly attacked the theory.[36] The scientific community had to react, and Fock led the counter-offensive. In his article of 1953 against the ignorant criticism of Soviet philosophers,[37] he ferociously denounced the damages caused to modern physics by Maksimov and his followers.[38]

However, that same article was actually the first one where Fock used the "Mach argument". And even if Fock's recourse to the "Mach argument" was part of a solid scientific argumentation, it remained a typical rhetorical tool used by the philosophers who attacked the General Relativity. Then, why did Fock take up this argument, at the exact time when his defense of the theory was the most necessary? An answer can be found in the correspondence Fock had with his colleague Igor Tamm.[39] Indeed, Tamm himself was disturbed by Fock's attitude.

of this book: Alexei B. Kojevnikov, "Einstein and Soviet Dogma; An elusive Relationship", in: *Physics Today*, 55/9, 2002, pp. 59–60.

[35]Fock, "Polveka velikogo otkrytiya. O teorii otnositel'nosti Al'berta Eynshteyna", *op.cit*.

[36]Alexander A. Maksimov et al. (eds.), *Filosofskie voprosy sovremennoi fiziki*, Moscow: Izdatelstvo Akademii Nauk SSSR, 1952.

[37]Fock, "Protiv nevezhestvennoy kritiki sovremennykh fizicheskikh teoriy", *op.cit*.

[38]For more on that episode, and particularly the way Fock obtained the help of part of the scientific community which intervened directly with the authorities to publish his article, see Vladimir Vizgin, "The nuclear shield in the 'thirty-year war' of physicists against ignorant criticism of modern physical theories", in: *Physics-Uspekhi*, 42, 1999, pp. 1259–1283. As indicate by its title, this article is particularly rich to what concerns all the attacks on modern physics in the Soviet Union from the 1930s to the 1950s.

[39]Igor Tamm was a Soviet theoretical physicist working in Moscow, a Nobel laureate in 1958 with Ilya Frank and Pavel Cherenkov for their discovery and interpretation of Cherenkov radiation.

When the latter published in 1956 his *Pravda* article on Einstein,[40] Tamm thought that it was inappropriate, especially given the jubilee circumstances. But Fock gave the following justification:

> [. . .] I had to mention the erroneous philosophical declarations of Einstein. To occult them would be a tactical error. The only manner to give the theory of relativity (but also quantum mechanics) immunity against the attacks of philosophers, is that the physicist himself recognize the philosophical errors of the author of the theory, and separate these errors from the substance of the theory.[41]

Fock’s conclusion exposed clearly his tactics: in the context of the Soviet Union, to avoid a frontal clash with dialectical materialism, the defense of modern theories could not spare a critical revision of some of their concepts, but also alternate expositions and interpretations. Moreover, what really mattered was that the publication of his article in such a newspaper, known to represent the official line of the Communist Party, had to be considered as an official recognition of the theory. That Fock disagreed with Einstein was one thing, which had for him a deep scientific meaning. But it was another thing to protect Einstein’s theory from ignorant criticism, and Fock understood that to put forth his own interpretation, influenced by dialectical materialism, could have a consequent effect.

Clearly, the use of the “Mach argument” participated to that process of defense of the theory. Fock was conscious of the role played by rhetoric in the scientific discourse, and to protect the modern theories, he needed the support of the political authorities. As highlighted by Kremenstov in a more general case, Fock simply accepted the politicization of the Soviet professional culture, and adopted the lexicon and the polemic style of the authorities.

20.5 Conclusion

Fock’s situation was complex. The necessity to defend the modern theories of physics against undue ideological attacks in the Soviet Union was somehow in contradiction with his own conviction that their interpretations needed to be revised. The Soviet physicist had to elaborate a strategy that allowed him both to put forward General Relativity as a great achievement of physics while underlying some major issues of its interpretation. In this direction, Fock accepted to follow some implicit rules of his specific context. His practice of criticism, his repeated references to Lenin in his publications, his adoption of a lexicon that emphasized an opposition between “idealism” and “materialism” are all elements that shows Fock as a scientist who mastered the Soviet scientific discourse.

[40] Fock, “Polveka velikogo otkrytiya. O teorii otnositel’nosti Al’berta Eynshteyna”, *op.cit.*

[41] Letter from Fock to Tamm, November 17, 1955. Archives of the Russian Academy of Sciences, Saint-Petersburg, 1034-3-160.

Mach is a symbol of all the perversions of the "Stalinist science". However, in that case, the "Mach argument" helps us to show that Fock did not politicize his professional culture at any price, and that in no manner he abandoned his traditional scientific values, and betrayed his principles. The scientific content carried by the "Mach argument" in the case of Einstein was primordial, and was probably the only reason why Fock considered its use to be legitimate. Concerning Quantum Mechanics Fock was living a similar situation. Although defending the theory against ignorant criticism he developed a slightly different interpretation than the mainstream one led by Niels Bohr. Fock then criticized Bohr as he did Einstein. But, while the "Mach argument" was also generalized in the Soviet Union against Bohr, Fock did not used it in that case. Indeed, he could not identify a striking technical or even philosophical point which directly connected Mach to Bohr. Then, he simply elaborated on the reasons why he considered Bohr's approach as "idealist".[42] In that, for having always favored the correctness of his scientific content, Fock's adaptation to the Soviet context was remarkable.

The abandon of the "Mach argument" from 1957 was not due to an inflexion in Fock's interpretation of General Relativity which remained the same until his death in 1974. In the Soviet Union, the name of Mach continued to be waved like a scarecrow, but simply, the Marxist philosophers dealing with physics had lost their influence. Physicists, partly thanks to their achievement in the nuclear program had won more autonomy with respect to the authorities.[43] Fock's audience had changed, especially as his opinion began to find some echo abroad. Then, gradually, the Soviet rhetorical features of his scientific discourse just dissipated.

[42] Vladimir A. Fock, "Kritika vzglyadov Bora na kvantovuyu mekhaniku", in: *Uspekhi fizicheskikh nauk*, 45/1, 1951, pp. 3–14.

[43] See Vizgin, "The nuclear shield in the 'thirty-year war' of physicists against ignorant criticism of modern physical theories", *op.cit*.

Chapter 21
The Scientific World-Conception in the Making: Towards the Ideological Roots of Logical Empiricism in Berlin and in Vienna

Günther Sandner

Abstract The essay examines the ideas and organizations of 'late enlightenment' in both European centers of interwar Logical Empiricism, Berlin and Vienna. It aims to demonstrate that secular, laically and (partly) anti-clerical movements such as the Monists, the Freethinkers and other groups promoting non-religious ethics anticipated and, in part, conceptualized the idea of a scientific world conception. The scientific-world conception, however, was not a purely scientific enterprise. Rather, it continued the historical tradition of a socially liberal enlightened reform project, whose political manifestations ranged from decidedly Marxist to a social-oriented, liberal-bourgeois spectrum.

21.1 Are There Any Ideological Roots of Logical Empiricism?

The answer to the question of whether there are any ideological roots of Logical Empiricism is far from self-evident. Logical Empiricism is a theory in epistemology, as well as a historical movement within Western philosophy of science.[1] It is not a political ideology; however, research on the history of philosophy of science has convincingly demonstrated that politics and the philosophy of science cannot be strictly separated. Like all philosophical discourses, logical empiricist ones must be viewed within their own historical framework and related to the social conflicts and

FWF—Austrian Science Fund (P 24306-G17): The Politics of Logical Empiricism.

[1] Alan Richardson/Thomas Uebel (Eds.), *The Cambridge Companion of Logical Empiricism*. Cambridge: Cambridge University Press 2007.

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F. Stadler (ed.), *Ernst Mach – Life, Work, Influence*, Vienna Circle Institute Yearbook 22, https://doi.org/10.1007/978-3-030-04378-0_21

controversies of their particular time. The Vienna Circle or some of its members constitute a striking example of the complex relationship between philosophy, science and politics.[2]

What can be said about the ideological roots of Logical Empiricism? Aside from a particularly liberal-left wing of the youth movement,[3] "late enlightenment" ideas and organizations[4] defined an ideological milieu in which many later philosophers of the logical empiricist environment were shaped. Although these two traditions must be analyzed as separate phenomena, they are also connected in a number of ways. Influential philosophers and intellectuals who espoused logical empiricist ideas—including liberal philosopher Friedrich Jodl—were active in both movements. A leading monist and chairman of the Ethical Culture society Gesellschaft für ethische Kultur, Jodl was also one of the speakers at the youth movement's famous 1913 ceremony at the top of the Hohen Meißner, a mountain in Hessian, Germany[5]; he is also mentioned in the "historical background" section of the Vienna Circle Manifesto.[6]

The debate over the ideological roots of Logical Empiricism does not necessarily imply that the movement was politically or ideologically oriented, at least not in explicit terms. In fact, many of the later logical empiricists stressed the apolitical and non-ideological character of their intellectual work, and focused only on its

[2]Thomas E. Uebel, "Political Philosophy of Science in Logical Empiricism: The Left Vienna Circle," in: *Studies in History and Philosophy of Science*, Vol. 36, 2005, pp. 754–773. Günther Sandner, "Political Polyphony. Otto Neurath and Politics Reconsidered", in: Maria Carla Galavotti/ Elisabeth Nemeth/ Friedrich Stadler (Eds.), *European Philosophy of Science –Philosophy of Science in Europe and the Viennese Heritage*. Dordrecht, Heidelberg, New York, London: Springer 2014, pp. 211–222. George Reisch, *How the Cold War Transformed Philosophy of Science: To the Icy Slopes of Logic*. Cambridge, New York: Cambridge University Press 2005. Donata Romizzi, "War die wissenschaftliche Weltauffassung des Wiener Kreises nicht doch auch eine Weltanschauung?" In: Elisabeth Nemeth/ Friedrich Stadler (Eds.), *Die europäische Wissenschaftsphilosophie und das Wiener Erbe*. Wien: Springer 2013, pp. 127–151. Donata Romizzi, "The Vienna Circle's 'Scientific World-Conception': Philosophy of Science in the Political Arena", in: *Hopos: The Journal of the International Society for the History of Philosophy of Science*, Vol. 2, No. 2, 2012, pp. 205–242.

[3]This will be the subject of an edition currently in progress: Christian Damböck/ Günther Sandner/ Meike Werner (Eds.), *Logical Empiricism, Life Reform and the German Youth Movement*. Dordrecht: Springer 2019 (forthcoming).

[4]Friedrich Stadler coined this term in his essay "Spätaufklärung und Sozialdemokratie in Wien 1918–1938", in: Franz Kadrnoska (Ed.), *Aufbruch und Untergang*. Wien, München, Zürich: Europa 1981, pp. 441–473.

[5]The Journal *Aufklärung und Kritik*, Vol. 21, No. 3, 2014 published a special issue on Friedrich Jodl ("Friedrich Jodl und das Erbe der Aufklärung"). For Jodl as a speaker at the Hohen Meißner Treffen cf.: Jürgen Reulecke, see "Utopische Erwartungen an die Jugendbewegung 1900–1933", in: Wolfgang Hardtwig, *Utopie und politische Herrschaft im Europa der Zwischenkriegszeit.* München: Oldenburg 2003, pp. 199–218, p. 199. Otto Neurath, for instance, discussed his unrealized plans for a habilitation at the University of Vienna with Friedrich Jodl. Otto Neurath to Friedrich Jodl, 12 October 1903 (Wienbibliothek, Sammlung Wilhelm Börner).

[6]Friedrich Stadler/ Thomas Uebel (Eds.), *The Scientific World-Conception. The Vienna Circle*, Wien, New York: Springer 2012, pp. 75–116, p. 76.

scientific relevance. Not only philosophers such as Moritz Schlick rejected any political ambitions of their intellectual work, even such forceful political thinkers as Otto Neurath stressed repeatedly the apolitical character of their scientific expertise.[7] A historical approach to the subject, however, demonstrates the clear existence of a political and ideological milieu in which many later representatives of Logical Empiricism were actively involved.

During the years between WWI and WWII, Vienna and Berlin were the centers of logical empiricist thought in continental Europe, and in the late 1920s, a similar organizational structure existed in both cities. Relatively open forums and discussion groups served both core and associated members, while an official association promoted communication and advanced scientific knowledge; in Berlin, the Society for Empirical/Scientific Philosophy, and in Vienna, the Ernst Mach Association. Although there were far-reaching personnel overlaps, the associations and discussion groups were not identical and pursued different goals. While both the Berlin Group and the Vienna Circle restricted their forum activities to the exchange of philosophical ideas, their respective associations addressed a wider audience. They organized lectures, seminars and congresses, edited a journal as a joint venture ("Erkenntnis") and in Vienna's case, published the 1929 programmatic manifesto "The Scientific Conception of the World."[8] Although the Berlin Group published no comparable manifesto, however, its representatives did release several programmatic texts, such as Alexander Herzberg's newspaper article on "Empirical Philosophy," in which he advocated a unified world view based upon experience.[9]

The most prominent members of the Berlin society included Hans Reichenbach, Walter Dubislav, Kurt Grelling and Alexander Herzberg, while the Viennese Ernst Mach Association was represented by its chairman, Moritz Schlick, and additionally by Otto Neurath, Rudolf Carnap, Hans Hahn and Philipp Frank. Additionally, politically prominent associates such as Karl Korsch (Berlin) and Edgar Zilsel (Vienna) are worth noting although they were just peripheral members.

The following essay examines the second part of these intellectual influences mentioned above—that is, the ideas and organizations of late enlightenment—and focuses on both European centers of interwar logical empiricism, Berlin and Vienna. It aims to demonstrate, that secular, laically and (partly) anti-clerical movements such as the Monists, the Freethinkers and other groups promoting non-religious ethics anticipated and, in part, conceptualized the making of a scientific world view. To that end, I argue that the scientific-world conception was not a purely scientific enterprise. Rather, it continued the historical tradition of a socially

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[7] For Otto Neurath's self-image as an apolitical social engineer ("Gesellschaftstechniker") cf. Sandner, Otto Neurath, loc. cit., pp. 114–147.

[8] Stadler/Uebel, Scientific World-Conception, loc. cit.

[9] Alexander Herzberg, "Empirische Philosophie", in: Vossische Zeitung, 8. August 1928, p. 11. For a detailed discussion on possible quasi-manifestos of the Berlin Society cf. Nikolay Milkov, "Einleitung des Herausgebers", in: Nikolay Milkov (Ed.), *Die Berliner Gruppe. Texte zum Logischen Empirismus*, Hamburg: Meiner 2015, pp. ix–lxi.

liberal enlightened reform project, whose political manifestations ranged from decidedly Marxist to a social-oriented, liberal-bourgeois spectrum as Friedrich Stadler demonstrated the problem using the examples of Moritz Schlick and Otto Neurath.[10]

This political milieu, however, was defined not only positively—in terms of its common ideological and political convictions—but also negatively, by its common opponents irrational philosophy, Catholic clericalism, religious dogmatism, nationalism, and, not least, anti-Semitism. Many prominent logical empiricists, including Otto Neurath and Hans Reichenbach, were of Jewish extraction. Whether or not they self-identified as practicing or religious Jews, anti-Semites nonetheless identified and attacked them as such.[11] Scientific knowledge and the promotion of free and liberal discourse were set on the political agenda against reactionary, metaphysical attempts in the field of politics. However, the scientific world-conception was not intended only a scientific idea, but as a political one as well, as Otto Neurath argued in a socialist daily newspaper. In an article with the same title as the manifesto ("Scientific World-Conception,") Neurath praised Marx and Mach as visionaries who liberated humankind from traditional thinking and paved the way for the scientific world-conception.[12]

21.2 Late Enlightenment and Scientific World-Conception

In both Vienna and Berlin, a number of associations in the spirit of the "late enlightenment" were active. The majority of them were founded during the late nineteenth century, but remained active during the interwar years. They included the Monist League, the Freethinker's Association, the German Society for Ethical Culture, and the Ethical Society or, as it was called from 1919 onwards, the Ethical Community in Vienna. All of them combined scientific secular and non- or antireligious thinking in their programs.[13]

[10] Friedrich Stadler, *Der Wiener Kreis. Ursprung, Entwicklung und Wirkung des Logischen Empirismus im Kontext*. Wien: Springer 2015, pp. 285–292.

[11] By 1906, Gustav Schmoller attributed "Jewish race properties" ("jüdische Rasseeigenschaften") to Otto Neurath. The young Neurath was a Roman-Catholic with a Jewish father who converted to Catholicism before Neurath's birth (Sandner 2014, pp. 47–48). In the 1920s, the journal "Schulwacht," Vol. 9, No. 2, 1923, pp. 19–20, published an anti-Semitic satire of Otto Neurath.

[12] Otto Neurath, "Wissenschaftliche Weltauffassung", in: Arbeiter-Zeitung, 15. Oktober 1929, pp. 17–18.

[13] For Germany cf. Horst Groschopp, *Dissidenten. Freidenkerei und Kultur in Deutschland*. Berlin: Dietz 1997. Jochen-Christoph Kaiser, *Arbeiterbewegung und organisierte Religionskritik*. Stuttgart: Klett-Cotta 1981. For Austria: Stadler, Spätaufklärung, loc. cit.; Marcus Patka, *Freimaurerei und Sozialreform. Der Kampf für Menschenrechte, Pazifismus und Zivilgesellschaft in Österreich 1869–1938*, Wien: Löcker 2011.

The political climate was similar in both Germany and Austria, where the capitals represented a socialist and liberal intellectual and cultural hegemony. Thus, conservative provinces treated the major cities with hostility. Additionally, nationalists rejected the cosmopolitan 'flair' they perceived in the capitals, often defining this atmosphere as typically "Jewish." Despite the modern and liberal atmosphere of Vienna and Berlin, however, there were also strong counterforces not only around but also within the capitals. In addition to a liberal and "red" political and intellectual climate, a "black" one also existed[14]; particularly in Austria, the universities were focal points of this climate.[15]

Nevertheless, from the turn of the century to the years between WWI and WWII, both the German and the Austrian capital were breeding grounds for modern social and cultural reform movements. In 1906, zoologist and Darwinist Ernst Haeckel founded the "German Monist League," and in 1913, sociologist Rudolf Goldscheid—who is also mentioned in the Vienna Circle's manifesto—[16] established an Austrian branch of the League. The German and Austrian monists cooperated closely with another and formed an alliance with the Freethinker's Association. In Austria, the "Free Federation of Cultural Associations" ("Freier Bund kultureller Vereine") was an umbrella organization for many of these associations.[17] Additionally, there was a close association between members of the federation and the Social Democratic Worker's Party (SDAP) that ruled "Red Vienna" with an absolute majority of seats in the interwar years.[18]

While the Freethinker's Association played a crucial role in the foundation of the Ernst Mach Association, many leading Monists were also involved in the foundation of the Berlin Society for Empirical Philosophy.[19] Although a certain distance

[14]Cf. Anson Rabinbach, *The Crisis of Austrian Socialism: From Red Vienna to Civil War, 1927–1934*, Chicago: University of Chicago Press 1983; Janek Wasserman, *Black Vienna. The radical right in the red city, 1918–1938*. Ithaca/NY: Cornell University Press 2014.

[15]Klaus Taschwer, *Hochburg des Antisemitismus. Der Niedergang der Universität Wien im 20. Jahrhundert*. Wien: Czernin 2015; For Berlin University cf. Aleksandra Pawliczek, *Akademischer Alltag zwischen Ausgrenzung und Erfolg. Jüdische Dozenten an der Berliner Universität 1871–1933*, Stuttgart: Steiner 2011. Aleksandra Pawliczek, "Kontinuität des informellen Konsenses. Die Berufungspolitik der Universität Berlin und ihre jüdischen Dozenten im Kaiserreich und in der Weimarer Republik", in: Rüdiger Bruch (Ed.), *Kontinuitäten und Diskontinuitäten der Wissenschaftsgeschichte des 20. Jahrhunderts*, Stuttgart: Steiner 2006, pp. 69–92. Georg G. Iggers, "Academic Anti-Semitism in Germany 1870–1933. A Comparative International Perspective", in: *Tel Aviver Jahrbuch für deutsche Geschichte*, Vol. XXVII, 1998, pp. 473–489; Notker Hammerstein, *Antisemitismus und deutsche Universitäten 1871–1933*, Frankfurt/M./New York: Campus 1995.

[16]Stadler/ Uebel, Scientific World-Conception, loc. cit., p. 79.

[17]Stadler, Spätaufklärung, loc. cit., p. 441.

[18]Helmut Gruber, *Red Vienna. Experiment in Working-Class Culture 1919–1934*, New York, Oxford: Oxford University Press 1991.

[19]Friedrich Stadler, *Vom Positivismus zur "wissenschaftlichen Weltauffassung". Am Beispiel der Wirkungsgeschichte von Ernst Mach in Österreich von 1895 bis 1934*, Wien, München: Löcker 1982, pp. 171–173; Sandner/Pape, Late Enlightenment to Logical Empiricism, loc. cit., Dieter Hoffmann, "The Society for Empirical /Scientific Philosophy", in: Alan Richardson/ Thomas

existed between modern Logical Empiricism and the "old-fashioned arguments"—as Neurath polemically described them—of monism and freethinking,[20] there were obvious programmatic links. In fact, many elements of the Vienna Circle's manifesto "The Scientific World-Conception" were anticipated in the discourses of the Monist movement.

From the very beginning, in announcements and proclamations, the Monist League strictly distinguished between the church's religious beliefs on the one hand and a modern scientific conception of the world on the other.[21] Later, founding members of the Berlin Society such as psychologist Alexander Herzberg, an activist and member of the German Monist League, repeatedly used the term "scientific world view" ("Wissenschaftliche Weltanschauung") to describe and characterize the program of Monism.[22] In the same article, however, Herzberg also used the Monist phrase "scientific world-conception" ("wissenschaftliche Welt- und Lebensauffassung") to characterize the monist's aim.[23]

In this context, however, it is particularly the case of Rudolf Goldscheid that matters. Goldscheid, co-founder of the Sociological Society in 1907, was probably the most important Austrian monist.[24] He heard lectures of Ernst Mach at the University of Vienna already in the 1880s.[25] Between 1913 and 1917 he was chairman of the Austrian Section of the Monist League. Goldscheid was a colorful figure, with a multi-faceted intellectual profile: he worked as both a demographer and an economist, and developed the controversial concept of "human economy" ("Menschenökonomie").[26] In contrast to leading monists in Germany such as Ernst Haeckel and Wilhelm Ostwald, however, Goldscheid was a committed pacifist who

Uebel (eds.): *The Cambridge Companion to Logical Empiricism*, Cambridge 2007, pp. 41–57, p. 44.

[20]Otto Neurath, "Die Philosophie im Kampf gegen die Wissenschaft" (1932), in: Rudolf Haller/Heiner Rutte (Eds.), *Otto Neurath. Gesammelte philosophische und methodologische Schriften*. Band 2. Wien: Hölder-Pichler-Tempsky 1981, pp. 571–576, p. 573. ("Es ist kein erfreulicher Anblick, wenn die modern aufgeputzten Lehren der Halbtheologen und Schulphilosophen von Freidenkern, Monisten und anderen Gegnern mit altmodischen Argumenten bekämpft werden, die vor einer Generation schon recht matt und lahm waren").

[21]"Aufruf des Monistenbundes in Österreich", in: Rudolf Goldscheid, *Monismus und Politik*. Vortrag gehalten auf der Magdeburger Tagung des Deutschen Monistenbundes im Herbst 1912, Wien, Leipzig: Anzengruber 1912. ("Zwischen der von den staatlich anerkannten Kirchen verkündeten "Religion"und der heutigen wissenschaftlichen Welt- und Lebensauffassung hat sich eine unüberbrückbare Kluft gebildet").

[22]Alexander Herzberg, "Wissenschaft und Monismus", in: Monistische Monatshefte, Vol. 8, No. 1, 1923, pp. 1–7. ("Der moderne Monismus, wie ihn der Monistenbund vertritt, soll nach der Erklärung seiner Anhänger wissenschaftliche Weltanschauung und Lebensgestaltung sein").

[23]Ibid., p. 1.

[24]Gudrun Exner, *Die "Soziologische Gesellschaft in Wien" und die Bedeutung Rudolf Goldscheids für ihre Vereinstätigkeit*, Wien: New Academic Press 2013.

[25]Helge Peukert, *Rudolf Goldscheid. Menschenökonom und Finanzsoziologe*, Frankfurt/M., New York: Peter Lang 2004, p. 9.

[26]Ulrich Bröckling, "Menschenökonomie, Humankapital", in: *Mittelweg 36*, No. 1, 2003, 3–22.

opposed war and militarism even in 1914, when few others did. In a way, he also belonged to the initiators of the scientific world-conception. He used the term "scientific world-conception" years before the Vienna Circle Manifesto (1929) and introduced it into the philosophical and ideological debates of his days.[27]

Goldscheid initially developed his scientific world-conception in negative terms, by focusing on its opposite. He emphasized that the dominant, "official" scientific establishment of that era was not an ally. In contrast, scientific training grounds—universities—have become breeding grounds of an anti-progressive and reactionary thinking. Thus, any realization of the scientific world-conception requires the liberation of the university from reactionary political forces. For Goldscheid, the social and political fight for the scientific world-conception was also a fight for the democratization of the universities, and for freedom of research and teaching. He stressed the fact that every meaningful statement is based upon science, and espoused the Monist slogan, "Scientific World-Conception and a corresponding personal life."[28] Thus, the paradox was that science has to be defended against its official representatives: the universities and a vast majority of its professors.

This paradox was also noticed by the authors (anonymously published but most probably written mainly by Neurath, Hahn and Carnap)[29] of the Vienna Circle's manifesto. It begins with the observation "that metaphysical and theologizing thought is again on the rise today, not only in life but also in science." A look "at the topics of university courses and the titles of philosophical publications" confirms this assertion.[30] Despite the manifesto's focus on progressive developments in different scientific fields and their consequences for the scientific world-conception, some sections are written in a rather militant and political terminology that is very similar to, for instance, Goldscheid's writing style: "The representatives of the scientific world-conception resolutely stand on the ground of simple human experience. They confidently set to work on the task of removing the metaphysical and theological debris of millennia."[31] However, the manifesto warns that the "increase of metaphysical and theologizing leanings ... seems to be based on the fierce social and economic struggles of the present." The authors were convinced that while hard social and political battles awaited them, in the end, the scientific world-conception would win through.[32]

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[27] Rudolf Goldscheid, "Die Pflanzstätten der Wissenschaft als Brutstätten der Reaktion", in: *Die Wage*, Vol. 4, 1923, pp. 137–143.

[28] Ibid., 138. ("Wissenschaftliche Weltauffassung und ihr entsprechende Lebensgestaltung").

[29] For a detailed analysis of genesis and authorship cf. Thomas Uebel, "On the Production History and Early Reception of The Scientific Conception of the World. The Vienna Circle", in: Stadler/Uebel, *Scientific World-Conception*, loc. cit., pp. 291–314.

[30] Stadler/Uebel, *Scientific World-Conception*, loc. cit., p. 78.

[31] Ibid., p. 89.

[32] Ibid., p. 90.

Despite Neurath's critique, many of the Vienna Circle's representatives worked as supporters or, at least, as speakers for the Ethical Community (Schlick, Carnap, Kraft), the Monist League (Schlick, Neurath, Feigl) and the Freethinkers' Association (Neurath and Frank). On the other side, a number of Berlin Society representatives were active in or supportive of the Monist League—for example, by contributing to their journal—such as Alexander Herzberg, Max Deri, Georg Graf von Arco, Kurt Grelling, and Hans Reichenbach.[33]

21.3 Founding Fathers: Joseph Petzoldt and Ernst Mach

Both Ernst Mach and Joseph Petzoldt may be considered founding fathers of the logical empiricist associations in Vienna and Berlin; their roles, however, were decidedly different. While the Ernst Mach Association was founded only in the spirit of its namesake, Joseph Petzoldt was physically present among the early members of the Berlin Society for Empirical Philosophy, founded on 27 February 1927 in the apartment of Georg Graf von Arco.[34] Joseph Petzoldt (1862–1929) and Ernst Mach (1838–1916) knew each other well, and followed the same or at least similar philosophical ideas. Both were influenced by late enlightenment ideas and, in turn, influenced the scientific world-conception.

By 1912, Petzoldt had founded the Berlin Society's forerunner "Society for Positivistic Philosophy" that was integrated into the Kant Society in 1921. He worked for large parts of his professional life as a schoolteacher, finally rising to the position of professor in 1922, at the Technical University Charlottenburg.[35] Petzoldt praised Ernst Mach as a great man and educator[36]; nevertheless, he was also a programmatic thinker. In his essay "Positivistic Philosophy," the emphasis on empiricism, the rejection of metaphysics and a critique of the separation of the humanities and the natural sciences were crucial elements.[37] The opening session of the Berlin Society for Empircal Philosophy started with a programmatic lecture by Petzoldt entitled "Rational and Empirical Thinking" ("Rationales und empirisches Denken").[38]

[33] Sandner/Pape, Late Enlightenment to Logical Empiricism, loc. cit.

[34] On Petzoldt and the Berlin Society cf. Sandner/Pape, Late Enlightenment to Logical Empiricism, loc. cit. Dieter Hoffmann, "The Society for Empirical/Scientific Philosophy", in: Alan Richardson/ Thomas Uebel (Eds.): *The Cambridge Companion to Logical Empiricism*. Cambridge: Cambridge University Press 2007, pp. 41–57, p. 44.

[35] Walter Dubislav, "Joseph Petzoldt in memoriam", in: *Annalen der Philosophie und philosophischen Kritik*, Vol. 8, 1929, pp. 289–295. Dieter Hoffmann, The Society, loc. cit., pp. 45–48.

[36] Joseph Petzoldt, "Ernst Mach", in: *Der Kunstwart*, Vol. XXIX, No. 12, 1916, pp. 232–233.

[37] Joseph Petzoldt, "Positivistische Philosophie", in: *Zeitschrift für positivistische Philosophie,* Vol. 1, 1913, pp. 1–16.

[38] Joseph Petzoldt, "Rationales und empirisches Denken", in: *Annalen der Philosophie und philosophischen Kritik*, Vol. 6, 1927, pp. 145–160, p. 153.

Ernst Mach died in 1916, well before the Ernst Mach Association was founded (mainly by Austrian Freethinkers) in 1928.[39] For his followers, Mach stood for intellectual freedom, progressive enlightenment, and political commitment. After having suffered a stroke in 1898, he came as an ill person to the upper house of the Austrian Parliament (where he retained his membership after his retirement) to vote for the nine hour day and later for manhood suffrage.[40] Although Mach's intellectual work was influential in many respects, "he did not establish a school of philosophy in his lifetime."[41] Nevertheless, his intellectual influence was apparent in the Vienna Manifesto.[42] Later logical empiricists appreciated both men on many occasions.[43]

Both Mach and Petzoldt were intellectually close to monism. Mach was a follower of a "Monist scientific conception of the world,"[44] while Petzoldt was asked to become a board member of the German Monist League. Since leaving the church was a precondition and he refused to do so, however, he was forced to decline the offer.[45]

21.4 Modernism and Anti-Modernism

Despite their long historical tradition, in the interwar years both Berlin and Vienna were modern cities; still, a certain tension characterized the capitals' identification with the past versus the present. On one hand, conservatism and rightwing nationalism dominated considerable parts of intellectual life. On the other, modern science and culture constituted a challenging progressive social and political project. Science and scientific knowledge played a crucial role in ideas and projects of social and political transformation. Therefore, there were at times fierce fighting—not solely of the intellectual variety—between modernism and anti-modernism.

The logical empiricist organizations were essentially modernist movements. This was not only a self-image but also an ascription. They wanted to overcome traditional philosophy, and insisted that there is no authority above science. Many

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[39] Stadler, *Vom Positivismus*, loc. cit., pp. 170–173.

[40] Friedrich Stadler, "Ernst Mach – Leben, Werk und Wirkung", in: Rudolf Haller/ Friedrich Stadler (Eds.), *Ernst Mach – Werk und Wirkung*, Hölder-Pichler-Tempsky: Wien 1988, pp. 11–63, pp. 24–25.

[41] Brian F. McGuinness, "Ernst Mach and His Influence", in: Wolfgang L. Gombocz/ Heiner Rutte/ Werner Sauer (Eds.), *Traditionen und Perspektiven der analytischen Philosophie. Festschrift für Rudolf Haller*. Wien: Hölder-Pichler-Tempsky 1989, pp. 149–156, p. 153. For a detailed discussion of Mach's influence cf. Stadler, Ernst Mach, loc. cit., pp. 34–57.

[42] Scientific World-Conception, loc. cit., pp. 78–79.

[43] Otto Neurath, Ernst Machs Vermächtnis, in: *Arbeiterzeitung*, 27.07.1921, p. 5. Philipp Frank: Zum 100. Geburtstag Ernst Machs, in: *Neue Freie Presse*, 15.02.1938, p.7.

[44] Stadler, Ernst Mach, loc. cit., p. 33.

[45] German Monist League to Joseph Petzoldt, 25.10.1922 (Estate Petzoldt, TU Berlin, Pe 306–5). Later he became a board member of the local branch in Hannover (cf. document Pe 30 e).

of their followers and members were liberal or leftwing intellectuals (although only a few were politically active), and almost none of them supported right-wing movements. Logical Empiricism was in many respects connected to cultural progress and change. Despite their scientific orientation, however, representatives of Berlin and Viennese Logical Empiricism emerged from modern social and cultural movements and represented a spirit of modernity that entered an ideological battleground.

Several examples serve to illustrate this precarious relationship. Oskar Vogt—though no philosopher and no logical empiricist—was one of the founding members of the Berlin Society for Empircial Philosophy. A famous neuroscientist and researcher (he dissected Lenin's brain),[46] he advocated modern science as a necessary element of social progress and modern life. Even before the First World War, Vogt saw contemporary science as a collective endeavor. Therefore, he demanded, for instance, the organization of study groups; he believed science could and should not be done by individual researchers alone. Most of all, Vogt was an advocate for the internationalization of science. He designed the modern image of a future international scientific community based upon labor division, coordination, collaboration, and cooperation.[47]

After the revolution of 1918, Oskar and his wife Cécile Vogt published an essay on the relation between science and the modern state in Germany. In their view, modern science was closely connected with modern man, who sought to appropriate science and make it the foundation of his actions. The more science-oriented a state, the more modern it was.[48] The Vogts were especially critical of the German state, feeling that by this criteria, it was still far from modernity. In lieu of cultural and religious freedom, Germany demanded strict obedience to the emperor and other authorities. From an empirical scientific perspective, Cécile and Oskar Vogt also expressed their sympathies for Marxism and for the German Social Democratic Party as the political movement closest to the interests and needs of modern science. Moreover, they called for the promotion of scientific disciplines such as sociology, individual psychology and civic education. They were convinced that those intellectual fields, neglected in the German Empire, were of the utmost significance for a future modern society.

Another example is Lily Herzberg, wife of leading Berlin Society representative, psychologist and monist Alexander Herzberg and herself a member of the Monist League. She examined in her dissertation the intellectual history of Monism and

[46]Walter Kirsche, *Oskar Vogt (1870–1959). Leben und Werk und dessen Beziehung zur Hirnforschung der Gegenwart. Ein Beitrag zur 25. Wiederkehr seines Todestages*, Berlin: Akademie-Verlag 1986.

[47]Oskar Vogt, "Über Forscher und Organisation der Forschung", in: *Nord und Süd. Eine deutsche Monatsschrift*, Vol. 37, No. 459, Dezember 1912, pp. 346–357.

[48]Cécile und Oskar Vogt, "Wissenschaftliche Forderungen an den modernen Staat", in: *Nord und Süd*, Vol. 43, No. 534, März 1919, pp. 245–250.

published her study in a two-part essay in the journal “Annalen der Philosophie”.[49] In her essay, Herzberg identified different “philosophical mainstreams” of Monism. According to her, Monism was a continuum in the history of philosophy that appeared in many different times and in many different forms. Meanwhile, she traced the roots of modern Monism to three philosophical movements: positivism, materialism and critical relativism. (Critical realism not categorized separately, but as a part of positivism).

Herzberg maintained that these political philosophies were united around the belief that science promotes social progress and—especially in the case of ethical positivism—an emphasis on human happiness. Historical materialism, however, is related to Marxism. For Herzberg, especially the Austrian Rudolf Goldscheid was an excellent example for someone who combined Marxist analysis of society and economy with the ideology of Monism.[50] There is, she claims, a commonness of positivism, materialism and Marxism such as their positive orientation on the natural sciences, for instance. Thus, most of the followers of Monism came from one of those ideological and philosophical camps. The typical monist is a theoretical and philosophically educated person on the one hand, and a socialist-oriented on the other, she concludes.[51] Implicitly, she claims that monism and a scientific orientation will pave the way for a modern society. Incidentally, Lily Herzberg was one of the very few women who participated in that era’s discourse on scientifically-oriented philosophy.

21.5 Conclusion

In the years following the foundation of the Ernst Mach Association (1928) and the Berlin Society for Empirical Philosophy (1927), both organizations became more deeply embedded in scientific communities, leaving behind the ideological clashes between opposing political and intellectual cultures. They focused on publishing the journal “Erkenntnis” (with Reichenbach and Carnap as editors), addressed to the scientific community, and not a medium for the popularization of scientific knowledge. Additionally, they continued to organize international conferences and similar activities.[52] They tried to distance themselves from political and ideological controversies. In fact, Moritz Schlick overarticulated this approach, when in times of political repression (Austrian civil war in 1934) he stressed in letters to Austrian

[49] Lily Herzberg, “Die philosophischen Hauptströmungen im Monistenbund”, in: *Annalen der Philosophie*, Vol. 7, 1928, pp. 113–135, pp. 177–199.

[50] Ibid., pp. 192–194.

[51] Ibid., p. 199.

[52] Sandner/Pape 2017, Late Enlightenment to Logical Empiricism, loc. cit. For the development of the Berlin Group cf. Nikolay Milkov/ Volker Peckhaus (Eds.), *The Berlin Group and the Philosophy of Logical Empiricism*, Heidelberg; New York, London: Springer 2013.

dictator Engelbert Dollfuß the apolitical character of the association's activities and his loyalty to the dictatorial regime.[53] Fascism and National Socialism, nevertheless, signified the violent end of any progressive intellectual activities.

In sum, representatives of ideologically-oriented associations in turn-of-the century Berlin and Vienna anticipated some of the basic ideas of the scientific world-conception. Among these ideas are an emphasis on science as a transformative force in human history, and the conviction that scientific progress results in or decisively promotes social progress and political democratization. Additionally, there was the conviction that although science itself can never represent an unquestioned system of truth, there is no authority above science, and traditional or political authorities who claimed superiority over science needed to be challenged. Furthermore, they followed a critique of hegemonic manifestations of philosophy and science ("school-philosophy", metaphysics, contemporary doctrine on the universities) and were convinced that, in the end, a scientific world-conception will be successful.

[53] Sandner, Neurath, loc. cit., pp. 226–227.

Chapter 22
Mach's Reception in Pre-revolutionary Russia

Daniela Steila

Abstract Mach had an extraordinary reception in Russia: his works were translated in Russian so promptly and completely as in no other language, and his thought was discussed on the press, in salons, in political debates. Such a success has been considered mainly through Lenin's *Materialism and Empiriocriticism*. But a harsh polemic work is not a reliable source to grasp the positions of its rivals. J.T. Blackmore, in 1972, successfully inquired into Ernst Mach Institut Archive in Freiburg in order to sketch out Mach's Russian reception. However he could not investigate Russian sources. Relying on Mach's correspondence, and on a general reconstruction of the "second positivism" in Russia, the paper sketches out three main aspects of Mach's influence in Russia: Mach's direct contact with Russian scholars and teachers; the work of P. K. Engel'mejer, Mach's main popularizer in Russia, and the "Machomakija" that enlivened Russian Marxism in 1905–1910.

In the late nineteenth – early twentieth century, Mach's thought had an extraordinary impact in Russia: his works were translated in Russian so promptly and completely as in no other language, and his thought was discussed in the press, in salons, in political debates. Challenging writings about Empirio-Criticism were debated among Social-Democrats and Social-Revolutionaries, workers, and even political prisoners. Austro-Marxists, in particular Friedrich Adler, tried to combine Marxism and Empirio-Criticism too,[1] but in the Western Europe no schism took place in Mach's name. In Russia, on the contrary, particularly between 1905 and 1910, "Machism" became a central focus of the political struggle within the Social-Democratic Party, specifically in the Bolshevik faction.

[1]See Mark E. Blum, William Smaldone (Eds.), *Austro-Marxism: The Ideology of Unity. Austro-Marxist Theory and Strategy*, vol. 1, Leiden-Boston: Brill 2015, pp. 66–76; 455–488.

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That Empirio-Criticism has had such a wide success in Russia has been well known in the West, since *Materialism and Empirio-Criticism*, the famous work by Lenin, testified by itself the existence of a Marxist reception of Mach's thought in pre-revolutionary Russia. However, the fact that a polemic work, written within the context of a harsh political struggle, became the main source to understand its rivals' positions, had important consequences. On the one hand, the so-called Machists' ideas were mainly isolated from the context of their authors' general reflections; on the other hand, the Marxist reception of Mach in Russia could not be considered on the background of the much wider Russian interest for the so-called "second positivism". James T. Blackmore, whose work *Ernst Mach*, in 1972, devoted a chapter to Mach's success in Russia, had the great merit to inquire into the Archive, at that time held at the Ernst Mach Institute in Freiburg. There he found some interesting letters written by Russians in German, but he could not take into consideration any Russian source. So he was forced to consider only what he could find in the German letters, or could be directly assumed from them.[2]

As an attempt to fill such a gap, my essay will briefly sketch out three main aspects of Mach's influence in pre-revolutionary Russia, mainly relying on Mach's correspondence and different Russian sources[3]: first of all, Mach's direct contacts with Russian scholars and teachers; secondly, the work of Pëtr K. Engel'mejer, the main popularizer of Mach's thought in Russia; and finally, the so-called *Makhomakija* that enlivened Russian Marxism in 1905–1910.

1. Many letters kept in Ernst Mach's Archive show that many Russian young scholars and physics teachers have approached Mach with many different requests since the 1880s. They mainly wanted to come and visit his laboratory, or asked for advices. A certain G. Osnobishin, for instance, after he came back to Russia, wrote to Mach to thank him, because he had let him work in his laboratory. Twelve years later an assistant in the Laboratory of Physics at the University of Warsaw wrote to Mach, asking to be admitted as a student in his very laboratory.[4]

Mach became very popular also because his handbooks of physics were widely used all over the Empire, and often translated into Russian. Bruno Kolbe, who was a professor at Saint Anne's School in St. Petersburg, he himself the author of some works on electronics and physics, and the inventor of many instruments that were used to explain physic experiments to students, wrote to Mach in 1891 that he had

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[2]John T. Blackmore, *Ernst Mach: His Life, Work, and Influence*, Berkeley: University of California Press 1972, pp. 236–246.

[3]For a wider reconstruction of Mach's fortune in Russia, see Daniela Steila, *Nauka i revoljucija. Recepcija empiriokriticizma v russkoj kul'ture (1877–1910)*, Moskva: Akademicheskij proekt 2013.

[4]See G. Osnobishin to Ernst Mach, Jan. 7 (19), 1883; A. Trussevich to Ernst Mach, April 10, 1895. I examined the documents in Ernst Mach's Archive when it was held at the Ernst Mach Institute in Freiburg. Mach's papers are nowadays at the Deutsches Museum in Münich. On Osnobishin (Osnobschin), see J.T. Blackmore, *op.cit.*, p. 236.

been using the latter's *Grundriss der Naturlehre* with his students, and with great success.[5] One year later a professor at the Academy of Cadets in Simbirsk asked Mach for advices for his own lectures on "cosmography".[6]

Mach's handbooks had such a great success in Russia, that Bruno Kolbe informed Mach that an unauthorized translation was circulating, by a certain Kuroldov, professor at the Corps of Cadets in Petersburg, who was supposed to have written "a new (!) handbook of physics, in which 9/10 are a literally translation of Yours *Naturlehre*!!".[7] Four years later Kolbe wrote to Mach about another unauthorized translation, and emphasized that the case was quite frequent, "since there is unfortunately no convention about literary rights between Russia and other states".[8] In 1900 a gymnasium teacher wrote another handbook in physics, on the model of Mach's work.[9]

2. At the end of the century, Mach became very popular in Russia as a philosopher, as well. The first exposition of Mach's epistemology was a lecture held at the Moscow "Psychological Society" by Pëtr Klimentich Engel'mejer, who was an engineer and a philosopher, and aimed at disseminating Mach's ideas among the «Russian educated public».[10] Engel'mejer's correspondence with Mach was quite intense since 1894 to 1912, first from Stuttgart, then from Paris, Prague and finally Moscow. It shows both Engel'mejer's enthusiasm in spreading Empirio-Criticism in Russia, and the depth of his relationship with Mach.

According to Engel'mejer, the best trait of Empirio-Criticism consisted in the idea that creativity and production, theory and practice, are strictly entwined both in knowledge and technique. In his *Theory of Creativity*, he explained that "discovery" and "invention" are equivalent to a certain extent: to discover never means to reveal something pre-existing, but to modify the already acquired scientific concepts in order to explain a new fact in the most economic way. Invention is addressed to the solution of a practical problem in the same way.[11] In his Preface to Engel'mejer's work, Mach maintained:

> It is not by chance, that the author [Engel'mejer – *d.s.*] finds in the writer of these lines [Mach – *d.s.*] one of his most grateful readers. If the latter has often looked at the field of craft and technique in order to clarify the genesis of science, the first has followed

[5] Bruno Kolbe to Ernst Mach, November 16 (28), 1891.

[6] Aleksandr Zindeberg to Ernst Mach, October 5, 1892. See J.T. Blackmore, *op.cit.*

[7] Bruno Kolbe to Ernst Mach, November 16 (28), 1891.

[8] Bruno Kolbe to Ernst Mach, March 1 (13), 1895.

[9] See Pëtr K. Engel'mejer to Ernst Mach, March 28 (April 10), 1900.

[10] Pëtr K. Engel'mejer to Ernst Mach, January 29 (February 10), 1897; Id., "Teorija poznanija Ernsta Makha", in: *Voprosy filosofii i psikhologii*, 3, 1897, pp. 443–455. On Engel'mejer, see Vitalij G. Gorokhov, *Pëtr Kliment'evich Engel'mejer. Inzhener-mekhanik i filosof tekhniki. 1855–1941*. Moskva: Nauka 1997; Id., *Technikphilosophie und Technikfolgenforschung in Russland*. Bad Neuenahr-Ahrweiler: Europäische Akademie zur Erforschung von Folgen wissenschaftlich-technischer Entwicklungen 2001, pp. 10–23.

[11] See Pëtr K. Engel'mejer, *Teorija tvorchestva*, Sankt Peterburg: Obrazovanie 1910, p. 52.

> the opposite way, finding new contacts, links and similarities among apparently unrelated phenomena. It was impossible for them not to meet, not to bump into each other. Both, for instance, completely agree that the difference between discovery and invention is just in their aims. The mental construction, which eliminates an intellectual distress, is a discovery; if the question regards a practical need, the liberating thought is an invention.[12]

While discussing the common basis of both Machism and his own philosophy of technique, Engel'mejer emphasized that, according to both, science develops from the technical motivation for modifying the world. Engel'mejer deemed that his "Technicism" was nothing else than "an offshoot and an approximation of [Mach's] system".[13] Machism mainly considered the human being in his internal aspects, while Technicism chiefly considered the external side of human actions.[14]

Engel'mejer was not only the main supporter of Mach's thought in Russia, but also one of his critics. In a couple of his letters to Mach, in 1895, the Russian engineer developed quite a firm, though – as he wrote – "half serious, half playful" critique of Mach's theory of elements.[15] In his Preface to the first Russian translation of Mach's *Popular Essays*, which Engel'mejer edited himself, the latter found the weak point in Mach's theories in a question that remained without a convincing answer: "what are 'sensations' independently from the 'sensing' subject?".[16] In one of his letters to Mach, Engel'mejer summarized his doubts as follows:

> 1) what is the number and species of these elements that do not actually get mixed up, as, for instance, the colors in a continuous spectrum? 2) (. . .) where do these elements exist? Since they should be somewhere in order to be elements. When one says: 'A certain combination of these elements gives what it is called 'I' according to the economy of thought', that means that they exist outside this 'I'. But what does the independent existence of sensations mean, and how should we conceive it?[17]

Engel'mejer considered completely unprovable and unproved that "constant connections of sensations, labeled as 'bodies', 'I' etc. could not have a ground for their occurring again and again always in the same sequence".[18] In other words, it seemed impossible to him that there was no objective, real basis, no criterium, according to which we could separate and clearly distinguish being and appearing. According to Engel'mejer, in Mach's opinion "there is no difference between appearing and being. He says exactly that 'senses are neither deceitful, nor

[12] Ernst Mach, "Predislovie", in: Engel'mejer, *op. cit.*, p. 4.

[13] Pëtr K. Engel'mejer to Ernst Mach, June 6, 1912.

[14] See Pëtr K. Engel'mejer, *Filosofija tekhniki.* Moskva: Zoon tekhnikon 1912, vol. II, pp. 91, 96.

[15] These letters have been partly published in Karl D. Heller (Ed.), *Ernst Mach. Wegbereiter der modernen Physik.* Wien-New York: Springer 1964, pp. 71–75.

[16] Pëtr K. Engel'mejer, "Vvedenie", in: Ernst Mach, *Nauchno-populjarnye ocherki*, Moskva: A. Ju. Manockova 1901, p. XVIII. Many letters testify to Engel'mejer's involvement in the translation of Mach's work, though the title-page of the book refers to A. A. Mejer as its translator. See Pëtr K. Engel'mejer to Ernst Mach, August 4 (17), 1900; September 13 (26); November 15 (28), 1900.

[17] Pëtr K. Engel'mejer to Ernst Mach, November 23, 1895.

[18] Pëtr K. Engel'mejer to Ernst Mach, October 26, 1895.

reliable'".[19] So a "ball turns yellow before a sodium lamp (. . .). But if we take santonin, the ball turns yellow too".[20] The two sensations are identical from the subject's standpoint, but they are not the same. As a joke, Engel'mejer compared Mach

> to the Chinese Emperor, whose name I don't remember, whose wise government is described by H. Heine. This model king noticed that when he took (not santonin, but) wine, everything around him turned (not yellow, but) cheerful. Since he was keen on sacrifice, he drank continuously, in order to make his people happy.[21]

Mach's answers are unfortunately lost (as far as I know), but they should have been quite friendly, since Engel'mejer's letters keep the same informal tone, without hints of apology. After repeating once again his most serious doubts, Engel'mejer explained that "everything else is just a joke and I allowed it to myself in order to show how one can find faults within too concise a text by sticking to the words".[22]

Although Engel'mejer had serious doubts about Mach's theory of elements, he was however convinced that Mach's epistemology represented the highest point in the contemporary philosophy of science.[23] Moreover, exactly the fact that Mach had not yet answered all the questions, "that (. . .) he had not said his last word in the development of his own thought, only means that he is faithful to himself, since he maintains that the progress of thought is as infinite as the evolution of life on earth".[24]

3. After the revolution of 1905, Mach's thought became so popular that his portraits were hanging on the walls in many of his Russian admirers' rooms. Levintov from Odessa asked Mach a photograph, and so did another young student from Ekaterinoslav; Sharvin wrote that, though they never met personally, Mach's image "embellished" his own room.[25] Russian authors sent to him their works, both on physics and philosophy and, although Mach could not read Russian, we find quite a number of books in Russian in the catalogue of his library.[26] In Mach's archive a postal card can be found, which a certain Aleksandr N. Panov sent him together with a work on universal attraction, which he had been working on for the past 15 years[27]; and a letter by Vladimir Zvonkin, a scholar from Lithuania, who had got his doctorate in Bern in 1909 with a thesis on a

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[19] *Ibid.*

[20] Ernst Mach, *Beiträge zur Analyse der Empfindungen*, Jena: G. Fischer 1886, p. 12.

[21] Pëtr K. Engel'mejer to Ernst Mach, October 26, 1895.

[22] Pëtr K. Engel'mejer to Ernst Mach, November 23, 1895.

[23] See Pëtr K. Engel'mejer, "Vvedenie", *loc. cit.*, p. XVI.

[24] *Ibid.*, p. XX.

[25] I. L. Levintov to Ernst Mach, s.d. (1901); V. Nokhotovich to Ernst Mach, April 27, 1908; February 7, 1910; February 26, 1910; Vasilij V. Sharvin to Ernst Mach, February 27, 1906.

[26] See *Bibliothek Ernst Machs, Katalog 634–636*, München: Theodor Ackermann – Antiquariat 1959–1960.

[27] Aleksandr N. Panov to Ernst Mach, March 27, 1913.

specific interpretation of Raskolnikov, the main character of Dostoevsky's *Crime and Punishment*, through Holzapfel's moral categories. In 1914, Zvonkin sent to Mach a work, which he defined as his "attempt to apply Rudolf Holzapfel's psychology (...) to a whole epoch of Russian spiritual development", in particular to the second half of the XIX century.[28] Russians asked Mach for advices in different fields, including politics; many traces in Mach's Archive testify to such a wide interest. For instance in 1907, once the Second Duma was dismissed, Mach, together with other well–known intellectuals, was asked his opinion by a Russian journal, although we don't know whether he answered and what.[29] A little while later, an unknown A. V. Stolovskij wrote to Mach a passionate letter in Russian, denouncing the difficult conditions of Jews in the Tsarist Empire.[30]

Mach developed himself a certain interest for Russia. Apparently on Mach's request, a very well known mathematician in Kazan' University, Aleksandr V. Vasil'ev, sent him in 1904 a whole list of names, both University professors and not, who had been writing about epistemology in Russia.[31] Vasil'ev suggested to Mach to write their addresses in cyrillic on the envelops, thereby letting us know that there had been some ideas about contacting those people. Mach never wrote to them, at least not to all of them; it is however curious that he developed an interest in Russian discussions on epistemology. The number and the enthusiasm of his Russian admirers were surely enough to awake his own curiosity.

Mach's books and articles were very widely translated in Russian. One of his most important translator, Gedal Kotljar, wrote directly to Mach asking for suggestions about some terminological problems, and some traces of Mach's advices remain in Kotljar's partial translation of *Erkenntnis und Irrtum*.[32] Many works about Empirio-Criticism were translated as well. In 1905, an enthusiastic work on Mach by Theodor Beer, firstly published as a series of essays on the "Neue Freie Presse", then as a volume in German, was translated for the Marxist journal "Pravda", and then published as a separate book in 1200 copies, which sold out immediately.[33] Beer's work was so panegyrical that Mach himself requested

[28] Vladimir A. Zvonik to Ernst Mach, January, 1914; Id., *Dostojewsky's "Raskolnikow" im Lichte der Gewissenspsychologie.* Zürich: A. Schereschewsky-Vogel 1913; Id. [Astrov], *Ne nashli puti; iz istorii religioznogo krizisa: Stankevich – Belinskij – Herzen – Kireevskij – Dostoevskij*, Sankt Peterburg: M. M. Stasjulevich 1914.

[29] "Correspondance russe" to Ernst Mach, s.d.

[30] A. V. Stolovskij to Ernst Mach, January 27 (February 4), 1910.

[31] Aleksandr V. Vasil'ev to Ernst Mach, October 4, 1904.

[32] Gedal Kotljar, May 10, 1906 – October 18, 1909; Ernst Mach, "Filosofskoe i estestvenno-nauchnoe myshlenie", in: *Novye idei v filosofii*, sb. I: *Filosofija i ee problemy*, Sankt Peterburg: Obrazovanie 1912, pp. 101–102 footnote.

[33] Theodor Beer, "Mirovozzrenie odnogo sovremennogo estestvoispytatelja (Nekriticheskij referat sochinenija E. Makha *Analiz oshchushchenij*)", in: *Pravda* 2, 1905, pp. 1–64; Id., *Mirovozzrenie Ernsta Makha. Nerkiticheskij referat sochinenija ego "Analiz oshchushchenij"*, Moskva: Pravda 1905; 2nd ed. Sankt Peterburg: Obrazovanie 1911 (Russian translations of: Id., *Die Weltanschau-*

its author to attenuate his enthusiasm. When Beer asked Mach to be authorized to put a photo-portrait in his book, Mach answered (and Beer mentioned it in the book):

> If you want to do me a great favor, I would insist to use the chance of the second edition of your book to attenuate as much as you can your too strong expressions of appraisal and respect... I repeat: I had a great pleasure while studying these subjects, although I often had to engage a harsh and unpleasant struggle against my own prejudices, but I do not find anything I can claim as my special merit.[34]

In 1906 Enge'mejer could write to Mach: "The intellectual situation in Russia is very favorable for the acceptance of your views – naturally not at the *immediate* moment when politics is everything".[35] But it was actually in the field of politics that the deepest interest in Mach's philosophical reflections developed in Russia. In general, "scientific philosophy" was considered a meaningful shock for traditional prejudices among Russian *intelligencija*. As early as in 1899, a young admirer of Mach's wrote to him that he had the merit "to awake the reader's thoughts, without letting him sleep over opinions that have the only worth of being shared by the majority of people".[36] Another of his Russian admirers, Vasilij V. Sharvin, later wrote to Mach from Moscow that, while he was studying Mach's works, he felt "such a liberating and clarifying spiritual shock" as he had felt only once before, "when he had encountered Darwin's theory".[37] Sharvin was a professor in a technical school in Moscow, where he held a popular exposition of Mach's theory of knowledge in March 1905. Engel'mejer informed Mach about it, and commented:

> Sharvin described Your conceptions in details and very well; he did not quote whole pages, but only a few words, in good Russian (...). Since he is a chemist, he presented several examples from Chemistry and explained them all (...). Moreover, his small book has been sold at a very low price (50 kopecks),[38]

which obviously helped its spreading. Sharvin sent his text to Mach on the latter's request, and wrote to him very proudly:

> In general I succeeded in provoking in many people a lively interest in Your work and a lively desire to know it. Already during my lecture, I received many questions and even more after the lecture has been published on a journal.[39]

ung eines modernene Naturforschers: Ein nicht-kritisches Referat über Mach's "Analyse der Empfindungen", Dresden-Leipzig: C. Reissner 1903).

[34]Theodor Beer, *op. cit.,* 2nd ed., p. 123.

[35]Pëtr K. Engel'mejer to Ernst Mach, February 17 (March 2), 1906. English translation in J. T. Blackmore, *op. cit.*, p. 237.

[36]I. L. Levintov to Ernst Mach, December 19 (31), 1899.

[37]Vasilij V. Sharvin to Ernst Mach, February 27, 1906.

[38]Pëtr K. Engel'mejer to Ernst Mach, April 27 (14), 1906; February 17 (March 2), 1906. See Vasilij V. Sharvin, "Kak sozdaetsja nauka (Vozzrenija Ernsta Makha)", in *Russkaja mysl'*, 10, 1905, pp. 28–60; Moskva: tip. T-va I. N. Kushnerev i Ko. 1906.

[39]Vasilij V. Sharvin to Ernst Mach, February 27, 1906. See also V. V. Sharvin, *Khimija na sluzhbe cheloveka*, Moskva: tip. T-va I. N. Kushnerev i Ko., 1903; Id., *Kak sozdaetsja nauka*, *op. cit.*, p. 8.

Mach was depicted as “the real philosopher of our times, a direct follower of Bacon and Comte”, the philosopher who definitely overcame metaphysics and opened a safe path for the development of science. According to Sharvin, Mach acknowledged that the unique possible object of study is experience, considered as a “various combination of our sensations”.[40] Any other kind of knowledge would have just been metaphysics. The aim of science, in his opinion, was the most complete and comprehensive description possible of natural phenomena. Since our observations are necessarily fragmentary, science needs to fill the gaps by using analogies, knowing that a complete description of all the natural phenomena is unreachable.[41] Science had to be continuously improved, though it can never reach perfection. Science becomes a better and better instrument for adaptation to the world; it enlarges our horizons; it continuously corrects our world-view, it helps us to understand the conditions of our life and to get along with them.[42] Sharvin shared Mach’s idea of knowledge as an “economic” enterprise to the aim of survival.[43]

But for Sharvin, as well as for others of his contemporary Russians, science should also lead humankind in the difficult moments of history, when – as he wrote to Mach – “three revolutions (political, social and national) are taking place once again”. While the revolution of 1905 was just finishing, Sharvin wrote to Mach:

> the darkest the night, the brightest are the stars. The most shameless and noisy will the barbaric uprising of the blind reaction be, the most harmonic will the names sound of those few who will be able to show to their similar human beings the right way to the spiritual liberation from everything barbaric, small-minded, and mean....

And concluded: “you are one of those very few”.[44] Sharvin thought that the different “political” interpretations of Machism were basically wrong, because they read Mach’s ideas “in the false light of preconcieved opinions”.[45] Nevertheless, he claimed that Empirio-Criticism should orientate people not only within epistemology, philosophy, science, but also in political and social life.

In those days Empirio-Criticism became one of the central elements of the political debates within the Russian Social-Democratic Party. Russian journals noticed that “many Marxists nowadays abandon materialism and even consider it as a calumny against Marx”.[46] Mach himself was informed about this peculiar situation. In 1907 a young follower of his ideas wrote to him that, in Russia, “the greatest majority of the people supporting Your and R. Avenarius’ ideas are at the same time followers of Marx”.[47] Friedrich Adler knew what was going on in Russia, since his wife was Russian herself and helped him to read journals and books.

[40] *Ibid.*, p. 26.
[41] *Ibid.*, pp. 20–32.
[42] *Ibid.*, pp. 55–56.
[43] See Vasilij V. Sharvin to Ernst Mach, February 27, 1906.
[44] Vasilij V. Sharvin to Ernst Mach, October 21, 1906.
[45] Vasilij V. Sharvin to Ernst Mach, February 27, 1906.
[46] N. I. “Recenzija: G. V. Plekhanov, *My i oni*”, in: *Sovremennyj mir*, 12, 1907, pp. 148–149.
[47] N. Valentinov, *Ernst Makh i marksizm*, Moskva: Sotrudnik provincii 1908, p. 7.

In 1909, Adler wrote to Mach that "the struggle over Mach" was continuing in Russia.[48] One year later another Russian follower wrote to him from Ekaterinoslav that "around Your name (which I think will surprise you a lot) furious battles are fought in the press (. . .). There exists even a specific name: 'Machism'".[49] In 1911, Hans Kleinpeter, who had met some Russian thinkers at the International Congress in Bologna, wrote to Mach about the "increasing influence of your ideas in Russia".[50]

Mach's ideas actually spread over the entire Russian Empire. Since 1907, the philosophical debate, which, until that moment, was basically limited to Petersburg, Moscow and Russian emigrées in Europe, spread in Georgia, Armenia, Azerbajdzhan...[51] Subjects such as the concept of reality, the relativity of truth, sensualism in epistemology, were discussed everywhere, in workers' circles of self-instruction as well as in jail among political prisoners.

What is quite characteristic of this first phase of the political debates on Machism in Russia, until 1908, is that the fracture between "Orthodox" and "Critical" Marxists involved both Mensheviks and Bolsheviks: among the Orthodox Marxists, there was Plekhanov, who was a Menshevik, but also Lenin, who was a Bolshevik; among the critics, there were Bogdanov, Lunacharskij, Bazarov, who were Bolsheviks, but also Pavel Jushkevich who was a Menshevik. Since 1904, Bogdanov and Lenin had signed what they called a sort of "philosophical truce" in order to keep all the philosophical discussions out of the Party press. So Russian Machists mainly published their works at legal publishing houses and in legal journals. Therefore, they had a certain exchange with other people involved in spreading Mach's ideas in Russia, but who were not directly involved in the revolutionary movement. For instance Lunacharskij was asked by Mach's translator Kotljar to write a preface to the Russian translation of Petzold's *Introduction in the Philosophy of Pure Experience* in 1909. Lunacharskij did not write it in the end.[52] But Bogdanov did write a Preface to the first Russian translation of Mach's *Analysis of Sensations*. Bogdanov's work was not appreciated by "liberal" philosophers, such as Semen

[48] Friedrich Adler to Ernst Mach, July 23, 1909, in: Rudolf Haller – Friedrich Stadler (Eds.), *Ernst Mach. Werk und Wirkung.* Wien: Hölder – Pichler – Tempsky 1988, p. 287.

[49] V. Nokhotovich to Ernst Mach, February 26, 1910.

[50] Hans Kleinpeter to Ernst Mach, May 5, 1911.

[51] See Lev Leonov, *Star'e voskreslo! (Otvet na referat odnogo makhista F. N.)*. Tiflis: Progress, 1909; U. N. Bakirov, *Iz istorii bor'by V. I. Lenina protiv makhizma v Rossii*. Avtoreferat. Moskva: AON pri CK KPSS 1970; Fido K. Nadibaidze, *Iz istorii bor'by protiv makhizma v Gruzii. Social'no-politicheskie i filosofskie vzgljady M.N. Davitashvili*. Avtoreferat. Tbilisi: TGU 1965; Fido K. Nadibaidze, *Osnovnye techenija filosofskoj mysli XX veka v Gruzii. 1900–1921*. Avtoreferat. Tbilisi: TGU 1983; V. K. Sevjan, *Kriticheskij analiz armjanskoj burzhuaznoj filosofii (nachalo XX v.)*. Avtoreferat. Erevan: EGU 1971; Karapet A. Mamikonjan, *Bol'shevistskie organizacii Zakavkaz'ja*. Erevan: Aiastan 1973.

[52] *Literaturnoe nasledstvo*, t. 80: *V. I. Lenin i A. V. Lunacharskij. Perepiska, doklady, dokumenty*. Moskva: Nauka 1971, p. 619; Iosif Petzoldt, *Vvedenie v filosofiju chistogo opyta*. Sankt Peterburg: Shipovnik 1909.

Frank, who wrote: “we complain that Mr. Bogdanov bothered to write a preface that Mach had not requested”.[53] Sharvin wrote to Mach:

> It is very definitely to be regretted that Mr. Bogdanov has taken so much trouble to write such a completely unsuitable preface to your work. This juxtaposition clashes so disharmoniously, as if someone wanted to play Offenbach as an introduction to Beethoven’s Fifth Symphony. Why this agitation handbill? Why does ‘comrade’ Bogdanov polemicize against ‘comrade’ Plekhanov? What has Carl Marx and “the revolutionary proletariat” to do with your *Analysis*? This preface can only have a very damaging effect, naturally not for your majestic work, but for the unknowing people who will lay your book aside because of Bogdanov’s work, without ever becoming acquainted with the beauty of your ideas.[54]

In his Preface, Bogdanov counterposed Mach’s critical attitude to Plekhanov’s blind commitment to the Orthodox Marxist dogmas:

> In Mach’s thought there is much to learn. And in our turbulent time, in our country covered with blood, what he teaches is especially precious: a calm steadiness of thought, a strict objectivism of methods, a merciless analysis of everything that is taken by faith, a merciless destruction of all the idols of thought.[55]

Bogdanov’s Preface had an interesting fate. In the Ernst Mach Archive a type-printed German translation of Bogdanov’s essay can be found, with some handwritten corrections that were accepted in the published German version, which appeared in *Die Neue Zeit* in order to celebrate the seventieth anniversary of Mach’s birth in 1908.[56] Some political references to the Russian situation were eliminated from the text; *Die Neue Zeit*, however, published a short foreword by the anonymous translator:

> Russian Social-Democracy, unfortunately, reveals a strong tendency to making this or that attitude towards Mach a question of factional division within the party. Grave tactical differences of opinion between the Bolsheviks and the Mensheviks are aggravated by a controversy on a question, which, in our opinion, has no bearing whatever on these differences, namely, whether Marxism, from the point of view of theory, is compatible with the teaching of Spinoza and Holbach, or of Mach and Avenarius.[57]

The Bolsheviks’ answer was immediate. The Mensheviks had already been attacking the Bolsheviks by emphasizing that Bolshevism and Machism were different expressions of the same “subjective whim and vulgar empiricism”.[58] Lenin could not accept that such an opinion was supported by the authoritative organ of

[53] Semen L. Frank, “Recenzija: E. Mach, *Analiz oshchushchenij i otnoshenie fizicheskogo k psikhicheskomu*”, in: *Russkaja mysl’*, 11, 1907, p. 230.

[54] Vasilij V. Sharvin, October 4, 1907. English translation in J. T. Blackmore, *op.cit.*, p. 239.

[55] Aleksandr A. Bogdanov, “Chego isskat’ russkomu chitatelju u Ernsta Makha?”, in: Ernst Mach, *Analiz oshchushchenij i otnoshenie fizicheskogo k psikhicheskomu*. Moskva: Skirmunt 1907, p. XII.

[56] Aleksandr A. Bogdanov, “Ernst Mach und die Revolution”, in: *Die Neue Zeit*, Jhrg. XXVI, Bd. I, pp. 695–700.

[57] *Ibid.*, pp. 695–696, English translation in: Vladimir I. Lenin, *Collected Works*, Moscow: Progress Publishers 1978, vol. 13, p. 447.

[58] Ljubov’ I. Aksel’rod (Ortodoks), “Dva techenija”, in: Id., *Na rubezhe. K kharakteristike sovremennykh iskanij*. Sankt Peterburg: Nashe vremja 1909, p. 265.

German Social-Democracy. So he published the following statement on the official journal of the Bolshevik fraction *Proletary*:

> In this connection the Editorial Board of *Proletary*, as the ideological spokesman of the Bolshevik trend, deems it necessary to state the following. Actually, this philosophical controversy is not a factional one and, in the opinion of the Editorial Board, should not be so; any attempt to represent these differences of opinion as factional is radically erroneous. Both factions contain adherents of the two philosophical trends.[59]

At the beginning of 1908, a new volume came out, as a collection of essays by different "critical" Marxists.[60] According to Lenin, "the book, *Studies in the Philosophy of Marxism*, has considerably sharpened the old differences among the Bolsheviks on questions of philosophy".[61] In his letter to Maxim Gorky, Lenin concluded that "some sort of fight among the Bolsheviks on the question of philosophy" was "quite unavoidable".[62] Right away, Gorky, who at that time sided with Bogdanov and Lunacharsky, reported to Bogdanov that Lenin "snorts like a boiling *samovar*, puffs in every direction with his polemic steam, and I am afraid somebody might get burnt".[63] As it is well know, the result of this polemic steam was *Materialism and Empirio-Criticism*, which should be considered as an important, but not at all exclusive episode in a very long *Makhomjakija*, as Izgoev called the conflict within Russian Maxism about Mach and his thought.[64] Machism became, in the words of Pavel Jushkevich, "a synonim of the critical spirit, of the attempt to follow the development of science".[65]

Then a very sharp philosopher, Semen Frank, criticized "the Russian Marxists' attempt to mix this subtle, original and aristocratic product of disenchantment and philosophical contemporary *Blasiertheit*, with the naive dogmas of revolutionary socialism",[66] but in Russian the word "Machism" entered the common language with the meaning of a critical revolutionary thought. In a novel published in 1907, *During the Holidays* by N. Oliger, the coroner who has to inspect the body of a young revolutionary victim of suicide, finds the dead's papers and comments: "They are translations from German, some philosophical book. Look at this: 'Mach's followers find that critical monism in its development'... – It does not matter, it's revolutionary stuff...».[67]

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[59] Vladimir I. Lenin, "Statement of the Editors of *Proletary*", in Id.: *Collected Works*, *op. cit.*, vol. 13, p. 447.

[60] *Ocherki po filosofii marksizma*, Sankt Peterburg: Zerno 1908.

[61] Vladimir I. Lenin to A. M. Gorky, February 25, 1908, in: Id., *op. cit.*, p. 448.

[62] *Ibid.*, p. 453.

[63] Maksim Gorky, *Neizdannaja perepiska*, Moskva: Nasledie 1998, p. 36.

[64] Aleksandr S. Izgoev, "Na perevale. III. Makhomakija v lagere marksistov", in: *Russkaja mysl'*, 2, 1910, pp. 106–114.

[65] Pavel S. Jushkevich, "Na temu dnja. K voprosu o filosofskom brozhenii v marksizme", in: *Vershiny*, 1909, kn. I, p. 371.

[66] Semen L. Frank, "Recenzija: N. Valentinov, *Filosofskie postroenija marksizma*; A. Bogdanov, *Prikljuchenija odnoj filosofskoj shkoly*; P. Jushkevich, *Materializm i kriticheskij realizm*", in: *Russkaja mysl'*, 12, 1908, p. 273.

[67] Nikolaj F. Oliger, "V chasy otdykha", in: *Obrazovanie*, 12, 1907, p. 3.

Chapter 23
Ernst Mach as an Applicant and the Candidate *secundo loco* for two Professorships of Physics in Prague in 1866–67

Emilie Těšínská

Abstract Within the winter semester of school year 1866/67, two professorships of physics were announced to be vacant in Prague with the beginning of the following summer semester, namely the only professorship of physics at "Karl Ferdinands-Universität" (KFU) and one of two professorships of general and technical physics at the "Polytechnisches Landes-Institut des Kőnigreiches Böhmen" (PLI). Ernst Mach, a 28-year-old Professor of Physics at "Karl Franzens-Universität" in Graz, applied for both of the Prague professorships at the end of 1866. By the Supreme decision of 11 March 1867, he was appointed as professor of physics at the KFU, where he then spent a full 28 prolific years of his life and professional career.

This paper focuses on the consideration of Ernst Mach's candidacy for the two Prague Professorships of Physics by the bodies of professors of the respective higher education establishments in the context of other applicants and the qualification criteria set for either of the posts.

The paper is predominately based on historical sources found in archives in Prague, which, however, are quite fragmentary on the topic. Complementary documents and data were provided by courtesy of some foreign archives. The aim of the paper is to contribute, though just a small amount, to the existing biographical literature on Ernst Mach. It can also serve as a case illustration on career mobility and professional contacts within the academic community in the Austro-Hungarian monarchy and neighbouring German-language countries in the second half of the nineteenth century.

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23.1 Introduction

Within the winter semester of school year 1866/67, two professorships of physics were announced to be vacant in Prague with the beginning of the following summer semester, namely the only professorship of physics at “Karl Ferdinands-Universität” (KFU) and one of two professorships of general and technical physics at the “Polytechnisches Landes-Institut des Kőnigreiches Böhmen” (PLI). Ernst Mach, a 28-year-old Professor of Physics at “Karl Franzens-Universität” in Graz, applied for both of the Prague professorships at the end of 1866. By the Supreme decision of 11 March 1867, he was appointed as professor of physics at the KFU, where he then spent a full 28 prolific years of his life and professional career.

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The aim of the paper is to contribute, though just a small amount, to the existing biographical literature on Ernst Mach. It can also serve as a case illustration on career mobility and professional contacts within the academic community in the Austro-Hungarian monarchy and neighbouring German-language countries in the second half of the nineteenth century.[1]

The paper is predominately based on historical sources found in archives in Prague, which, however, are quite fragmentary on the topic. Complementary documents and data were provided by courtesy of some foreign archives.

23.2 Ernst Mach’s Predecessor in Prague and his Departure for Vienna

By the Supreme decision of 13 October 1866, the professor of physics at the University in Prague (KFU), 47 year-old Viktor Pierre (1819–1886), was appointed to the professorship of physics at the Polytechnic in Vienna, as the successor to Ferdinand Hessler (who died a year before). With regard to the already begun school year, however, Pierre’s departure to Vienna was postponed up to the summer semester of 1867.

Pierre was not in line as a candidate for the professorship of physics at Vienna Polytechnic until the second round, after failed negotiations with the first three candidates, who were Rudolf Clausius (at that time professor of physics at the Polytechnic in Zurich), Josef Stefan (professor of higher mathematics and physics at the University in Vienna) and Ernst Mach (from February 1864 professor

[1]Cf. Walter Rüegg (Ed.), *A history of the university in Europe. Vol. 3. Universities in the nineteenth and early twentieth centuries*. Cambridge: Cambridge University Press 2004.

of mathematics, and from April 1866 professor of mathematical physics at the University in Graz). In the second round Pierre was proposed to the professorship in first place, whereas the second place candidate was Adolph Wüllner (at that time "Privat Dozent" at the University of Bonn).[2]

23.3 Two Chairs of Physics Held by Viktor Pierre in Prague

Viktor Pierre was sitting on two chairs of physics in Prague, so to speak. In addition to the full professorship of physics at KFU (a post he had held from the 1857/58 school year) he was also substituting for a full professorship of general and technical physics taught in German at PLI. In connection with Pierre's recruitment for Vienna it was therefore necessary to fill the vacancies of two professorships of physics in Prague.

23.3.1 Pierre's Chair of Physics at KFU

At KFU at that time there was only one professorship of physics. Its holder had at his disposal a Physics Institute ("physikalisches Kabinet"), having a seat at the address "Obstmarkt Nr. 562-I", and with an annual subsidy of 800 florins of the Austrian currency, an inventory of about 1000 items ("Instrumenten und Apparaten"), one paid-assistant position, and an institutional servant.[3]

The main task of this professorship was to ensure lectures and demonstrations in physics for students of the Faculty of Philosophy (candidates for teaching at secondary schools) and for students of two-year pharmaceutical courses.

Pierre had specified in his teaching instructions that "especially to benefit teaching candidates" he had to carry out practical exercises and demonstrations from various fields of physics. He did perform such exercises[4] but rarely allowed students to carry out experimentation themselves because he feared that his Physics Institute's equipment would be damaged.[5]

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[2]Gustav Jäger, „Die Lehrkanzel der Physik und ihre Sammlungen", in: Joseph Neuwirth (Ed.): *Die k. k. Technische Hochschule in Wien 1815–1915 (Gedenkschrift)*. Wien: Selbstverlag der k. k. technischen Hochschule in Wien 1915, p. 393ff.

[3]The National Archives, Prague (NA), České místodržitelství 1856–1910 (ČM), sign. 25/12/2, b. 1007.

[4]The Archive of Charles University, Prague (AUK), Ordnung der Vorlesungen an der k. k. Universitaet zu Prag im Winter Semester 1865–6.

[5]The Masaryk Institute and Archives of the AS CR, Prague (MÚA), Jednota čs. matematiků a fyziků (JČMF), inv. no. 1815, b. 82 (recollections of Czech mathematician Gabriel Blažek (1842–1910), manuscript dated 24. 3. 1887).

In 1858, shortly after his appointment at KFU, Pierre also agreed to giving a colloquium on experimental physics for students of medicine. Such a colloquium was claimed by professors of the Faculty of Medicine with reference to lectures on physics for medical students held at the University in Vienna. Students of medicine in Prague, however, did not show interest in the colloquium, perhaps because of Pierre's reputation as a rigorous examiner, and the colloquium was ceased.[6]

Pierre's teaching load at KFU amounted to a total of 8 h per week. He also had to sit on the State examination commission ("die k. k. wissenschaftliche Prüfungs-Commission für das Gymnasial-Lehramt in Prag") as an examiner for the group of mathematical and natural sciences subjects; the examinations took place twice a year in Prague and were preceded each time with voluminous paperwork.[7]

In addition to the physics lectures given by professor Pierre, professors of mathematics Wilhelm Matzka (1798–1891) and Karl Hornstein (1824–1882) lectured on selected topics of mathematical physics and analytical mechanics at KFU.[8] Not irrelevant to our topic is the fact that Karl Hornstein came to Prague in 1864 from the University in Graz, where he was succeeded by Ernst Mach.[9]

It should also be mentioned that until 1882, when KFU split up into two independent universities, a German one and a Czech one, the main language of instruction at the University was German. Nevertheless, some lectures took place in Czech there from the 1860s.[10]

23.3.2 Two Chairs of Physics at PLI

The PLI was a higher education establishment of the Bohemian kingdom and according to its statute of 1863, two professorships were established at it for each of nine main subjects of instruction (including physics), one taught in German and one in Czech.[11]

Karel Václav Zenger (1830–1908) was appointed the Czech physics professor there in 1863.[12] The professorship of physics taught in German remained unoccu-

[6] NA, ČM, sign. 25/12/8, b. 1007.

[7] Deutsches Museum Archiv, München, Wissenschaftliche Nachlass von Ernst Mach, Allgemeine Korrespondenz, NL 174/2518 (V. Pierre an E. Mach, Prag, 16. 4. 1867).

[8] AUK, Ordnung der Vorlesungen, l. c.

[9] Cf. Klemens Rumpf (Ed.): *Von Naturbeobachtungen zur Nanophysik*. Publikationen aus dem Archiv der Universität Graz, Bd. 40. Graz: Akademische Druck- u. Verlagsanstalt 2003, p. 283.

[10] *Reichsgesetzblatt für die im Reichsrathe vertretenen Kőnigreiche und Ländern, Jg. 1882*. Wien: Staatsdruckerei 1882, VIII. Stück (3. 3. 1882), p. 33 (Gesetz vom 28. Februar 1882 betreffend die k. k. Karl Ferdinands-Universität in Prag).

[11] Albert Vojtěch Velflík, *Dějiny technického učení v Praze. Díl prvý.* Praha: Česká Matice technická 1906 and 1909, pp. 408–416.

[12] K. V. Zenger studied at KFU in 1848–53. In 1853, he acquired approbation for teaching mathematics and physics at grammar schools in both Czech and German. In 1853–1862, he worked as a teacher at a catholic grammar school in Banská Bystrica (Slovakia). In 1861, he received a leave that enabled him a half-a-year stay in Vienna, at the Physics Institute headed by A. von

pied and its supplementation was provisionally entrusted to professor Pierre from the 1864/65 school year.[13]

The teaching of both physics professors at PLI included lectures on general physics (5 h per week) and on technical physics (2 h per week). The both professors, however, had to share one Physics Institute ("physikalisches Kabinet").

Specifically, in the 1865/66 school year at PLI, 79 students of general physics in German and 65 students of technical physics in German were enrolled in Pierre's lectures; 104 and 90 students were enrolled in the same lectures in Czech taught by Professor Zenger. The inventory of the Physics Institute there showed 395 items (ie. less than half of the inventory of the Physics Institute at KFU) in that school year.[14]

As soon as in 1869 (ie. 13 years earlier than KFU), PLI split up into two independent institutes according to the teaching language, a German one and a Czech one. Each professorship of physics was thereafter equipped with a separate physics institute.[15]

23.4 Launch of the Nomination Proceedings

The academic councils of the two aforementioned higher education establishments in Prague were officially informed about the impending departure of Professor Pierre to Vienna at the turn of October and November 1866, and were invited to submit – in proper time – a proposal for the filling of the respective physics professorship to be vacated.[16]

23.5 Proposal for the Professorship at KFU

Professors Pierre, Matzka and Hornstein were entrusted with drafting a proposal of suitable candidates for the professorship of physics at KFU. A skilled experimenter and experienced university teacher was required for this professorship, if possible

Ettingshausen. Zenger planned to apply for "venia docendi" at Vienna Polytechnic, but then he accepted an invitation to PLI where he habilitated for physics taught both in Czech and German (in 1862) and was appointed as a full professor of physics taught in Czech (24 June 1863 provisionally, 27 April 1864 definitively). The Archives of the Czech Technical University, Prag (AČVUT), Polytechnický ústav (PÚ), b. 127, P14/1; A. F. Velflík, *Dějiny*, p. 400ff.

[13] NA, Zemský výbor v Čechách 1791–1873 (ZV), sign. 85/50/II/p, b. 1319.

[14] NA, ZV, sign. 85/50/Vd, b. 1352; A. F. Velflík, *Dějiny*, p. 469.

[15] *Landes-Gesetz-Blatt für das Königreich Böhmen*, *Jg. 1869*. Prag 1869, pp. 118–127 (Nr. 73. Kundmachung des k. k. Statthaltereileiters, 2. Juni 1869, Z. 29,119).

[16] AUK, Filosofická fakulta 1849–1885 (FF), Geschäftsprotokol des phil. Professoren Collegiums im Studienjahre 1866–67, b. 15; NA, ZV, sign. 85/50/IIp, b. 1319.

one who was also knowledgeable about the needs and practice of teaching physics at secondary schools.[17]

Though mathematical-theoretical erudition was not viewed as a crucial qualification for this professorship (qualified as a professorship of experimental physics), the drafting committee fully recognized that the education of candidates for teaching physics at grammar schools also needed some advanced lectures in mathematical-theoretical physics. Keeping this in mind, a statement of the insufficiency of the only one professorship of physics at KFU was incorporated in the final proposal.[18]

Four inland candidates were taken into consideration by the drafting committee. The first ever person that showed interest in this professorship was the 46 year-old Doctor of Philosophy Ferdinad Peche, at that time director of a "Oberrealschule" in Rakovać on the Austrian-Serbian military border. His request was registered by the Faculty of Philosophy in Prague on 6 November 1866.[19] Peche had learned of the two vacated professorships of physics in Prague most probably through his relative Franz Peche, an official of the "Finanz-Landes-Direktion" in Prague. The information that Ferdinad Peche had received did not evidently provide him with a correct idea of the profiles of the two Prague professorships. This can be deduced from the plan of a higher 3-year physics course that he intended to give in Prague and that he attached to his application (for either professorship).[20]

The other two applicants for the professorship of physics at KFU were: 38-year old Adalbert von Waltenhofen (Professor of physics at the University in Innsbruck) and 28-year old Ernst Mach (Professor of physics at the University in Graz); their candidacies were registered by the Faculty of Philosophy in Prague on 17 December 1866. The fourth candidate taken into consideration was 28-year old Ferdinand Lippich, a graduate of PLI, from October 1865 acting as a full professor

[17]Österreichisches Staatsarchiv, Wien (ÖStA), AVA, Unterricht-Allg., b. 1219, PA Ernst Mach, Zl. 2014/1867 (K. k. philosophischen Professoren-Collegium, Prag, 30. Dezember 1866, No. Exh. 207).

[18]The requirement for the establishment of a second professorship for (higher) physics (namely teaching in Czech language) at KFU came from students of the Faculty of Philosophy with a deep interest in mathematics and physics. Cf. Emilie Těšínská, „Profesor Ernst Mach, jeho příchod na pražskou univerzitu a vazby s formující se Jednotou českých matematiků a fyziků", in: *Pokroky matematiky, fyziky a astronomie* 61, 2, 2016, pp. 137–159.

[19]AUK, FF, Gescheftsprotocoll, l. c.

[20]Ferdinand Peche (1820–1898) was born in Bohemia, studied mathematics and natural sciences at KFU (1845 graduated as a doctor of philosophy, 1851 passed the state examination in mathematics and physics). Then he worked in the civil service as a telegrapher and as a secondary school teacher. In April 1854, he habilitated for analytical physics and mechanics at the University in Graz. In 1864, he already applied at PLI for a professorship of mathematics taught in German, and was proposed as the candidate in first place but was not nominated. At last, by the Supreme decision of 12 June 1868, he was appointed as professor of mathematical physics at the University in Innsbruck. NA, ZV, sign. 85/50/Vd, b. 1352.

of theoretical and applied statics and mechanics at "Joanneum" in Graz, before that for 6 years as an assistant to professor Pierre in Prague.[21]

After a thorough review of the scientific and pedagogical eligibility of the four listed candidates, the three-member drafting committee proposed for the professorship of physics at KFU in first place Adalbert von Waltenhofen, in second place Ernst Mach; and did not list a candidate in third place. Such a proposal, dated 30 December 1866, was approved by the council of the Faculty of Philosophy and on 12 January 1867 it was submitted to the "Staatsminiserium" in Vienna for their final redaction.[22]

The nomination of Waltenhofen in first place was justified by his long-time teaching (at university and high school), his publishing activities in the field of experimental physics, his experience with the building of physics institutes of Austrian provincial universities (with limited financial resources), and his held academic positions.[23]

A. von Waltenhofen (1828–1914) studied mathematics and physics at both the University and Polytechnic in Vienna, he started his academic career as an assistant at the University in Graz, where he then taught mathematics and physics at a grammar school for 2 years and temporarily substituted for physics at the "Joanneum". In 1866 he had already held the post of professor of physics at the University in Innsbruck for 14 years, where he was twice elected Dean of the Faculty of Philosophy and in 1861 Rector.[24]

In assessing the candidacy of Ernst Mach, the proposal highlighted his scientific quality. It noted that Mach had already published a "not insignificant number of scientific papers"; these works were largely focused on the field of physiology and medical physics; were not only experimental in nature, but also demonstrating Mach's high mathematical-theoretical erudition. In comparison with Waltenhofen, Mach lacked longer academic experience and merit – this was stated in the proposal with a remark that this did not in any way underestimate Mach's teaching and scientific-organizational capabilities.[25]

[21] Ferdinand Lippich (1838–1913) was born in Padua, where his father-physician worked at the university. After his father's death, his mother, siblings and he moved to Prague (at the invitation of their uncle Franz Kőstl, professor of psychiatry at KFU). Lippich then studied at PLI (1855–59) and worked as an assistant to professor Pierre at KFU (1859–56) and from 1864 also at PLI, where he habilitated in 1863 for mathematical physics. On 1 October 1865, he took up the regular professorship of "theoretischen und angewandten Statik und Mechanik" at "Joanneum" in Graz. NA, Ministerstvo kultu a vyučování Vídeň 1882–1918 (MKV-R), sign. 5, b. 115, Lippich Ferdinand; Anton Lampa, „Ferdinand Lippich †", in: *Lotos* 62, 1914, pp. 13–18.

[22] AUK, FF, Gescheftsprotocoll, l. c.

[23] ÖStA, l. c.

[24] AČVUT, PÚ, b. 128, P24.

[25] ÖStA, l. c.

23.6 Proposal for the Professorship at PLI

A public competition was announced by the Bohemian Provincial Committee ("Landesausschuss des Kőnigreiches Bőhmen") on 12 November 1866 for the professorship of general and technical physics taught in German at PLI. The announcement was published bilingually in Prague and Vienna gazettes and communicated by letter to 15 educational institutions in Austria and abroad (in the German-language area). The deadline for submitting applications was set until the end of December 1866. The salary conditions of this professorship were better: the salary of the lowest pay grade was 2000 fl. (compared to 1360 fl. at KFU).[26]

Physicists Pierre and Zenger and the professor of higher mathematics (taught in German) Heinrich Durège (1821–1893) were entrusted with considering the presented applications and drawing up a proposal of the most suitable candidates for this professorship.[27]

An expert with scientific prestige and teaching experience was again sought after. A specific requirement of this time was to be properly qualified to meet the needs of teaching physics for engineers. As it was stated in the introduction to the final draft, for engineers physics was not only a subject of scientific knowledge but also (or above all) the basis for intelligent practical work. Therefore, applicants with scientific publications in applied physics rather than in mathematical physics or pure mathematics were given preference.[28]

Interest in the professorship of physics (taught in German) at PLI was great (due to the good salary, and also to the announced public competition). In the overview of the applications received, dated on 4 January 1867, 16 applicants were shown, 14 from Austria and 2 from abroad: Adam Weiss (45 years, professor of higher mathematics and physics at the Polytechnic in Nuremberg) and Eugen Lommel (30 years, "Oberlehrer an der Kantonsschule" and "Privat Dozent" at the University and Polytechnic in Zurich). The already mentioned four candidates for the professorship of physics at KFU featured in the list.[29]

Adalbert von Waltenhofen was the first ever applicant for this professorship. His carefully substantiated application was dated 24 November 1866 and addressed directly to the Bohemian Provincial Committee. It was accompanied by 18 annexes documenting Waltenhofen's education and professional career. He stressed his rich pedagogical and scientific-organizational experience. He also mentioned that his previous appointments were made by the Austrian minister of education in 1849–1860 count Lev Thun (who was closely linked to the Czech lands). On top of that,

[26] AČVUT, PÚ, b. 128, P24 (Landesauschuss des Königreiches Böhmen, 12. 11. 1866, Concurs-Ausschreibung No. 13734).

[27] NA, ZV, sign. 85/50/IIp, b. 1319.

[28] AČVUT, PÚ, b. 128, P24 (Vorschlag zur Besetzung der am k. böhm. polytechn. Landesinstitute erledigten Lehrkanzel der Physik mit deutscher Unterrichtsprache, 23. 2. 1867).

[29] Ibd. Cf. Emilie Těšínská, "Okolnosti povolání Ernsta Macha na profesuru fyziky na pražské univerzitě v roce 1867", in: *Práce z dějin Akademie věd,* 8, 1, 2016, pp. 1–32.

Waltenhofen sent a forthcoming letter to the professorial staff of PLI, informing them of his candidacy, outlining his teaching and scientific organizational plans (if he received the professorship) and expressing his firm belief in their mutual understanding.[30]

Ernst Mach's application for the professorship at PLI was dated 2 December 1866 and addressed to the Rector's Office (keeping with the instructions given in the competition announcement). Mach's application was factual and modest, neatly handwritten and fee stamped. He stressed that: he had worked successfully as a university teacher for 6 years; that he spoke French, German and Czech (given in that order); that he had published numerous scientific papers (which he substantiated with by listing 19 publications in scientific periodicals and 4 books). Finally, he added that some of his students in Graz, namely Camillo Bondy and Anton Šantel, had carried out scientific work under his leadership. Mach did not attach any enclosure to his application, just promised to provide a more complete bibliography of his publications later.

A favourite for the professorship of physics at PLI – in the eyes of some members of the professorial staff there – was Ferdinand Lippich, who was apparently invited to participate in the competition from Prague. Lippich communicated his position and requirements with respect to this professorship in a letter sent before Christmas 1866 to the Rector of PLI Karel Kořistka.[31] He wrote that he was satisfied professionally with his position in Graz and in terms of local collegial relationships there. Pivotal for his candidature for the professorship of physics at PLI was (as at KFU) the question of pay. In Graz, he received an annual salary of 1600 fl. In the case of both Prague professorships he demanded the granting (or an evening up in the form of personal bonuses) of a salary in the second pay grade (ie. in the case of the university 1680 fl., in the case of the polytechnic 2500 fl.); to achieve this grade, however, he was missing 8 years of service. In addition to the basic course in general and technical physics, Lippich also wanted to deliver lectures on selected topics in mathematical and applied physics at PLI (for a special reward).[32]

The drafting committee included F. Lippich to the applicants for the professorship at PLI. When assessing his candidacy for the post, the committee recognized his promising talent of a physicist and also his good knowledge of the local circumstances, but they could not accept his salary request. Like this, Lippich was not included in the final nomination for the professorship. Five years later,

[30] AČVUT, PÚ, b. 133, W21.

[31] Karel Kořistka (1825–1906), from 1851 professor of practical geometry (geodesy) and elementary mathematics at PLI, in 1866–67 rector. In 1841–43, he studied at the University and Polytechnic in Vienna (where he attended, among others, lectures on physics by A. von Ettingshausen, and on astronomy by K. Littrow). In 1843–49, he was assistant to Christian Doppler at the chair of mathematics and physics at the Mining Academy in Banska Štiavnica (Slovakia). In 1864, Kořistka become also a member of the "k. k. Unterrichts-Rath" in Vienna. Cf. A. F. Velflík, *Dějiny,* pp. 453–460.

[32] AČVUT, PÚ, b. 133, W21 (F. Lippich to the Rector of PLI, s.d. [end of December 1866]).

however, by the Supreme decision of 10 February 1872, he was appointed Professor of mathematical physics at KFU (ie. to a newly systemized, second physics professorship) and became E. Mach's departmental colleague in Prague.[33]

Despite the large number of applications for the professorship of physics at PLI, the drafting committee was not satisfied with them, probably because the most promising applicants – Waltenhofen and Mach – had already been proposed for the professorship of physics at KFU. Under the given situation, professor Heinrich Durège, who before coming to Prague in 1864 held a post of titular Professor at the Polytechnic in Zurich, took the initiative and turned to the President of the Swiss School Board in Zurich Johann Karl Kappeler (1816–1888), asking him for some (more) tips on suitable candidates for the physics professorship at PLI.

Kappeler was in charge of filling teaching posts at Swiss higher educational establishments and had a good overview of physicists in the quest for a satisfying position all over Europe. He recommended primarily Adolph Wüllner (1835–1908), at that time already an extraordinary Professor at the University in Bonn, and Karl Adolf Paalzow (1823–1908), a "Privat Dozent" teaching at the "Artillerie- und Ingenieurschule" in Berlin. The name of professor of physics at the University in Vienna Josef Stefan (1835–1893) was also mentioned, with the highest ranking as a physicist, but as someone whose acquisition for (provincial) Prague would have no chance of success.[34]

The drafting committee at PLI launched negotiations with Adolph Wüllner. For Wüllner, the joint Physics Institue at PLI (with the uncertain powers of both physics professors and without a fixed subsidy) was a serious weakness of the professorship. He wanted the administration of the Physics Institute be subordinated to him, and that he would be awarded a fixed subsidy of 1000 fl. for new scientific and teaching equipment. In addition to this (similar to F. Lippich), he demanded a salary of 2500 fl. per year; the 2000 fl. were allegedly equivalent to what he received in Bonn, and were not motivating for him.[35]

On account of negotiating with Wüllner, the preparation of the final draft for the professorship of physics at PLI was delayed. Wüllner was included among the applicants for the professorship and selected as one of the three most important, together with Waltenhofen and Mach. After a thorough comparison of the qualifications of these three candidates and a discussion on their strongest points, the drafting committee came to the conclusion that all three of them were on the same level even though each excelled in a different way. Professors Durège and Pierre therefore suggested that the three candidates be proposed for the professorship *ex aequo*, ie.

[33]NA, MKV-R, sign. 5, b. 115, Lippich Ferdinand.

[34]Physicists Emil Meier (Breslau), August Kundt (Berlin) and Johann W. Hittorf (Munich) were mentioned by Kappeler as other possible candidates for the professorship of physics at PLI. AČVUT, PÚ, b. 128, P24 (Antrag des Prof. Durège betreffend die Überreichung einiger Mittheilungen an die Commission zur Besetzung der Professur für Physik mit deutscher Unterrichtssprache, Präs. 28. Jäner 1867, Nr. 496).

[35]AČVUT, PÚ, b. 128, P24 (Auszug aus einem Briefe des Herrn Prof. Dr. Wüllner, s.d.).

without determining the order. Professor Zenger, however, pushed for priority being given to the Austrian candidates (for economical reasons), and Waltenhofen was nominated in first place (for his pedagogical experience), Mach in second place.[36]

The final proposal for the professorship of physics at PLI, drawn up by the committee and dated on 23 February 1867, was completely identical to the proposal for the professorship of physics at KFU, that had been referred to Vienna in January of that year: Waltenhofen was nominated in first place and Mach in second; a candidate in third place was not listed.[37]

Such a puzzled result was due to the fact that the drafting committee finally withdrew the nomination of Wüllner. Although the committee identified Wüllner's requirements regarding the physics institute as fully justified, in the short term they viewed them as impossible. The committee concluded that Wüllner's call-up to PLI would necessarily be at the expense of his scientific work, which, on the other hand, was the strongest argument in favour of his nomination. None of the other applicants for the professorship complied with the qualification requirements stipulated by the committee.

In the stated form, the proposal was approved by the professorial staff of PLI (on their meeting of 11 March 1867) and on 14 March it was referred to the Bohemian Provincial Committee in Prague to their decision.[38]

23.7 Redaction Made by Experts in Vienna

Meanwhile the Ministry of Culture and Education Department in Vienna asked the Austrian School Board ("der k. k. Unterrichts-Rath"), its section for the Faculty of Philosophy, for their expert view on the proposal for the professorship of physics at the University in Prague (KFU).

Three members of the School Board, professors of Vienna University Karl Littrow (astronomer), Franz Miklosich (Slavic philologist) and Robert von Zimmermann (philosopher), in a unanimous testimonial from 24 February 1867 – after reviewing the arguments of professors of Prague Faculty of Philosophy, and with reference to the laudatory statements of professor Josef Stefan about Ernst Mach – reversed the order of the two nominated candidates, ie. they recommended as the candidate in first place Ernst Mach and in second place Adalbert von Waltenhofen (who incidentally was, at the same time, nominated as the first place candidate for the professorship of physics at PLI).[39]

[36] Ibd. (Vorschlag zur Besetzung, l. c.).

[37] Ibd.

[38] NA, ZV, sign. 85/50/II/p, b. 1319.

[39] ÖStA, l. c. (Gutachten des Unterrichtsrathes, Sektion für philosophische Fakultäten, zur Z. 528/CU.867, 24. 2. 1967, an Friedrich von Beust, den provisorischen Leiters des k. k. Staatsministeriums).

Joseph Stefan was just 3 years older than Ernst Mach, and, at the University in Vienna, was the successor to professor Andreas von Ettingshausen under whose tutorship Mach had began his academic career as an assistant. In his reference (with all due respect to Waltenhofen) Stephan emphasized Mach's versatility as a physicist and the credit he had already received in scientific circles. In his view, Mach was a convenient candidate for the Prague professorship in all respects.

23.8 The Supreme Decisions

The two professorships of physics in Prague, vacated by professor Viktor Pierre, were finally filled as follows.

Ernst Mach was appointed as professor of physics at KFU by the Supreme decision of 11 March 1867, and with a starting salary of 1365 fl. per year (ie. about 105 fl. higher than he had received in Graz).[40] He arrived in Prague before the beginning of the summer semester in 1867: on 27 April he introduced himself to the Dean of the Faculty of Philosophy at KFU and on 29 April he took over the Physics Institute from Professor Pierre. In May, with the beginning of the summer semester, he commenced his lectures and seminars.[41]

Adalbert von Waltehnhofen was approved as professor of general and technical physics taught in German at PLI by the Decree of the Bohemian Provincial Committe from 27 March 1867 (confirmed by the monarch on 11 May of that year).[42] He assumed his duties in Prague from the beginning of the 1867/68 school year. Shortly afterwards, the PLI divided into two independent institutes according to the language of tutelage. Waltenhofen, along with his professorship, passed on to the German Polytechnic Institute in Prague, where he then set up a separate, newly equipped physics institute.

Mach remained in Prague for 28 years; after the division of KFU in 1882 he moved with his professorship and physics institute to the German KFU. He left Prague in the summer of 1895, for a professorship of philosophy at the University in Vienna. His successor in Prague became Ernst Lecher (1856–1926), before that professor of physics at the University in Innsbruck.

Waltenhofen worked in Prague for 15 years; apart from physics he also lectured on electrical engineering from 1881. He left Prague in 1883 for a professorship at the Polytechnic in Vienna. His successor in Prague became Johann Puluj (1845–1918), called up to the professorship from Vienna.

Both Ernst Mach and Adalbert von Waltenhofen were highly respected figures within the academic bodies of both Prague higher education establishments in the second half of the nineteenth century. The legacy of Ernst Mach on the history, however, was broader and more significant, as it went beyond the boundaries of the field of physics, the Austro-Hungarian monarchy and even its time.

[40] ÖStA, l. c. (K. k. Ministerium für Cultus und Unterricht, 1867, P. Nr. 2014/C.U.).

[41] AUK, FF, Geschäftsprotokol, l. c.

[42] NA, PÚ, b. 133, W21.

23.9 Conclusions

In 1866, Ernst Mach applied for a professorship of physics at both the University and the Polytechnic in Prague. A desire to have a physics institute at his disposal and/or an echo of Prague scientific traditions (the work of Christian Doppler in Prague in the past or Jan Evangelist Purkinje who was still active in Prague in 1866) might be his reasons.

For the professorship of physics at both the University and the Polytechnic in Prague, a renowned physicist and experienced academic teacher was searched for, who would raise the prestige of these establishments.

Ernst Mach's prolific scientific publications were highly appraised by the professorial bodies of the both Prague higher education establishments. His relatively young age and short academic career, however, played against him compared with another applicant for the two professorships, the older and more experienced academic teacher and dignitary Adalbert von Waltenhofen.

Adolph Wüllner, a foreigner, was a strong candidate for the professorship of physics at Prague Polytechnic. His stipulations and ambitions, however, could not be met. His nomination was abandoned at the very last moment. Due to this fact, the final proposals for the two vacant professorships of physics in Prague, as presented by the professorial bodies of these establishments, became identical: Waltenhofen proposed in first place ("primo loco"), and Mach in second place ("secundo loco"). A laudatory statement on Ernst Mach by Josef Stefan in Vienna contributed to the appointment of Mach as professor of physics at Prague University in March 1867, whereas Waltenhofen was appointed as Professor of Physics at Prague Polytechnic in May 1867.

Acknowledgements It is my pleasant duty to thank all the archives and people who were helpful and encouraged me to the research on the topic.

Part IV
Mach, Physics, and the Natural Sciences

Chapter 24
Mach's Influence on Einstein's "Biggest Blunder" and the Consequences for Modern Cosmology

Peter C. Aichelburg

Abstract It is well known that Einstein was strongly influenced by Mach's ideas in his struggle for a new theory of gravitation. In 1915 he published what he thought to be the final equations, but not much later he modified them by adding a "cosmological constant". One of the reasons for this modification was to implement what Einstein called "Mach's principle". I discuss the history of the cosmological constant and the puzzle of modern cosmology.

Let me start by explaining what Einstein himself called the underlying principles of his theory of General Relativity (Einstein 1918):

(i) Relativity Principle
(ii) Equivalence Principle
(iii) Mach's Principle

24.1 The Relativity Principle

The Relativity Principle goes back to Galileo and Newton. At the time it was established that systems in uniform motion with respect to each other show the same physical behaviour, i.e. any experiment in one will give the same result as

This article is based on a talk given at the "Mach Centenary Conference 2016" in Vienna. It gives an elementary outline of how Mach's ideas influenced Einstein seeking for a new theory of gravity. There are many versions of Mach's principle and it is a still ongoing debate on how Mach's principle is implemented in the theory of General Relativity. For readers who would like to penetrate deeper into the subject, I recommend the excellent book on "Mach's Principle, From Newton's Bucket to Quantum Gravity" with many contributions from experts in the field (Barbour 1995)

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F. Stadler (ed.), *Ernst Mach – Life, Work, Influence*, Vienna Circle Institute Yearbook 22, https://doi.org/10.1007/978-3-030-04378-0_24

in the other. Of course in those days experiments referred mostly to the motion of bodies. In the nineteenth century however a new phenomenon was discovered: electromagnetic waves. James C. Maxwell (1831–1879) formulated the theory and Heinrich Hertz (1857–1898) proved their existence. Light turned out to be a special case with a definite interval of wave lengths to which our eyes are adapted. As for any known wave phenomena, it was thought that electromagnetic waves would need a substrate to propagate. This substrate was called aether and would define a rest frame relative to which motion is absolute, thus breaking the classical Relativity Principle. But despite considerable efforts the aether could not be detected. On this basis Einstein formulated in 1905 what is known as the theory of Special Relativity (SR) in which he abandoned the existence of the aether and extended the Relativity Principle to the whole of physics, including electromagnetism (Einstein 1905). This had far reaching consequences for our understanding of space and time and also led him to the famous relation between mass and energy.

Although velocity is relative in SR, acceleration is absolute in the sense that it can be detected without any reference to another system due to the appearance of inertial forces. In order to change the velocity of a body a force is needed because the body has the tendency to keep its motion. This property is called inertia. We all experience inertia e.g. when sitting in a car which accelerates or brakes. But why is velocity relative and acceleration absolute and what is the origin of inertia? “Is it conceivable that the principle of relativity is also valid for systems that are accelerated to each other?” asked Einstein already in 1907, (Einstein 1907). Six years later, speaking at the meeting “Der Gesellschaft der Deutschen Naturforscher und Ärzte” in Vienna (Einstein 1913), he was convinced that: „It does not make sense to speak about motion, including acceleration of a body itself. It is only possible to speak about motion or acceleration of a body with respect to other bodies“ With this idea he not only extended the Relativity Principle to the whole of physics but also to be valid in any reference system. The laws of physics must be of such nature that they apply to system of reference in any kind of motion“ writes Einstein in his “The Foundation of the General Theory of Relativity” in 1916 (Einstein 1916). But how is the asymmetry between velocity and acceleration resolved?

24.2 Inertia and Gravity: The Principle of Equivalence

Since the days of Galileo it was known that all bodies fall with equal acceleration independent of their masses. (This contradicts our everyday experience, but is meant to apply when there is no air resistance.)The reason for this is that the acceleration of a body due to a gravitational force is proportional to its mass and so is its inertia. In simple words: the more mass the larger the gravitational force but also the larger the resistance against the influence of the force. In his famous lecture in Kyoto Einstein reminisced: “I was sitting in my chair at the “Berner Patentamt” when suddenly the following idea came into my mind: If a person is in free fall it will not feel his own weight. I was astonished. This made a deep impression on me and drove me towards a theory of gravity” (Pais 1982) (Figs. 24.1 and 24.2).

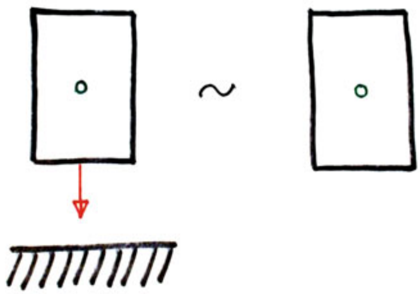


Fig. 24.1 All bodies fall with equal acceleration under the force of gravity. Thus the falling mass remains in place relative to the falling cabin, thus being weightless

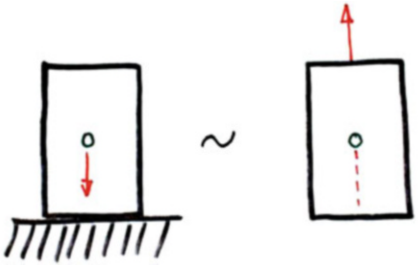


Fig. 24.2 The equivalence of gravity and acceleration. A body in a cabin at rest under a gravitational force falls to the floor, equivalently a force free body within an accelerated cabin shows the same behaviour

Later he called it his happiest idea of his life. That gravity can be compensated by acceleration leads to the *Equivalence Principle*: The effect of gravity and acceleration are locally indistinguishable, (There are several versions of this principle, but I shall not discuss these here). In March 1914, already on his way to the theory of general relativity, Einstein in a letter to Heinrich Zangger, writes: "I succeeded in proving that the gravit. equations hold for arbitrary moving reference systems, thus the hypothesis of the equivalence of acceleration and the gravitational field is absolutely correct, in the widest sense" (Einstein 1914).

24.3 Mach's Principle as Guiding Idea

Let me now concentrate on the main topic, the influence of Ernst Mach on Einstein when he was searching for a theory of gravity. Mach in his book "The Science of Mechanics: A Critical and Historical Account of its Developments" challenged Newton's concepts of space and time. Newton argued that inertia manifests itself whenever a body undergoes acceleration with respect to absolute space. He showed this by the famous bucket experiment in which a liquid that rotates within a rotating bucket is driven to the walls of the bucket by what we call centrifugal forces. This force arises according to Newton, because of the rotation of the liquid against absolute space. Mach disagrees strongly by saying (Mach 1960): „Newton‘s experiment with the rotating vessel simply inform us . . . that centrifugal forces are produced by its relative rotation with respect to the mass of the earth and other

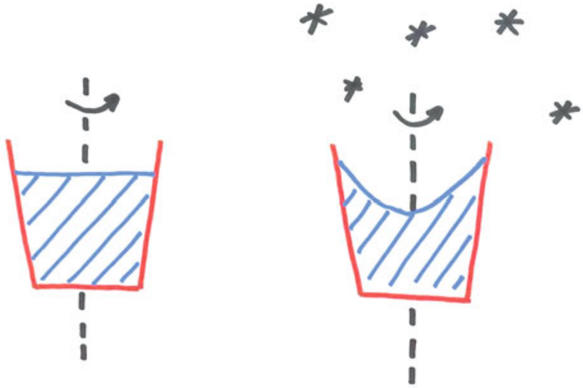


Fig. 24.3 Illustration of Mach's ideas on Newton's bucket: Centrifugal forces on the liquid in the rotating bucket arise due to the influence of the other bodies in the universe

celestial bodies“. This was much in the spirit of Einstein in that inertia is a relative phenomenon, depending on the distribution of matter in the universe. In a paper in 1912 he writes (Einstein 1912)“ ... makes it plausible that the entire inertia of a point mass is the effect of the presence of all other masses, deriving from a kind of interaction with the latter”. In the talk at the meeting in Vienna 1913 he says (Einstein 1913): „... that resistance of inertia is nothing else than the resistance of the body against the relative acceleration with respect to the totality of all other bodies“. Later he called this “Mach's Principle” (Einstein 1918) and it was for him a guiding line on his way to General Relativity.

But how do the distance masses influence local inertia? It is the Equivalence Principle which relates acceleration with gravity: The gravitational interaction is the cause that a body shows inertia, concluded Einstein. Of course it would be hard to prove Mach's assertion, since we cannot empty the universe from all masses, but if we could, Newton's bucket should not show any effect on rotation because it does not rotate against any masses (Fig. 24.3).

24.4 The Cosmological Constant

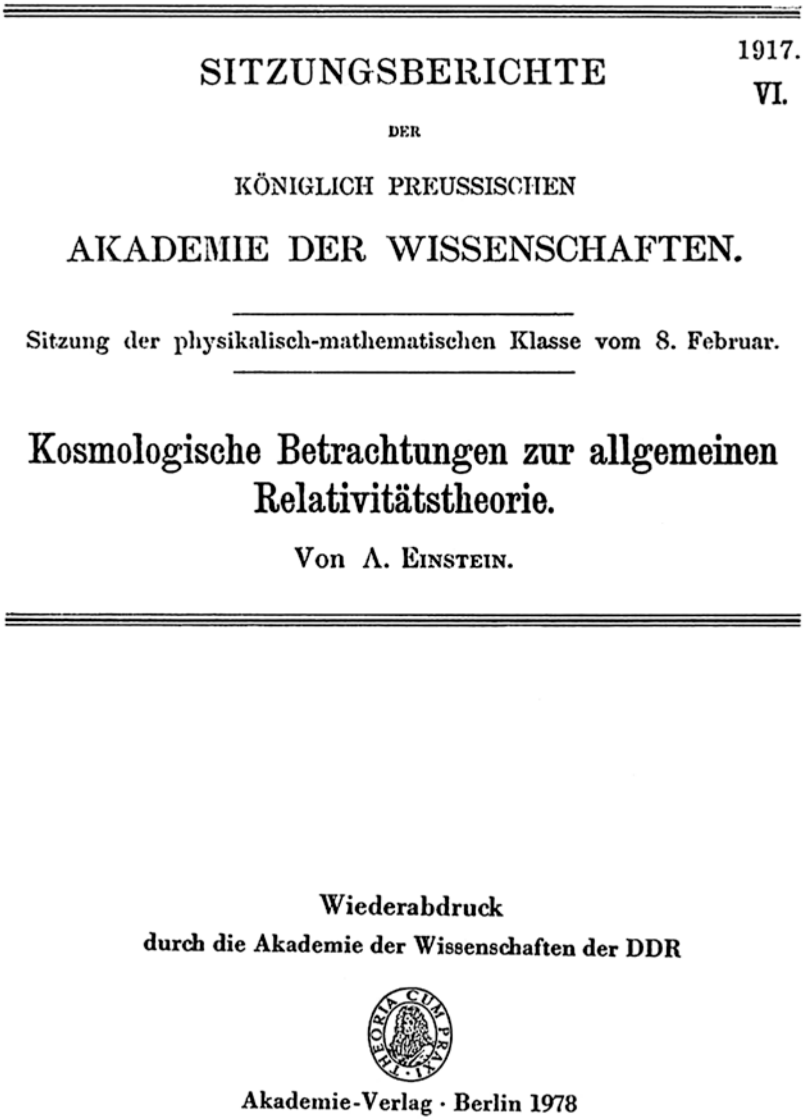
By the end of 1915, after several year of severe struggle, Einstein finally formulated his theory of General Relativity (Einstein 1915). In his theory, gravity is not a force like electric or magnetic force, but a property of space and time. Space is no longer the stage on which physical phenomena take place but the geometry itself becomes dynamically, influenced by the distribution of masses and energy in the universe. But Einstein carries the idea of Mach further: while Newton's concepts imply that: “... if matter would disappear, space and time alone would remain (as a kind of stage for all physical events)” (Einstein 1988) while “In my opinion it would be dissatisfying, if there were a conceivable world without matter” he writes in a letter to Wilhelm de Sitter in 1917, (Einstein 1998). At this stage the existence of space and time for Einstein was tied to the presence of matter. I would call this the strong Mach's Principle.

24.5 Mach's Principle in Cosmology

About a year after publishing his new theory, Einstein searched for a cosmological solution to find out whether his theory satisfies Mach's Principle (in the strong sense). In those days the universe was considered to be static. Therefore he looked for a static solution but in addition space should also have the property that (Einstein 1917) „If I remove a mass to a sufficient distance from all other masses in the universe, its inertia must fall to zero" (Fig. 24.4).

Soon he realized that his equations did not allow for such solutions. He found a way out by modifying his original equations in adding the term with the famous cosmological constant. On Feb. 4th 1917 he writes to his colleague and friend Paul Ehrenfest in Leiden (Einstein 1998): „I have again perpetrated something relating to the theory of gravitation that might endanger me for being committed to a madhouse" The effect of this cosmological constant was threefold: First of all, the constant had a repulsive effect and, if properly chosen, it counterbalanced the gravitational attraction to allow a static universe. Second, Einstein could overcome the problem of inertia by a brilliant idea (Einstein 1917): „. . . if it was possible to regard the universe as a continuum which is finite (closed) with respect to its spatial dimensions . . . " General Relativity allows for geometries different from the Euclidean one, to which we are accustomed in everyday life. Einstein found a cosmological solution where space is closed, i.e. finite, but unbounded. (The surface of a ball would be the two-dimensional analogy.) In such a space a body could not be brought to a "sufficient distance from all masses in the universe". And thirdly, and maybe most important, he thought that introducing the cosmological constant would not allow for vacuum solution of his modified equations, since "Matter should determine the g-field, it should not exist without" (Einstein 1998) The g-field is the metric which determines the geometrical properties of space and time, actually of space-time, since in General Relativity space and time are unified. This strict connection between matter and the geometry of space-time by Einstein is astonishing because already in 1916 he published a paper in which he showed that disturbances in the geometry can travel in form of gravitational waves (Einstein 1916). Proving that space-time has degrees of freedom of its own, independent of matter.

Einstein's cosmological solution later became known as the Einstein Cosmos. The expectations concerning the strong Mach's Principle, that there should be no space-time without matter, turned out to be wrong: In the same year as Einstein published his cosmological solution, the astronomer Wilhelm DeSitter (1872–1934) found a cosmological solution with cosmological constant, but free of matter (deSitter 1917). Einstein tried to show that this solution has deficiencies by arguing that (Einstein 1918) „. . . until the opposite is proven, we have to assume that the De Sitter solution has a genuine singularity . . . it does not satisfy the field equation" and further „the De Sitter system does not look at all like a world free of matter, but rather like a world whose matter is concentrated entirely on the surface . . . ". In the same article Einstein for the first time questions the idea of a cosmological constant:



SITZUNGSBERICHTE

1917.
VI.

DER

KÖNIGLICH PREUSSISCHEN

AKADEMIE DER WISSENSCHAFTEN.

Sitzung der physikalisch-mathematischen Klasse vom 8. Februar.

Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie.

Von A. Einstein.

Wiederabdruck
durch die Akademie der Wissenschaften der DDR

THEORIA CUM PRAXI

Akademie-Verlag · Berlin 1978

Fig. 24.4 Reprint of the front page of Einstein's publication on Cosmology in 1917

"If the De Sitter solution were valid everywhere, it would show that the introduction of the lambda -term (cosmological constant) does not fulfil the purpose I intended. Because in my opinion, the general theory of relativity is a satisfying system only if it shows that the physical qualities of space are *completely* determined by matter. Therefore . . . no space-time continuum is possible without matter that generates it"

In the years from 1922 to 1924 the mathematician Alexander Friedmann (1888–1925) publishes two papers on cosmological models with different geometries (Friedmann 1924). Since these models were non-static his work was almost unnoticed. But it showed that the cosmological constant is not a necessary condition to have a closed universe.

Another backlash for the cosmological constant came from observation: The astronomer Edwin Hubble (1889–1953), making use of the new powerful telescope on Mount Wilson looked at distant nebulae and resolved them as a giant accumulation of stars, similar to our own galaxy (milky way). And what is more important, he noticed that these other galaxies are all moving away from us. He also concluded that this recession velocity is proportional to the distance to the galaxies (Hubble law). But it was the Belgic priest and scientist George Lemaitre (1894–1966), who in 1927 first postulated that the universe undergoes an expansion as a whole and by extrapolating backwards in time, concluded that it must have had a beginning (Georges 1927). Already in 1923, well before the expansion of the universe was an established fact, Einstein writes to Hermann Weyl (Straumann 2002): „If there is no quasi-static world then away with the cosmological term". Was thus the introduction of the cosmological constant his "biggest blunder" as reported by George Gamow (1970). Well, Einstein could have predicted a non-static universe if he would have trusted his original equations. On the other hand the cosmological constant has undergone a renaissance, although with a different meaning.

24.6 From the Cosmological Constant to Dark Energy

Modern cosmology is based on Einstein's General Relativity. The standard "big bang" theory says that our universe has undergone a dramatic evolution, starting from a dense and hot stage with a highly homogenous distribution of matter and radiation. Since then the universe has expanded and cooled down giving rise to all the structures we see today. Evidence for this picture comes from three essential observations: The cosmic microwave background (CMB) radiation, the Hubble expansion and the abundance of light elements. I do not want to go into details of why these observations are the cornerstones for the big bang theory, but concentrate on the issue of the cosmological constant. In the late 90s of last century, observation of the recession velocities of very distant objects showed a puzzling result: they seemed to indicate that the expansion rate of the universe was slower in the past then it is today. This is in contrast to what one expects from theory: matter (energy) in the universe should gradually slow down the expansion rate due to their mutual gravitational attraction. In the meantime data have accumulated to give strong evidence that the universe undergoes an accelerated expansion. What is the cause? Ordinary matter is always attractive. Already Einstein took advantage of the cosmological constant to stabilize his cosmos against gravitational attraction. The idea is to postulate a substrate with the same properties as the cosmological constant which would drive the accelerated expansion. This unknown substrate is called Dark Energy. (Formally it amounts to shift the cosmological constant term in Einstein's equation from the left to the right hand side, thus acting as a source for gravity. Dark, because its manifests itself only via the gravitational interaction. Energy, because modern quantum field theory predicts that the vacuum, i.e. the lowest possible energy state, has exactly the effect of a cosmological constant.

$$R_{ab} - \frac{1}{2}\, g_{ab} R + \Lambda g_{ab} = \kappa T_{ab} \tag{24.1}$$

$$R_{ab} - \frac{1}{2}\, g_{ab} R = -\Lambda g_{ab} + \kappa T_{ab} \tag{24.2}$$

Equation (24.1): Einstein's equation relates matter (energy) with geometry, the 3ed term on the l.h.s. is the cosmological constant added in 1917
Equation (24.2): The same equation as Eq. (24.1), with the cosmological constant shifted to the r.h.s. called dark energy

It was Wolfgang Pauli (1900–1958) who already in the 1920s and much later Yakov Borisovich Zel'dovich (1914–1987) asked themselves if this vacuum energy should not have a gravitational effect (Zeldovich 1967). Unfortunately the magnitude of this vacuum energy cannot be calculated in an un-ambiguous way, since formally it would be unbounded. Reasonable so called cut-offs, leads to values which are about 120 orders of magnitude larger than what would be needed to cause the accelerated expansion. Whether dark energy is due to the vacuum energy of fields, a still unknown substrate or simply a cosmological constant in the sense of Einstein, is an open question.

24.7 Inflation

Even before the accelerated expansion was observed, standard cosmology was plagued by another problem: why was the universe at early times highly homogeneous? In 1965 Arno Penzias (1933–) and Robert Wilson (1936–) observed what we now call the cosmic microwave background (CMB) radiation, a thermal electromagnetic radiation, coming uniformly from all directions of the sky (Penzias and Robert Wilson 1965). The CMB was soon identified to be a remnant of the early universe going back to a time of roughly 400,000 years after the big bang. Since signals can maximally travel at the speed of light, how can it be that regions which at the time could not have been thermalized, show the same temperature of the CMB? This "horizon problem" is solved by an idea due to Alan Harvey Guth (1947–) and Andrei Dmitriyevich Linde (1948–). They proposed that at very early times, the cosmos did undergo a rapid expansion, called inflation. This would allow that today we only see a region of the CMB that was in causal connection and thus could have thermalized. In order to achieve this they postulated a field, the *inflation,* which acts for a short time like a cosmological constant, driving the cosmos apart. (see e.g (Guth 1997).). Today there are several models of how inflation could have taken place, but it is fair to say that we do not know whether the inflation exists or not. On the other hand many details in the CMB can be explained by assuming the mechanism of inflation (Figs. 24.5 and 24.6).

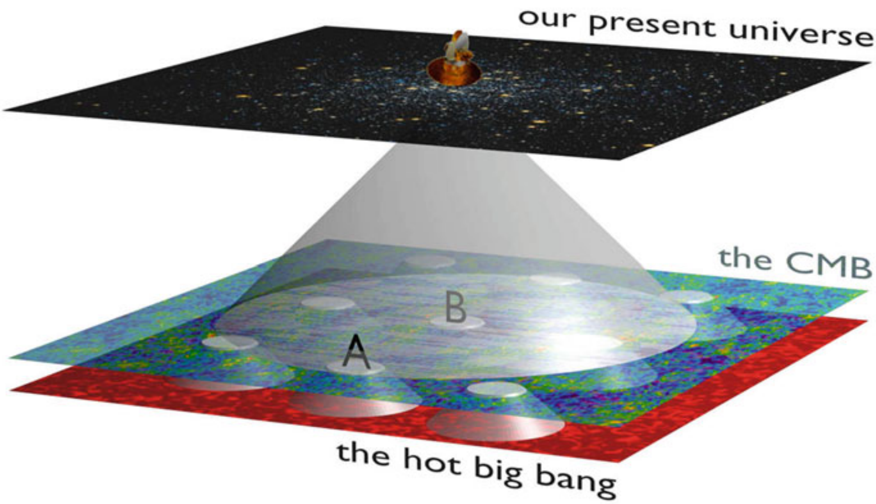
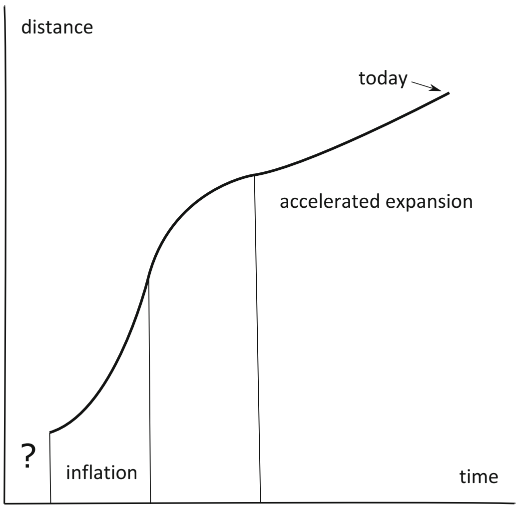


Fig. 24.5 The horizon Problem: a space time diagram of (a part) of the universe, time points upward and space (reduced to 2 dimensions) is horizontally. Starting from the big bang light can only travel a certain distance to the CMB. Regions A and B could therefore not have had causal contact. Nevertheless we see them to have the same temperature to a high degree. (Courtesy: Yi Wang, Dept. of Physics, Univ. of Hong Kong)

Fig. 24.6 shows schematically the change of overall distances in the Universe with time as postulated in modern cosmological models. There is an early stage of rapid expansion, called inflation followed by a phase of deceleration until acceleration takes over due to dark energy. The? indicates that competing quantum gravity theories speculate about this very early stage of the universe



Let me come back to Mach and his influence on Einstein. There is no doubt that Mach's ideas were of eminent importance for Einstein's struggle in understanding inertia and on his way toward a new theory of gravity. The introduction of the cosmological constant however, whose goal was to implement Mach's ideas into the theory, was unsuccessful. The question in which way Mach's principle is incorporated in General Relativity is still today under discussion, since there exist many versions of this principle (Barbour 1995). True is that Einstein himself in 1954, one year before his death, wrote to Felix Pirani „As a matter of fact, one should no longer speak of Mach‘s principle at all“ (Pirani 1982).

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Chapter 25
"Direct Observation": A Controversy About Ernst Mach's and Peter Salcher's Ballistic-Photographic Experiments

Christoph Hoffmann

Abstract In spring 1888, an anonymous critic raised severe doubts about Ernst Mach's and Peter Salcher's studies, published 1 year before, on the processes in the air caused by very rapid projectiles. Paraphrasing the experiments for the French popular science magazine *La Nature*, the critic insinuated that the photographs upon which Mach and Salcher's argument were ostensibly based must have been of such low quality that they did not allow any well-founded conclusion. The critic did not deny the phenomena Mach and Salcher had presented in their article; he denied that the photographs taken in the course of the experiments could permit any observation of the phenomena. I take the resulting quarrel as a window into the actors' ideas on the requirements of "good observations" and the role of technical devices in this case. In particular I enquire how the various arguments relate to Lorraine Daston's and Peter Galison's framing of photography as an emblem of "mechanical objectivity." We will see that in the case under debate, actors considered naked-eye observation, observation by telescope and photography mainly with regard to the challenges of the particular research object.

25.1 "Crudely Observed"

In March 1888 the French popular weekly *La Nature* raised severe doubt about Ernst Mach's and Peter Salcher's studies on the processes in the air around a very fast flying projectile, which they had published 1 year earlier.[1] The crucial point was very simple: Taking into account the speed of the projectile and the necessary

[1] See Ernst Mach and Peter Salcher, "Photographische Fixirung der durch Projectile in der Luft eingeleiteten Vorgänge", in: *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften [Wien], Mathematisch-Naturwissenschaftliche Classe* 95, Abt. 2, 1887, pp. 764–780.

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exposure time Mach's and Salcher's famous photographs of the projectiles together with the surrounding wave systems actually could not have been very distinct and clear. Suspicion was fuelled further by the fact that the examples included in Mach's and Salcher's paper were reproduced as lithographs based on sketches done by hand (Fig. 25.1). The anonymous author of *La Nature* concluded: "We do not deny that Mr. Mach and Mr. Salcher have produced photographs of projectiles in motion, but we think that they have reproduced in their drawings what they have crudely observed in the more or less blurred photographs they obtained."[2] One may suspect that the author of the article rejected Mach's and Salcher's findings for that reason as well. Yet, he stated that the reported phenomena "are all in all in accordance with the ones that for some time were established by direct observation at the École normale de tir", that is, at the French artillery school.[3]

Thus the attack turned out to be a dispute about priority. French military men claimed for themselves the honour of first observing the waves and disturbances in the air around a fast flying projectile. The rest of the story can be recounted very rapidly. Mach forwarded some of the original negatives to the editor of *La Nature*, Gaston Tissandier.[4] Tissandier in turn invited Mach to publish an article on the experiments in his magazine, which some weeks later was personally concluded

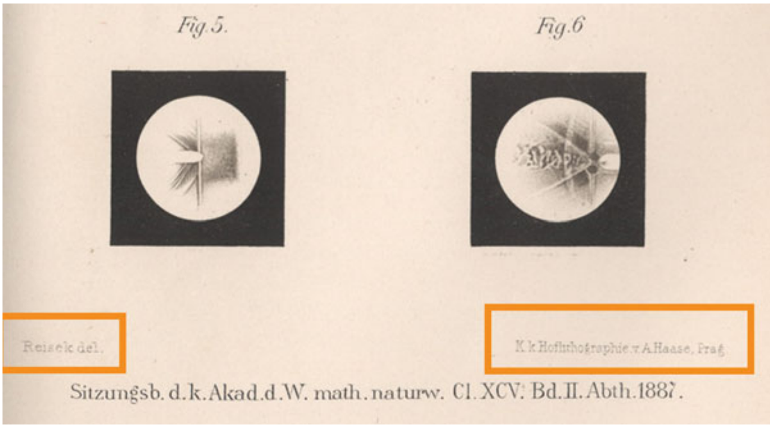

Fig. 25.1 Part of the table added to Ernst Mach's and Peter Salcher's article "Photographische Fixirung der durch Projectile in der Luft eingeleiteten Vorgänge" (1887). Above two reproductions of original negatives. Imprinted at the bottom left the signature of the draughtsman "Reisek del.[ineavit]", at the bottom right the name of the printer "K.K. Hoflithographie v. A. Hasse". See Ernst Mach and Peter Salcher, "Photographische Fixirung der durch Projectile in der Luft eingeleiteten Vorgänge", in: *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften [Wien], Mathematisch-Naturwissenschaftliche Classe* 95, Abt. 2, 1887, pp. 764–780, table

[2] Anonymous, "Photographies des Projectiles Pendant le Tir", in: *La Nature* 16, No. 770, March 3, 1888, pp. 210–211, p. 210.

[3] Ibid.

[4] Gaston Tissandier to Ernst Mach, Paris, April 28, 1888. In: Archive of the Deutsches Museum, Munich, Ernst Mach Papers, NL 174/3065.

by the editor with some remarks, that were full of praise for Mach’s and Salcher’s “marvelous results, which to some had appeared almost unlikely”.[5] At this point the controversy came to an end. The “suspicion of fraud,” as Mach’s co-author Salcher had put it,[6] was lifted, and later that year the remaining claim to priority was – at least in Mach’s eyes – successfully refuted as well.[7] Ultimately it had been little more than a brief quarrel that was very soon consigned to oblivion like hundreds before and since.

While scientific “controversies are to be looked at as an endemic and vital motor in the production of scientific knowledge”,[8] it is quite difficult to identify in this case what benefit might have come from the affair. No new research technologies evolved, no new problems were solved, no important addition was made to the basic theoretical framework. But controversies also allow glimpses into the epistemological prerequisites of the actors insofar as they “arise from different modes of production of knowledge and their use”.[9] Comparable to the analysis of what Michael Lynch in Science Studies has called the ‘critical inquiry’ inside the lab,[10] our case offers an opportunity to analyse the rationales, in a certain context at a certain time, for producing scientific knowledge. An otherwise trivial quarrel may thus become interesting because things usually taken for granted without debate now become tangible through the manner by which the argument is developed.

One keyword in this respect has already been mentioned: “direct observation.” As a reminder: the author of the article in *La Nature* emphasized that the findings of the French military men relied on “direct observation.” By saying this he suggested that Mach’s and Salcher’s work relied on a somehow different mode of observation. In other words: taking photographs was – in this case – defined as a less direct way of studying the phenomena in question. Whoever closely follows the discussions on the role of photography in late nineteenth-century research practice will be surprised by this idea. We all know Lorraine Daston’s and Peter Galison’s basic assumption, that in those days scientists preferred photography precisely because of its apparently unmediated mode of representation. Photography constituted, according to their argument, the “essence and emblem of mechanical objectivity”.[11] In this respect

[5]Anonymous [Ernst Mach], “La Photographie des Projectiles Pendant le Tir”, in: *La Nature* 16, No. 781, May 19, 1888, pp. 387–388, p. 388.

[6]Peter Salcher to Ernst Mach, Fiume, April 26, 1888. In: Archive of the Deutsches Museum, Munich, Ernst Mach Papers, NL 174/2821.

[7]See Ernst Mach, “Über die Fortpflanzungsgeschwindigkeit des durch scharfe Schüsse erregten Schalles”, in: *Sitzungberichte der Kaiserlichen Akademie der Wissenschaften [Wien], Mathematisch-Naturwissenschaftliche Classe* 97, Abt. 2a, 1888, pp. 1045–1052, p. 1045 and p. 1049.

[8]Helga Nowotny, “Controversies in Science. Remarks on the Different Modes of Production of Knowledge and their Use”, in: *Zeitschrift für Soziologie* 4, 1975, pp. 34–45, p. 37.

[9]Ibid.

[10]See Michael Lynch, “Technical Work and Critical Inquiry. Investigations in a Scientific Laboratory”, in: *Social Studies of Science* 12, 1982, pp. 499–533.

[11]Lorraine Daston and Peter Galison, “The Image of Objectivity”, in: *Representations* 40, 1992, pp. 81–128, p. 123.

nothing seems more counterintuitive than the claim in *La Nature*. If at that time valuable, which is to say: objective scientific insights had to be based on methods that minimized any kind of intervention, what mode of observation could be more desirable than photography? What are the standards of the anonymous critic such that he can qualify photography as a somehow less direct mode of observation? And thus: What characterizes in his eyes the 'directness' of an observation?

In the following I will focus on this last question. I first discuss what for the author of the article in *La Nature* counts as "direct observation" and why photography seemed to be less favourable in this respect. Then I turn to Ernst Mach's understanding of photography as a means of observation. To what extent did Mach share the prerequisites of his critique? To what extent did he comply with the image of photography developed by Daston and Galison? Finally we will see what kinds of measures Mach took to avoid future quarrels about the photographic output of his experiments. Overall I would like to show how in this trivial episode from the archives of science very practical and substantially epistemological aspects came together.

25.2 "Sharpness and Clarity"

First of all we must bear in mind that the research object at the centre of the affair was a most delicate one.[12] On the level of theory, shock waves, to use today's terminology, confronted classical acoustics with a completely new set of problems that demanded novel approaches and only gradually led to a deeper understanding of the processes under inquiry.[13] But before theory could become a challenge, observation had to be mastered. In the words of Ernst Mach: "Our task is that of observing a bullet or other projectile which is rushing through space at a velocity of many hundred yards a second, together with the disturbances which the bullet causes in the surrounding atmosphere".[14] Counterintuitively, such a research object is not necessarily invisible to the human eye. When the observer places himself directly behind the gun and follows the projectile's path by looking through a telescope with strong magnification, both the projectile and a conical envelope that develops around the projectile can be seen. According to the anonymous author of the article in *La Nature*, it was this arrangement by which "thousands of projectiles" had been "observed" by French artillerists.[15]

We can now analyse what the notion of "direct observation" implies in this context. As the usage of the telescope emphasizes, observing something directly

[12]On Mach's and Salcher's experiments see Christoph Hoffmann and Peter Berz (Eds.), *Über Schall. Ernst Machs und Peter Salchers Geschoßfotografien*, Göttingen: Wallstein 2001.

[13]See Peter Krehl, *History of Shock Waves, Explosions and Impact. A Chronological and Biographical Reference*, Berlin, Heidelberg: Springer 2009, ch. 2.4.

[14]Ernst Mach, "On Some Phenomena Attending the Flight of Projectiles", in: *Popular Scientific Lectures*, transl. by Thomas J. McCormack, La Salle/Ill.: Open Court 1898, pp. 309–337, p. 310f.

[15]Anonymous, "Photographies des Projectiles Pendant le Tir", loc. cit., p. 210.

was, first of all, not synonymous with observing something without any additional help. The confrontation was not between seeing with the naked eye and observation by instruments, and consequently we cannot say that the human organ of sight was favoured over technological artefacts. A positive definition of "direct observation" is more difficult. If we conventionally oppose 'direct' to 'indirect,' we must introduce parameters of mediation. But why should a view through a telescope be less mediated than viewing a set of photographs? Both, the images seen through a telescope and those produced by a photographic apparatus, result from processes of comparable complexity. The last point, however, gives us a clue as to how "direct observation" can be defined most appropriately; direct here seems to be equivalent to simple. An observation was more direct the more it relied on a procedure of observation that involved a minimum number of steps to obtain an impression of the phenomena. In this respect, for the author of the article in *La Nature* the combination of eye and telescope clearly had an advantage over Mach's and Salcher's procedure. Why take photographs, which, because of their poor quality (as the author assumed), do not show much without additional measures, when the processes in the air are easily visible through the telescope?

The anonymous critic of Mach's and Salcher's work did not prefer human perception to the use of technical means, nor did he favour instruments of registration, like photography, over the capacities of the eye. In terms of Daston and Galison, he was not fully in accordance with the epistemic virtues of the regime of "mechanical objectivity." Rather, the critic took a third position. The demarcation line ran not between observation with or without human interference, but between observation based on more or less complex procedures. In saying this I am well aware that the issue of observation and the issue of objectivity do not coincide completely, yet in some respect they are coupled. Daston and Galison emphasize that they do not recount the history of an abstract notion. On the contrary, "[s]cientific objectivity resolves into the gestures, techniques, habits, and temperament ingrained by training and daily repetition".[16] The ways of making observations then can be considered as one channel through which patterns of objectivity come to dominate scientific practice. In fact, the whole argument of the article in *La Nature* implies that the observations at the *École normale de tir*, because they are "direct observations," are therefore also 'better observations.' The argument would otherwise be meaningless in the author's attempt to downplay the significance of Mach's and Salcher's work. This does not automatically imply that for him "direct observations" were those imbued with objectivity. But a less direct observation was doubtless considered an observation that should not be given too much weight.

What was, in turn, Ernst Mach's approach toward observation? And more specifically: How did Mach understand the role of the eye, of instruments, and of registration apparatuses in the observational process? For answering these questions I rely on a text that is very close in subject and publication date to the debated experiments. The short article "Bemerkungen über wissenschaftliche Anwendungen

[16] Lorraine Daston and Peter Galison, *Objectivity* (2007), New York: Zone Books 2010, p. 52.

der Photographie" [Remarks on the Scientific Application of Photography], published in 1888, Mach discussed inscription devices and any sort of "graphical arts" as aids in the visualization of phenomena. Taking for granted "that all scientific knowledge emanates from sense perception," Mach's main point was that by the usage of representational tools the "*power* of sense perception [...] can be even more *enhanced* and its *scope expanded*".[17] Photography was thus characterized as a means either for "*temporal expansion*" or for "*temporal diminution*," the former by fixing "the individual phases of a movement that proceeds too rapidly for our immediate perception with *instantaneous photography*," the latter by fixing stages of a slow process like "the growth stages of a plant" and "exhibiting them in a quick series of successive 'magic lantern pictures'".[18]

Three epistemological premises determine Mach's account. First, human vision and representations that rely on instruments formed a continuum. There was no sharp demarcation line between things visible and invisible to the naked eye. Rather, technical means could be understood as "an artificial extension of the senses," as Mach later remarked in *Knowledge and Error*.[19] Second, everything subject to observation was for Mach ultimately seen. Regardless of whether phenomena were observed by the naked eye or given shape by instruments, in every case experience and subsequent insights are bound to the gaze of the researcher. For example, "instantaneous photographs of flying projectiles along with induced air movements," on which Mach's and Salcher's study of shock waves was based, ultimately gained relevance through the fact that they "exhibit" the interesting processes "to our perception in as slow a sequence as we should like".[20] Third, the capacity of photography was defined in relation to the capacity of the various further aids to visualization. Their relation to one another was not that of a hierarchy, with photography and registration apparatuses on the top and the eye at the bottom (or whatever hierarchy one might suggest), but that of functional specificity. One tool is good for this type of problem, the next for another type of problem.

Once again we see how Daston's and Galison's account of photography as central means and agent of "mechanical objectivity" does not match very well with the actors' ideas. The primary concept in Mach's reflections is "sense perception." The way in which perception is achieved is not considered in terms of 'bad' intervention or 'good' non-intervention, but with respect to the challenges of the examined phenomena. For Mach a photograph of a plant was not automatically to be preferred over a drawing, for example. Only when a researcher is intrigued by the plant's growth cycle does the rapid projection of a series of photographs become a more suitable tool than a number of sketches displayed side by side. How then do Mach's

[17]Ernst Mach, "Remarks on the Scientific Application of Photography" (1888), in: *Science in Context* 29, No. 4, 2016, pp. 441–442, p. 441.

[18]Ibid, p. 441f.

[19]Ernst Mach, *Knowledge and Error. Sketches on the Psychology of Enquiry* (1905/5th ed 1926), Dordrecht, Boston: D. Reidel 1976, p. 106.

[20]Mach, "Remarks on the Scientific Application of Photography", loc. cit., p. 441.

reflections relate to those in the article in *La Nature*? What do they have in common, and how did Mach react to the qualification of the observations at the *École normale de tir* as direct?

To address the first question: it is likely that neither Mach nor the author of the article in *La Nature* had a general preference for one observational procedure over another. With regard to the nature of the observational means, they share an epistemologically neutral position. What is crucial is rather the relation between the task and the procedure of observation. The concept of 'directness,' central for the author of the article in *La Nature*, has no immediate equivalent in Mach's framework of functional specificity. But to some extent Mach might have been sympathetic to the premise that, in observations, procedures that make the investigated phenomena perceivable through the simplest arrangement should be privileged. Although it is not directly stated, behind this assumption lurks an idea of economy that resonates with Mach's general concept of the "economic nature of physical inquiry".[21] Yet, by and large, Mach was not convinced by the observational procedure elaborated in *La Nature*.

Mach addressed the issue in a paper published in the *Sitzungsberichte* of the Imperial Academy of Science towards the end of 1888. In the aftermath of the quarrel with *La Nature*, he had learned about three articles published earlier that year that had summarized the results of the research at the *École normale de tir*. The studies at the French artillery school were now associated with a name; it was Capitaine Journée who had conducted the experiments to which the article in *La Nature* alluded. Mach's discussion mainly focused on the interpretation of the phenomena and the issue of priority. But in a footnote he also went into detail about the procedure by which Journée had observed the processes in the air around the projectile. The summary is unambiguous. Without a doubt, the phenomena are perceivable through a telescope, but the resulting impressions cannot match Mach's and Salcher's photographs: "In sharpness and clarity the images Mr Journée showed must of course play second fiddle to ours, since the former are not instantaneous images but rather consist of a superimposition of images belonging to different moments in time, not to mention the fact that they offer an unfavourable perspective."[22]

Mach turned the tables on Journée. It was not his photographs that were "without much clarity," as the anonymous author of the article in *La Nature* had suggested,[23] but rather the French observations. The crucial point was not that Journée had to rely on visual impressions whereas Mach and Salcher used a recording device. For Mach a light-sensitive plate mounted behind the telescope would not automatically have diminished the disadvantage of Journée's mode of observation: A 'good

[21] Ernst Mach, "On the Economical Nature of Physical Inquiry" (1882), in: *Popular Scientific Lectures*, transl. by Thomas J. McCormack, La Salle/Ill.: Open Court 1898, pp. 186–213.

[22] Mach, "Über die Fortpflanzungsgeschwindigkeit des durch scharfe Schüsse erregten Schalles", loc. cit, p. 1048.

[23] Anonymous, "Photographies des Projectiles Pendant le Tir", loc. cit., p. 210.

observation' was for Mach equivalent to one that shows discrete moments of the investigated phenomena, and a 'good', functionally appropriate observational procedure was, accordingly, the one that possessed the power to dissect the overall impression into bits and pieces. "Sharpness and clarity," which Mach attributed to his photographs, thus denote more than the qualities of the pictures. Sharpness and clarity are instead essential requirements for the process of analysis. In Mach's eyes any understanding of nature must be built upon discrete, i.e. 'sharp,' 'clear' elements in space and time. Mach never made reference to the notion of "direct observation" that the anonymous author in *La Nature* had set in opposition to the photographs. But if the notion had made sense to Mach at all, he probably would have considered those observations most direct which resolve the total impression of a process into a number of well-defined momentary sensations.

25.3 Collotype Printing

Ultimately, in one respect, the whole affair did indeed have consequences. As we will see they did not affect Mach's basic epistemological presuppositions but rather concerned the way in which he presented the photographic output of his experiments to the scientific community. In October 1888 Mach sent a letter to the office of the Imperial Academy of Science. In the near future, he explained, he would like to present a paper to the academy, for which a "collotype table" should be produced.[24] The anticipated price for 800 copies, 80 Austrian Gulden, represented a considerable sum. But Mach had good reason to ask for the required subvention. Justifying the additional expenditure he emphasized: "Because this is a matter of continuing the ballistic experiments that some scholars still confront with disbelief, I would like to avoid a hand drawing and for that very reason attach especial importance to collotype printing."[25]

Half a year after the quarrel with *La Nature*, Mach drew his conclusions. With collotype print he foreclosed any future criticism by insisting on a printing process by which the original negatives could be reproduced without retracing them by hand.[26] When the announced paper was published in the Academy's *Sitzungsberichte*, two tables were added, each of them bearing on the bottom of the page the imprints "Negative by Dr. J. M. Eder" and "Collotype Printing by J. Löwy in Vienna" (Fig. 25.2). In the end it seems that Mach was very much in accordance with the epistemic virtues of "mechanical objectivity." Hand drawings, i.e. human

[24]Ernst Mach to the Imperial Academy of Science, Prague, October 29, 1888. In: Archive of the Austrian Academy of Sciences, Vienna, Allgemeine Akten, No. 861/1888, at No. 850/1889.

[25]Ibid.

[26]On the collotype and the photolithographic printing process see Bamber Gascoigne, *How to Identify Prints. A Complete Guide to Manual and Mechanical Processes from Woodcut to Inkjet*, 2nd Edition, London: Thames & Hudson 2004, ch. 40–41.

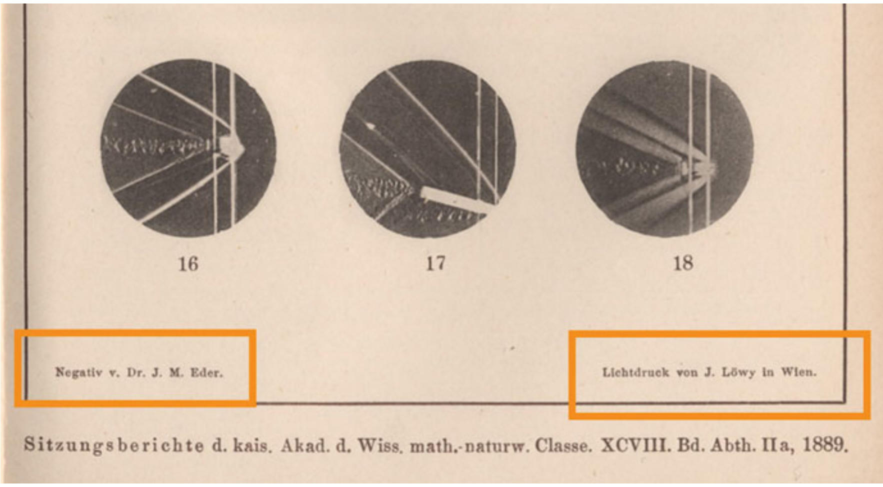

Fig. 25.2 Part of the table added to Ernst Mach’s and Ludwig Mach’s article “Weitere ballistisch-photographische Versuche” (1889). Above three reproductions of original negatives. Imprinted at the bottom left the signature of Joseph Maria Eder, director of the “K. K. Graphische Lehr- und Versuchsanstalt” in Vienna, who personally had supervised the production of the negatives, which were used in printing. The imprint at the bottom right refers to the printing process and the name of the printer “Lichtdruck by J. Löwy in Wien”. See Ernst Mach and Ludwig Mach, “Weitere ballistisch-photographische Versuche”, in: *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften [Wien], Mathematisch-Naturwissenschaftliche Classe* 98, Abt. 2a, 1889, pp. 1310–1326, Table 2

agency, invited potential doubt and mistrust regarding the presented phenomena while collotype print, i.e. non-interventionist reproduction, would silence sceptical colleagues. There is, however, a kind of ironic twist in Mach’s request. The incredulity expressed about Mach’s and Salcher’s observations focused not so much on the fact that the lithographic reproductions added to the 1887 paper relied on hand drawings. Rather, the necessary retracing by hand indicated to the critic in *La Nature* that the original photographs did not depict much more than some indistinct blurred traces of the described phenomena. With this in mind, Mach’s request for the collotype print was not primarily meant to establish the trustworthiness of the phenomena visible in the reproductions. Rather, one type of mechanical reproduction should secure a second type of mechanical reproduction; collotype print was ultimately used to show that the original photographs were of exactly the same quality as the reproductions before the reader’s eyes.[27]

[27] A more extended version of the article appeared in *Science in Context* 29, No. 4, 2016, pp. 409–427.

Chapter 26
New Water in Old Buckets: Hypothetical and Counterfactual Reasoning in Mach's Economy of Science

Lydia Patton

Abstract Ernst Mach's defense of relativist theories of motion in *Die Mechanik* involves a well-known criticism of Newton's theory appealing to absolute space, and of Newton's "bucket" experiment. Sympathetic readers (Norton 1995) and critics (Stein 1967, 1977) agree that there's a tension in Mach's view: he allows for some constructed scientific concepts, but not others, and some kinds of reasoning about unobserved phenomena, but not others. Following Banks (2003), I argue that this tension can be interpreted as a constructive one, springing from Mach's approach to scientific reasoning. Mach's "economy of science" allows for a principled distinction to be made between natural and artificial hypothetical reasoning, and Mach defends a division of labor between the sciences in a 1903 paper for *The Monist*, "Space and Geometry from the Point of View of Physical Inquiry". That division supports counterfactual reasoning in Mach's system, something that's long been denied is possible for him.

26.1 Debating Mach's Principle: Empiricism, Counterfactual Reasoning, and Economy

The history of Mach's Principle has been tied closely to the history of the theory of relativity, and thus, more broadly, to the history of relativistic theories of motion. On relativistic theories, a body in motion must be in motion relative to some other body, and not to absolute space. As Norton notes, acceleration often is a "stumbling block"

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for relativistic theories.[1] For instance, in the "two spheres" thought experiment, two spheres are separated by a string. The spheres rotate around each other. When they are rotating quickly with respect to each other, the string is taut. When the spheres slow down, the string slackens. The string reflects the existence of a force. But on a relativistic theory, since the two spheres are rotating only with respect to each other, there is nothing with respect to which the entire two sphere system is rotating. But if the system is not in motion with respect to any body outside it, then what is the source of the tension on the string?

In Mach's comments on Newton's reasoning, in the famous 'bucket experiment', Mach criticizes Newton's appeal to absolute space and time. Newton argues that the centrifugal force in the bucket experiment, and the force on the string in the two spheres experiment, result from the rotation of the bucket and the spheres with respect to absolute space. Mach asserts three things in response: (1) that "no one is competent to predicate things about absolute space and absolute motion", since these are not facts but creatures of thought,[2] (2) that the water in Newton's bucket, or the two rotating spheres, could be rotating with respect to some more distant inertial frame, such as the fixed stars; and (3) that the physicist's task in evaluating these experiments is to analyze the facts before her, and not "arbitrary fictions of the imagination".[3] Mach concludes that "the phenomena of centrifugal forces compel us not to postulate an absolute reference-system but to recognize the law of inertia as a mere empirical generalization about the motions of bodies relative to the fixed stars".[4]

On Norton's reading, Mach's principle is that "the motion of a body is caused entirely by an interaction with other bodies" (*op. cit*., p. 10). While Mach himself did not formulate this principle, scientists after him, most famously Einstein, took it as a methodological or physical principle. Moritz Schlick appears to have been among the first to formulate the principle. He "referred to Mach's general proposal for a relativity of all motion, from which, Schlick noted, it follows that 'the cause of inertia must be assumed to be an interaction of masses'".[5] Thus, prima facie, we may read Mach's principle either as a simple statement of a relativist theory of motion, or as a physical statement about the cause of inertia.

Since its formulation, the principle has been controversial. One set of views of its significance appeals to Mach's so-called "phenomenalism". On this reading, which we can attribute to Howard Stein and others, Mach is guilty of an "abusive empiricism" that sets unreasonable criteria for scientific reasoning. *All* conceptual

[1] Norton, John. "Mach's Principle Before Einstein", in: Julian Barbour and Herbert Pfister (Eds.). *Mach's Principle: From Newton's Bucket to Quantum Gravity.* Einstein Studies, Vol. 6. Boston: Birkhäuser. 1995, pp. 9–57.

[2] Mach, Ernst. *The Science of Mechanics*. Chicago: Open Court. 1960 / 1883, p. 280.

[3] Mach, *Science of Mechanics* (1960), *loc. cit.*, p. 284.

[4] DiSalle, Robert. "Carl Gottfried Neumann", *Science in Context* 6, 1, 1993, p. 350.

[5] Schlick, Moritz. "Die philosophische Bedeutung des Relativitätsprincips," *Zeitschrift für Philosophie und Philosophische Kritik* 159, 1915, p. 171; Norton, *op. cit.*, p. 47.

or formal notions used in science must be observable, a requirement Stein finds unreasonable.

Another view, found in Norton (1995), is more sympathetic. On Norton's reading, Mach's criticism of Newton is not intended to lay out a new physical argument or mechanism. Rather, Mach intended only to *redescribe* Newton's experiments without the term "space," which had an indeterminate meaning. He did not intend to give a causal argument or mechanism. As Norton points out, this reading leads to a puzzle. If Mach didn't intend to give a causal argument, why does he accept without comment the many people who said, in his presence or in works he read, that he did?

As Norton points out, what Mach meant by a "causal" argument was simply a functional dependence between two observed variables (Norton, *op. cit.*, pp. 27–29). In the case of the bucket experiment, that functional dependence can be captured by pointing out that centrifugal forces are produced by the relative rotation of the water in the bucket with respect to "the masses of the earth and the other celestial bodies".[6]

As Norton notes, even with this heroic save, the original puzzle remains. Einstein wrote to Mach saying that "*inertia* has its origins in a kind of *interaction* of bodies, quite in the sense of your reflections on Newton's bucket experiment" (cited in Norton, *op. cit.,* p. 29). But on Norton's reading, Mach's reflections quite deliberately didn't amount to a general claim about inertia or its sources. Rather, they amount to a re-description of the bucket experiment itself without using the notion of "space" to explain the origins of inertia. As Norton points out, "Einstein's notion of causal interaction extended well beyond the simple functional relations of phenomena. It included relations on hypothetical and counterfactual systems of precisely the type denounced by Mach" (*op. cit.,* p. 29).

Here, there is an unexpected agreement between Stein's critical and Norton's sympathetic reading. As DiSalle summarizes Stein's position,

> Stein characterized Mach's philosophical opposition to Newton as "abusive empiricism"—meaning by this not merely the prejudice against theories involving unobservable entities or far-reaching counterfactual implications, but, more important, the absurd willingness to accept empirically unmotivated hypotheses about cosmic geography, boundary conditions, and so on, just to avoid theories of that sort.[7]

Stein makes a point closely related to Norton's: that Mach's pronouncements on hypothetical reasoning seem inconsistent.

> Mach's opposition to the kinetic-molecular theory is based upon the fact that, as he puts it, atoms are "mental artifices." But what about perfectly ordinary objects? "Ordinary matter," Mach says, is a "highly natural, unconsciously constructed mental symbol for a relatively stable complex of sensational elements"; the only distinction he finds to the disadvantage of atoms is that of the "natural unconscious construction" versus the "artificial hypothetical" one. To conclude, as Mach does, on the basis of this distinction, that atomic theories should eventually he replaced by some "more naturally attained" substitute is is very strange: not

[6]Cited Norton, *op. cit.,* p. 29.

[7]DiSalle, Robert. "Reconsidering Ernst Mach on space, time, and motion", in: David B. Malament (Ed.), *Reading Natural Philosophy*. Chicago: Open Court 2002, pp. 169–170.

> only is the argument at right angles to Mach's view of the "economic" objective of science, it actually accords a preference to the instinctive and unconscious over the conceptual and deliberate mental processes.[8]

On the one hand, Mach seems to be arguing that "artificial entities" like "absolute space", "atoms", and the like are to be eliminated from physical reasoning. On the other hand, Mach appears willing to accept "empirically unmotivated" claims about cosmic boundary conditions, the global conditions of matter, and the like, in order to avoid absolute space and the atomic theory.

Moreover, as Norton observes, Mach does not object to Einstein's interpretation of Mach's reasoning about the bucket experiment. But Einstein's interpretation has it that Mach is making a general point about the origins of inertial forces, which implies that Mach is making a strong causal claim beyond functional dependence. That stronger claim involves hypothetical and counterfactual reasoning that is supposed to be anti-Machian.

The accounts of Norton and Stein suggest a criticism of Mach. Mach uses his well-known reasoning about the "naturalness" of concepts and the "economy" of science to oppose concepts like absolute space and atoms. But when it is a matter of his own preferred concepts or results, like ordinary matter, global boundary conditions, or the origins of inertial force, Mach appears willing to violate his own criteria. Those criteria then appear to be ad hoc, not scientific. That is why Stein calls Mach's empiricism "abusive": from a Newtonian perspective, Mach is picking and choosing which "conceptual monsters" he will allow within his system, and violating his own criteria to do so. And, as we've seen, Norton agrees that Mach's position appears internally inconsistent in this way.

26.2 A Division of Labor Within Mach's Economy of Science

If your friends and your foes agree that you have a fault, it may be that you do have that fault. Or, it may be that, despite the heroic efforts even of your sympathetic readers, there is still some misunderstanding.

To a certain extent, Mach has been misunderstood. But the misunderstanding stems, not from his physics, but from his account of the "economy of science", found in Mach's work *The Development of Mechanics, Presented Historico-Critically*.[9]

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[8]Stein, Howard. "Some Philosophical Prehistory of General Relativity", in: John Earman, Clark Glymour, and John Stachel (Eds.). *Foundations of Space-Time Theories* (Minnesota Studies in the Philosophy of Science, vol. VIII), Minneapolis: University of Minnesota Press, 1977, pp. 14. See also Stein, Howard. "Newtonian Space-Time", *Texas Quarterly* 10, 1967, pp. 174–200.

[9]The original impetus for this paper came from a discussion of that "economy" on the HOPOS listserv, with references provided from Erik Banks, Don Howard, Alan Richardson, and others, to the works of Banks himself, of Margaret Schabas, and of others. This discussion led me to look more carefully at Mach's work *The Development of Mechanics, Presented Historico-Critically* (*Die Mechanik in ihrer Entwickelung historisch-kritisch Dargestellt*). This work is usually mis-

This work is the site of, and crucial context for, Mach's interpretation of Newton's bucket experiment.

A thorough reading of *The Development of Mechanics* leads one to question the usual reading of Mach on the economy of science. According to that reading, Mach argues that the "principles" of mechanics, like the principles of least action or of the straightest path, are "economical" in the sense that they allow for computational efficiency or ease of memory. Many scientific results are encapsulated in the least action principle, for instance, but humans don't have memories that can store and recall all of those results with ease. But the least action principle takes a few minutes to memorize. Moreover, it encapsulates more results. Thus, if the principle is used in an inference, it allows for more computational power: we can more easily determine what is derivable from what.

I don't disagree with this interpretation as a partial reading of Mach on the economy of science. However, Mach's account is much richer than this. Mach presents the economy of science, not just as a static set of principles that allow us to compute more easily, but also as a system that develops over time. That system is dynamic. Certain ways of proceeding will promote the economy of science, while certain others will detract from it.

Typology of the Economy of Science

Methods that Promote Economy	*The Effects of These Methods*
"Instinctive knowledge"	Transparency
The method of differences	Empirical fruitfulness
The law of continuity of experience	The ability to disregard details
Relations of the whole	Computational power
	Minimization
	Completion of experience

One can identify ten elements in *The Development of Mechanics* relevant to the economy of science. The elements on the left hand side of the chart above, the "methods", are ways to promote the economy of science. The elements on the right hand side, the "effects", are results of employing these methods. Computational

translated, especially the title. As Don Howard has emphasized in personal communication, the second part of the title, *Presented Historico-Critically*, responds to the nineteenth century tradition of Biblical criticism, and to the reception of hermeneutic, humanistic methods of Biblical criticism by historians including Karl-David Ilgen and Julius Wellhausen. Mach would have expected nineteenth century readers to be aware of this crucial context. His presentation of mechanics in this context implies strongly that the achievements of mechanics, like the doctrines of the Church, are products of human activity. The discussion in Nemeth, Elisabeth. "Freeing up one's point of view – Neurath's Machian Heritage Compared With Schumpeter's", in: Elisabeth Nemeth, Thomas E. Uebel, Stefan W. Schmitz (Eds.) *Otto Neurath's Economics in Context.* Vienna Circle Institute Yearbook 13. Dordrecht: Springer 2007, and in personal discussions that have been very illuminating, emphasize the role of "freeing up one's point of view" for Mach. I explore that notion in sect. 3, below, from a distinct but complementary standpoint.

power, according to this chart, should be seen not (just) as an absolute property of a principle of science, but as the result of employing an economical method.

One example of an economical method is the "method of differences", which Mach discusses in his lecture "On the Conservation of Energy". Experience teaches us that some sensed elements of the world are interdependent - pressure, volume, and heat in a gas, for example. But there are differences as well as dependence.

> Facts may be so nearly related as to contain the same kind of [elements], but the relation be such that the [elements] of the one differ from the [elements] of the other only by the number of equal parts into which they can be divided ... if rules can be given for deducing from one another the numbers which are the measures of these [elements], then we possess in such rules the most general expression of a group of facts ... This is the goal of quantitative investigation ... what we have found is that between the [elements] of a group of facts ... a number of equations exists. The simple fact of change brings it about that the number of these equations must be smaller than the number of the [elements]. If the former be smaller by one than the latter, then one portion of the [elements] is uniquely determined by the other portion.[10]

Theories should be analyzed in terms of their observable "elements".[11] The goal of science is to show that some elements of a theory (variables such as pressure and volume) are dependent on other elements of the theory (variables such as motion and density). To show that the independent group is smaller than the dependent group is to promote economy in science. Mach calls this the "method of differences". As Banks notes,

> The tension between the [observed] elements and their ordering into this general manifold of space, time, and matter is a general problem in Mach's philosophy of nature. The divide falls between his heraclitean view that the elements are transitory unique events, arising and vanishing and possessing always an individual existence, and his view that space, time, and matter, however unreal they may be on a fundamental level, represent for Mach economical permanencies that must be acknowledged as a task of science ... Mach said that he considered the real facts of nature to be the existence of "differences" or inequalities ... Mach's elements are the differences of state in the world and, by a careful tracking of their effects on one another, the determinations of the rates and magnitudes of those effects, Mach thought one could deduce the existence of independent potential sources and relations of intensity from this raw data by finding orderings in it.[12]

The tension Banks notes, between "transitory unique events, arising and vanishing and possessing always an individual existence", and "his view that space, time, and matter, however unreal they may be on a fundamental level, represent for Mach economical permanencies", is precisely the tension identified by Norton and Stein as a problem for Mach. But Norton and Stein see the tension as a problem in a negative sense: as an inconsistency, or as an un-scientific element in Mach's view.

[10] Mach, Ernst. "On the Principle of the Conservation of Energy", in: *Popular Scientific Lectures*, Thomas McCormack (Ed.). Chicago: Open Court 1895, pp. 180–181. First published in *The Monist* (1894).

[11] See Banks, Erik. *Ernst Mach's World Elements: A Study in Natural Philosophy*. Dordrecht: Kluwer. 2003, for a wealth of discussion of Mach's "world-elements".

[12] Banks 2003, p. 239.

On Banks's reading, we can see the tension as a "problem" in a positive sense: one aim of science is to resolve the tension between transitory world-elements that are experienced only once, and the "economical permanencies" of space, time, matter, and the like.

Concepts like space, time, and matter can be economical in distinct ways. In *The Development of Mechanics*, Mach provides a thoroughgoing, if disjointed, account of how the economy of science is promoted. And this account can serve as a way to explain why, for him, some concepts can be used to support hypothetical systems and counterfactual reasoning, and some should not. Such an explanation will not make all of Mach's stated positions consistent. But it will clear up the question, asked by Norton, Stein, and others, of why Mach seemed to allow for such reasoning in some cases and not in others.

Stein argues that

> Mach says, in a famous and true remark, that the world is given to us only once, and he concludes that it is "not permitted to us to say how things would be" if the world were to be other than it is... But Mach does not make it a general rule for science that in every statement based upon experience there should appear a list of all the circumstances over which we have no control (the universe being given only once), in order to avoid seeming to claim that we know that the statement would continue to be true even if these things were otherwise. Such a rule would not only grievously violate Mach's "economy of thought", it would make science impossible (*op. cit.* 1977, p. 15).

It's rare, fortunately, to have the dreadful responsibility of contradicting Howard Stein. Even so, Mach does make it a general rule for science that we cannot neglect the rest of the world even when concentrating only on two observed facts or elements.

> even in the simplest case, in which apparently we deal with the mutual action of only two masses, the neglecting of the rest of the world is impossible. Nature does not begin with elements, as we are obliged to begin with them. It is certainly fortunate for us, that we can, from time to time, turn aside our eyes from the overpowering unity of the whole, and allow them to rest on individual details. But we should not neglect ultimately to complete and to correct our views by a thorough consideration of the things which for the time being we left out of account... In fact, science can accomplish nothing by the consideration of individual facts: from time to time it must cast its glance at the world as a whole. Galileo's laws of falling bodies, Huygens's principle of vis viva, the principle of virtual velocities, nay, even the concept of mass, could not, as we saw, be obtained, except by the alternate consideration of individual facts and of nature as a totality.[13]

As we learn from Banks, the tension between the elements, the heraclitean world "given only once," and the consideration of "nature as a totality" is a fundamental problem for Mach's account of science. But it is a problem that Mach sees as one we must try to solve, and he thinks that the framework of a solution must be built into science itself.

[13] *Die Mechanik in ihrer Entwickelung historisch-kritisch Dargestellt*. Leipzig: F. A. Brockhaus. 1883, p. 235. All translations cited as from the 1883 edition are by L. Patton for this essay.

Mach's "law of continuity of experience" is a crucial element of that framework. This "law" is in fact more of a method or rule. It states that any principle of mechanics must be considered, not as a universal and necessary proposition, but as an assertion that is being checked constantly by experience.

> The most important result of our investigations is that precisely the apparently simplest mechanical principles are of a very complicated character, that these principles are founded on uncompleted experiences, nay on experiences that never can be fully completed, that practically, indeed, they are sufficiently secured, in view of the tolerable stability of our environment, to serve as the foundation of mathematical deduction, but that they can by no means themselves be regarded as mathematically established truths but only as principles that not only admit of constant control by experience but also require it (*op. cit.,* 1883, pp. 237–8).

The law of continuity is the basis of Mach's reasoning about the "completion" of experience through science, one of the products of the economy of science.

> The function of science, as we take it, is to replace experience. Thus, on the one hand, science must remain in the province of experience, but, on the other, must hasten beyond it, constantly expecting confirmation, constantly expecting the reverse. Where neither confirmation nor refutation is possible, science is not concerned. Science acts and acts only in the domain of *uncompleted* experience. Exemplars of such branches of science are the theories of elasticity and of the conduction of heat, both of which ascribe to the smallest particles of matter only such properties as observation supplies in the study of the larger portions. The comparison of theory and experience may be farther and farther extended, as our means of observation increase in refinement (*op. cit.,* 1883, p. 490).

This passage alone contradicts the reading of Mach as a reductive phenomenalist or as an "abusive empiricist" about science. Neither would suggest that science "must hasten beyond" experience. Neither would suggest, either, that science "acts and acts only in the domain of *uncompleted* experience". Certainly, Mach says that our completion of experience is based on observed properties and relations. But, immediately following this passage, Mach explains that those observed properties and relations can be supplemented, and even can be hypothetical:

> When we mentally add to those actions of a human being which we can perceive, sensations and ideas like our own which we cannot perceive, the object of the idea we so form is economical. The idea makes experience intelligible to us; it supplements and supplants experience. This idea is not regarded as a great scientific discovery, only because its formation is so natural that every child conceives it. Now, this is exactly what we do when we imagine a moving body which has just disappeared behind a pillar, or a comet at the moment invisible, as continuing its motion and retaining its previously observed properties. We do this that we may not be surprised by its reappearance. We fill out the gaps in experience by the ideas that experience suggests.[14]

From Mach's statements thus far, we can make a distinction fundamental to his economy of science, between natural and artificial hypothetical reasoning. The distinction is not found in Mach himself, but it is, I believe, a minor and straightforward inference from his own account.

[14]Mach, *Science of Mechanics* (1883), *loc. cit.,* pp. 490–1.

Natural hypothetical reasoning "fills out the gaps in experience by the ideas that experience suggests" with "sensations and ideas like our own".

Artificial hypothetical reasoning either:

(a) Does not merely fill in gaps in experience, but rather postulates a speculative kind of experience, or
(b) Uses sensations and ideas that do *not* resemble our own to assemble speculative systems.

The application of this distinction to Newton's bucket, and to the two spheres experiment, is clear. If we appeal to the "fixed stars" or to global boundary conditions that can be cashed out in terms of observations like our own, then we are engaging in natural hypothetical reasoning. We are filling in the gaps of experience, but with experiences that we ourselves could have had. On Mach's reading, if we appeal to Newtonian absolute space and time, then we must construct a speculative hypothetical system based on the sensorium of God. Such an appeal does not fill in gaps in human experience – it goes outside any possible human experience.[15] Newton's account of the bucket experiment is artificial hypothetical reasoning, according to this distinction.

The first conclusion for which I want to argue is that, with a deeper understanding of Mach's economy of science, the vicious tension identified by Stein and Norton can become the more virtuous tension identified by Banks. The question, for Mach, is how to fill out the gaps left by a mere description of observation. To move from the punctiform mosaic of world-elements to a continuous, coherent physical system, we must complete experience with some form of hypothetical reasoning. But that reasoning must be natural, in Mach's terms. It must complete experience using the instruments that experience suggests.

26.3 Mathematics and Mach's Principle

The account in sect. 2 above appears to suggest the following way of reading Mach. Mach does not rule out a certain kind of hypothetical reasoning, "natural" hypothetical reasoning. And he does make a principled distinction between natural and artificial hypothetical reasoning, which should clear him of the charge of "abusive" empiricism.

Nonetheless, it seems that Mach still does not allow for *counterfactual* mathematical reasoning, for which we might fault him. After all, Mach was among those engaged in debate over non-Euclidean geometry in the nineteenth century, and he

[15] Newton did not appeal only to the sensorium of God in giving an account of absolute space and time. For instance, Newton argued that we could model absolute time using the notion of a "fluxion" of natural magnitudes from his calculus, a notion that is robustly observable (Newton, Isaac. "Methodus fluxionum et serriarrum infinitarum cum ejusdem applicatione ad curvarum geometriam", in: J. Castillion (Ed.). *Opuscula mathematica, philosophica et philologica*, Volume 1. Lausanne and Geneva. 1744.).

was well aware of the work of Eugenio Beltrami, Nikolai Lobachevsky, Hermann von Helmholtz, Bernhard Riemann, and Carl Friedrich Gauss. Mach's principle is part of the background to relativity theory, but so are the advances in group theory, continuous transformations, non-Euclidean geometry, and allied fields. But these areas all involve robustly counterfactual reasoning – for instance, about the rigid motions possible for a body in certain circumstances, or the paths a body can take through space, or the different ways of determining metric relationships.

In the above section, we saw that Mach's account of scientific reasoning is based on the tension between "transitory unique events, arising and vanishing and possessing always an individual existence", and "his view that space, time, and matter, however unreal they may be on a fundamental level, represent for Mach economical permanencies".[16] Moreover, as Banks remarks, the observed elements for Mach are *real*, while spatiotemporal relationships are not (necessarily): "A full appreciation for Ernst Mach's doctrine of the economy of thought must take account of his direct realism about particulars (elements) and his anti-realism about space-time laws as economical constructions".[17]

Twenty years after the publication of the first edition of *The Development of Mechanics,* we find Mach engaging in an extended reflection on the distinction between physiological, physical, and metric space, in an essay for *The Monist*, "Space and Geometry from the Point of View of Physical Inquiry".[18]

> Our notions of space are rooted in our *physiological* constitution. Geometric concepts are the product of the idealisation of *physical* experiences of space. Systems of geometry, finally, originate in the logical classification of the conceptual materials so gathered. All three factors have left their indubitable traces in modern geometry. Epistemological inquiries regarding space and geometry accordingly concern the physiologist, the psychologist, the physicist, the mathematician, the philosopher, and the logician alike, and they can be gradually carried to their definitive solution only by the consideration of the widely disparate points of view which are here offered.[19]

Here, we find another aspect of Mach's "economy" of science. "Economy" can refer to a way of minimizing or saving, as in effort, computation, or money. But it can refer equally well to a *managed* economy, in which there is a division of labor, for instance, within a society or community. As Schabas details, this latter notion of an economy had a broad currency by the end of the nineteenth century.[20]

Mach refers to the division of labor in the *epistemology* of space and of geometry. The physicist is concerned with what happens once: with the specific setup of

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[16] Banks 2003, p. 239.

[17] Banks, Erik. "The Philosophical Origins of Mach's Economy of Thought", in: *Synthese* 139, 1, 2004, p. 23.

[18] The German version of this essay is reprinted as the twenty-second chapter of *Erkenntnis und Irrtum* (1905). The version in *The Monist* was translated by Thomas McCormack.

[19] Mach, Ernst. "Space and Geometry from the Point of View of Physical Inquiry", *The Monist* 14, 1, 1903, p. 1.

[20] Schabas, Margaret. *The Natural Origins of Economics*. Chicago: University of Chicago Press. 2005.

an experiment, and with the observed phenomena of the world before us. The physiologist deals with how these Heraclitean sensations arise from an interaction between our physical constitution and the events in question. The geometer is not restricted to the private sphere of "individual intuitive space", but can move freely from physiological to physical to metric space, which gives room for abstract and even counterfactual speculation.[21] Such speculation is not robustly physical – Mach certainly spoke against it in some physical contexts. But in this essay, he argues that the division of labor in the epistemology of space allows the physicist to appreciate geometrical and hypothetical reasoning:

> It little accords with the principles of a physicist to make suppositions regarding the deportment of geometrical constructs in infinity and non-accessible places, then subsequently to compare them with our immediate experience and adapt them to it. He prefers ... to regard what is directly given as the source of his ideas, which he considers applicable also to what is inaccessible until obliged to change them. But [the physicist] too may be extremely grateful for the discovery that there exist *several* sufficing geometries, that we can manage also with a *finite space*, etc., - grateful, in short, for the abolition of certain *conventional barriers* of thought (Mach, "Space and Geometry", *loc. cit.*, p. 1).

The person who took trouble to type the words above, and then send them to Paul Carus for publication in *The Monist,* is not the Ernst Mach who allegedly opposed all counterfactual or abstract mathematical reasoning. But he is the Ernst Mach who wrote the chapter "On Experiments in Thought" in *Knowledge and Error* (1905). In this chapter, Mach emphasizes that

> the experiment in thought is a necessary *precondition* of the physical experiment. Each experimenter, each inventor must have the arrangement that led there in mind, before he translates it into action. Although [George] Stephenson also knew the train car, the track, and the steam engine from experience, he still had to model in thought the combination of a train car resting on the tracks driven by a steam engine before he could go on to execute it. No less must Galileo see the arrangements of the investigation of falling motion in front of him in imagination before he implements them.[22]

The physicist, the engineer, and the inventor must engage in robustly empirical reasoning. The dramatic narrative of the first chapters of Mach's *Development of Mechanics* follows the failure of the search for a perpetual motion machine. A physicist – or an inventor! – who continues doggedly to build perpetual motion machines will fail. Mach is quite clear that that failure must be accepted, and that recognizing the fact of failure aids in the construction of future experiments and instruments.

[21] See Mach 1903, p. 2, as cited below.

[22] Mach, Ernst. *Erkenntnis und Irrtum*. Leipzig: Johann Ambrosius Barth. 1905, p. 184, emphasis in original. Thanks are due to Erik Angner, Erik Banks, Daniel Breazeale, Uljana Feest, Katrin Hohl, Don Howard, Robin O'Keefe, Flavia Padovani, Dirk Schlimm, January Simpson, Thomas Sturm, and Richard Zach for advice on this translation. "Arrangement" is translated "Anordnung". As several people pointed out, "Anordnung" could be translated "setup" as well, to refer to an experimental setup.

But Mach leaves room for truly imaginary counterfactual or hypothetical reasoning that makes no claim to be physical, or to work in practice. Galileo made experiments, and Stephenson made steam engines, that worked. In both cases, a dynamic mental model of how the experimental setup would be, or how the invention would work, was a "necessary precondition" of the experiment itself. But in "Space and Geometry" and in *Knowledge and Error*, Mach emphasizes that mathematicians can help physicists by freeing their imaginations from mental constraints that restrict the construction of new models, abolishing "conventional barriers to thought", and clearing the way for new methods. No harm is done, on Mach's view, as long as the physicist, the physiologist, and the mathematician respect the epistemological division of labor.

It is possible that between Mach's pronouncements on Newton in 1883, and his essay on geometry for *The Monist* twenty years later, Mach had warmed to counterfactual and abstract reasoning. There are reasons why we might think so. As DiSalle (2003, 1993) details, Mach had learned much more about the mathematics of inertial frames and about relativity theory in the meantime, and he may have accepted that some abstract or counterfactual reasoning in this area was productive and even necessary.

But it is also possible that Mach's appreciation of one kind of counterfactual reasoning was in place already in 1883.[23] Most of the classic experiments in thought from Poincaré, Helmholtz, Beltrami, and others that probed the metric structure of the universe (including Poincaré's expanding gas universe, Helmholtz's convex mirror, and Beltrami's pseudosphere) were expressed in the 1860s and 1870s. In the introductory passages of his 1903 essay, Mach cites Riemann's "Über die Hypothesen, welche der Geometrie zu Grunde liegen", which was published in 1867 and given as a lecture in 1854; and letters from Gauss to Bessel from the 1820s and 1830s. Later he refers to Helmholtz's "Ueber die Thatsachen, welche der Geometrie zu Grunde liegen", which he cites as published in the *Göttinger Nachrichten* in 1868.[24]

[23]We can make a distinction here similar to the one above between natural and artificial hypothetical reasoning, on the basis of Mach's texts from 1903 and 1905:

> **Heuristic counterfactual reasoning** frees the physicist from conventional barriers of thought, and is the contribution of mathematicians and metric thought to the epistemology of space. It is used to build models in thought and imagination that inform the setup of experiments that work. If successful, this allows us to understand our experience more fully using heuristic methods.
>
> **Artificial counterfactual reasoning** uses unnatural and non-empirical concepts to expand the range of models and theories beyond observed physical phenomena. It is not used to understand experience more fully. Rather, it is intended to expand the reach of theories and models artificially, using constructed concepts that are never intended to be tested. Thus, it is similar to artificial hypothetical reasoning.

[24]David Hyder has emphasized to me that there is some question about the proper dating of this publication, but certainly it would not have been published after 1883.

It is possible, of course, that Mach had been aware of these sources for decades but had recognized their true import only much later. But if we respect Mach's division of labor for the epistemology of space, we might try to argue that his remarks in 1883 are coherent with the views expressed in 1903.

Making the effort to find common ground between the "Mach" of the two time periods, the 1880s and the early 1900s, is instructive.[25] We can try to reconcile the two by recognizing that the Mach of the 1880s was reading the Newton of the bucket and two spheres experiments as a *physicist*, and not as a mathematician. Mach's moralizing about the vocation of the physicist assigns to Newton the task of finding a way to implement his experiments in thought, just as Galileo and Stephenson had done. But Newton's experiments in thought contain artificial elements that cannot be made empirical. Stephenson's tracks, train cars, and engines can be made manifest; Newton's absolute space drives no trains.

What's the difference between Riemann and Newton? Why does the Mach of the 1900s approve of Riemann's investigations in thought, but not of Newton's? Riemann took the object of his study to be the manifold itself. Thus, he was probing a universal geometrical concept. As Mach writes,

> By the recognition of permanency as coincident with spatial displacement, the various constituents of our intuition of space are rendered *comparable* with one another,—at first in the *physiological* sense. By the comparison of different bodies with one another, by the introduction of *physical* measures, this comparability is rendered quantitative and more exact... Thus, in the place of an individual and non-transmittable intuition of space are substituted the universal concepts of geometry, which hold good for all men. Each person has his own individual intuitive space; geometric space is common to all. Between the space of intuition and metric space, which contains physical experiences, we must sharply distinguish (Mach, "Space and Geometry", *loc. cit.*, p. 2).

According to Mach, Riemann's metric space is based on comparison via physical measurements.[26] But it is also "universal" and common to all experiences of space, and thus is a valid basis for abstract reasoning. Mach approves of Riemann because he keeps such reasoning within the appropriate realm in the managed economy of science. His arguments are mathematical – Riemann does not argue from the properties of metric space to the existence of a physical force, for instance.

In the 1883 edition of *The Development of Mechanics*, Mach argues that Newton had made two errors. He made assertions about absolute space, a space not derived from comparison of observable phenomena and thus artificial. And he argued from the properties of artificial absolute space to the existence of a physical force.

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[25] Mach's illness makes things much less simple. In 1898, he suffered what was probably a stroke, and was paralyzed on his right side. Gereon Wolters has questioned the authenticity of much of the work that postdates Mach's illness and subsequent paralysis, distinguishing between Mach I and Mach II. However, the work cited here in 1903, 1905, and later 1912 (see below) is consistent with, or at least a natural development of, Mach's earlier views.

[26] Arguably, Mach's reading of Riemann takes Riemann to be much closer to Helmholtz than Riemann really was, because Helmholtz bases metric geometry much more on the observed facts [*Tatsachen*] than Riemann did.

Later in his life, Mach modified his assessment of Newton himself, though not his assessment of the "monstrous conceptions" of absolute space and time.[27] The Supplement to the third English edition of *The Development of Mechanics* contains Philip Jourdain's transcription and translation of Mach's revisions to the seventh German edition, published in 1912. Those revisions include a number of passages that provide context for Mach's assessment of Newton's bucket and two spheres experiments.

> while Galileo, in his theory of the tides, quite naively chose the sphere of the fixed stars as the basis of a new system of co-ordinates, we see doubts expressed by Newton as to whether a given fixed star is at rest only apparently or really (*Principia*, 1687, p. 11). This appeared to him to cause the difficulty of distinguishing between true (absolute) and apparent (relative) motion. By this he was also impelled to set up the conception of absolute space. By further investigations in this direction – the discussion of the experiment of the rotating spheres which are connected together by a cord and that of the rotating water-bucket (pp. 9, 11) – he believed that he could prove an absolute rotation ... "But how we are to collect," says Newton in the Scholium at the end of the Definitions, "the true motions from their causes, effects, and apparent differences, and vice versa; how from the motions, either true or apparent, we may come to the knowledge of their causes and effects, shall be explained more at large in the following Tract." ... do not the words quoted in inverted commas give the impression that Newton was glad to be able now to pass over to less precarious questions that could be tested by experience?[28]

In the section following, Mach suggests that Newton was guided by *empirical* considerations in his postulation of absolute space. According to Mach, when Newton read Galileo on the principles of mechanics, Newton rejected Galileo's use of the postulate of an earth at rest in the explanation of the law of inertia. Newton knew that the earth was rotating. Thus, instead, Newton "imagined a momentary terrestrial system of co-ordinates, for which the law of inertia is valid, held fast in space without any rotation relatively to the fixed stars".[29] He did so "in order to have a generally valid system of reference" (*Ibid.*). Newton could assign a system "any initial position and any uniform translation relatively to the above momentary terrestrial system" (*Ibid.*).

Mach emphasizes that the postulate of absolute space was not necessary, for Newton. In fact, as Mach observes, the reference system Newton constructs is relativist: it's just that the target system is moving relative to the hypothetical terrestrial coordinate system. In making this move, Mach urges, "Newton was correctly led by the *tact of the natural investigator*. This is particularly to be noticed, since, in former editions of this book, it was not sufficiently emphasised. How far and how accurately the conjecture will hold good in future is of course undecided".[30]

[27] Mach, Ernst. *The Science of Mechanics*. Supplement to the third English edition, trans. and annotated by Philip Jourdain. Chicago: Open Court. 1915, p. xii.

[28] Citations from Newton, Isaac. *Philosophiae Naturalis Principia Mathematica* ("*Mathematical Principles of Natural Philosophy*"), London, 1687. Main text Mach *op. cit.,* 1915, pp. 33–34.

[29] Mach, *Science of Mechanics* (Supplement 1915)*, loc. cit.,* p. 35.

[30] Mach *Science of Mechanics* (Supplement 1915)*, loc. cit.,* p. 36.

What we might call "the Mach-Newton conjecture" is the question of whether all target systems can be defined relative to the terrestrial coordinate system defined by Newton, and whether the law of inertia is valid for all motions relative to such a reference system. It is an intriguing question whether this conjecture has been, or can be, empirically or mathematically verified.

Mach concludes in this later edition that Newton was a good physicist, who gave a physically meaningful characterization of the law of inertia in terms of coordinate systems. The postulate of absolute space was not necessary for Newton. Instead, Mach suggests, Newton should have used only the formal apparatus necessary to give a "generally valid" characterization of inertial motion with respect to a system of coordinates. This would satisfy Mach's law of continuity of experience, according to which gaps in the explanation of experience should be filled by the ideas suggested by experience.

Newton's use of a hypothetical terrestrial coordinate system is a nice example of Mach's division of labor between physics and mathematics. When Newton is led to postulate absolute space, Mach accuses him of using an artificial concept and thus of engaging in artificial hypothetical reasoning. But the hypothesis of a terrestrial system at rest with respect to the fixed stars is an empirically possible hypothesis, and is a natural kind of hypothetical reasoning.

Mach's economy of science often is appealed to as a kind of minimization argument, or as an economy of thought or of effort. The above should cast significant doubt on any such reading of Mach on economy. Mach argues that reasoning that allows us to extend what's observable and thus to promote the "continuity" of experience is economical.

Mach allows even for hypothetical and counterfactual reasoning to contribute to the progress of science. It extends the circle of what is observable by appeal to what is accessible via well founded hypothetical reasoning. It is doubtful that Mach's reasoning about the division of labor between mathematics, physics, and physiology can be supported in practice. But understanding Mach's economy of science allows us to understand some of his more notorious arguments, including his polemics against absolute space and time.

Finally, Mach's philosophical reasoning is part of the recognized background to general relativity. The above account pushes against some of the more limited readings of Mach's relativist theories of space, and urges a deeper understanding of Mach's reception of Newton and of Newtonian methods.

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University, at which Sergio Gallegos, Elizabeth Goodnick, Vijay Mascarenhas, Daniel Krasner, and of course Sean Morris himself pushed the narrative of the paper in novel directions and identified threads of that narrative I hadn't considered. I am grateful to all of those who participated in discussion and analysis of the paper, and regret only that I haven't made better use of their excellent suggestions.

Chapter 27
Revisiting Einstein's Happiest Thought. From the Physiology of Perception to Experimental Propositions and Principles in the History of Relativity

Richard Staley

Abstract Mach has long been an important figure in the history of relativity, but the nature of his role has remained controversial. This essay contributes to this discussion by connecting Mach's critical philosophical perspective more fully to his diverse experimental research and pedagogical contributions to mechanics, and charting his changing presentations of these over some time. In particular, linking Mach's early research in sense perception and psychophysics to his conceptual critiques of mechanics offers new perspectives on relativist physics in general and Einstein's debts to Mach in particular. Mach's early work on the Doppler effect, together with studies of visual and motor perception explored subtle interrelations between physiology, physics and psychology, and offered new approaches to physiological space and time (which Mach contrasted to geometrical space). These informed the critical conceptual attacks on Newtonian absolutes that Mach famously outlined in *The Science of Mechanics* in 1883, as well as his positive account of the fundamental laws of physics in terms of experimental propositions and definitions. Mach's critiques helped form a foundation for later work in electrodynamics in which he did not participate. Yet revisiting Mach's early work will suggest he was still more important to the development of new approaches to inertia and gravitation than has been commonly appreciated. In addition to what Einstein later called "Mach's principle," I argue that a thought experiment on falling bodies in Mach's *Science of Mechanics* also provided a point of inspiration for the happy thought that led Einstein to the equivalence principle.

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27.1 Ernst Mach's Influence on Special and General Relativity

Ernst Mach is commonly thought to have had an important but somewhat diffuse role in the development of the theories of special and general relativity that were articulated by Einstein and others in the early twentieth century. Historians have often noted the presence of Mach's *Die Mechanik in ihrer Entwickelung historisch-kritisch dargestellt* (first published in 1883 with a fifth edition in 1904) and his 1896 *Die Principien der Wärmelehre* in the reading list of the informal group of friends who met as the Olympia Academy and helped shape the unusually broad and critically nuanced intellectual agenda underlying Einstein's surprising group of papers in 1905. Yet noting that in a letter to Moritz Schlick in 1915 Einstein paired the positivist line of thinking of Mach and Hume and said the latter's influence was still greater, John Norton has argued that while both stressed the close and critical relations between experience and concepts, Einstein could not accept what Norton describes as Mach's general opposition to the introduction of arbitrary concepts – so Hume was the better guide to the need for invention and the freedom to construct concepts (Norton 2010, 359–60, 372–74; but for a different perspective see Sterrett 1998). Further, while Mach's work had performed the significant service of shaking physicists from their dogmatic faith in the foundational status of Newtonian mechanics, as Einstein put it in his informal "obituary" (Einstein 1949, 21), much of Mach's thought had already been taken up by others, sometimes in ways directly pertinent for Einstein's work in electrodynamics. Einstein and his colleagues may have read Henri Poincaré's *La Science et l'hypothèse* in its 1904 German translation; Poincaré's now well-known list of denials clearly began on Machian ground in abjuring absolute space and time for mechanical understanding, but then brought this to questions of simultaneity that Mach hadn't considered, but which were critical for Einstein's approach to what became known as special relativity (Poincaré 1902, 111–12, 1904, 91–92). Poincaré's work was also significant for raising questions about the precise relations between principles of mechanics and electrodynamics in critical discussions of Lorentz's theory of the electron (Darrigol 2004).

Turning to general relativity, it has long been evident that one particular aspect of Mach's work played a more major but perhaps also unfulfilled role in Einstein's conceptual path. Returning to consider the foundations of general relativity in the light of critical discussions in 1918, Einstein pointed to the significance of three interrelated principles in the development of his theory of gravitation and christened the third "Mach's principle," because it was a generalization of Mach's demand that inertia had to be traced back to the interaction of bodies. Mach had first expressed this argument in 1872 but stated it most influentially in the sections of his *Mechanik* devoted to his criticism of Newton's concepts of absolute time and space (Mach 1872, 47–50; 1883, ch. 2 § 6). Einstein noted that he had pursued this possibility without distinguishing it clearly enough from the first principle he listed, a generalized principle of relativity (stating that natural laws concern space time coincidences alone and should be expressed in generally covariant laws of nature). Einstein also recognized that Mach's principle was not widely shared by his contemporaries (Einstein 1918). While he initially regarded it as a central goal and believed that general relativity should and did exemplify Mach's principle, he later came to think he was mistaken on both these scores; but the status of the principle has remained controversial to the present day. Notably the physicist Julian Barbour has argued that Einstein misunderstood Mach's view, but in fact general relativity realises it appropriately (Barbour 1989, 1990, 2007; Barbour and Pfister, eds. 1995).

The situation is very different with regard to the principle Einstein listed second. Einstein described the "equivalence principle" as the starting point for the whole theory and as having brought the principle of relativity along with it, and his later account of its origins has helped make it one of his best known thought experiments. In a manuscript that he first drafted for publication in *Nature* in 1920, Einstein stated that in 1907, the happiest thought (or best idea) of his life had come to him in the following form:

> The gravitational field has only a relative existence to an observer, similar to the electric field produced by magneto-electric induction. *This is because for an observer falling freely from the roof of a house there exists during his fall* – at least in his immediate environment – *no gravitational field.* If the observer lets a body go, it will remain at rest relative to him or in uniform motion, independent of its chemical and physical nature. The observer is justified in thinking of his state as being 'at rest.' (Einstein 2002 [1920], 265).

Einstein's recognition that a uniform acceleration could be regarded as equivalent to a constant gravitational field has often been celebrated and elaborated pedagogically, graphically illustrated with diagrams of lifts and spaceships. Yet beyond noting Galileo's much earlier thought experiment arguing against the Aristotelian view that a lighter body might slow the fall of a heavier one, the equivalence principle has rarely been given a history. Indeed, in a recent authoritative account of Einstein's quest for general relativity Michel Janssen writes that here "Einstein only had his imagination to go on" (Janssen 2014, 174).

Building on an earlier study, this chapter will offer a new account of the origins of Einstein's happiest thought, arguing that although he remained unconscious of it, in this instance Einstein's imagination was importantly shaped by the work of Ernst Mach (Staley 2013). Sustained study over the past 15 years from historians such as Norton, Janssen, Jürgen Renn and Matthias Schemmel has shown that the detailed physical strategies that Einstein followed in formulating the equations of the gravitational field were at least as significant as the principles on which he focused in many of his descriptions of the theory (and we have already seen that the principles were themselves the subject of complex and subtle shifts in meaning). Yet in contrast to recent historiographical emphasis on relating principles to practice, leading accounts of the significance of Mach's work for Einstein have usually focused narrowly on Mach's arguments on space and time in *Die Mechanik*, and understood them as largely philosophical critiques of Newtonian mechanics. Further, following the influential early work of Gerald Holton, understandings of Mach in general and of his relationship with Einstein in particular have often been shaped by drawing a strong contrast between Mach's empiricist anti-metaphysical stances and the more rationalist perspective that Einstein developed later (Holton 1988; but see also Wolters 1987, 2012). Norton's major article on Mach's principle before Einstein, for example, begins with his reading of later editions of Mach's work and interprets them in the light of the view that Mach's overall aim was the economical description of nature (Norton 1995, 2010). Similarly, Jürgen Renn's valuable 2007 study of Mach and Einstein does a great deal to set turn of the century thinking in the kind of context in which Einstein might have met it, but treats Mach's work as a philosophical critique without investigating the context in which Mach formulated it (Renn 2007, 21). I aim to show here that as well as delivering new insight into Mach we can even learn more about Einstein by relating the philosophical dimensions of Mach's physical thought to the diverse domains in which these were embedded. A first clue to the kind of pre-history I aim to give the equivalence principle comes in the title that Einstein gave the manuscript in which he described its orgin, "Grundgedanken und Methoden der Relativitätstheorie in ihrer Entwicklung dargestellt," with its echo of Mach's earlier book. Offering the beginnings of a developmental account I will show the value of integrating Mach's well known discussions of physical space both with more pedagogically oriented aspects of his account of mechanics, and with the earlier research in which Mach first developed his distinctively relational approach to motion and perception.

27.2 Mach's Development of a Relational Physics, Physiology and Psychology of the Perception of Bodies, Time and Space

It will not be possible to provide a fully fledged developmental account of Mach's early work here, although that task is once more beginning to be feasible given the breadth of studies offered in the proceedings of this conference, and it can now also be put on a more sensitive philosophical footing, in part as a result of the recent work of Erik Banks and Michael Heidelberger (Banks 2003, 2012, 2014; Heidelberger 2010). That we need both a more comprehensive and more sensitive foundation for our work on Mach is a consequence of the extent to which his legacy has been marked by two rather different forms of selectivity. One is simply that many valuable studies have focused on one or another aspect of Mach's research in different fields without paying particular attention to tracing potential relations with the rest of his work. Examples include Alex Hui's account of Mach's work on hearing, and even the multifaceted contributions that Christoph Hoffmann and colleagues have made to Mach's work on the speed of sound (Hui 2013, chap. 4, Hoffmann and Berz 2001, Hoffmann 2009, 2013). This kind of segmentation by subject matter also marked John Blackmore's early biography, otherwise the most comprehensive – but philosophically problematic – previous study, with its exploration of Mach's influence in physiology, physics and philosophy by turns (Blackmore 1972, but see also Henning 1915; Banks 2012). The second and more significant difficulty concerns the rather polarised image that emerged from the distinctive emphases of Mach's supporters, such as the logical positivists, and his opponents, notably ranging from the conservative physicist Max Planck faulting Mach for his empiricism and anti-atomism to the radical socialist Vladimir Lenin, who in contrast regarded Mach's philosophy as idealist and solipsistic (for a sensitive account of the Planck-Mach debates see (Wegener 2010)). Such diverse responses suggest that Mach's work was difficult to interpret, and partisanal simplifications may have been almost inevitable given the extent of the challenge that Mach put his discipline and culture in the two books that made his broader reputation. Mach's 1883 arguments against the central concepts and foundational status of mechanics were followed in 1886 by a probing analysis of perception in *Beiträge zur Analyse der Empfindungen* that offered an attack on the absolute ego, as well as a critical philosophy of scientific research across physics, physiology and psychology (Mach 1886). Although they took up rather different subject matters these books reflected common concerns that Mach had developed over the previous 25 years in a set of closely interrelated studies; for an account of some of their common elements and integrating his research and teaching, see (Staley 2017). This section offers a brief overview of Mach's early work before discussing a number of studies he undertook in the 1860s and 70s, in order to provide a new context for the more influential and widely read passages in which Mach stated his arguments about absolute space, time and gravitation.

Mach's early career was shaped productively by a combination of intellectual and institutional features. Institutionally, after completing his dissertation on electrical induction in Vienna in 1860, he first taught physics for medical students, and then held positions first as professor of mathematics at the University of Graz from 1864 and then as professor of physics from 1866, before moving to take up the post in experimental physics that he held at the University of Prague from 1867 to 1895 (Mach's final position as professor of philosophy in Vienna helped cement his status as a cultural figure, but the central lines of his thought were already established). Mach's early work shows a serious engagement with each of the fields he represented, which was importantly shaped by his intellectual commitment to the relationship between physics and psychology, or the soul and matter, that Gustav Fechner had christened "psychophysics" (Michael Heidelberger's contribution to this volume offers a close-grained study of Mach's diverse responses to Fechner). These broad-scale concerns played out in a series of research projects on sound, light and motion that began with empirical investigations of the Doppler effect but also involved investigations of the organs of hearing and sight in which Mach sought to establish the physiological basis for aesthetic preferences, or the organic basis for an exact psychology as he put it in one paper (Mach 1861, 224).

Even in this schematic overview it is easy to recognize the importance that experimental studies of relative motion in the Doppler effect might have had in orienting Mach towards affirming the dependence of knowledge of motion on relational measures. But it is also worth noting that Mach devised a rich variety of ways to examine the effect of the relative motion of a source of sound and the observer on the frequency observed. While large scale demonstrations of the effect with an audience and approaching and departing trains offer graphic illustrations still possible today, more characteristic were surely the devices that Mach built using a reed or siren attached to a rotating wheel (which became a common laboratory demonstration experiment), or a tuning fork attached to a turntable. These allowed a variation of precisely controlled conditions (such as vertical and horizontal rotation), and in some cases a closer examination of the sense organs, with Mach using tubes to explore the effect of the transmission of sound to each ear. Mach published a series of papers on these topics in the early 1860s, and then a collection in 1873 given the renewed interest occasioned by developments in astrophysics (Mach 1873(a)). I draw attention to his range of experiments partly because they initiated what became a long-lasting concern with rotation in different settings.

Pojmans and Hui have described how Mach sought evolutionary and physiological or cultural explanations for phenomena like the prominence of points of change in the visual field, or the way that paying attention alternatively to the high or low note of a chord could transform perception of a second chord (either revealing or obscuring the fact that there had in fact been a chord change) (Pojman 2011; Hui 2013). Considering visual phenomena, Mach's explorations of perception and aesthetics often turned on the effects of gravity on our organism. In an 1861 study in which he also probed Fechner's law relating the intensity of stimulus and reaction, Mach related perception of straight lines and angles to position, and to muscle movements of the eye and the retina (Mach 1861). He illustrated the point with the rather different impression made on us by two forms that although congruent differ only in position (see Fig. 27.1). Later he would use this image to indicate the differences between geometrical and physiological spaces.

Historians of science have devoted significant attention to the debates between Ewald Hering and Hermann von Helmholtz on the nature of visual perception and the question of how humans perceive the three dimensional nature of physical space, primarily because of their importance in the development of physiological understandings of vision (Hatfield 1990; Lenoir 1993; Turner 1993, 1994). Peter Pesic has also begun to explore the significance of an engagement with sound and colour for the geometrical insights of Bernhard Riemann and Helmholtz (Pesic

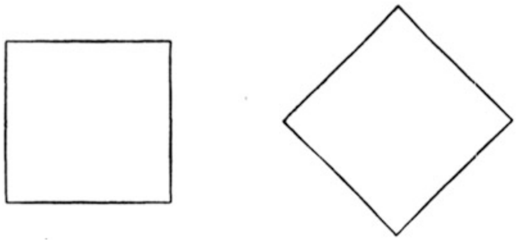

Fig. 27.1 Mach's illustration of the dependence of perception of form on position hinges on the view that we see the figure on the left as square and the figure on the right as a diamond, without immediately recognising that they are the same form, rotated. (Mach 1861, 223 see also 1886 Fig. 3)

2013). Yet Mach's work on the physiology and psychology of perception has gone without sustained historical study. It too led Mach to describe significant perspectives on space in a number of papers published between 1863 (when Mach described the musical scale as a one dimensional linear aural space) and 1866, well before both the posthumous publication of Riemann's major study of the hypotheses at the bases of geometry in 1868, and the well-known paper in which Helmholtz broadened his concept of space in the light of Riemann's discussion of manifolds. Mach outlined his early views most fully in a paper offering an account of the development of conceptions of space (Mach 1866). There Mach built upon Hering's earlier discussions of visual space, but elaborated a still greater range of spaces, beginning his paper with a discussion of the muscle movements and touch sensation which he thought were the basis for the first conceptions of space for sighted as well as blind people. Calling these muscle space and skin space, Mach described them as the space conceptions that have been least studied. Hering's understanding of visual space depended on the fact that each position of the retina developed a variable height, breadth and depth sensation as well as a variable light sensation; and Mach described these as differing essentially from geometrical spaces, which he called measurement space (Mach 1866, 227–28).

Building on his 1861 study, Mach went on to argue that the geometric definition of a line as the shortest distance between two points had no psychological importance (also noting critically that length measurements assumed the straight line). What gave straight lines a psychological advantage over other curves, he argued, is the fact that the straight line can be laid (vertically or horizontally) so that both retinal images fall at the same time on identical symmetrical places; and he described how inclined straight lines could nevertheless be recognized to appear similarly as straight. Mach made it clear that he understood the origins of geometry to be empirical rather than a priori, writing that the a priori sciences are empirical sciences, only ones in which we carry the experimental material in our organism; and he stated that he thought the stepladder of spatial conceptions could be extended to succeed to conceptions whose epitome he would like to call physical space (Mach 1866, 230).

At this point, rather than critiquing what he thought most already accepted were unsatisfactory conceptions of matter (which all depended on distance or spatial connection), Mach offered a conception of the fundamental force laws of nature that rather expressed a dependence between the states of matter, and an understanding of physical space which encompassed time because it expressed nothing other than the dependence of phenomena on each other. In a complete physics, predicting all spatial positions as a function of time meant stating how a phenomena depended on the position of the swinging pendulum and the earth, and so on; for the cosmos, the fact that all spatial positions are functions of time means that all spatial positions depend on each other. Mach concluded his paper by stating that no matter how crude his conceptions appeared and how trivial they might appear, he had also found them helpful in considering his physical studies. Speculatively, he advocated the possibility of thinking of the phenomena of both motion and light somewhat chemically (Mach 1866, 230–32).

The pathway I have reviewed here shows Mach moving between psychological effects and perceptual, geometric and physical spaces, offering an understanding of how the articulation of each depends upon the other. This is one aspect of the relational work Mach undertook, and we can see that it involved a continual elaboration of new concepts and distinctions, capable of yielding new perspectives on familiar phenomena: lines described psychologically and geometrically, as well as mathematically. It should be paired with the second aspect of Mach's relational work that is now more familiar to us, his investigations of relative motion, clarifying physical phenomena through a study of the relative motion of a source and the observer. Summing up this formative phase of his research I want to highlight the practical importance of rotation and gravitation in Mach's studies, and underline the interesting senses in which Mach's work made the a priori dependent on the organism, and physical space a matter of the relations between phenomena, built up through perceptual and geometrical or measuring spaces. In contrast to the perception that Mach's work was largely critical, reflecting positivist empiricism and anti-metaphysical strictures, we can see that his later discussions of absolute time and space emerged from constructive work with a rich variety of spaces. Note too that Mach elaborated on the psychological and physiological aspects of perception in *Beiträge zur Analyse der Empfindungen*, there reprinting a version of Fig. 27.1 (as Fig. 3) followed by a discussion of the vertical symmetry but horizontal asymmetry of the motor apparatus of the eye, governed as it is by gravity. In 1886 Mach took particular care to parse what he then described as the relations between physiological, geometrical and physical spaces, and time. He returned to these interrelations in the early 1900s, and made clear his appreciation for both Riemann's and Helmholtz's fundamental work in geometry (Mach 1886, 1901, 1902, 1903, 1906).

27.3 Critiquing Newton

In the midst of his studies of perception and motion, Mach published an apparently abstract paper on the definition of mass which involved an investigation of the relations between the a priori, hypothetical and empirical, advocating empirical measurement of the distance between mutually accelerating bodes as the basis for a completely scientific concept of mass. Mach's rigorous focus on empirical measurement and an operational definition is one source for the way that he was later taken up as an empirical positivist, but even here Mach indicates the unusual breadth of his perspective by stating early in the paper that the only thing he will take as a priori is the law of cause and effect, and "whether the law of cause and effect depends on a powerful induction or has its grounds in our psychic organisation can be left undecided, because in the psychic life also, similar effects follow similar causes." (Mach 1868, 355).

Mach also framed his considerations as a critique of Newton's formulations of the laws of motion by offering a brief but comprehensive set of statements that took the form of a sequence of experimental propositions (Erfahrungsätze) and definitions. It will be helpful to state the first of these in the terms Mach gave it, for it expresses something that Mach set as a distinctive goal:

> Experimental proposition: Bodies set opposite each other impart contrary accelerations in the direction of their line of junction. (The principle of inertia is contained within this.)
>
> Definition. Bodies which impart equal accelerations are defined as bodies of equal mass... (Mach 1868, 359).

On the one hand this formulation simplifies the expression of Newton's laws, or, using terms that Mach soon began to employ in his writings, offers a more economical description of them. On the other hand, it suggests the more radical challenge of encompassing inertia and acceleration (and by extension gravitational forces that impart acceleration) within the same conceptual framework.

Mach experienced some difficulty publishing these views, with his initial submission to the *Annalen der Physik* in 1867 being rejected a year later before he was able to find an alternative, less well known journal. His next major critique of Newton took up inertia itself and was published as a lengthy footnote to the 1872 publication of a lecture on the conservation of work that Mach gave to the Royal Bohemian Society of Sciences in Prague in 1871. There, stimulated by a recent paper from Carl Neumann to publish thoughts that he had first expressed independently in his 1868 lecture course "Über einige Hauptfragen der Physik," Mach noted that Newton's first law of motion is undefined if it is not specified in relation to which body or frame of reference a given body remains at rest or in uniform motion (Mach 1872, 47). Neumann's solution was to stipulate a hypothetical body in relation to which the motion could regarded as absolute, but as Mach noted this left praxis otherwise unchanged. He had more thoroughgoing aims for reform and to press the point noted the contrast between two alternatives, considering the earth rotating around its axis within the sphere of the fixed stars, or the earth stationary and the fixed stars in revolution. These are geometrically exactly the same, involving a relative rotation of the earth and heavenly bodies, in which the first case is astronomically more convenient and simpler. But if the earth is considered to be at rest, on current conceptions of the law of inertia there is no bulging at the equator, no effect on Foucault's pendulum. Rather than accepting the current expression as Neumann would, Mach argued the need for a new understanding of it: a need to refer to the masses of the universe in the expression of the law of inertia, for if something is required for adequate description, Mach thought it probably belongs to the essential conditions and the causal nexus of the phenomena (Mach 1872, 49). Noting that we are usually able to use a laboratory or the fixed stars as a frame of reference, but are too ready to neglect this in framing the law abstractly, Mach argued that we would all be aware of the need to relate every coordinate system to concrete bodies if we were to be beset by an earthquake, or if the heavens were to swarm in confusion. What would become of the law of inertia then, Mach asked, how would it be applied, and how would it be described? This was a dramatic way of underlining the need to understand the part that all bodies near and distant play in the law of inertia; and as we can now see, Mach's view of inertia reflected a perspective in common with that he had put in his earlier study of space, when arguing that all spatial positions depend on one another.

Mach's discussion of inertia, first published in a footnote (with the next note reproducing his 1868 discussion of mass), was later incorporated in his study of mechanics where it became the major source for what Einstein termed "Mach's principle." In my view this early formulation – less indebted to arguments against Newton's understanding of absolute space and time – also emphasizes that in contrast to Norton's claim, Mach did not seek a mere re-description of Newtonian physics that simply avoided the term space, but rather looked for a comprehensive new understanding, thinking that re-description might serve this aim. (Although it is licensed by ambiguities in some of Mach's expressions, I do not find Norton's reading of Mach's project in terms solely of this re-description and a stricture against arbitrary fictions convincing. It seems to confuse both the strength of the argument Mach thought he must make against Newton, and the specific difficulty he recognized in finding empirical purchase for a new perspective on this issue, with a more general stricture against hypothetical possibilities in physical thought and causal relations in physical phenomena, which Mach did not hold despite his preference for the language of functional relations over cause.) (Norton 1995; on the 1872 argument see 21–24).

27.4 Bodily Experience

Mach was stimulated to develop his engagement with perceptual spaces and gravitation still further as a result of an unusual experience while travelling on a train in the autumn of 1873. As his train rounded a bend, Mach suddenly saw the trees and houses and factory chimney pots inclined outwards – and took this unusual visual phenomenon (which you might also be able to experience) as an impulse to examine how we recognize the vertical direction. In his notebook he sketched a device that would allow the question to be examined more fully in the laboratory, a frame that could be rotated around an axis; and he penned down a set of thoughts that shows he expected that the sense would lie in the head (and specifically in the semicircular canals of the inner ear), linking centrifugal motion and the sense for gravity in probing the connection between motion and sight. It is characteristic that as well as a device that could explore directly the railway phenomena he had experienced, Mach also drew a system of pulleys with a tray like an Atwoods machine, and on the following page asked how long a ship takes to complete an oscillation and what vertical height it reaches (Mach 1873(b)). He was considering the sensations of rise and fall as well as those of rotation, and built a trolley to roll down an inclined plane erected between three rooms in the laboratory, along with a see-saw device to investigate this range of sensations. Indeed, in an 1865 paper on particles suspended in a fluid, Mach had commented on the fact that when one jumps from a significant height into the water holding a weight in one hand, one easily observes that the pressure ceases in fall; he knew that in fall or on see-saws the whole body behaves as if weightless, which he wrote was similar to the way one would feel if suddenly set down on a small planet (Mach 1865, 329–30) (Fig. 27.2).

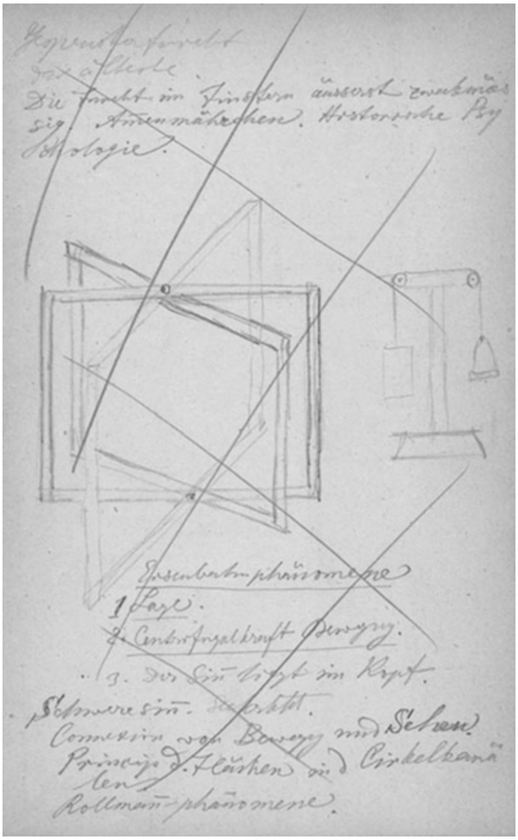

Fig. 27.2 Mach's notebook showing his response to the "railway phenomena". (Mach 1873(b))

Mach's investigations proved physiologically significant. He was able to show that we experience the resultant of the centrifugal acceleration and the gravitational acceleration as vertical, and to demonstrate that we perceive changes in orientation, but accommodate to constant effects. Without building an elaborate frame one can experience these phenomena on a playground turntable or merry-go-round (and those of rise and fall on a fairground ride), closing one's eyes to experience the sense of bodily orientation without visual cues. Spinning on a central axis one will first immediately perceive the direction of rotation, but if one rotates at a constant angular velocity, after a short time one will believe oneself to have come to rest (a surprising sensation), and then to spin in the opposite direction when one slows down (still more surprising, but a clear consequence of the relative rotation in deceleration). Set in rotation on the outer edge of a turntable one will feel as if one is leaning outwards – even when one actually remains upright – demonstrating that the resultant of the centrifugal and gravitational accelerations is perceived as vertical. Mach could explain these perceptions of orientation by showing that in each ear the fluids in the three semi-circular canals of the labyrinth, each oriented at a roughly 90 degree angle to the others, constitute a mechanical system capable of registering such phenomena sensitively. Responding to motion in each direction, the changing pressure of the fluids against membranes in ampullae located at the ends of the canals provides the basis for our sensation and for our distinction between angular acceleration and angular velocity.

Mach published the results of his long series of experiments in November 1873, shortly before the Viennese physiologist Josef Breuer and the Edinburgh chemist and mathematician Alexander Crum Brown came to similar conclusions, something that indicates the widespread contemporary significance of bodily physiology (Mach 1873(c)). If in the early 1870s Mach had developed conceptual discussions of the earth and stars in relative rotation to address Newton's principle of inertia, by the mid 1870s he had built up extraordinary bodily experience with sensations of orientation and rise and fall to complement his earlier awareness of visual location, and he had engaged in considerable studies of the relations between motion sensations and vision sensations, showing that visual sensations could be modified by motion sensation, but also that motion sensation can be initiated by visual means. In 1875 he published a comprehensive account of the studies that had emerged on this topic, moving from a discussion of the mechanical basis, of which he had a stronger appreciation than other researchers, and an extensive description of the experiments, to his interpretation of them; it represented his most sustained discussion of physical phenomena and sensation to date, elements that would be expanded significantly in his major books in the 1880s (Mach 1875). Mach also discussed his experiments on orientation in a public lecture first published in 1897 (Mach 1897(a)).

27.5 *Die Mechanik in ihrer Entwickelung historisch-kritisch dargestellt* and the Origins of the Equivalence Principle

To date historians and philosophers of science have usually focused on one critical section of Mach's book on mechanics, which occurs in his lengthy chapter on the development of the principles of dynamics. This is Sect. VI, "Newton's Views of Time, Space, and Motion," and it is also the section that Einstein pointed to as the source for what he later called Mach's principle, when first arguing that the entire inertia of a point mass derives from the interaction of matter (Einstein 1912, 39). Mach here offers an extended review of Newton's concepts of absolute time and absolute space, critiquing them as idle metaphysical conceptions and arguing that all our principles of mechanics are experimental knowledge concerning the relative positions and motions of bodies. While also pointing to the contrast between Ptolemaic and Copernican views and the relative motion of the stars and earth in a way that drew on his 1872 discussions of inertia, Mach discusses Newton's bucket experiment for the first time, arguing that Newton has neglected the possibility that the centrifugal forces arise as a result of the way the bucket's spin sets the water in rotation relative to the earth and distant stars (Mach 1883, 216–17).

In the light of our study of Mach's earlier work, we can now point to the significance of two aspects of Mach's research that he chose not to discuss here. The first concerns the framework in which Mach understood the relations between perceptual spaces, geometry, and physical space. In this instance his concern was clearly with physical time and physical space, attacking the customary understanding of them as absolute; but early in his discussion Mach included a footnote specifically noting that investigations of the physiological nature of time- and space sensations would be excluded (Mach 1883, 210). The final section of the book, too, took up the relations between physics and physiology, if somewhat abstractly. Mach addressed the relations between the specialized sciences and the totality of knowledge, emphasizing the danger of overvaluing the means with which one is customarily concerned, and regarding them as the essential goal of science rather than a practical tool. He thought this problem beset common understandings elevating physics above physiology, and briefly outlined his view that space and time are well-ordered systems of series of sensations, and the quantities in mechanical equations simply ordinal symbols representing those members of the series to be picked out conceptually. Similarly, he sketched his understanding of the relations between the elements of the world and of physiological perception, noting that one could only neglect the physical or the physiological provisionally, both were always present. Focusing on perception in this way, Mach wrote that even apparently purely mechanical processes were always also physiological and as such also electrical, chemical and the like. His final sentence argued that mechanics didn't grasp "the foundations of the world, nor even a part of it, but one side of it" (Mach 1883, 475–78). These concluding paragraphs foreshadow the relational approach to knowledge that Mach explicated much more fully in *Beiträge zur Analyse der Empfindungen*, as well as the subject matter of that book.

The second omission concerns Mach's decision not to discuss his experimental work on bodily orientation in particular, although Mach himself had spun like a bucket. This is perhaps surprising given both his view that the a priori sciences are simply those in which we carry the means of experiment within us, and the presence of a brief note interleaved between the manuscript notes for his 1880 lecture course on mechanics, which asserts that our own body is indispensible in establishing the laws of mechanics (Mach 1880). In his 1897 public lecture on bodily orientation, Mach said he thought Newton's unhappy speculations about absolute space would surely have been strengthened if he knew that rotation was perceptible without external cues (Mach 1897(a), 11). Thus Mach may not have discussed these experiments in 1883 because of the complexity of the arguments involved. However, incorporating a detailed treatment of the physiological mechanism underlying them would only have reinforced Mach's account of the significance of relative motion as well as underlining powerfully the full reach of Mach's research, encompassing as it did textual study of the writings of past physicists, countless laboratory experiments and demonstration devices, extensive bodily experience and his searching conceptual investigations (Mach 1880, 1897(a)).

Approaching the diverse facets of Mach's research before and after 1883 more comprehensively will surely give us a better understanding of their extent and interrelations, but my final argument emphasizes the importance of reading more fully in that book itself. Mach's discussions of space and time followed several sections in which he first discussed Newton's achievements, then discussed and illustrated the principle of reaction, and then went on to critique the principle of reaction and the concept of mass. Above all, Mach praised Newton's imagination (Phantasieleistung), describing the way that he had been able to synthesize intellectually the insights of those who had preceded him, and especially the boldness with which he had asked after the nature of the acceleration governing the planets in their curvilinear paths around the sun – and linked this to the gravitational acceleration experienced on earth (Mach 1883, 177). It was only after gaining a full understanding of the strength of Newton's achievements that Mach thought it appropriate to enter a detailed critique of them, so he worked through many problems and illustrations before addressing the assumptions underlying Newton's conceptions, introducing his own treatment of the concept of mass, and still later (after discussing space and time), offering his preferred expression of experimental propositions and definitions, a version of those he had expressed in 1868 (Mach 1883, see, e.g. 179, 227). For Mach's readers this was surely a training in critique, but perhaps also in physical imagination. It is notable that in discussing the principle of action and reaction, Mach chose to illustrate this with a treatment of fall that was dependent on his physiological experiments as well as upon his distinctive insistence on both the relativity of phenomena and the treatment of gravitation in terms of acceleration. Here is how he put it:

> We consider, say, a load L on a table T (fig. 134). The table is pressed by the load just so much, and so much only, as it in turn presses the load, that is prevents the same from falling. If p is the weight, m the mass, and g the acceleration of gravity, then by Newton's conception $p = mg$. If the table be let fall vertically downwards with the acceleration of free descent g, all pressure on it ceases. We discover thus, that the pressure on the table is determined by the relative acceleration of the load with respect to the table. (Mach 1883, 179) (Fig. 27.3).

In a typically rich and variegated discussion, after outlining this graphic thought experiment as a critical example of the principle – concluding with the statement that it is the relative acceleration which is determinative – Mach went on to discuss the thought experiment with which Galileo disproved Aristotelian conceptions, before considering the behavior of a pendulum in fall and discussing the sensations that we feel in fall, or would feel on other planets, finally going on to consider laboratory apparatus illustrating related principles. Mach's thought experiment was a variation on his 1865 discussion of his bodily experience, now informed by more recent experiments on fall, and it exemplifies too, Mach's pioneering discussion of the nature of thought experiments (Mach 1897(b)).

Einstein never recalled this thought experiment when discussing the origins of the equivalence principle, but I think we can say that his reading in Mach helped shape Einstein's creative imagination, as well as the ability to examine critically später dazu dienen, die Mängel dieser Aufstellungen leichter klar zu legen.

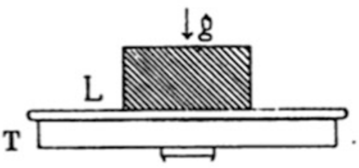

Fig. 134.

4. Wenden wir uns nun zu einigen anschaulichen physikalischen Beispielen für das Gegenwirkungsprincip. Betrachten wir eine Last L auf einem Tisch T. Der Tisch wird nur insofern durch die Last gedrückt, als er umgekehrt die Last drückt, dieselbe also am Fallen hindert. Heisst p das Gewicht, m die Masse und g die Beschleunigung der Schwere, so ist nach Newton's Anschauung $p = mg$. Lassen wir den Tisch mit der Beschleunigung des freien Falles g sich abwärts bewegen, so hört jeder Druck auf denselben auf. Wir erkennen also, dass der Druck auf den Tisch durch die Relativbeschleunigung der Last gegen den Tisch bestimmt ist. Fällt oder steigt der Tisch mit der Beschleunigung γ, so ist beziehungsweise der Druck auf denselben $m(g - \gamma)$ und $m(g + \gamma)$. Man bemerke aber wohl, dass durch eine constante Fall- oder Steigegeschwindigkeit keine Aenderung des Verhältnisses herbeigeführt wird. Die Relativbeschleunigung ist maassgebend.

Fig. 27.3 Mach's text and diagram illustrating action and reaction through a discussion of the free fall of a Table *T*, with a load *L*, and the acceleration *g*. (Mach 1883, 191 Fig. 134)

the foundations of physical principles that was so important to much of his work. Einstein's thought experiment is a variation on seeds that Mach had laid into his imagination. He went further than Mach too, of course, and critically he found new empirical purchase using novel conceptual tools. Recognizing the possibility of treating gravitation in the same way as acceleration was important for Einstein in 1907 because it allowed him to use mathematical techniques derived from his research in special relativity to develop empirical means of testing this new approach to gravitation, considering the way that clocks would be affected by a gravitational field, for example (Einstein 1907). On Mach's death in 1916, Einstein penned an obituary in which he tried to indicate just how pervasive aspects of Mach's thought had become, despite the opposition Mach had won for some of his stances, like his criticism of atomism. Einstein wrote that he believed "those who think of themselves as Mach's opponents are hardly aware of how much of Mach's way of thinking they imbibed, so to speak, with their mother's milk" (Einstein 1916). That was true of Einstein too.

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Chapter 28
Mach and Relativity Theory: A Neverending Story in HOPOSia?

Gereon Wolters

Abstract Michael Ende's bestseller/*The Neverending Story*/is set in a magical world called "Fantastica". In Fantastica, there are heroes and villains, just as in the world of universities and academies. There is even an entity, or better: a non-entity of shaky existence, das Nichts, the Nothingness – loved by some philosophers like Martin Heidegger. In Fantastica Nothingness is able to create trouble and destruction. The same is true in the land of academic history and philosophy of science – let us call it "HOPOSia". In HOPOSia, particularly in its Anglophone provinces, Nothingness of knowledge and information has succeeded in building up strong opinions about the topic "Mach and Relativity", and has created confusion and disinformation. However, you may slightly relax; our story in HOPOSia is less cruel so far and more peaceful than what happens in Fantastica. Sometimes it has even entertaining aspects. There are similarities, though: If there had not been lies and manipulation of believes, our story would have ended years ago. It went on instead and will possibly do so forever.

28.1 Introduction: Fantastica and HOPOSia

> When it comes to controlling human beings there is no better instrument than lies. Because, you see, humans live by beliefs. Moreover, beliefs can be manipulated. The power to manipulate beliefs is the only thing that counts. –

This is not an exactly optimistic assessment of human judgment and morality. We find it in Michael Ende's bestseller *The Neverending Story.*[1] That story is set in

[1] *Die unendliche Geschichte. Von A bis Z.* Mit Buchstaben und Bildern versehen von Roswitha Quadflieg, Stuttgart (Thienemann) 1979. The standard English translation, by Ralph Manheim, was first published in 1983.

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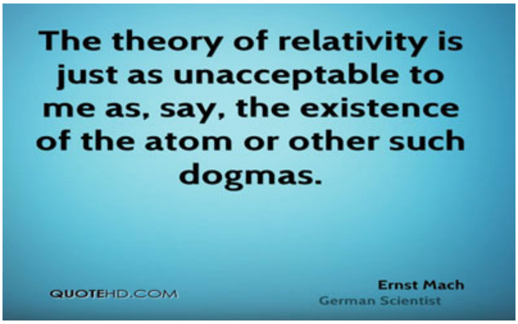
a magical world called "Fantastica". In *Fantastica*, there are heroes and villains, just as in the world of universities and academies. There is even an entity, or better: a *non*-entity of shaky existence, *das Nichts*, *the Nothingness* – loved by some philosophers like Martin Heidegger, to whom we owe the beautiful phrase "Das Nichts selbst nichtet".[2] In *Fantastica* Nothingness is able to create trouble and destruction. The same is true in the land of academic history and philosophy of science – let us call it "*HOPOSia*". In *HOPOSia*, particularly in its Anglophone provinces, in our case Nothingness of knowledge and information has succeeded in building up strong opinions and has created confusion and disinformation.[3] However, you may slightly relax; our story in *HOPOSia* is less cruel so far and more peaceful than what happens in *Fantastica*. Sometimes it has even entertaining aspects. There are similarities, though: If there had not been lies and manipulation of believes, our story would have ended years ago. It went on instead and will possibly do so forever. – Let us proceed step by step, and start with the present state of our (probably) neverending story.

28.2 First Step: What the WWW Teaches us, When We Google "Mach and Relativity"

Among the pictures that pop up in the web, we find a poster, where the "German scientist Ernst Mach" is quoted as saying the following:

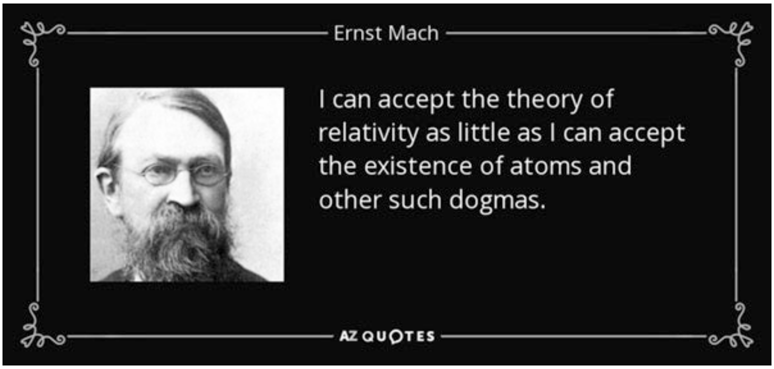


Sorry, my Austrian friends, in the wide transatlantic perspective such a geographical contraction of Germany and Austria may occur as normal. For those,

[2]This phrase is in German as senseless as the English translations "the nothing itself nothings" or "the nothing itself nihilates". – Rudolf Carnap, in his classic "Überwindung der Metaphysik durch logische Analyse der Sprache", has given already more than 80 years ago an equally timeless and devastating logical analysis of such philosophical nonsense (Carnap (1931)).

[3]At this point, I should issue a "trigger warning", in case innocent and sensitive American college students are among my readers. Here is the reason for this precautionary measure: "In the name of emotional well-being, college students are increasingly demanding protection from words and ideas they don't like." (Lukianoff/Haidt (2015)).

however, who might take offence at whatever sort of *Anschluss*, here is a poster neutral as to the nationality of Mach:



The Anglophone web, thus, seems to describe Mach as an anti-relativist and anti-atomist. Just to be on the safe side, let us have a look at *Wikipedia*. To my great relief the posters are confirmed. On relativity the entry "Mach, Ernst" informs us:

> [...]In 1930, he [Einstein] stated that "it is justified to consider Mach as the precursor of the general theory of relativity", though Mach, before his death, would reject Einstein's theory.[4]

The German *Wiki*, however, where the entry "Mach" even carries a quality star does not talk about Mach's position with respect to relativity, although it mentions Mach's influence on Einstein. The same is true for the other *Wikis* I checked with the exception of the Dutch. Just as an aside: Although I am very much in favor of Francis Bacon's *De nos ipsis silemus* (about ourselves we keep silent) I should mention that none of the 10 or so *Wiki* entries I have looked at, quotes my book on the topic *Mach I, Mach II, Einstein und die Relativitätstheorie. Eine Fälschung und ihre Folgen* (Wolters (1987)) – a book to which I frequently have to relate in what follows.[5]

The historical question we must put at this point is: are those texts on the web posters and on *Wiki* reliable? To answer this question, I would like to first deal with Mach's personal context.

[4] Seen May 2016.

[5] The English reader might consult Wolters (2012) for more extensive information than can be given in the present paper.

28.3 Second Step: Some Important Prehistory

The *first thing* I would like to mention is that Mach was by no means a theoretical physicist, although he plays – according to Einstein – a prominent role in the prehistory of relativity, one of the great pillars of modern theoretical physics. Mach was, rather, an experimental physicist and a sense physiologist. His importance for theoretical physics derives from methodological reflections in his work on the history of physics, particularly his *Die Mechanik in ihrer Entwicklung historisch-kritisch dargestellt.* The book that was so important for Einstein's development was published in 1883 and saw during Mach's lifetime seven revised and updated editions. It is, of course, – let me just insert a little advertising – part of the great new *Ernst-Mach-Studienausgabe*, for which the *Institut Wiener Kreis* and its director Friedrich Stadler are responsible (Mach (2012).[6] To sum up, Mach was not in any way involved in theoretical physics research connected with the theory of relativity.

This brings me to my *second point* that is of utmost importance. When in 1905 Einstein published his groundbreaking paper on special relativity, Mach was a very sick man of 67 years.[7] He had been sick for 7 years after an apoplectic stroke he suffered from on a train trip to Jena in July 1898. From this stroke resulted a series of secondary diseases, as hemiplegia that could never be reduced completely, a motoric aphasia that strongly influenced his faculty of speech. Furthermore, he reports in his correspondence problems with his urinary bladder that required catheterizing up to two times a day. In addition, he complains heavy sleep disorders, neuralgias, and frequent falls that confined him to bed for weeks and sometimes months. His state of health was so fragile that at first he was convinced that he would pass away soon. He writes, for example, in the preface to the second edition of the *Analyse der Empfindungen* in April 1900:

> I was unwilling to let slip this last opportunity without once again saying something on a subject which I have so much at heart. I have therefore added the supplements and elucidations most urgently required, principally by inserting short chapters in the original text.[8]

Similarly, in 1912, when Mach was confined to bed after a heavy fall he doubted that he would survive. On October 4, he wrote to Paul Carus, his American publisher and friend: "If this should this be my last letter, I ask you for an amicable remembrance."[9]

[6] As knowledgeable Anglophone colleagues have reported, the English translation of the *Mechanik* is, unfortunately, not consistently reliable.

[7] For a detailed presentation of Mach's medical history, see Wolters (1987), p. 276ff.

[8] Mach (2012), p. 3: "Ich möchte jedoch diese letzte Gelegenheit nicht vorübergehen lassen, ohne über den mir wichtigsten Gegenstand noch einmal das Wort zu ergreifen. Deshalb habe ich die notwendigsten Ergänzungen und Erläuterungen, meist in Form kurzer eingeschalteter Kapitel, eingefügt". (engl. transl., p. IX)

[9] "Sollte dies mein letzter Brief sein, so bitte ich um ein freundliches Andenken." ("Open Court Archive", in: Special Collections, Morris Library, Southern Illinois University at Carbondale).

Given his poor state of health, it is the more surprising that Mach continued working. Because his hemiplegia was on the right side, he even learned to write with his left hand and to use use a typewriter. He was able to bring his Viennese lectures to the press as *Erkenntnis und Irrtum*, to continue working on his *Prinzipien der physikalischen Optik*, to write the first part of his *Kultur und Mechanik* as well as several papers. He seems even to have done experimental work about electromagnetic interference. – This attests to the fact that Mach notwithstanding his poor state of health was full of energy. Here is a moving section in a letter to Paul Carus, of February 12, 1912:

> It is my wife, who has to suffer from my state of health. Certainly, it is not a trifle, to wash an adult person like a child every day and dress him, however without the prospect that he will grow up and become more independent and prudent. The only prospect is on a burial. If she had committed me to the doctors, I would have been long ago not only bankrupt but also for a long time dead. Things went in any case better than I could have thought. Who could have assumed that I would be still alive fourteen years after my apoplexy? I have even written new books since and repaired some defects of older writings in a satisfying way.[10]

Based on his correspondence and his notes, one can say that Mach took his 18-year sufferings with great patience and loyalty. There is no indication that embitterment about his condition might have caused unfair reactions to others. He was, by the way, in general not a friend of polemical arguments.

28.4 Third Step: How Einstein Saw Mach's Role

As is well known, and has never been contested so far, Einstein himself did not have the slightest doubts that Mach had exercised significant influence on the shaping of both special and general relativity. Three quotations may suffice.

The first is from Einstein's long and moving obituary on Mach in 1916, published in *Physikalische Zeitschrift*. Among other things, Einstein writes:

> It is not improbable that when physicists were considering the significance of the constancy of the velocity of light that had Mach's mind been young and fresh at that time he would have come across the theory of relativity. [. . .] His comments about Newton's bucket experiment show how near to his mind the demands of relativity in the more general sense (relativity of acceleration) lay.[11]

[10] "Wer darunter leidet, ist meine Frau. Denn es ist gewiss keine Kleinigkeit, einen erwachsenen Menschen täglich zu waschen und anzuziehen, wie ein Kind, jedoch ohne die Aussicht, dass es größer, selbständiger und gescheiter wird, sondern nur mit der Aussicht auf ein Begräbnis. Hätte sie mich den Ärzten überlassen, so wäre ich nicht nur längst bankerott, sondern auch längst tot. Es ist ohnehin besser ausgegangen, als ich denken konnte. Wer hätte annehmen können, dass ich 14 Jahre nach meiner Apoplexie noch leben würde. Ich habe seitdem noch neue Bücher geschrieben und manchen Defekt älterer Schriften noch in befriedigender Weise ausgeflickt." ("Open Court Archive", in: Special Collections, Morris Library, Southern Illinois University at Carbondale).

[11] Einstein (1916), p. 103: "Es ist nicht unwahrscheinlich, dass Mach auf die Relativitätstheorie gekommen wäre, wenn in der Zeit, als er jugendfrischen Geistes war, die Frage nach der Bedeutung

The second quotation is from Einstein's "Autobiographical Note" that he wrote in 1948 for the Schilpp-volume:

> It was Ernst Mach who, in his History of Mechanics, shook this dogmatic faith [in classical mechanics as firm and definite foundation for all physics]; this book exercised a profound influence upon me in this regard while I was a student.[12]

The third and last quotation is from an interview Einstein gave in 1955, only 2 weeks before his death, to I. B. Cohen:

> Although Einstein did not agree with the radical position adopted by Mach (with respect to the existence of atoms), he told me he admired Mach's writings, which had a great influence on him[13]

There are four letters of Einstein to Mach. Mach's letters are lost.[14] Einstein's last letter dates from the turn of the year 1913/14. He thanks Mach for what he describes as "friendly interest" in a paper he had published in 1913 together with his friend, the Zurich mathematician Marcel Grossmann. The paper that presents a new field theory of gravitation is an important step towards general relativity. It makes use of the mathematical tool of tensor analysis that Einstein did not know and learned only with Grossmann. Because Mach had obviously written that he did not understand the mathematics of the paper, Einstein admits:

> Unfortunately, the mathematical difficulties which one encounters in pursuing these ideas are enormous for me as well. I am tremendously pleased that the development of the theory brings to fore the depth and importance of your investigations on the foundation of classical mechanics. To this day, I still cannot understand how Planck, whom I have otherwise learned to prize like no one else, could show so little understanding for your endeavors. Incidentally, he also disapproves of my new theory.[15]

This was balm for Mach's soul, not only because the young shooting star of physics appreciated once again Mach's ideas and influence, but also because he defended him against Planck. Planck, in 1908, in a talk at the University of Leiden had launched a completely unprovoked attack on Mach's phenomenalist epistemology. Planck's attack can be justified at best partly as regards content. It is, however, tactless and aggressive as regards form. Planck closed his talk – alluding

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der Konstanz der Lichtgeschwindigkeit schon die Physiker bewegt hätte. [. . .] Die Betrachtungen über Newtons Eimerversuch zeigen, wie nahe seinem Geiste die Forderung der Relativität im allgemeineren Sinne (Relativität der Beschleunigungen) lag." (engl.transl. pp. 157ff.)

[12] In: Schilpp (ed.) 1970, p. 21.

[13] Cohen (1955), p. 72.

[14] Cf. Wolters (1987), Ch. 2, which presents the letters and analyzes their content.

[15] Einstein (1993), p. 583 f. – „Die mathematischen Schwierigkeiten, auf die man bei der Verfolgung dieser Gedanken stößt, sind leider auch für mich sehr große. Es freut mich außerordentlich, dass bei der Entwicklung der Theorie die Tiefe und Wichtigkeit Ihrer Untersuchungen über das Fundament der klassischen Mechanik offenkundig wird. Ich kann heute noch nicht begreifen, wie Planck, den ich sonst wie kaum einen zweiten hochschätzen gelernt habe, Ihren Bestrebungen so wenig Verständnis entgegenbringen konnte. Er steht übrigens auch meiner neuen Theorie ablehnend gegenüber."- Engl. transl., p. 370.

to Mach's refusal to acknowledge the reality of atoms – "in the serene trust in the power of the Word, which for over nineteen hundred years has taught us the ultimate indubitable sign of how to distinguish true from false prophets: *By their fruits shall ye know them!*[16] – I would like to call this the "Jesus-Planck-Criterion for the assessment of epistemological theories" – JESPLAC for short. JESPLAC will accompany us for the rest of this paper.

28.5 Fourth Step: How Mach Saw Relativity

It is time now to inspect the evidence we have of Mach's own assessment of relativity. *First,* one has to recall that in 1905, when Einstein's seminal paper on special relativity appeared, Mach was already a very sick man, who concentrated – as far as his weak forces allowed – on other things than the latest developments in theoretical physics. It is, therefore, no wonder that it took quite some time, before he learned about Einstein's new theory. All evidence suggests that it was the publication of Hermann Minkowski's famous talk at the 80th *Reunion of German Natural Scientists and Physicians* on September 21, 1908 in Cologne. This talk gave the canonical four-dimensional representation of special relativity that holds until this day. Mach had great difficulties to understand Minkowski's paper and asked the young physicist Philipp Frank (1884–1964) to explain it to him. Frank much later reported this story in a letter of 1959 to the East German historian of science Friedrich Herneck. He concludes:

> Back then got the impression that he completely agreed with Einstein's 'special' theory, and particularly with its philosophical foundation. Mach asked me to give him my presentation in written or printed form. This I did, and therefore exists as a printed text of the presentation of Einstein's theory that Mach agreed with.[17]

Frank's recollection that Mach agreed with special relativity fits nicely with Mach's own published pronouncements in this regard. Given Mach's limited competence with respect the latest developments in theoretical physics and his pure state of health, it is certainly not a coincidence that all three statements are just short footnotes.[18] They all occur in the context with the Planck-controversy and visibly

[16]Planck (1909), p. 51 of the reprint: Planck hat „das ruhige Vertrauen auf die Kraft desjenigen Wortes, welches seit nunmehr neunzehnhundert Jahren als letztes, untrügliches Kennzeichen die falschen Propheten von den wahren scheiden lehrt: An ihren *Früchten* sollt ihr sie erkennen!" - Engl. transl. p. 132

[17]Herneck (1966), p. 49: „Ich hatte damals den Eindruck, dass er vollständig mit Einsteins 'spezieller Theorie, übereinstimmte und auch besonders mit deren philosophischer Basis. Mach ersuchte mich, ihm meine Darstellung noch schriftlich oder gedruckt zu hinterlassen. Ich tat das auch, und daher ist die Darstellung der Einsteinschen Theorie, der Mach zustimme, auch in einem gedruckten Text vorhanden." (engl. transl. G.W.) – Frank's „printed text" is Frank (1910).

[18]There is no doubt: Had Mach already lived in *HOPOSia* he would have written a book or at least a long article praising his central role in the development of relativity.

aim at showing that Mach’s epistemological ideas, other than Planck had contended, bear delicious scientific fruits, and thus *positively* comply with JESPLAC. The first footnote occurs in a republication of his famous Prague talk of 1871 on the *History and root of the principle of the conservation of energy*. Mach wrote to Paul Carus (January 7, 1910) that the reprint of the talk was, in fact, “provoked” (*veranlasst*) through Planck’s attack”.[19]

> Space and time are not here conceived as independent entities, but as forms of the dependencies on one another. I subscribe then to the principle of relativity, which is also firmly upheld in my *Mechanics* and *Wärmelehre*. Cf. >Raum und Zeit physikalisch betrachtet< in >Erkenntnis und Irrtum< 1905, H. Minkowski, >Raum und Zeit 1909<.[20]

The second footnote we find in Mach’s explicit defense against Planck’s attack. He seems to be encouraged by Einstein’s gentle reaction in a letter of August 9, 1909 to Mach’s sending him the republication of the “Conservation of Energy”, and to use this reaction as positive JESPLAC:

> Even if the kinetic physical world picture, which in any case I consider hypothetical without intending thereby to degrade it, could ‘explain’ *all* physical appearances, I would still hold that the diversity of the world had not been exhausted, because for me *matter, space,* and *time* are also *problems*, which moreover, the physicists (*Lorentz, Einstein, Minkowski*) are also moving closer toward.[21]

The third and last footnote is again clearly in JESPLAC spirit. It can be found in Mach’s 1910 paper “Sensory Elements and Scientific Concepts”. Note that it is always *Mach*, who employs JESPLAC for *promoting* his philosophy. Planck and all the others, I will take on shortly, use it for *belittling* Mach:

> Similarly, one will have to distinguish between metrical and physical space, with time included in the latter. I have already carried this out in my book *Erhaltung der Arbeit* (1872), p. 35, suggested on p. 56, and in *Erkenntnis und Irrtum* (1906), p. 434ff.; it is also a direction in which essential progress has been made by the work of A. Einstein and H. Minkowski.[22]

[19] In: “Open Court Archive“, in: Special Collections, Morris Library, Southern Illinois University at Carbondale).

[20] Mach (1909), p. 60: “Raum und Zeit werden hier nicht als selbständige Wesen, sondern als Formen der Abhängigkeit der Phänomene voneinander aufgefasst. Ich steuere als auf das *Prinzip der Relativität* los, welches auch in ‚Mechanik‘ und ‚Wärmelehre‘ festgehalten wird. Vgl. ‚Zeit und Raum physikalisch betrachtet‘ in ‘Erkenntnis und Irrtum‘ 1905. Vgl. H. Minkowski, ‚Raum und Zeit‘ 1909.“ – engl. transl. p. 95.

[21] Mach (1910), p. 605: “Würde das kinetische physikalische Weltbild, welches ich allerdings für hypothetisch halte, ohne es deshalb degradieren zu wollen, auch *alle* physikalischen Erscheinungen ‚erklären‘, so würde ich die Mannigfaltigkeit der Welt hiermit nicht für erschöpft halten, denn für mich sind eben *Materie, Zeit* und *Raum* auch noch *Probleme*, welchen übrigens die Physiker (Lorentz, Einstein, Minkowski) allmählich auch näher rücken.“ – Engl. transl. p. 139.

[22] Mach (2014), 465: “Ähnlich wird man zwischen dem metrischen und dem physikalischen (die Zeit mit enthaltendem) Raum zu unterscheiden haben, wie dies schon in meiner Schrift “*Erhaltung der Arbeit*“ 1872, S. 35, 56 angedeutet, in „*Erkenntnis und Irrtum*“ 1906, S. 434ff. teilweise ausgeführt worden ist, in welcher Richtung durch die Arbeiten von A. Einstein und H. Minkowski wesentlich Fortschritte begründet worden sind.“ – Engl. transl. p. 125.

In a collection of typescript notes by Mach of about 1909/10 that were recently given to the Mach papers at *Deutsches Museum* in Munich (HS 2015–008) we find similar sketchy attempts to relate special relativity to his epistemology, particularly in its Minkowskian form. It seems clear that Mach after Planck's Leiden attack was pleased to see a continuity of his thinking with groundbreaking developments in physics, even if he could understand them only approximately.

Apart from these wait-and-see footnotes in JESPLAC spirit, Mach has not published a word about relativity. The reasons for such a restraint are obvious, and I mentioned them already. First, he was not a theoretical physicist. Second, his time of commenting the course of physics from an epistemological point of view, based on proper own understanding, was over. Third, Mach was an old and sick man, who had to devote his vanishing forces to finishing own work and to small popular papers. There does not exist the slightest indication that he intended to immerse himself into the quarrels in the theoretical physics community of his day about matters he could only partly understand.

One could certainly add, as did Einstein in his obituary of 1916, a few more merits Mach actually had in the genesis of special and general relativity. Time constraints do not allow this, unfortunately.

28.6 Fifth Step: The *Optics* Preface – Lies and Manipulations Enter the Story

Given the situation as described so far, even in our sometimes rather bold and imaginative *HOPOSia* probably nobody would have ever claimed that Mach rejected relativity, if there not had been the publication of his *Die Prinzipien der physikalischen Optik* in 1921, i.e. 5 years after his death. The text of the book itself, to a considerable degree handwritten by Mach before his stroke, i.e. before 1898, *does not even mention* relativity. Only the preface, signed "München-Vaterstetten, July 1913 Ernst Mach," – based on a typescript of 1921 by Mach's son Ludwig – surprises both with a straightforward rejection of relativity, devoid of any argument, and of any attempts of its alleged author to be regarded as one of its forerunners:

> I gather from the publications which have reached me, and especially from my correspondence that I am gradually becoming regarded as the forerunner of relativity. I am able even now to picture approximately what new expositions and interpretations many of the ideas expressed in my book on Mechanics will receive in the future from the point of view of relativity.
>
> It was to be expected that philosophers and physicists should carry on a crusade against me for, as I have repeatedly observed I was merely an unprejudiced rambler, endowed with original ideas, in varied fields of knowledge. I must, however, as assuredly disclaim to be forerunner of the relativists as I withhold from the atomistic belief of the present day. The reason why, and the extent to which, I discredit the present-day relativity theory, which I find to be growing more and more dogmatical, together with the particular reasons which have led me to such a view – the considerations based on the physiology of the senses,

> the theoretical ideas, and above all the conceptions resulting from my experiments – must remain to be treated in the sequel.
>
> The ever increasing amount of thought devoted to the study of relativity will not, indeed, be lost; it has already been both fruitful and of permanent value in mathematics. Will it, however, be able to maintain its position in the physical conception of the universe of some future period as the theory, which has to find a place in a universe enlarged by a multitude of new ideas. Will it prove to be more than a transitory inspiration in the history of science?[23]

Connoisseurs of Mach's work and of his language could easily dismiss this rather confused, un-Machian gibberish as not authentic.[24] The same holds for anti-relativity quotes, attributed to Mach, that one finds in the preface of Mach's son Ludwig to a new edition of Ernst Mach's *Mechanik* in 1933. When it comes to discarding those texts as forgeries, Ludwig Mach is the central figure.[25]

Born in 1868 at Prague, he studied medicine until 1885. Instead of entering the medical profession, Ludwig joined the Zeiss Company in Jena, famous for building high precision instruments. This was a wise step, indeed, because Ludwig was clearly not suited for working as a physician. Already as a student, however, he had acted as a kind of assistant in Mach's Prague Institute for experimental physics and had published seven papers, some together with his father. Those papers he published as sole author were also a fruit of the collaboration with his father. The papers deal above all with the interference refractometer, and with technical aspects of photography, particularly schlieren photography. Both techniques Mach had used to visibly represent the shockwaves of his supersonic velocity experiments. – In

[23] Mach (1921), p. VIIIf.: "Den mir zugegangenen Publikationen und vor allem meiner Korrespondenz entnehme ich, dass mir langsam die Rolle des Wegbereiters der Relativitätslehre zugedacht wird. Nun kann ich mir heute ein ungefähres Bild davon machen, welche Umdeutungen und Auslegungen manche der in meiner Mechanik niedergelegten Gedanken in Zukunft erfahren werden. Wenn Philosophen und Physiker den Kreuzzug gegen mich predigten, so musste ich dies natürlich finden, und war damit ganz einverstanden, denn ich war, wie ich dies wiederholt dargetan habe, auf den verschiedenen Gebieten doch nur ein unbefangener Spaziergänger mit eigenen Gedanken, muss es aber mit derselben Entschiedenheit ablehnen, den Relativisten vorangestellt zu werden, mit welcher ich die atomistische Glaubenslehre der heutigen Schule oder Kirche für meine Person abgelehnt habe. Warum aber und inwiefern ich die heutige mich immer dogmatischer anmutende Relativitätslehre für mich ablehne, welche sinnesphysiologischen Erwägungen, erkenntnistheoretischen Bedenken und vor allem experimentell gewonnene Einsichten mich hierzu im einzelnen veranlassten, das soll in der Fortsetzung dieses Werkes dargetan werden. Gewiss wird die auf das Studium der Relativität verwendete immer mehr anschwellende Gedankenarbeit nicht verloren gehen, sie ist heute schon für die Mathematik fruchtbringend und von bleibendem Wert, wird sie sich aber in dem physikalischen Weltbild einer ferneren Zeit, das sich in eine durch mannigfache weitere neue Einsichten erweiterten Welt einzupassen hat, behaupten können, wird sie in der Geschichte der Wissenschaft mehr als ein geistreiches Aperçu bedeuten? " – Engl. transl. p. VIII.

[24] As a native speaker of German, who has read almost all of Mach's writings as well as scores of letters of his son, I am surprised to see American researchers claim that the *Optics* preface was written in "the pure Machian style", as Banks (2003), p. 250 quotes approvingly J. Blackmore.

[25] For an extensive biographical account and Ludwig's role, see Wolters (1987), 286ff.

the first years of the twentieth century – thanks to a patent for "Magnalium", an aluminum-magnesium alloy – Ludwig Mach had become a well-to-do young man, and had moved to Berlin. In 1901 he had married, but obviously concealed for quite a while this family enlargement from his parents. In 1905, the young Mach couple moved to Munich. In 1910, Ludwig decided to build a house for his parents on an isolated plot in Vaterstetten near Munich. In May 1913, finally, Ernst Mach and his wife Louise, his sister Marie and Anna, the faithful handmaid moved in from Vienna, while Ludwig and his wife retained their apartment in town.

In World War I, Ludwig lost at least a large part of his fortune, that he, unfortunately, had invested in Austrian war bonds. The following decades until his death in 1951 were a continuous fight on the brink of the psychological and economical abyss.

When Ernst Mach and family moved to Vaterstetten in May 1913, Mach was 75 years old and certainly not in better shape than described earlier. There is no indication that Mach ever left the house during the three Vaterstetten years. In Vaterstetten, soon, begins a development that lead more and more to a sort of deprivation of the right of decision of Ernst Mach by Ludwig, who presumes the right to act as his father's guardian. This presumption is connected with Ludwig's ambition to "continue" the work of his father. Here are a few indications of Mach's incapacitation. When World War I broke out in August 1914, Ludwig – who seems to have acted also as physician of his father – decided that his patient should not be bothered with such bad news. Consequently, Ludwig had to arrange an information ban that included controlling and censuring Ernst Mach's correspondence. The first letter that seems to have fallen victim of Ludwig's censorship was a letter of August 1914 of Mach's faithful friend Joseph Petzoldt (1862–1929). Ludwig was, by the way, in a state of competition with Petzoldt, an ardent adherent of relativity and of Mach's role in its genesis. The reason for this competition is that Ludwig regarded himself not only as the guardian of his father in everyday matters, but also as the chosen one to manage and even continue his work – a gross overassessment of his capacities. Ludwig was a good technician, but poor in theory. He knew neither mathematical analysis nor central pieces of physical theory like Fourier Theory. Therefore, Mach in 1904 had made an addendum to his contract with the publisher Brockhaus, in which he entrusted new editions of the *Mechanik* to Petzoldt and gave him permission "to add his own remarks in appendices". Petzoldt should also participate in the royalties for the book – against his own wishes.

Sometime, probably in the second half of 1915, Ludwig seems to have informed his father about the disastrous course the world had taken for about a year. The first evidence we have for this, is in a letter of Ludwig of October 1915.

Another significant example of Ludwig's incapacitation of his father and of his own guardianship is the fact that in November 1915 Ludwig had sent the manuscript of the *Optik* to the publisher, obviously without informing his father, not to talk about asking his permission. Proof of this is a letter that Mach wrote on February 12, 1916 – 6 days before his death – to the Leipzig physicist Otto Wiener:

> You ask me how matters stand with respect to the *Optics*. Well, you have anticipated so much with your 'theory of light' and the wide theoretical outlook connected with it, that I cannot take any more pleasure in my own expositions. I as an aging man could no longer keep pace with the unimagined development of optics.[26]

The publication of the *Optik* had to be interrupted, because Ludwig was called up for military service. After the war, the publication could be resumed. However, there was a little problem. Ludwig now needed a new theoretical mentor to live his pretensions of managing and continuing his father's work.

One can distinguish three stages in the development of Ludwig's "position" on relativity. The *first stage* coincides with his father's lifetime. Ludwig did not find fault with relativity. In November 1914, for example, he wrote to the fervent relativist Petzoldt about one of Petzoldt's papers: "I share completely your standpoint with respect to the R-thing [i.e. relativity] and owe to your paper a lot of stimulating ideas, the *experimental* revaluation of which seems to me very valuable."[27] – Pay attention to the last part of this sentence. Here we find the core of the rest of the story. Ludwig Mach connects the concept of relativity with own experimental activity. As we will see shortly, he wants to bring his interferometer into play. The *second stage* was reached, when Ludwig had found a new mentor to replace his father. This was the theoretical physicist Friedrich Adler (1879–1960), son of Victor Adler, the founder of the Austrian Social Democratic Workers Party. Adler, in early 1918, had plenty of time because he served an 18-year prison sentence for having shot the Austrian prime minister Graf von Stürgkh in 1916. Adler helped Mach in proofreading of the 3rd edition of the *Wärmelehre* and of the first sheets of the *Optik.* On March 3, 1918 Ludwig, after he had learned that Adler was working on a book against relativity wrote to him: "On relativity theory you will find little in the *Optik*, on radiation nothing. – he [i.e. Mach] declared to me repeatedly that these chapters were still too unsettled for being included in the book." Then he reports about his father's stand: "Until his death he was a trifle ironic about ions and the new views of the relativists."[28] – Fact is that there is not only "little" about relativity in the *Optik* but nothing. This little word

[26]"Sie fragen mich wie es mit der *Optik* steht? Nun haben Sie mit ihrer „Lehre vom Licht" und den daran sich knüpfenden weiten theoretischen Ausblick so viel vorweggenommen, dass mir meine Ausführungen nicht mehr gefallen wollen. Mit der ungeahnten Entwicklung der Optik konnte ich, der alternde Mann, nicht mehr Schritt halten."(Universitätsbibliothek Leipzig, Nachlass Otto Wiener).

[27]"Ich teile völlig Ihren Standpunkt in der R-Sache – und ich verdanke Ihrem Aufsatz eine Reihe von Anregungen, deren *experimentelle* Umwertung mir sehr wertvollerscheint." (Technische Universität Berlin, Universitätsarchiv, Nachlass Joseph Petzoldt).

[28]"Über die Relativitätstheorie werden Sie wenig, über die Strahlung gar nichts in der *Optik* finden – er erklärte mir wiederholt, diese Capitel seien noch viel zu ungeklärt, um in die Darstellung aufgenommen zu werden. [...] Das wäre ja nett, wenn es uns gelänge, experimentell und theoretisch eine Bresche zu schlagen gegen dieses Überwuchern der Speculation. Er hatte bis zu seinem Tode etwas leises [!] Ironisierendes für die Ionen und die neuen Anschauungen der Relativisten." (Adler Archiv (Mappe 130), in: Archiv für die Geschichte der Arbeiterbewegung, Vienna).

"little" points, however, to the project Ludwig had alluded to already in 1914 in his letter to Petzoldt. In his letter to Adler continues: "That would be fine, if *we* succeeded to blow a breach experimentally and theoretically." – The Adler-project failed, because Adler was pardoned in late 1918 and returned to politics. The *third stage* was reached, when Ludwig had read the draft of Petzoldt's appendix to the 8th edition of the *Mechanik* that praised Mach as forerunner of relativity. Ludwig, in the meantime, had found a new, fervently anti-relativist Mentor, the mathematician-philosopher Hugo Dingler (1881–1954). Ludwig writes to his rival Petzoldt on February 14, 1920:

> I cannot *comment in his sense* on relativity [my emphasis], before the publication of the *second part of the Optics* [my emphasis]. You will become thoughtful through Dingler. The fact that E(instein) arrived at his ideas, because of the physical philosophy of the young E.M. (*physikalische Jugendphilosophie*) does not diminish his merits. I still have to deal with the bending of the light of stars in the gravitational field of the sun. If you take the trouble to realize just this once the program outlined in your letter, then I am grateful to you in the name of my father.[29]

This letter is the first known document that mentions a second part of the *Optik*. It makes also clear that what a second part of the *Optik* could reveal is at most *in the sense* of Mach, and depends on experiments Ludwig still has to make, in Ernst Mach's sense, as it were. From 1920 on Ludwig tried to raise money for financing such experiments, not least from anti-relativity Nazi sources. What Ludwig had in mind, was the fantastic project to measure with the help of his interferometer the bending of light rays through trees in his garden. This project was obviously motivated by the broadly published results of two British expeditions that in May 1919 had observed the bending of the light of stars by the mass of the sun on the occasion of a solar eclipse. Ludwig's insane project wandered like a ghost through his life for the next 30 years and is amply documented. His last appearance it made in a law suit against the electricity supplier *Isar-Amper Werke* that in November 1944 had chopped the trees on Mach's estate so badly needed for the experiments designed a quarter of a century ago and for finishing the alleged second volume of the *Optik*. In 1950, Ludwig succeeded in getting a compensation of 5000 *deutschmarks*, but he had to pay ¾ of the costs of the lawsuit.[30]

The third stage of Ludwig's development is characterized by many other curiosities. I mention only one. Dingler, who had come out as an anti-relativist some time before, feared in early 1920 that he had fallen in disgrace with Ludwig

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[29] "Ich *kann* vor der Publication des II. Teiles der Optik keine Stellung in seinem Sinn zur Relativität nehmen. Sie werden aber durch Dingler nachdenklich werden. Dass E(instein) auf Grund der physikalischen Jugendphilosophie (von) E. M. zu seinen Anschauungen gekommen ist, schmälert gewiss nicht sein Verdienst! Mit der Ablenkung des Sternlichts im Schwerefeld der Sonne muss ich mich speciell noch auseinandersetzen. Wenn Sie sich der Mühe unterziehen, das Programm Ihres Briefes für den *Mechanik*-Anhang für diesmal zu verwirklichen, dann danke ich Ihnen im Namen meines Vaters." (Technische Universität Berlin, Universitätsarchiv, Nachlass Joseph Petzoldt).

[30] For a presentation of court records, including the verdict, see Wolters (1987), 431ff.

because of his *anti*-relativist stand, because he believed that Ludwig sort of favored relativity as his father had done. Only in January 1921, Dingler learned to his surprise about the alleged existence of the anti-relativity preface. In addition, it is perhaps of interest to know that Ludwig, at least during 1920 and 1921, was addicted to cocaine, which might explain part of his almost abnormal behavior.

There does, of course, not exist a manuscript of the *Optik*-preface apart from the one Ludwig typed and sent to the publisher. In addition, in the huge amount of documentary material, there is no hint at a rejection of relativity by Ernst Mach. What one can observe, however, is Ludwig's pretension to communicate that after experiments of his own he would be in a position to deliver a judgment about relativity "*in the sense*" of his father.

28.7 Sixth Step: Our Story Goes on in *HOPOSia*

The reactions in *HOPOSia* to my forgery thesis are interesting in various respects. There were a few positive, even if not uncritical reactions.[31] More visible, however, is sometimes rather harsh criticism that comes from people that I myself, in turn, had taken on in a rather polemical way, and I am going on to do so in this paper. Most *HOPOSians*, who reject the forgery thesis use JESPLAC against Mach, in order to boost their own epistemological position.

Furthermore, American *HOPOSians*, who deal with the forgery thesis often show a degree of condescendence towards me personally and with respect to my research they would have hardly risked, if I were a member of the Anglophone community, working, say, at an American top-ranked research university.[32]

In the following, I would like to deal only with a few *HOPOSians* who succeed to create confusion from nothing like the Nothing in Ende's *Fantastica.*[33]

I would like to mention four examples[34]:

[31] I would like to mention Howard (1987) and Di Salle (1990).

[32] This is all the easier, because the book is not available for the usually monoglot American reader. An English translation of the book with Kluwer did not materialize. I have never been informed why, but I have some clues . . .

[33] Therefore, I do not deal with John Blackmore, a sharp critic of the forgery thesis. Mach research owes him much credit for his Mach biography (Blackmore 1992). The book contains an enormous amount of archival documentation. It can be regarded as the beginning of contemporary research on Mach. Blackmore's judgments about Mach and relativity are, unfortunately, completely obfuscated JESPLACwise by his epistemological fight for "representative realism" as shown in Wolters (1987) passim. The, say lively, discussion that ensued, in which Blackmore also brought into position Japanese auxiliary forces (who could not read my book, but knew that I was wrong), did not bring any new idea to the fore. – Nonetheless, I disliked a general negative remark by an American scholar about Blackmore's work at the Vienna Centenary Conference.

[34] In order to avoid useless polemics I do not give the names of HOPOSians living at the time of the conference.

One Mach researcher, who was also present at the Vienna Centenary Conference, calls my forgery thesis in a book on Mach "somewhat fanciful". Unfortunately, he does not tell us why. I guess, he has not read the book that he is slamming for whatever reason.[35] This is a fine example of how from Nothingness can arise something, *creatio ex nihilo* in *HOPOSia*.

Another fine example of this sort of *creatio ex nihilo* is an American scholar, whom I appreciate otherwise. After I had collected ample theoretical and documentary evidence for the thesis that the *Optik*-preface had been falsified and prior to the publication of my book, I talked to the British philosopher Rom Harré. Harré was immediately convinced of my findings, and commented briefly and positively about them, based on a paper of mine. Shortly afterwards our American colleague, writes in a footnote in one of his books, without even mentioning my name[36]:

> Recently it has been claimed that Mach's supposed rejection of relativity theory in the preface to the second edition of the *Optics* [there is, in fact, only a first one! G.W.] was a fabrication of his son Ludwig; see Harée 1986, pp. 15–16. Whatever the merits of this claim, it seems clear that a negative attitude toward relativity theory flows naturally from Mach's general philosophical orientation.[37]

The third American scholar that I will deal with more extensively has given JESPLAC an interesting twist: Mach's allegedly sensationalist phenomenalism bears the bad fruit of rejecting relativity; this he counts as support of his own epistemological realism. – Accordingly, he had to fight my forgery thesis, in order to defend epistemological realism. He achieved this in a very, say, innovative way:

First of all, he accuses me of „the new fashion of aggressive revisionism". "Aggressive revisionism" here obviously means outspoken criticism of somebody, who would like to give himself the aura of infallibility. *Second*, my critic complains that in my work „some of the most crucial historical documentation is absent. "Unfortunately, he does not quote even one piece of allegedly absent „crucial historical documentation". *Third,* it has been myself, who has found much of the relevant documentary material, sometimes literally on the attics. My critic now contends: „No documents seem to be available for independent study of Wolters's conjectures". If we simply dismiss the mental reservation, contained in the word "seems", the contrary is true. All those documents I had found were without any

[35] He does not seem to have read the *Optics* preface either, because in a footnote he contends: "Mach does not say he out-and-out rejects the theory. He merely says that it will form 'an aperçu' in the broader science of the future he envisions." –This is correctly quoted, but the preface says a bit more before the last sentence that contains the "aperçu": "The reason why, and the extent to which, *I discredit the present-day relativity theory* [emphasis G.W.], which I find to be growing more and more dogmatical, together with the particular reasons which have led me to such a view [. . .]" (see text of the preface above).

[36] The condescending attitude to talk about my forgery thesis without mentioning my name I found also with the late Finnish-American scholar Jaakko Hintikka (2001), p. 85 f.. – It results from what I have called "team asymmetry" between European and Anglophone universities in a recent paper on the consequences of English as *lingua franca* in academia (Wolters (2015), 192 f.)

[37] Earman (1989), fn. 16 to Ch. IV.

difficulty accessible for more than 30 years at the *Philosophisches Archiv* of the University of Konstanz, which is an institution of the archival system of the German state of *Baden Württemberg*.[38] I happen to be its founder and director and am not aware of any inquiry to study the respective holdings by our *HOPOSia*-scholar.

Fourth and finally, we find with our *HOPOSian* an impressive masterpiece of innovative dialectics: he agrees with me by attacking me. – I have emphasized and extensively documented that Mach was an old and very sick man who wanted to finish some work he had begun in his healthier days. I have at length pointed out that Mach was not a professional theoretical physicist, that he did not understand special relativity and asked for help, and was happy to be credited as one of its forerunners, particularly in his controversy with Planck. He did not understand the mathematical details of general relativity, either. Thus, in a sense, I could agree with the following conclusion of my critic: "it no longer matters *who* wrote Mach's disavowal dated July 1913. Whether he intended to accept it or to reject it, Ernst Mach would not have known at that point what relativity was about." I could agree, although Mach knew more about relativity than is insinuated here. The dialectical turn of my critic confirms in my view a remark of the great French biologist André Lwoff: „the bad thing about the profession of a researcher are the discoveries of the others".[39]

My favorite *HOPOSian* is in any case Paul Feyerabend, Mach's Viennese fellow compatriot and great admirer. When I first had told Paul about my findings in the mid-eighties and had shown him some documentation, he was enthusiastic and wrote on a postcard of May 7, 1985:

> I am eagerly awaiting to receive the complete text of the comedy thriller 'Mach and the learned world' and am anticipating pleasurable hours. (footnote: I pay for it, if necessary) Hurry up! Your opinion about the *Optik* preface is not only very plausible, it also 'saves' one of the features that I find so admirable with Mach, namely that he did not easily get baffled by the clamor of the idiots, but kept calm slightly ironically.[40]

In this sense, Feyerabend added an "Afterword" to the republication of his paper "Mach's Theory of Research and its Relation to Einstein" in his *Farewell to Reason*:

> It now appears that the foreword to the *Physikalische Optik* and the foreword to the 9th edition of the *Mechanik*, which contain passages critical of the special theory of relativity, were written by Ludwig Mach, Ernst Mach's son, and inserted without Ernst Mach's knowledge. In a word, both texts are a fake. The evidence, which is strong though circumstantial and which to me seems entirely convincing, has been assembled by Dr. Gereon Wolters of the University of Konstanz. I accept his conclusions and the

[38] At the end of 2015, the Konstanz material has been joined with the bulk of the Mach papers at *Deutsches Museum* in Munich.

[39] See his autobiography, Jacob (1988), p. 355.

[40] "Mit großer Spannung und in Antizipation vergnüglicher Stunden sehr ich den Empfang des *vollständigen Textes* (Fußnote: wenn nötig, zahle ich dafür) der Kriminalkomödie 'Mach und die Gelehrten'entgegen. Beeile Dich! Deine Auffassung vom Vorwort der Optik ist nicht nur sehr plausibel, sie 'rettet' auch eine der Eigenschaften, die ich beim Mach so bewundernswert finde, nämlich, dass er sich vom Geschrei der Idioten nicht leicht aus der Fassung bringen ließ, sondern eine leicht ironische Ruhe bewahrte."

interpretation he bases on them: see 'Atome und Relativitat – Was meinte Mach?', in R. Haller and E. Stadler, eds., *Ernst Mach: Leben, Werk und Wirkung*, Vienna 1986. My remarks on Mach and atomism remained untouched by these discoveries. (Feyerabend (1987), p. 218).

A year later, in a "Zusatz 1988" to the German translation of *Farewell to Reason* Feyerabend has changed his mind:

Gereon Wolters (*Mach I, Mach II, Einstein und die Relativitätstheorie,* Berlin/New York 1987) claims that the preface to the 9th edition of the *Mechanik* and the preface to the *Physikalische Optik*, that both contain critical remarks on relativity theory, were formulated by Ernst Mach's son Ludwig Mach without his father's knowledge. His argument rests on circumstantial evidence and has a certain persuasiveness. Mach, however, does not need a rescue of this sort. If we assume that the critical remarks are of himself – would that be really so bad? Mach wanted an encompassing theory that did not treat the psychical as separate from the physical. The more dogmatic followers of relativity wanted to pin down research on a more narrow area. Mach made a stand against this. The attempt to "save" Mach with the aid of a forgery theory takes a certain stage of physical research still too seriously to live up to Mach's own attitude.[41]

I am unable to see a connection between Mach's psychophysical theory and "the more dogmatic" (whatever that may be) positions with respect to relativity that are said to have motivated Mach's criticism. The only explanation for Feyerabend's new view on the forgery thesis that comes to my mind is that he wanted his hero Mach a bit more anarchical, a bit more Feyerabendian, as it were.

Given the general situation that I have characterized here with only four examples, we may hope that the unending story "Mach and Relativity" in *HOPOSia* will, indeed, go on. I do not think that the dangerous entry "Early philosophical interpretations of general relativity" (copyright 2012) in the "Stanford Encyclopedia of Philosophy" will change this:

Finally there was, for Einstein, an understandable awkwardness in learning of Mach's surprising disavowal of any role as forerunner to relativity theory in the Preface, dated 1913, to his posthumous book (1921) on physical optics, published by Mach's son Ludwig. Though Einstein died without knowing differently, a recent investigation has built a strong case that this statement was forged after Mach's death by his son Ludwig, under the influence of a rival guardian of Mach's legacy and opponent of relativity theory, the philosopher Hugo Dingler (Wolters, 1987).[42]

Notwithstanding this "strong case"-assessment of my forgery thesis, I am rather confident and see no indication whatsoever that our story in *HOPOSia* will end any

[41] "Gereon Wolters [. . .] behauptet, dass das Vorwort zur 9. Auflage der *Mechanik* und das Vorwort zur *Physikalischen Optik*, die beide kritische Bemerkungen zur Relativitätstheorie enthalten, von Ludwig Mach, Ernst Machs Sohn, ohne dessen Wissen formuliert wurden. Sein Argument beruht auf Indizien und hat eine gewisse Überzeugungskraft. Doch hat Mach eine Rettung dieser Art nicht nötig. Nehmen wir an, die kritischen Bemerkungen stammten von ihm – wäre das wirklich so schlimm? Mach wollte eine umfassende Theorie, die das Psychische nicht als vom Physischen getrennt behandelt. Die dogmatischeren Anhänger der Relativität wollten die Forschung auf einen engeren Bereich festnageln – dem widersetzte sich Mach." (Feyerabend (1987), German ed. 311).

[42] Ryckman (2014).

time soon. I could imagine that it would do so in a world with Chinese as the *lingua franca,* say a 100 years from now. I see an ambitious postdoc from the Chinese Academy of Science, who happens to know this exotic and dying language German and who is interested in the prehistory of relativity. She thinks that it would be a good idea to have a look at the papers the *Deutsches Museum* in Munich and has the equally brilliant idea to connect this short research stay with visiting the *Oktoberfest* in late September 2116. There she hits one morning, still a bit dizzy from the evening before in the *Paulaner-Bierzelt* but wide-awake, on all the material that I have found. It had rested there for more than a century without anybody ever looking at it. She suddenly gets thrilled and convinces herself that the *Optik*-preface had been forged. She prolongs her stay in Munich beyond the *Oktoberfest* and starts writing a book (in Chinese, of course) that documents this thesis. The book becomes a world-wide success. It is even translated in English to reach those last old school *HOPOSians,* who have not managed to read Chinese.

Such a scenario in *HOPOSia*, however, seems even more fantastic than everything in Michael Ende's *Fantastica*. So, our neverending story about Mach and relativity theory will go on in *HOPOSia*.

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Chapter 29
Peter Salcher – Mach's Corresponding Collaborator

Ana Alebic-Juretic

Abstract Among the nowadays well known and top physicists who collaborated with Ernst Mach, like Boltzmann and Einstein, there is one less known, almost forgotten – Dr. Peter Salcher, professor of physics and mechanics at i.&r. Naval Academy in Fiume (now Rijeka, Croatia).

Interestingly, it was Mach's iniciative for collaboration, who sent him a letter with the proposal to make the experiment with flying bullet. That was the first of more than 150 letters written between Fiume and Prag, with description and discussion of the experimental results. According to the letters, Mach visited Fiume only once, in spring 1887. Though these experiments were decisive for Mach's acouistic theory, the role of Salcher was forgotten. Even Einstein, in the obituary to Mach, mentioned students as collaborators in physical experiments, including those in acoustics (Költsch P, Schriftenreihe zur Geschichte der Akustik, Heft 6: Von der Luftsirene bis zur russichen Aeroakustik- der Strömungschall stimuliert die Akustik, Deutsche Gesellschaft für Akustik e.V., Berlin, pp 61–101, 2014). Subsequent to fiding the missing Mach's leters, the role of Petar Salcher in early investigation of the gas dynamic and supersonic aerodynamic phenomena is mostly clarified. According to some scientists, who were involved in the subject, the Salcher's role in the work was underrated and this injustice should be corrected, at least, giving his name to some unnamed phenomena in this area, if existed (Settle SG, Schlieren and shadowgraph techniques, Springer, Berlin, p 13, 2001). In my opinion, it would be better to return the name to the phenomena he himself observed (Salcher Lyra, today known as Mach Disk) and technical set-up he proposed (wind tunnel).

Besides this world known experiment, during his 35 years of teaching at the I&R. Naval Academy in Fiume, he was active in other fields of research, including very early experiments with X rays and its use in diagnostic purposes, meteorology and

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monitoring sea water radioactivity in the Kvarner bay. As one of the founders and active member of the Club for natural sciences in Fiume, he was also included in the social life of the town.

Keywords Peter Salcher · Rijeka/Fiume · Acoustic experiments · X rays · Meteorology · Sea radioactivity · Club for natural sciences in Fiume (Rijeka) · Röntgen apparatus

29.1 How the Collaboration Started

In the ocassion of the centennary from Ernst Mach's death the Austrian Academy of Science organized international conference on his work in physics, phylosophy and pedagogy. One of the section was devoted to Mach's collborators, a top physicist, like Boltzmann and Einstein, but there is one, almost forgotten – Dr. Peter Salcher (Fig. 29.1), professor of physics and mechanics at i.&r. Naval Academy in Fiume (now Rijeka, Croatia). The peculerity of this collaboration was that it was realized completely through correspondence. Even Einstein, in the obituary to Mach, mentioned students as collaborators in physical experiments, including those in acoustics (Költsch 2014). Interestingly, it was Mach's iniciative for collaboration, who sent him a letter with the proposal to make the experiment with flying bullet. In the first letter to Salcher dated January 25th 1886 (Pohl and Salcher 2001) Mach wrote:

> *«Highly estimated Mr. Professor,*
> *My old friend Peterin*[1] *told me, that you might be the right person for helping me to carry out an experiment, therefore I would be exceptionally grateful.*
> *In the attachment that I am sending you there is a draft of a (experimental) set-up that I drew you. So I beg you, to look at this discourse, and than kindly answer me, if You would be engaged in this experiment. In Vienna in 1883 our exhibition objects were exposed (standing) close one to another, but I had no chance to meet you there,*
> *With highly respectable regards*
> *Your .... E. Mach"*

The exhibition that Mach mentioned in the letter was the International Electric Exhibition held in Vienna in 1883, where Mach exhibited some electric devices at No 275 while Salcher at No 270 (Salcher 2011). The answer from Salcher came soon, so in the second letter from February 16th 1868 Mach wrote (Pohl 2011):

> *«Highly estimated Mr. Professor,*
> *I am very obliged to thank you for your friendly intention to carry on the experiment, and allow me immediately here to notify some experiences, and add some remarks."*

After giving some advices, the letter ended with:

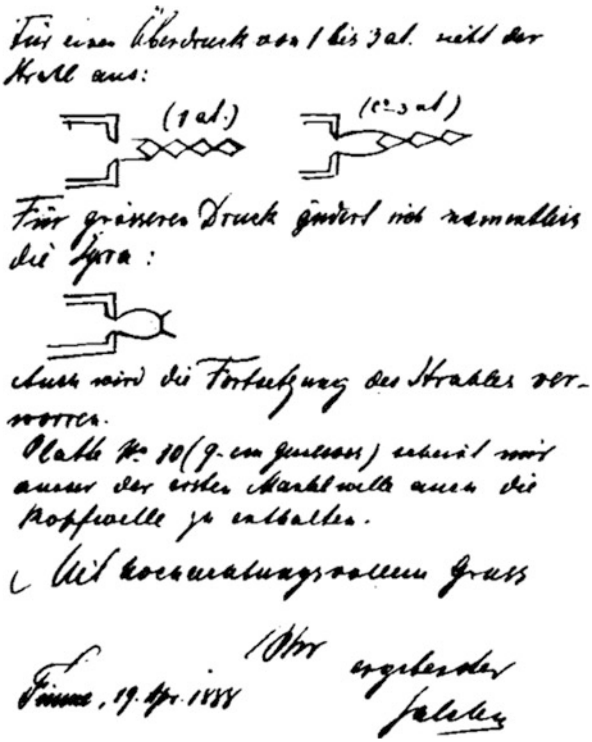
> *"I would be very happy if you would succeed with the experiment. I am entirely happy with the fact making a stimulation (experiment) for."*

Fig. 29.1 Peter Salcher

His enthusiasm about the possible success of the experiment was understandable since his assistant, Dr. Vincenz Dvoržak, later first professor of physics at the newly founded University of Zagreb, although expert in photographic techniques, did not get satisfactory result. After 3 months of work with his colleague from Hungarium gymnasium in Fiume Alassandro (Sandor) Riegler, on May 6th 1886, Salcher gave a lecture entitled "Taking photographs of fast movements" at the Club for natural sciences in Fiume (Rijeka) (Mittheilungen 1896). The subsequent year Mach presented the results in the Viannese Academy of Science and published in their Annales (Mach and Salcher 1887).

The collaboration through correspondence between Mach and Salcher lasted from 1886 to 1890, and they exchanged more than 150 letters. From these letters it is clear that Mach visited Fiume in spring 1887, but since no notice was found in local daily news La Bilancia, that published regularly hotel records in Fiume, he probably stayed with family Salcher. Mach and Salcher published together two more common papers in the Annales (Mach and Salcher 1889, 1889a), while Salcher and Whitehead (1889) another one "About the flow of highly preassured air" (Űber den Ausfluss stark verdichteter Luft). Looking from the nowadays perspective these papers represent definitively highlights in physics for both scientists, subsequent to which Mach turned to philosophy and pedagogy at the University of Vienna, while Salcher continued to work in the fields of physics, with considerable importance for local community.

Though these ballistic experiments were decisive for Mach's acouistic theory, the role of Salcher was forgotten. Subsequent to fiding the missing Mach's leters in mid-nineties, the role of Petar Salcher in early investigation of the gas dynamic and supersonic aerodynamic phenomena is mostly clarified. According to some scientists, who were involved in the subject, the Salcher's role in the work was underrated and this injustice should be corrected, at least, giving his name to some unnamed phenomena in this area, if existed (Settle 2001). In my opinion, it would be better to return the name to the phenomena he himself observed: Salcher Lyra, as he described and named in the letter to Mach written on February 18th, 1888 (Fig. 29.2) today known as Mach Disk, and technical set-up he proposed for further


Für einen Überdruck von 1 bis 3 at. sieht der Strahl aus:

(1 at.) (2–3 at.)

Für grösseren Druck ändert sich namentlich die Lyra:

Auch wird die Fortsetzung des Strahles verworren.

Platte Nr. 10 (9 cm gemessen) scheint mir ausser der ersten Machwelle auch die Kopfwelle zu enthalten.

Mit hochachtungsvollem Gruss

Fiume, 19. Apr. 1888

Ihr ergebender Salcher

Fig. 29.2 Letter of Salcher to Mach describing the Lyra, today known as Mach's disk. (From Reichenberg 1983) aerodynamic studies, known today as «supersonic wind tunnel» (Reichenbach 1983). Both phenomena are acknowledged as Salcher's merit already by Mach himself, and he is certainly not to blame for later negligence. In the second common paper with Salcher (Mach and Salcher 1889) he stated in the introduction:

> In the occasion of the experiments involving photographing projectiles in flight, Salcher had an idea of investigating the reverse case of the air mooving and the test body at rest in order to verify the results obtained. The possibility to carry out these experiments is kindly given by Mr. John Whitehead, who provided space and material to carry on such experiments

and subsequently on:

> Characteristic lines appear at the extention of the jet exit, to which extensions Salcher gave the name Lyra...

The Croatian Academy of Science and Faculty of Engineering, University of Rijeka organized in 2004 a symposium «Peter Salcher & Ernst Mach – A Succecfull Teamwork» where this collaboration was analysed from various points of view and published in a beautifull (by content and by sight) trilingual proceedings (Frankovic and Pohl 2011), the result of Croatian-Austrian collaboration.

29.2 Peter Salcher

A native Austrian, born in 1848 in Kreuzen (Carinthia) he graduated and obtained doctor degree in physics in 1872 at the University of Graz. After internship in Gymnasium in Graz, he got his first position at the Higher State Gymnasium in Triest. In 1875 he was appointed professor of physics and mechanics at i. & r. Naval Academy in Fiume (Rijeka), succeding the late Emil Stahlberger, described by Salcher as «spiritus movens» of oceanographic research in the Kvarner Bay and the Adriatic Sea (Salcher 1902). We do not know where he lived in Fiume for the first 15 years, but since nineties his family lived in a residence house built and owned by his wife Adriana (Fig. 29.3). The house is still existing, now in the Mose Albahari St. No 13, close to the city center. After his retirement in 1910, Salcher mooved to Triest, but returned in 1914 and stayed with his daughter Irma in Sušak, a settlement on the left river bank of the river Eneo/Rečina, dividing the Italian Fiume from newly formed Yugoslav (Croatian) Sušak after World War I. He died in 1928 and was burried in the municipal graveyard Kozala in Fiume (Rijeka).

He was honorary member of the Austrian Academy of Science and French Physical Society (in spite of dispute about the photographs with French colleagues). He was awarded Order of Franz Joseph Knight and Medal for military merits, but also honorary recognition at Millenium Exhibition in Budapest for physics, and Maria Theresia golden medal for photography.

Fig. 29.3 Residence house in Rijeka (Moše Albaharija St.13) where Salcher lived from mid-nineties until 1910

29.3 Club for Natural Sciences in Fiume

During 35 years of teaching at the i. & r. Naval Academy in Fiume, he was active in other fields of research, as well as in social life in the town. He was one of the founders of the Club for natural sciences in Rijeka (Naturwissentsaftliche Club in Fiume) that was founded on October 23rd 1883, as first of that kind in nowadays Croatia. He held all the important positions, as secretary, vice-president and president within the Club. His merit was also publishing the Bulletin of the Club for natural sciences (Mittheilungen des Naturwissentsaftlichew Clubs in Fiume), a bilingual (Italian-German) annual publication reporting not only the activities and lectures held in the Club, but also quality papers on various subjects of interest for the municipality. He himself gave 33 lectures in 20 years, mostly dealing with physics and technique, but also medicine and education. Some of his lectures are still very interesting from nowasdays points of view. In addition, he was founder of two subgroups/sections within the club: The Röntgen Committee and Photographic section.

Only 3 weeks after the famous Röntgen lecture in Wurtzburg, on February 20th 1896 Salcher gave similar lecture in the Club entitled: «About Röntgen Rays»(Über Röntgen Sthralen). At the end, first two photograph with X-rays were taken: hands of Baroness Vraniczany and a box with metal objects within. The photographs were developed by the teacher Salvatore Brattanich (Mittheilungen 1896). The lecture was a great success, repeated a week later in Italian (Salcher held his lectures always in German) after that a Röntgen Committee was founded with the task to purchase the Röntgen apparatus. This was realized in mid 1897, and accompanied with the second lectures with Milan Gorup on X-rays on June 23rd 1887, where he gave a plausible explanation (almost correct) of the X-rays nature as:

> The nature of this rays is little clarified: they are not light rays, since they are not subjected to reflection or refraction and so on, though they exhibit some optical (photographic) properties, but they are penetrating through metals, that are opaque for light rays. The electrical rays are they not, since as the light rays they have the possibility of reflection and so on. The exceptional X-rays should perhaps be considered as the finest light rays, and as such, they are subjected to approx 1000 bilions oscilations per second in the ether, while the light rays oscilations are only 400–750 billions per second (Mittheilungen 1897).

The nature of X-rays was proved only in 1914 by von Laue.

The apparatus was used for medical diagnosis and 2 years later was ceased to the municipal hospital. This is considered as the beginning of the Radiology in Rijeka.

Two more lectures held in Club were of particular concern: «The connection between light and electricity» (Über den Zusammenhang zwischen Licht und Elektricität, April 12th 1894.) giving the very modern view (though not entirely correct) about equality of light and electricity, that was theoretically proven only in 1924 by Louis de Broglie, stating:

> There is no basic difference between electrical and optical oscilations, but purely quantitative; electrical waves have length of several meters, while optical (waves) reach only a few thousanth parts of a milimeter, as shown by Hugyes, Yug and Fresenel, the founders of the ondulatory theory of light. Therefore, it is possible to admitt that the electrical waves are approaching the optical (waves), so far as smaller they are (Bilancia 1894).

Out of his profession, Salcher hold three lactures, first «On moral education of youth» (Die moralische Erzieung der reiferen männliche Jugend, November 12th 1892) where he adviced the ethics education be separated from religion, as religion has dogmas that are sometimes in conflict with ethics (Mittheilungen 1896).

Two subsequent lectures «Promotion of health and natural way of healing» (Gesundheitsphlege und naturheilverfaren, October 11th and November 25th 1895), where he indicated water, light, nutrition and movements as factors affecting the health, similarly as today, but also pointed out on irritative action of airborne particulates on human respiratory system, stating that air quality is good, but:

> . . . not in our principal street Corsia Deak (today Krešimirova St). The children there are screaming on walking, so that dust is inhaled through throat down to the lungs, it penetrates eyes and ears, mechanically irritating the mucus where germs of different diseases are accumulated. Because of low humidity (slightly over 20%) and low temperature, high frequency of soar throat does not surprise. (Mittheilungen 1896).

The dominant influence of aerosols on human respiratory system was established in environmental health only in mid-1980'. During the big London episode in December 1952, sulphur dioxide was blamed for excess morbidity and mortality. It is hard to say if these up to date oppinions on natural sciences and medicine that appeared 100 and more years ago were originally Salcher's own or wider accepted in scientifuc community. The latter case poses a question: how were they forgotten? Maybe another consequence of the World War I, when new political reality in Europe with many new established countries supressed any «old» achievment.

At the turn of the century Salcher gave the lecture in the Club on January 12th 1901 that dealt with «Scientific and technical progress in the last century» He pointed out the progress in physics and "*spectral analysis, that represents revolution in study of chemistry, and is indispensable in quantitative analysis*", as well as "*the theory of electricity, that underwent such a development since the beginning of XIX century, that is hard to believe to find another sources than induction*". He considered telegraphy as the most important technical innovation "… *though it is hard to decide what should be more respected regarding the steam machine: its mechanical or moral power induced in the nations, this is still far from being perfect machine, while Marconi who invented wireless telegraph made it perfect. So that is really the most popular invention"* (Mittheilungen 1902). His last lecture given in 1904 in the Club was dedicated just to wireless telegraphy – (Mittheilungen 1905). For the forthcoming twentieth century Salcher predicted further progress in natural sciences, weather regulation, improvement of communications, education and social conditions (Mittheilungen 1902) that were in fact realized.

29.4 Meteorological Measurements

After prof. Stahlberger's sudden death in 1875, Salcher, his successor in the Chair of Physics, took charge of the meteorological station. The station was founded by the Viennase Academy and Adriatic Commision in November 1868. After the disolution of Adriatic Commission in 1880, the station was incorporated in the Physical laboratory of the Naval Academy. He wrote the first book on «The Climate in Fiume and Abbazia» (Klima von Fiume und Abbazzia 1884, Fig. 29.4). In this book Salcher gathered and analysed 15 years data (1869–1884) from Fiume (Rijeka), according to the principles defined in 1873 during the first congress of International Meteorological Organization, that are still valid today (Fig. 29.5). For that reason these data could be used for comparative purposes (Alebic-Juretic 2012). Salcher described the climate in Fiume as*:*

> On the average, the coolest month is January (5.6 °C), while the warmest is July (24 °C). The average temperature in April (13 °C) and October (14.6 °C) are closest to the annual average (14.1 °C). The difference between the coolest and the warmest month (18.4 °C), classifies the climate in Fiume/Rijeka as changeble (Salcher 1884).

Comparing these values with climate normal (1961–1990) and the last two decades (1991–2010): both January minimum (5.3 °C in both periods) and July maximum (22.8 °C and 23.3 °C, respectively) are somewhat lower. The multiyear average (Fig. 29.6) for the warmest last two decades (1991–2010) is exactly the same as those for the period 1869–1884 (14.1 °C), but is higher than the climate normal (13.6 °C). That means, although the average temperatures in the last two

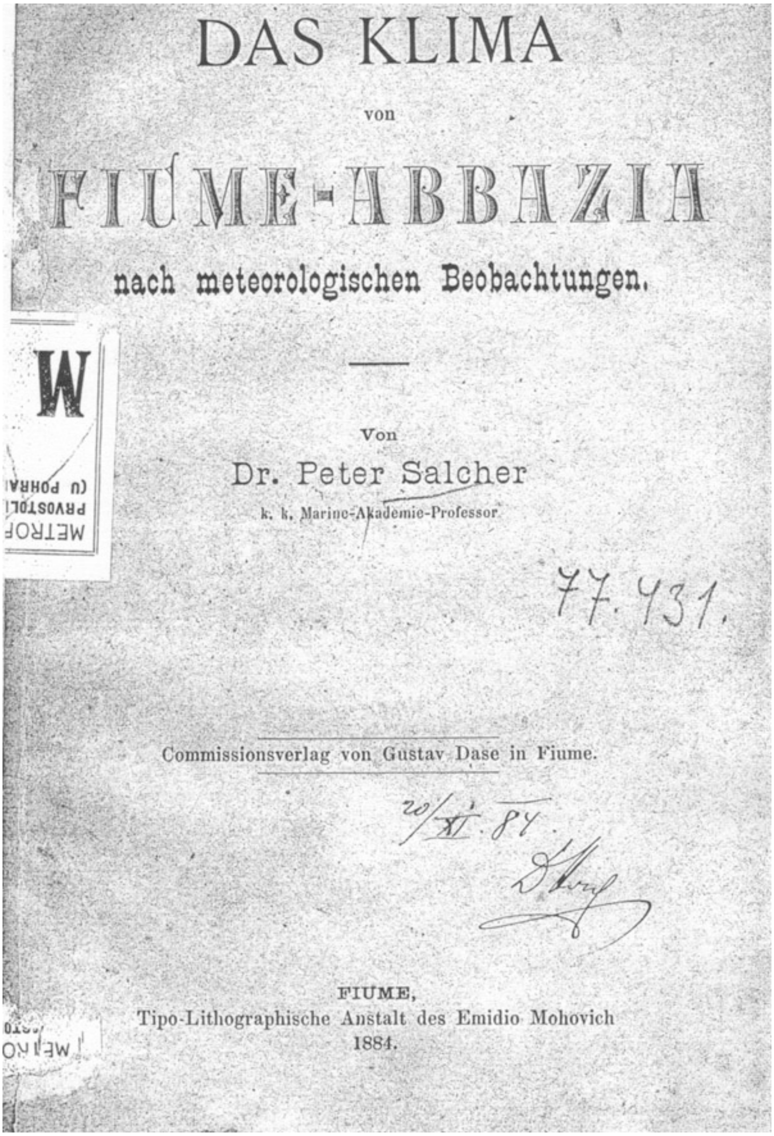


Fig. 29.4 Cover page of the book Klimate of Fiume – Abbazzia

decades are higher than the climate normal (1961–1990), these values fall within the range already measured in the second half of the nineteenth century (Alebic-Juretic 2012), prior to high industrial emissions, that might have caused the global warming. (If the measured temperature profiles do not differ from those measured in nineteenth century, the present warmer period is three times longer than previously).

Zur Klimatologie von Fiume.

Aus den an der k. u. k. Marine-Akademie angestellten meteorologischen Beobachtungen der Jahre 1869 bis 1892 (24 Jahre) ergeben sich folgende Mittelwerte:

Im Monat	Mittlere Temperatur	Mittleres Temperatur-		Beobachtete Windrichtungen in Procenten								Tage mit Windstärken über 5 (Scala 0—10)	Mittlere Feuchtigkeit in Procenten	Mittlere Regenmenge in m/m	Tage mit			
		Maxim.	Minim.	N	NE	E	SE	S	SW	W	NW				Regen	Schnee	Hagel	Gewitter
Jänner	5·[illegible]	15·2	—3·2	20	34	15	8	7	6	3	7	1	68	98	8	2	0	0
Februar	6·2	15·9	—3·1	18	28	18	9	7	9	5	6	1	66	78	8	1	0	1
März	8·5	18·3	—1·4	12	24	14	12	11	12	8	7	1	67	119	10	1	1	1
April	12·7	22·6	4·6	9	18	14	13	11	13	13	9	1	69	137	14	0	0	1
Mai	16·[illegible]	29·0	8·3	10	15	15	12	10	15	13	10	1	70	106	13	0	0	3
Juni	20·5	30·5	11·2	13	15	10	11	7	19	15	10	0	71	147	13	0	0	6
Juli	23·7	33·5	14·0	13	16	11	10	6	19	14	11	1	65	69	9	0	0	6
August	22·[illegible]	32·4	13·1	13	18	14	10	5	16	13	11	1	67	115	9	0	0	5
September	19·2	28·8	9·9	14	23	14	9	9	10	12	9	1	70	162	10	0	0	5
October	14·3	23·6	4·4	14	26	16	9	11	11	6	7	2	75	261	15	0	0	3
November	9·3	19·1	0·1	18	29	17	7	12	8	3	6	1	72	185	14	0	0	2
December	6·5	16·0	—2·7	18	32	16	8	7	7	5	7	1	70	142	12	1	0	1
Im Jahre	13·[illegible]	23·7	4·6	14	23	15	10	9	12	[illegible]	8	12	69	1619	135	5	1	34

Mittlere Temperatur { im Winter (December, Jänner, Februar): 6·00. im Sommer (Juni, Juli, August): 22·40. Mittlerer Barometer-Stand: 761·2 mm.

Fig. 29.5 Multiyear averages of meteorological data for 1869–1895. (Mitheilungen 1896)

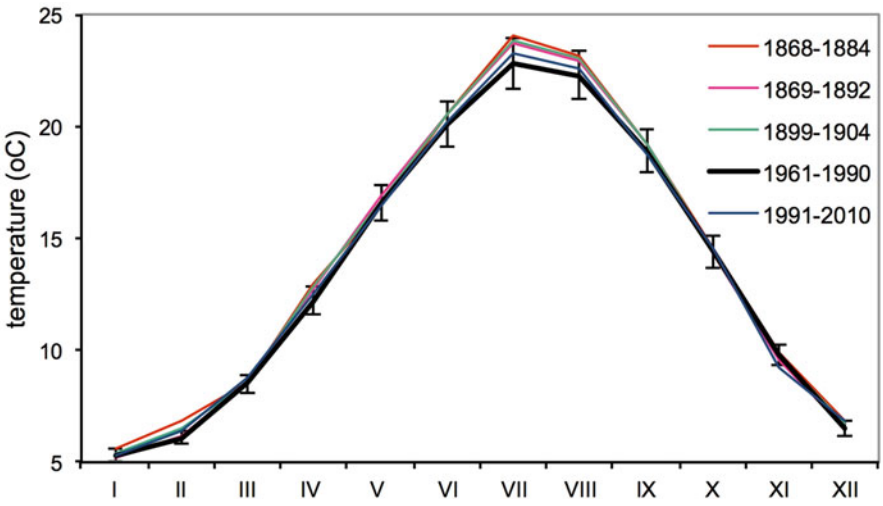
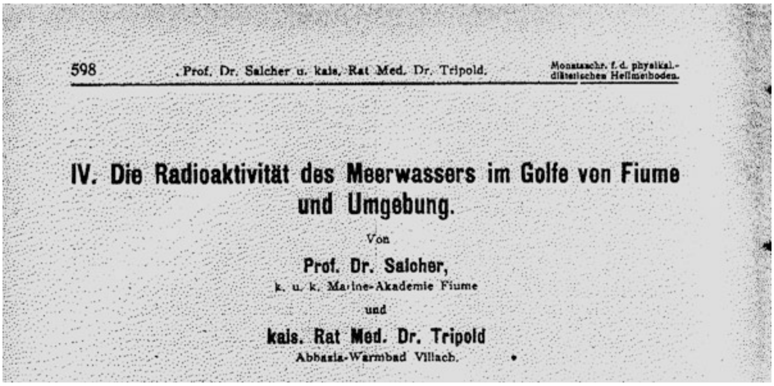


Fig. 29.6 Multiyear average profile for temperature in Rijeka: three oldest profiles are data from Salcher. (Alebic-Juretic 2012)

It is worth mentioning that the meteorological measurements in Abbazia started in 1883, and Salcher was involved in starting up the monitoring station (Fig. 29.7). As he observed the big difference in daily summer temperature (up to 3 °C) relative to Fiume, the thermometer was adjusted properly afterwards, so that the official measurements started only in 1885 (Salcher 1884). This is another proof of his sharp mind.

Fig. 29.7 Meteorological station in Opatija (former Abazzia) that was positioned by Salcher



598 Prof. Dr. Salcher u. kais. Rat Med. Dr. Tripold. Monatsschr. f. d. physikal.-diätetischen Heilmethoden.

IV. Die Radioaktivität des Meerwassers im Golfe von Fiume und Umgebung.

Von

Prof. Dr. Salcher,
k. u. k. Marine-Akademie Fiume

und

kais. Rat Med. Dr. Tripold
Abbazia-Warmbad Villach.

Fig. 29.8 Paper on radioactivity of sea water in the Kvarner bay

29.5 Measurement of Radioactivity

At the end of his professional career, in 1909, with Dr. Franz Tripold from Abbazia (Opatija) he undertook measurements of radioactivity of sea water in the Rijeka Bay using an electroscope. The paper entitled «Radioactivity of sea water in the Rijeka Bay and its surrounding" (Die Radioaktivität der Meerwasser im Golfe von Fiume und Umgebung) was published in Monatsschr.f.f.physikal-diätetischen Heilmethoden (Tripold and Salcher 1909), a journal devoted to health improvement and wellbeing in spa. The results indicated that: a. the radioactivity was bigger in the Rijeka Bay than in open sea, b. close to the sea surface in the whole coastal area Rijeka- Opatija the radioactivity show a decline (due to high outflow water from rivers and springs at the coast) and c. the radioactivity is rising with a depth, than declining and rising again in higher depth. Such a radioactivity depth profile was compared with the oceanographic results of the Rijeka Bay that his colleagues, J. Wolf, J. Luksch and Dr. J. Koetsttorfer (1877–1879) from the Academy have done previously. Having noticed that the radioactivity was higher in the vicinity of the settlements, he concluded that it should be of antropogenic origin and therefore called for reexamining the use of radioactivity (emanations) for welness purposes: «*In any case, the whole knowledge about using emanations for therapeutic purposes deserves further proved control and clarification*." (at that time radioactivity gases-emanates were inhaled for wellbeing).

29.6 Photographic Section

Peter Salcher was one of the founders of the photographic section within the Club for Natural Sciences in 1897 (Mittheilungen 1897), but the leading role was given to his colleague Alessandro (Sandor) Riegler, who helped him to take a photograph of the flying bullet (Mittheilungen 1896) The section was very active and they organized annual exhibitions. In fact, the reappearance of Peter Salcher in the early-nineties was connected to the exhibition about Photography in Rijeka and the book proceeding (Dubrović 1995). Besides the well known technical shots taken on Mach request, the other photographs exhibited mostly maritime motives. Some of these photographs are still in use in various occasions. The most famous one is without any doubt the photograph of Naval Academy at the turn of the centuries (Fig. 29.9), also used in his book on Academy's history (Salcher 1902). One of the photographs of the sail-boats in the harbour (Fig. 29.10) was used as cover page for a book of poetry (Brazzaduro 1996).

In addition, as mirror images were very popular among photographers and painters (e.g. Lea von Littrow, also born in Fiume-Rijeka), Salcher published a book about « Mirror images on water » (Die Wasser-spiegelbilder), giving scientific explanation for the phenomenon (Salcher 1903).

Fig. 29.9 Photograph of I&R Naval Academy taken by Salcher at the turn of the centuries, the photograph was often used to illustrate the building. (Salcher 1902)

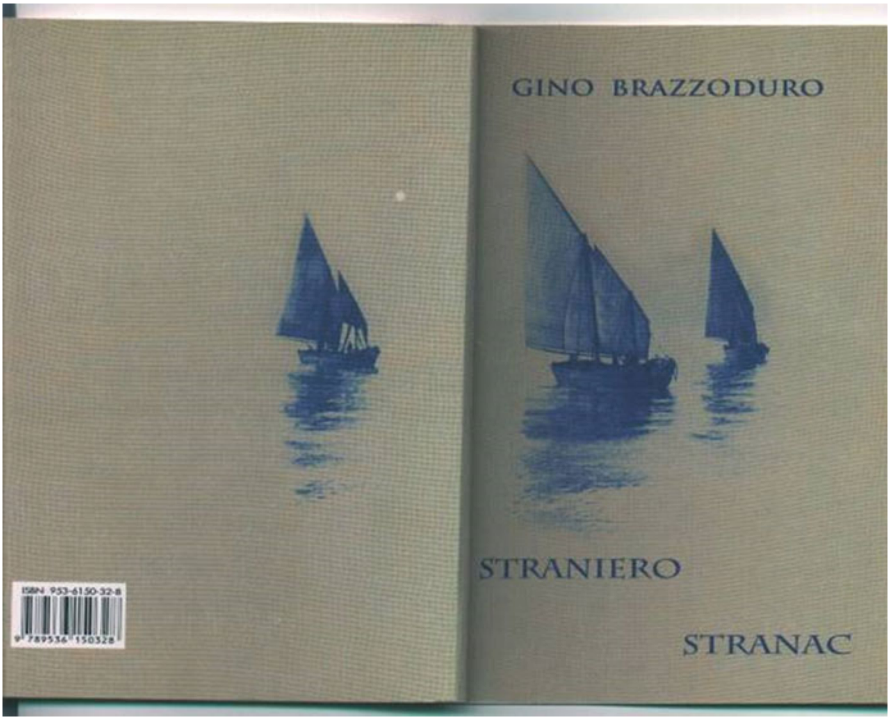


Fig. 29.10 Salcher's photograph as cover page of the book of poems. (Brazzoduro 1996)

Last, but not least, in the occasion of a centennary of I&R Naval Academy foundation, Salcher wrote a book «History of I&rR Naval Academy« (Geschichte der k u k Marine Akademie) based on historic documents (Salcher 1902). This is practically the only evidence from the period the Academy spent in Fiume (1866–1914), as all documentation is lost during turnoils of the twentieth century. In the introduction of the book Salcher wrote:

> The author is not the historian by profession, rather member of natural scientists. But being convinced that natural laws govern also the course of history, he dared to undertake this work. In this occasion he was encouraged by long experience in teaching acquired knowledge about situation in the Academy. This knowledge was also a stimulus for.

Writing about Salcher- a corresponding collaborator of Mach- I could write almost the same: I am not historian nor physicist, but as a natural scientist (chemist) I hope to have evaluated correctly his work done more than a 100 years ago and I could only wish that the injustice done so long to him could be corrected.

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Chapter 30
Light and Shadow – The Experimental Collaboration Between Ernst Mach and Ludwig Mach, Father and Son

Johannes-Geert Hagmann

30.1 Introduction

Only few subjects in physics are as affecting as the lessons of light. Through the human visual faculty, light directly connects to the sensations. Its properties are possibly therefore among the oldest areas of study in the natural sciences. However, in contrast to the objects that convey the laws of mechanics to human understanding, the carrier of light seems immaterial and therefore impalpable. Hence, the more strange some of the optical phenomena appear at first sight, as they do not tie to intuition and only can be apprehended by adopting a wave model for the study of light. The phenomenon of interference, i.e. the superposition of waves upon their coalition, is a particular striking example in this category. It is only through the image of waves that one can understand why at the union of light ray with another light ray, their result not only shows brightness but also darkness.

The constructive and destructive combination of two waves – as amplification and annihilation, as mixing and "entanglement" up to indiscernibility – seems a well suited image for the description of the experimental collaboration of Ernst Mach and Ludwig Mach, father and son. First, it is apparent within their joint work, optics and in particular the study of interference phenomena had a central role. Second, the

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F. Stadler (ed.), *Ernst Mach – Life, Work, Influence*, Vienna Circle Institute Yearbook 22, https://doi.org/10.1007/978-3-030-04378-0_30

linking of the works of both scientists can also be traced biographically, leading to a superposition in their scientific papers that leaves open questions regarding the originator of scientific work.

In physics, interference patterns that result from the superposition of waves are often recorded photographically. Yet, through this form of recording, only the intensity of the resulting patterns can be retained. Some information relying on the wave nature of light is lost in the process. Following this image, it seems at first, but also often at second sight at the entangled papers of Ernst Mach and his eldest son Ludwig Mach that the exact reconstruction of the initial setting before the superposition cannot be recreated in view of missing information. At the same time it can be seen through close inspection of the papers that a simplified prescription – Ernst Mach the genius mentor and Ludwig Mach the scientifically modest assistant – is not applicable.

Based on the work with original sources including papers and scientific instruments, the following article analyzes the interdependency between Ernst Mach and Ludwig Mach regarding their experimental work in optics. Based on published articles between Ludwig Machs first year at the University of Prague (1887) and the death of Ernst Mach in the house of his son in Vaterstetten (1916), major emphasis is given to the field of interferometry that remained Ludwig Mach's center of scientific study for many years.

30.2 Overview on Sources

In 2015, the Mach papers remaining in the Philosophical Archive of the University of Kosntanz were unified with the Ernst Mach Papers at the Archives of the Deutsches Museum in Munich.[1] From these records the following items are notable for the reconstruction of the experimental work of Ludwig Mach and Ernst Mach from a lifetime perspective:

- The dated notebooks of Ernst Mach from the time between 1870 and 1914.[2] These contain a mixture of notes – aide memoire, examination results, letter drafts and many others. The content also includes mostly fragmentary experimental observations with sketches and calculations.[3]

[1] For a detailed account on the origin of the papers see Wilhelm Füßl, „Die Nachlässe von Ernst und Ludwig Mach im Archiv des Deutschen Museums. Eine Bestandsgeschichte.", in: Wilhelm Füßl, Johannes-Geert Hagmann, *Licht und Schatten. Ernst Mach|Ludwig Mach.* Munich: Deutsches Museum Verlag (2017), pp. 47–56.

[2] Deutsches Museum, München, Archiv (DMA), Nachlass (NL) 174/505 to NL V174/557.

[3] On the quality oft he notebooks as sources see Christoph Hoffmann, "Machs Notizbuch: Einführung.", in Christoph Hoffmann and Peter Berz, *Über Schall. Ernst Machs und Peter Salchers Geschoßfotografien.,* Göttingen: Wallstein Verlag (2001), pp. 39–46 and references therein.

- The experimental notebook written by Ludwig Mach, dated from 1887 to 1911.[4] The book contains records about a large number of optical experiments. It is only roughly organized in chronology order. Taking a critical perspective on sources, it should be noted that the volume at times contains large chronological jumps, also going backwards on consecutive pages. In contrast to the notebooks of Ernst Mach this volume is clearly organized, it contains detailed sketches of experiments, records of continuous series of photographies and chronicles of observations during experimentation. Yet, this book contains almost no calculations or theoretical derivations.
- The correspondence between Ernst Mach and Ludwig Mach in the years 1896 to 1900.[5] This exchange of letters that mainly took place between Jena and Vienna contains both scientific an family related information.

30.3 Course of the Collaboration and Joint Published Work

The collaboration of Ludwig Mach and Ernst Mach in the years 1887 to 1916 can be divided into three phases according to their respective periods of life and whereabouts[6]:

- 1887 to 1895: Father and son work together during the medical studies of Ludwig Mach, mostly in Prague.
- 1896 to 1912: Ernst Mach moves to the University of Vienna. Ludwig Mach works in different places, including Jena, Berlin, Hamburg, Munich and Vienna.
- 1913 to 1916: Ludwig Mach turns his attention towards his father. Ernst Mach lived from 1913 until his death in his son's house in Vaterstetten near Munich.

In the years 1889 to 1904, Ludwig Mach published a total of 22 papers in different journals.[7] Four of these papers are joint articles with his father as coauthor. Disregarding introductions, collected paper volumes, new editions and translation into foreign languages, around 100 papers and works of Ernst Mach appeared between 1887 and 1916.[8] About 25 of these works, of which the majority was published after his move to Vienna, deal with experimental research in physics (Fig. 30.1).

[4]DMA, NL Mach, Konstanzer Abgabe, Nr. 44.

[5]DMA, Konstanzer Abgabe, Nr 58. and DMA, NL 174/2054 to NL174/2115.

[6]Klaus Hentschel, „Mach, Ernst", in *Neue Deutsche Biographie* 15 (1987), pp. 605–609. [online version 30.11.2016] https://www.deutsche-biographie.de/gnd118575767.html#ndbcontent

[7]DMA, Konstanzer Abgabe, Nr. 36 „Abhandlungen von Ludwig Mach". In the list compiled by Ludwig Mach, one joint publication from 1904 with Ernst Mach is not mentioned.

[8]See Peter Mahr, „Bibliographie. Ernst Machs Publikationen von 1860", Vienna [online version 30.11.2016] http://homepage.univie.ac.at/peter.mahr/2016.1.html

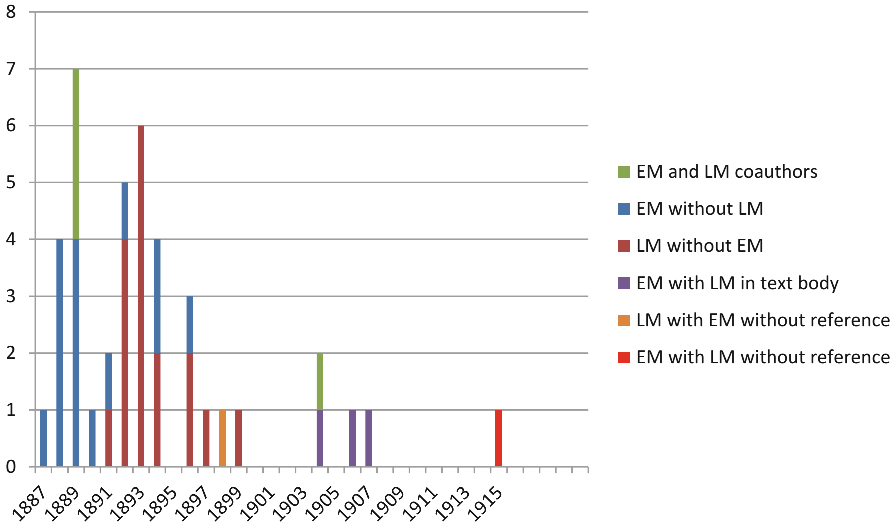

Fig. 30.1 Published experimental papers by Ernst Mach and Ludwig Mach, 1887–1916

In this figure, we differentiated between papers that were published by Ludwig Mach and Ernst Mach with changing roles, eventually the participation of the other through coauthorship or references in the text body of the article. Such works can be found in several cases for Ernst Mach: all of his experimental papers in optics published after suffering from a stroke in 1898 have been carried out with the help of his son. In the last article published in 1915, we find that the paper is the sole work of Ludwig Mach published under the disguise of Ernst Mach. The reverse case though is also present: Ernst Mach intensively contributed to a work published in 1898 by Ludwig Mach, but also saw to the fact that his participation would not become public.

30.3.1 1887–1895

In 1887, Ludwig Mach started his studies of medicine at his father's university in Prague. According to his own words, the eldest son of the famed physicist already had been working at his father's laboratory while still being in school.[9] As it happens, Ludwig Mach's name already appears in his freshmen year in the Zeitschrift für Elektrotechnik, the outlet of the Elektrotechnischer Verein in Vienna.

[9] See handwritten autobiographical notice of Ludwig Machs cited in Gereon Wolters, *Mach I, Mach II, Einstein und die Relativitätstheorie. Eine Fälschung und ihre Folgen.* Berlin: de Gruyter (1987), p. 295.

In a footnote to the discussion of a method proposed by the Britsh-American engineer Elihu Thomson (1853–1937) on electric soldering it is stated that "Ludwig Mach, the talented son of Prof. E. Mach in Prag [. . .] two years ago came up with the proposal that this important operation should be carried out with electricity."[10] Ernst Mach was thankful for his son's experimental help. However, his staff did not share his favorable opinion, as the presence of Ludwig Mach became a source of conflict.[11]

The first recordings on the joint work are described in Ludwig Mach's notebook under the headline „Schiessversuche Sommer 87–88". In this short set of notes that apparently describe observations o supersonic bullets in continuation of Schlieren technique experiments started by Ernst Mach and Peter Salcher (1848–1928) in 1886,[12] Ludwig Mach only wrote down the results apparent on the photographs of projectiles of varying length, materiality and geometry as well as the variation of conditions for electrical release for photography. While in addition experiments in water are also described here, the location used for experimentation is unknown. In August 1888, Ernst Mach and Ludwig Mach carried out sets of experiments at the shooting range of Krupp in Meppen with canon bullets of larger diameter (40 mm) than those described in the notebook.[13] Plans made for the train journey for "two persons" from Prague to Hannover as well as sketches of bullets can be found in Ernst Mach's notebook 28.[14] Characteristically for Ernst Mach's notebooks, only fragments of this trip are recorded. In the vast amount of erratic thoughts at least the geographic location is clearly marked by a hand drawn musical sheet recording the sound of a bell, followed by the political remark "The bells of Meppen. Windhorst's chimes of triumph."[15] In the follow up of his notes, the physicist already devised a first draft of his paper on the continuation of his experiments with Salcher for

[10]Note: all translations of citations from German to English were made by the author. Anonymous signed „K", probably Josef Kareis, „Das Schweissen mittels Elektrizität", *Zeitschrift für Elektrotechnik* 5. Jahrgang 1. Januar (1887), p. 48. Thomsons method was published in 1886 in English language journals, see Karl T. Compton, "Biographical Memoir of Elihu Thomson, 1853–1937." *Washington: National Academy of Sciences Biographical Memoirs Volume* 21 (1939), pp. 143–179.

[11]See John T. Blackmore, "*Ernst Mach. His Life, Work, and Influence*", Berkeley: University of California Press (1972) p. 145.

[12]Ernst Mach and Peter Salcher, „Photographische Fixierung der durch Projectile in der Luft eingeleiteten Vorgänge", *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften, Mathematisch Naturwissenschaftliche Classe* 2a, Band 95 (1887), pp. 150–167. See also Hoffmann, Berz (2001), *ibid*, for a detailed account of the precursors to the experiments.

[13]Ernst Mach, „Ueber weitere Fortschritte in der Momentphotographie." In: Josef Maria Eder (ed.), *Jahrbuch der Photographie und Reproduktionstechnik,* 15. Jahrgang, Halle: Wilhelm Knapp (1891), pp. 166–167.

[14]DMA, NL 174/532, p. 14 and p. 28.

[15]DMA, NL 174/532, p. 16. Ludwig Windthorst (1812–1891) was a leading figure of the central party in the German parliament for the electoral ward Meppen-Lingen-Bentheim and a political opponent of Otto von Bismarck (1815–1898). The revision of the laws often entitled „Kulturkampfgesetzte" against political catholicism int he years 1886 and 1887 that also had been targeting Windhorst were a political defeat of Bismarck. In 1888, a few weeks prior to the visit

the journal of the Vienna Academy. The participation of Mr. "Med. Stud. Ludwig Mach" to the experiments received its first appearance through the publication of 1889.[16]

In the same year, three out of the four joint publications of Ernst Mach and Ludwig Mach appeared in the proceedings of the Vienna Academy.[17] These articles deal with different physical subjects recorded however with the same method, momentum photography. In addition to a longer sequel devoted to the analysis of shock waves in front of bullets the two other shorter publications deal with acustics, wave propagation in glass and the superposition (interference) of sound waves in air. Both works are follow up studies to earlier research of Ernst Mach carried out in parts more than 10 years prior to this publication. These experiments were now repeated with modern and superior technology compared to previous studies. For the experiments on the propagation of waves in glass Ludwig Mach filled the position of another medical student working with Ernst Mach who died in a laboratory accident with a petroleum lamp. Ludwig Mach's notebook contains a few lines on these experiments, yet the other joint subjects with his father are not listed in his record. Ernst Mach apparently devised the plan to publish the three articles already in early 1888. In addition to his reminder notes mentioning "Preliminary Notice of Salcher" and "Enlargement Eder",[18] Mach listed the subject of the subsequent articles with his in his notebook.[19]

In the first of the three papers published in the Academy proceedings dated November 7th 1889, Ernst Mach and Ludwig Mach described observations made in the university laboratory in Prague concerning the photographic recording of supersonic bullets. The introduction to the articles clarifies the respective roles of the coauthors in their joint work. According to the text, Ernst Mach made plans for the experiments, whereas Ludwig Mach carried out "almost all technical operations, the fabrication of the apparatus, the projectiles and the photographies", or in short, the entire experimental work. The required weapons for the experiments had been received as a loan from members of the military in Prague and Karolinenthal (todays

of the Machs in Meppen, Windhorst was made honorary citizen of the city of Meppen. See e.g. Volker Ullrich, „Die kleine Exzellenz." *Die Zeit* 3/2012.

[16]Ernst Mach and Peter Salcher, „Über die in Pola und Meppen angestellten ballistisch-photographischen Versuche", *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften, Mathematisch Naturwissenschaftliche Classe* 2a, Band 98 (1889), pp. 41–50.

[17]Ernst Mach and Ludwig Mach, „Weitere ballistisch-photographische Versuche", *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften, Mathematisch Naturwissenschaftliche Classe* 2a, Band 98 (1889), pp. 1310–1326; Ernst Mach and Ludwig Mach, „Ueber longitudinal fortschreitende Wellen im Glase", *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften, Mathematisch Naturwissenschaftliche Classe* 2a, Band 98 (1889), pp. 1327–1332; Ernst Mach and Ludwig Mach, „Ueber die Interferenz von Schallwellen von großer Excursion", *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften, Mathematisch Naturwissenschaftliche Classe* 2a, Band 98 (1889), pp. 1333–1336.

[18]The enlargements of the photographies for the Academy proceedings were realized by the renowned photochemist Josef Maria Eder (1855–1944).

[19]DMA, NL 174/531, p. 51.

Kalìn). The description of the bullet shapes and dimenions mostly match with the short records on the first pages of Ludwig Mach's experimental notebook. However, the book does not contain any examination of the recorded photographies. By contrast, Ernst Machs notebooks Nr. 28 and 29 from the year 1888[20] do contain a number of derivations and data analysis, e.g. the regarding the influence of denser areas of air on the deviation of light. In view of the lack of continuous experimental records by both authors, the impression seems to be that the publications in facts do represent the actual experimental protocols. This view is backed by the fact that the publications report the experiments in every detail and in chronological order, taking note of every hand movement necessary for their execution. In addition, the content of the publication is also remarkable for a second reason. In the discussion of their results, Ernst Mach and Ludwig Mach extensively deliberate about the infliction of wounds through the effect of projectiles, including the possible consequences of shock waves. Such discussions were not included in Ernst Mach's previous publications on the subject. In addition to specialized journals on scientific photography, a particular tribute to this work of Ernst Mach and Ludwig Mach was presented by the ballistic physics researcher Carl Cranz (1858–1945) who continued on their scientific pathway.

The instrument collection of the Physical Institute at the University of Prague with its strong focus on optical equipment was a key precondition for the joint research of Ernst Mach and Ludwig Mach (Fig. 30.3). The handwritten inventories of the institute, kept in both sets of scientific papers[21] very likely going back to the period between 1890 and 1895, do mention in the group "XII optics" about 400 inventory numbers with optical instruments, elements, crystal samples and parts. These include e.g. the camera systems used for momentum photography: a small Voigtländer photographic apparatus, a Darlot photographic apparatus with equipment, a Steinheil photographic objective with a Goldmann box and tripod, as well as an old Daguerreotype unit. Whether these cameras coexisted in Prague at the same time cannot be reconstructed with certainty. The inventories show proof of different time phases including revisions and reconstitution of groups through the crossing of dysfunctional equipment. Moreover, the roughly 200 photographies taken in the Institute that are spread in different sections of the scientific papers[22] provide evidence on the scope of the institute's collections at the time. The pictures mostly show unique instruments photographed in front of an improvised white canvas. Only few images do show the rooms of the institute, one image presents Ernst Mach's desk, next to which the year 1895 can be read from a calendar. Some of the images have been used as illustrations in Ludwig Mach's publications. It is plausible that the photographic documentation of the equipment is related to Ernst Mach's move from Prague to Vienna. Unfortunately, it appears from this previously considerable collection of instruments none have been preserved in Prague until today.[23]

[20] DMA, NL 174/532 and NL 174/533.

[21] DMA, Konstanzer Abgabe, Nr. 26; DMA, NL 174/4125.

[22] DMA, Konstanzer Abgabe, Nr. 53; DMA, NL 174/4121

[23] Personal communication of Ms. Emilie Tesinska, Prague, 19.06.2014 and Mr. Lubos Veverka, University of Prague, 10.06.2014.

From the study of letters from the Physics Institute exchanged with different mechanical engineering companies supplying instruments,[24] it is obvious that Ludwig Mach often served as main correspondent for the order of instruments and equipment for the laboratory of his father and sent precise technical assignments to the companies. Quite often the young student is addressed by the titles "Doktor" or "Professor", possibly due to a mix-up with his father, but most likely also due to his self-conscious and often demanding tone resembling an established figure of the institute. An example can be found in the letter exchange with the company Carl August Steinheil and Sons that produced mirrors and plane glass plates. This supplier is directly connected to Ludwig Mach's most important experimental contributions in the field of interferometery. In the 1890s, Ludwig Mach published his first articles as a single author in the proceeding of the Academy. These publications include his first article on the new "Intererfernce-Refractometer",[25] an enhancement over the Jamin-Interferometer using four separate glass plates that today carries the name of "Mach-Zehnder interferometer". This invention in the past was often erroneously attributed to his father,[26] but even today some modern textbooks in optics[27] as well as studies in the history of science[28] wrongly quote the originator of this instrument. In fact Ernst Mach himself clarified on the contribution of his son in the Academy proceeding published on November 5th 1891[29]: „In order to continue observations described in earlier works [. . .] [Mr.] med. stud. Ludwig Mach has devised a modification of the Jamin intereference refractometer and built this instrument in the past summer 1891 by his own hand. [. . .] This communication is provoked by a publication just received by Dr. L. Zehnder [. . .] which contains the description of an apparatus based on the same principle."

[24] DMA, Konstanzer Abgabe, Nr. 10.

[25] Ludwig Mach, „Über ein Interferenzrefractometer", *Sitzungsberichte der mathematisch-naturwissenschaftlichen Klasse der kaiserlichen Akademie der Wissenschaften Wien* 101 (1892), pp. 5–10; Ludwig Mach, „Über einen Interferenzrefraktor", Zeitschrift für Instrumentenkunde 12 (1892), pp. 89–93; Ludwig Mach, „Über ein Interferenzrefractometer (II. Mitteilung)", *Sitzungsberichte der mathematisch-naturwissenschaftlichen Klasse der kaiserlichen Akademie der Wissenschaften Wien* 102 (1893), pp. 1035–1056.

[26] See e.g. in the seminal book by Max Born, *Optik*. 2. Auflage, Berlin: Springer (1933), p. 127.

[27] See e.g. Judith F. Donelly und Nicholas M. Massa, *Light: Introduction to Optics and Photonics*. Boston: The New England Board of Higher Education (2007), p. 177; Bernd Dörband, Herbert Gross, Henriette Müller, *Handbook of Optical Systems, Metrology of Optical Components and Systems,* Weinheim: Wiley-VCH (2012) p. 62; Abdul Al-Azzawi, *Photonics: Principles and Practices,* Boca Raton: CRC-Press (2007), p. 400.

[28] Sean F. Johnston, *Holographic Visions. A History of a New Science,* Oxford: Oxford University Press (2006), p. 54; Andrew Warwick, "Interferometer" In: Robert Bud and Deborah Jean Warner (eds.), *Instruments of Science: An Historical Encyclopedia,* London: Garland Publishing (1998), p. 399.

[29] Ludwig Mach, „Modification und Ausführung des Jamin'schen Interfernzrefractometers", *Anzeiger der Kaiserlichen Akademie der Wissenschaften, Mathematisch-Naturwissenschaftliche Classe* 28 (1891), pp. 223–224.

The cited work of the Swiss physicist Ludwig Zehnder (1854–1949) already appeared in August 1891.[30] In this article, Zehnder described a four-plate interferometer with two beam splitters and two mirrors that had been developped during his time as an assistant to Wilhelm Conrad Röntgen (1845–1923) in Würzburg. The Mach-Zehnder interferometer today is a central instrument for precision measurements and for quantum optics. It consists of a stand with two mirrors and two semipervious glass plates facing each other in a rectangular setting. Incident light is divided into two half beams through the first glass plate. The two beams now follow separate paths through the instrument. Two mirrors reflect the beams on the second glass plate where the light is reunified. The constructive and destructive superposition of waves of the two beams creates an image with light and dark stripes. Through this method small difference in the pathways of the two beams of the order of a fraction of their wavelength, i.e. less than one thousandth of a millimeter, can be measured. Tiny differences in the density of the air on the two pathways of light lead to visual changes on the stripe pattern. These can for example be induced through changes in the air pressure or temperature. Interferometry quickly became a standard method for ballistic research and later for imaging in wind channels.

In order to claim at least the simultaneous development of the instrument, Ernst Mach and Ludwig Mach apparently felt pressured to quickly publish a short communication without sketches or construction details in order to have more time for the preparation of two long papers on the subject. In Ludwig Mach's laboratory notebook, the earliest records on the new interferometer relate to its manual adjustment with a date from July 1892. Yet, at this time two detailed article by Ludwig Mach as a single author had already been published. At the end of his third work on the new instrument from the year 1893,[31] Ludwig Mach noted that "some suggestions that I owe to my father Prof. E. Mach have significantly simplified the theoretical interpretation of the apparatus." A first sketch of the instrument set-up can be found in Ernst Mach's notebook Nr. 30[32] which he filled between January and August 1889. Detailed records on the composition of the interferometer, its adjustment and different experimental problems were described in several following notebooks. It is remarkable to observe the conformity of sketches and keywords in Ernst Mach's notebook Nr. 33 (started in December 1891) with the first publication of Ludwig Mach, thus proving experimental collaboration and not only theoretical support through his father.

Together with the Jamin-Interferometer (Inv.Nr. 75281), that judging from a note left by Ernst Mach in the laboratory inventory had been procured between 1883 and 1884,[33] the Mach-Zehnder interferometer (Inv.Nr. 75280) from 1891/1892 is

[30] Ludwig Zehnder, „Ein neuer Interferenzrefraktor", *Zeitschrift für Instrumentenkunde* 11 (1891), pp. 275–285.

[31] Ref. 3 in Fußnote 23.

[32] DMA, NL 174/534, p. 47

[33] DMA, NL 174/4131.

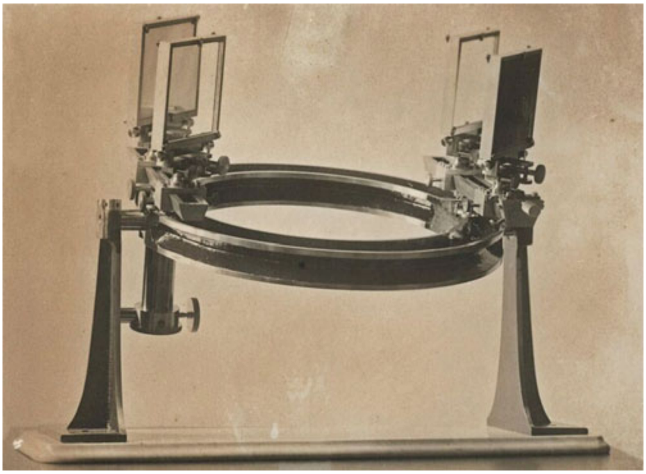

Fig. 30.2 Interferometer developed by Ludwig Mach, ca. 1892. Source: Deutsches Museum Archives

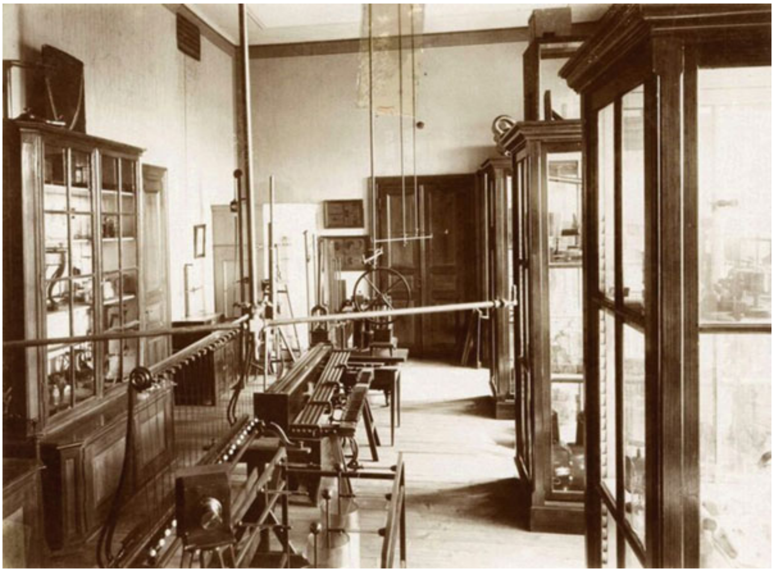

Fig. 30.3 Image taken in the Physics Institute of the University of Prague, ca. 1895. Source: Deutsches Museum Archives

one of the few original objects from the instrument collection of Ernst Mach and Ludwig Mach that has been preserved until today (Fig. 30.2).[34] Other publications beyond the subject of interferometry were published by Ludwig Mach in the year

[34]On the provenance of these instruments see footnote 1.

1891 to 1894 that do not have a correspondence in Ernst Mach's experimental notes. These works include Ludwig Mach's research on series photography[35] that followed the growth of a pumpkin plant over the period of 6 weeks. The original photographic plates made for these experiments today a preserved in the archives of the Deutsches Museum.[36] The cylindrical projection apparatus which can also be seen on a photograph together with Ludwig Mach at an advanced age, unfortunately seems to have been lost.

30.3.2 1896–1912

The applications of the Schlieren technique and of interferometry for the continuation and generalization of a number of experiments originally started by Ernst Mach are described in detail in Ludwig Mach's laboratory notebook. To this end, Ludwig Mach intensively worked during the year 1893 and built a number of varying set-ups, including those for the study of bullets and for the analysis of the gas flow. The publications related to these observations that Ludwig Mach published own his own appeared with some delay in the year 1896 to 1897[37] at a time, when Ernst Mach worked in Vienna and Ludwig Mach in Jena. The articles include the complementary experiment to the study of bullets through the inversion of the physical reference system: for the observation of air flow around static profiles of bullets, Ludwig Mach devised a wind channel experiment that later caught the attention of Étienne-Jules Marey (1830–1904).[38] In contrast to the experiments carried out during his time in Prague where discussion between father and son were local and direct, and thus by consequence almost no written sources keep record of the preparation of publications, the exchange of letters between the two scientists in this second phase gives a better picture on their assignments and roles. A lively correspondence shows proof of Ernst Mach's support to Ludwig Mach, but also the father's concerns about his son's scientific weaknesses that sometimes translated into reprimand with respect to his education. From these letters one also learns that

[35]Ludwig Mach, „Ueber das Princip der Zeitverkürzung in der Serienphotographie", *Photographische Rundschau* Heft 4 (1893), pp. 121–128. The apparatus is also sketched in Ernst Mach's notebook Nr. 32 DMA, NL 174/536, p.76.

[36]DMA, NL 174/4116.

[37]Ludwig Mach „Weitere Versuche über Projectile", *Sitzungsberichte der mathematisch-naturwissenschaftlichen Klasse der kaiserlichen Akademie der Wissenschaften Wien* 105 (1896), pp. 605–633; Ludwig Mach, „Ueber die Sichtbarmachung von Luftstromlinien." *Zeitschrift für Luftschiffahrt und Physik der Atmosphäre* Heft 6 (1896), pp. 129–187; Ludwig Mach, „Optische Untersuchung von Luftstrahlen", *Sitzungsberichte der mathematisch-naturwissenschaftlichen Klasse der kaiserlichen Akademie der Wissenschaften Wien* 106 (1896), pp. 1025–1074.

[38]See Christoph Hoffmann, „Superpositions: Ludwig Mach and Étienne-Jules Marey's studies in streamline photography", *Studies in the History and Philosophy of Science* Part A. Volume 44 Issue 1 (2013), pp. 1–11.

Ernst Mach helped Ludwig Mach, whose scientific objectives at the Zeiss company were others, to complete his publications and promote their appearance. On the experiments analyzing air flow, he wrote to his son upon reception of the draft paper: “These are splendid images, and I now understand quite well that it took you a lot of time to make them.”[39] In the following months his father seeked to complete the publication. In October, he finally wrote to his son: “I thus added a few sentences to the paper, formulated the conclusions, and handed it over yesterday [to the Academy]. Everything is quite clean now.”[40] „The publication will only carry your name.“[41] “It does not have to be said, where and when this happened, but it can be emphasized that all major experiments where completed in Prague. The publication shall read: M.M. Dr. Ludwig Mach.”[42] Therefore, at least one of the publications of Ludwig Mach in the year from 1890–1900, the work of his father is hidden without further notice. At the same time, however, Ludwig Mach also proposed his support to his father for experimental work: “You know want to use all the matters in a book and here I really would like to be helpful to you. Schlieren and interference instruments are now continuously produced and sold, it is simple for me to do the add-on experiments [. . .] While you are writing you will find some lacuna (maybe also for the bullets), it would be then my pleasure if I could complement the experimental series.”[43]

This situation radically changed in July 1898 when Ernst Mach suffered from a stroke. From now on it was not only the son who was relying on the scientific consultancy and support of his father. Being partially paralyzed and restricted in movement it became difficult for Ernst Mach to carry out experiments without help. In one of the many letters written by typewriter with one hand, he called on Ludwig Mach and pressured him morally with a reference to his own transience: “However something has to happen with experimenting soon, if I am to do anything at all. We made our last joint work in 1889. We now are in the year 1899. I do not have another decade at my disposal.”[44] The return to practical experimental work was difficult for Ernst Mach. In 1900 he wrote to Ludwig Mach: “Little by little I return to experimentation. After a 5-year break I yet was somewhat out of practice, also with the changed situation – restriction to one hand and slow limping movement – I would hardly be able to do something on my own. Victor [Ernst Mach’s second son] is a major help”[45] In the following time Ernst Mach wrote down into his notebooks (starting from Nr. 42 which he began in Mai 1898) less experimental work than before, and more sketches of philosophical and historical considerations can be found in his notes.

[39] Ernst Mach to Ludwig Mach, Wien, 12.03.1897; DMA, Konstanzer Abgabe, Nr. 58.

[40] Ernst Mach to Ludwig Mach, Wien, 15.10.1897; loc. cit.

[41] Ernst Mach to Ludwig Mach, Wien, 19.10.1897; loc. cit.

[42] Ernst Mach to Ludwig Mach, Wien, 24.10.1897; loc. cit.

[43] Ludwig Mach to Ernst Mach 18.09.1897; DMA, NL 174/2099.

[44] Ernst Mach to Ludwig Mach, Wien, 01.10.1899; loc. cit.

[45] Ernst Mach to Ludwig Mach, Wien, 21.07.1900; loc. cit.

In the long phase from the stroke to the year 1912, only four papers of Ernst Mach deal with experimental work in physics. Only one of them from 1904 was coauthored by father and son. Their fourth joint publication entitled "Versuche über Totalreflexion und deren Anwendung",[46] which appeared after a break of 15 years in the proceedings of the Academy, summarizes the results of several years of collaborative work going back to the student years of Ludwig Mach in Prague. A first draft of the paper can already be found in Ernst Mach's notebook from 1893.[47] This paper, too, is the continuation of an earlier work started by Ernst Mach in the 1870s with different coauthors. Ludwig Mach's notes and sketches on the subject range from September 1893 and August 1903. However, from 1905, records of his experiments with a Michelson interferometer dominate the records of his notebook.

The three other experimental publications[48] by Ernst Mach only mention the colloboration with Ludwig Mach in the text body or in footnotes. Two of them did not appear in scientific journals with large distribution, but rather as small contributions to edited books. He hence wrote in the Festschrift for Ludwig Boltzmann: "With my suffering that makes it impossible to me to experiment on my own I have to restrict myself to the planning of experiments. My oldest son, Dr. med Ludwig Mach, has carried out the experiments in great detail, while I supervised the setting and the results." It is not clear where these experiments have been carried out. The correspondence between father and son contains important breaks in the years 1900 to 1912, possibly resulting from an extended stay of Ludwig Mach in Vienna.

30.3.3 1913–1916

Prior to Ernst Mach's movement to Vaterstetten, his son gave promise of the return to their collaborative work in his house: "I will catch up with the deficit in optical work and do everything to support you."[49] By doing so, Ludwig Mach not only wanted to help his father, but also though of his own advancement: "You will see –

[46]Ernst Mach and Ludwig Mach, „Versuche über Totalreflexion und deren Anwendung“, *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften, Mathematisch Naturwissenschaftliche Classe* 2a, Band 113 (1904), pp. 1219–1230.

[47]DMA, NL 174/538, p. 66.

[48]Ernst Mach, „Objektive Darstellung der Interferenz des polarisierten Lichts“ In: *Festschrift, Ludwig Boltzmann gewidmet zum 60. Geburtstag*, Leipzig: Ambrosius Barth (1904), pp. 441–447; Ernst Mach, Ueber die Phasenänderung des Lichtes durch Reflexion, In: *Festschrift, Adolf Lieben zum fünfzigjährigen Doktorjubiläum und zum siebzigsten Geburtstage von Freunden, Verehrern und Schülern gewidmet*, Leipzig: C.F. Winter'sche Verlagsbuchhandlung (1906), pp. 291–296; Ernst Mach, „Die Phasenverschiebung durch Reflexion an den Jamin'schen Platten. *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften in Wien. Mathematisch-naturwissenschaftliche Classe* Band 116, Abt. 2a, (1907), pp. 997–1000.

[49]Ludwig Mach to Ernst Mach 13.02.1913; DMA, NL 174/2113.

given my height we can overcome stairs. In good air, in the forest, it will do again – convince yourself at least once that I still can to something, too!"[50]

Only a single experimental publication goes back to the phase in Vaterstetten. In contrast to prior publications of Ernst Mach, in which Ludwig Mach's participation was at least stated within the text, this final physics paper of him before his death, published for the Festschrift for the Austrian philosopher Wilhelm Jerusalem (1854–1923), is an exception. The paper contains mostly observations with a Michelson interferometer – a subject on which Ludwig Mach had worked since his time in Jena and on which a large number of records are contained in his notebook. In Ernst Mach's last notebook which he began in 1910, the last page contains a note on Jerusalem's birthday, but no references at all that would match with the publication. In fact, the paper is a product of Ludwig Mach's writing. This can be shown on the one hand by inspection of the proofs[51] and the correspondence with the editor. In these letters, Ludwig Mach put himself in the position of his father's secretary and asked the editor not to reveal their correspondence to his father.[52] Moreover, the publication is referred to as "the final joint work"[53] in Ludwig Mach's papers where he describes the article as a "clarification of my own views". It is thus not surprising that among reprints of the article a version signed by Ludwig Mach as the true originator of the experiments can be found.[54] The completion of the numerous superspositions that one could call a reciprocal theft of identity finds its culmination in the posthumously published book on optics by Ernst Mach, edited by his son Ludwig Mach, in 1921.[55] The index of the book only contains one "Mach", which unifies the works of the father and the son. No other scientific publications by Ludwig Mach appeared under his own name until his death in 1951.

30.4 Conclusion

To characterize the almost 30 years of collaboration between Ernst Mach and Ludwig Mach as "interferences" presumes that their results are more than the sum of its parts. This is revealed on the one hand through the methodological complementarity, the experimental technique and the physical understanding that is not only applied to the works where the collaboration is explicitly mentioned. After suffering from a stroke, Ernst Mach was reliant on his son's help for the continuation

[50] Ludwig Mach to Ernst Mach, undated, probably 1912 or 1913; DMA NL 174/2115.

[51] DMA, Konstanzer Abgabe, Nr. 3.

[52] Rudolf Goldscheid to Ludwig Mach, 02.07.1914; DMA, NL 174/1329.

[53] DMA, Konstanzer Abgabe, Nr. 24.

[54] DMA, Konstanzer Abgabe, Nr. 24.

[55] Ernst Mach, *Die Prinzipien der physikalischen Optik*. Leipzig: Ambrosius Barth (1921). See also a detailed account in Gereon Wolters, *Mach I, Mach II, Einstein und die Relativitätstheorie. Eine Fälschung und ihre Folgen.* Berlin: de Gruyter (1987).

of his experimental work. Likewise, Ludwig Mach could not achieve scientific independence from his father after moving away from Prague, and did not show willing or capable to stand on his own scientific ground after his father's death. At the same time, this observation should not incite to project the main scientific results of the optical work only to Ernst Mach and to disregard some of the remarkable results of Ludwig Mach in particular during his time in Prague and Jena. The result of superpositions of the biographies and the scientific work at times is creating and complex image whose decryption may only be successful in part – similar to the reconstruction of an interference image that provides information on the intensities, but not on the superposing waves. With the reunification of the Mach Papers in Munich, the preconditions for future historical Mach studies, and a differentiated view on the collaboration between father and son, have been created.

Chapter 31
Experiment and Experience. On Ernst Mach's Theory of Scientific Experimentation

Eva-Maria Jung

Abstract This paper focuses on Ernst Mach's theory of scientific experimentation. As I shall show, Mach presents an extraordinarily wide perspective on scientific experiments, bringing together heuristic, evolutionary, historical and didactical aspects. For Mach, experimentation is not reduced to controlled testing in a laboratory. It rather describes a quite general human, and even animal, activity to explore the world. By relying on such a broad notion of experiment, however, his theory has to deal with a wide range of objections. I shall analyse these objections by confronting Mach's theory with Franz Brentano's straightforward criticism. I shall conclude that Mach's theory entails some unsolvable inconsistencies. These inconsistencies lead to some important questions that still pose challenges to the philosophy of scientific experimentation.

31.1 Introduction

The systematic neglect of the significance of scientific experiments in modern philosophy of science was the target of criticism that proponents of the *New Experimentalism* brought up in the 1980s. This neglect served as the starting point for bringing into focus the experiment's 'life of its own', independently from theories and their dynamics, and to investigate the various roles that experimental practices play for the development and the success of the sciences.[1]

To be sure, New Experimentalists were right insofar as most of the proponents of Logical Positivism did not spend much time for investigations about the specific features of experimental practices and assigned a purely *critical role* to

[1]Cf. Ian Hacking, *Representing and Intervening. Introductory topics in the philosophy of natural science*. Cambridge et al.: Cambridge University Press 2010 [1983], p. 149ff.

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them. In other words, scientific experiments were understood as offering empirical facts, which, once formulated in observation sentences, verify or falsify theory.[2] Moreover, some authors went even further and rejected the idea that experiments do have this critical role. To give an example, Otto Neurath, in a review article of Karl R. Popper's *Logik der Forschung*, denies that experiments, taken as such, can be used to falsify theories. As a result, he claims that 'we can sketch ourselves a model of a scientific development that does not know experiments at all.'[3]

However, these most obvious cases of the systematic neglect of experiment do not represent the whole history of philosophy of science. Against the proponents of the New Experimentalists one can in turn object that they presented a too narrow view of philosophy of science and had therefore been blind against some philosophers, primarily Ernst Mach and Hugo Dingler, who indeed investigated the various features of scientific experimentation in more detail and gained important insights long before the New Experimentalism was born.[4]

The aim of this paper is to show that Ernst Mach belongs to those philosophers who offered an unconventional approach to the experiment according to which its role is not reduced to the testing of theories. Rather he presents a wide perspective on scientific experimentation, bringing together heuristic, evolutionary, historical and didactical aspects. By doing so, his view has to deal with a wide range of objections. The main problems of Mach's position can be made perspicuous through Franz Brentano's straightforward criticism. As we shall see, Brentano points to some inconsistencies in Mach's general picture of experimentation. These inconsistencies lead to some important questions that still pose challenges to the philosophy of experiment.

31.2 Mach on Scientific Experiments: A First Outline

At first glance, it might be surprising even to assign Mach a theory of experiment at all. To be sure, he did not present an extensive examination that covers all relevant aspects of scientific experimentation. In his *Knowledge and Error* (*Erkenntnis und Irrtum*), however, Mach devotes two whole chapters to experiments, the thirteenth

[2]Cf. Michael Heidelberger, "Die Erweiterung der Wirklichkeit im Experiment", in: M. Heidelberger\F. Steinle (Eds.): *Experimental Essays – Versuche zum Experiment*. Baden-Baden: Nomos 1998, pp. 71–92, here p. 72.

[3]Otto Neurath, "Pseudorationalismus der Falsifikation", in: *Erkenntnis* 5, 1, 1935, pp. 353–365, here pp. 360–361. Neurath rejects the idea of an 'experimentum crucis' by referring to a Duhemian holism. It might surprise that Neurath accuses Popper of over-emphasizing the importance of experiments because New Experimentalists, in turn, regarded Popper as a philosopher who systematically neglected the role of experiments by narrowing it to its critical role.

[4]Cf. Peter Janich, "Methodisch-kulturalistische Theorie des Experiments", in: M. Heidelberger\F. Steinle (Eds.): *Experimental Essays – Versuche zum Experiment*. Baden-Baden: Nomos 1998, pp. 93–112, here p. 94.

chapter to thought experiments and the fourteenth chapter to the physical experiment and its leading features.[5] Both chapters are deeply connected to each other—a fact that becomes most obvious in the way Mach describes the physical experiment. It is, according to him, 'a natural sequel' of the thought experiment.[6]

His way to approach the physical experiment is thus mediated, though not restricted, through his view of thought experiments. At this point, it is interesting to note that Mach has often been regarded as having coined the notion of thought experiment. Although this is not true because other authors have used the notion before him, there is no doubt that he had a huge influence on the reflection about thought experimentation.[7] In any case, he was one of the first philosophers of science who acknowledged the great importance of thought experiments in the scientific process and in the development of human life.

What unites thought experiment and physical experiments, according to Mach, is the basic *method of variation*.[8] In physical experiments we vary natural circumstances, in thought experiments imagined circumstances with the aim to investigate the consequences of this variation. In a nutshell, experiments are understood as 'the autonomous search for new reactions and their relations, respectively.'[9]

These first descriptions of the experiment show that Mach emphasizes the experiment as something deeply connected to the deliberate action of the experimenter. In light of this, the experiment is the active counterpart of passive observation. As he puts it:

> Human beings collect experiences by observing changes in their surroundings. However, the most interesting and instructive changes for them are those that they can influence through their own intervention and deliberate movements. With regard to such changes they need not remain purely passive, they can actively adapt them to their own needs; furthermore, they are for them of the highest economic, practical and intellectual importance. That is what makes experiments so valuable.[10]

In his emphasis on the active part of the experimental process the similarities of his position and the basic ideas of the New Experimentalism movement become obvious. One of the key words of this movement is the active 'intervention' that is

[5]Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*. Ed. by E. Nemeth and F. Stadtler, Berlin: Xenomoi 2011, pp. 193–229. The fourteenth chapter about thought experiments had partly been published before as "Über Gedankenexperimente", in: *Poskes Zeitschrift für physikalischen und chemischen Unterricht* 10, 1, 1897, pp. 1–5.

[6]Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*. loc. cit., p. 198.

[7]Cf. Aspasia S. Moue/Kyriakos A. Masavetas/Haido Karayianni, "Tracing the Development of Thought Experiments in the Philosophy of Natural Sciences", in: *Journal for General Philosophy of Science* 37, 1, 2006, pp. 61–75. Mach introduced the notion of thought experiment in his *Die Mechanik in ihrer Entwicklung* (see Ernst Mach*, Die Mechanik in ihrer Entwicklung. Historisch-kritisch dargestellt*. Ed. by G. Wolters and G. Hon, Berlin: Xenomoi 2012, p. 43.)

[8]Cf. Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit., p. 193.

[9]Cf. Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit., p. 211.

[10]Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit., p. 193.

considered as the core of scientific experimentation and its distinguishing feature from passive observation.[11] It should however be noted that Mach himself regarded the distinction between experiment and observation as a *gradual* one.[12]

Furthermore, and somehow surprisingly, for Mach experiments are not exclusively performed by human beings. As he states, 'animals, too, may be observed experimenting'.[13] The hamster's attempt to bring to fall the lid of a feed box, for instance, can for Mach be regarded as a basic form of experimentation. Although he claims that the intellectual experiment that is guided by thoughts is the basis of all scientific disciplines, he argues that we should nonetheless keep in mind that the experiment is shaped by instincts and habits as well. He speaks of an *instinctive experimentation*[14] that occurs when perceptions lead instinctively to a motor behaviour through which we gain knowledge about certain relations and their connections. This can already be observed in children exploring the sensitivity of their limbs or the features of their mirror image. Human beings share this raw kind of experimentation with other animals, even though for the latter the scope of interest is usually narrower. The borderline between experiments guided by thought and those guided by instinct is, according to Mach, not a sharp one.

We have already seen that Mach's view of the physical experiment is partly transmitted from his conception of thought experiments. Mach assigns thought experiments to a higher intellectual level than physical ones.[15] As he states, our thoughts are easier and more comfortable at hand as physical facts. In other words, in thought experimentation we are not confronted with any physical resistances from the real world, such that we 'do experiment with thoughts, so to say, at lower costs.'[16] By being so easily applicable, thought experiments often precede physical experiments. Whenever a result of the former is obvious, any proof through its physical counterpart becomes unnecessary. This is often the case when our thoughts lead to paradoxes. Thus, it might suffice to perform thought experiments if we want to show that a certain rule leads ad absurdum.[17] The more obscure and unstable the result of the imagined experiment is, however, the more it calls for the physical experiment as its natural sequel.[18] It is important to note that Mach does not only state that the thought experiment usually precedes the physical one. He makes an even stronger claim, namely, that the former is 'a necessary precondition of the latter.'[19]

[11] See, e.g., the title of one of the most important book for the movement, Ian Hacking's *Representing and Intervening*, loc. cit.

[12] Cf. Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit., p. 195.

[13] Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit., p. 195.

[14] Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit., p. 211.

[15] Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit, p. 196.

[16] Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit, p. 197.

[17] Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit, p. 201.

[18] Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit, p. 198.

[19] Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit, p. 197.

Mach also claims, and this is another surprising statement, that experiments are not only important within the realm of physics and other natural sciences. Rather, they do play a crucial role in mathematics as well.[20] As he states, arithmetic, geometry, and mathematics in general can ultimately be traced back to individual experiences such us the counting and measuring of physical objects. He states that one could suggest that the method of physical and thought experiment has its primary root in mathematics and was then transferred to the natural sciences.[21] According to Mach, there is, therefore, no gulf between deduction and experiment. Rather experimentation includes both deductive and inductive reasoning. In all cases it is the thought-economical principle that is at play, namely, the correspondence of thoughts and facts or of thoughts among themselves.

Mach's account of the physical experiment includes, to a great extent, the characterization of certain *leading motives* ('Leitmotive'), under which he subsumes, among others, isolation and simplification. A thorough discussion of these motives would go beyond the scope of this article. I merely want to put focus on the methodology by which Mach tries to establish these motives. As he puts it:

> The formative motives of experiments here described have been abstracted from experiments actually carried out. The list is not complete, for ingenious enquirers go on adding new items to it; neither is it a classification, since different features do not in general exclude one another, so that several of them may be united in the experiment.[22]

Thus, Mach does not lay claim to the completeness of his list or to a mutual independence of the particular features. Furthermore, he does not put focus on an *epistemic* perspective; he describes the leading features mostly from a *heuristic* perspective. His aim is not to proof in how far we are justified to apply them in scientific experimentation. He rather tries to capture the methods that are actually used in experiments that have already been performed in the history of science.

At this point, this relatively brief reconstruction of Mach's view on experimentation shall suffice. Before going into detail, I will consider some objections Franz Brentano put forward against Mach's approach.

31.3 Brentano's Criticism: A Far Too Broad Notion of Experiment

In his book *Über Ernst Machs 'Erkenntnis und Irrtum'*, which was probably written in 1905/06, but only published posthumously, more than 80 years later in 1988, Franz von Brentano presents a thorough criticism on Mach's book and, accordingly, on Mach's theory of experimentation. As Brentano states clearly from

[20] Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit, p. 207.
[21] Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit, p. 209.
[22] Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit, p. 224.

the beginning, it is not *the details* of Mach's theoretical approach that seem new and interesting to him but rather Mach's extremely wide use of the notion of experiment. According to Brentano, 'Mach stretches the concept of experiment to an unusual extent',[23] and it is this fact that gives rise to a variety of critical objections. Although Brentano's criticism primarily concerns the use of the notion of experiment in Mach's theory, he emphasizes that we should not merely dispute about words. If Mach wants to use the notion of experiment in the unusual broad way subsuming each and every kind of searching behaviour that applies the method of variation, he is free to do it. By doing so, however, he would not say something philosophically important and his account would furthermore lead to several confusions insofar as the default notion of experiment contains some crucial insights that have already been established in the history of philosophy.

A first point of criticism concerns the fact that Mach subsumes any kind of reasoning—even *deductive reasoning* from purely *a priori* premises, under the notion of experiment. This leads, according to Brentano, to the collapse of the difference between the natural sciences as *empirical* disciplines, on the one hand, and *a priori* disciplines such as mathematics or logics, on the other hand. For if we accept Mach's approach, a priori reasoning in these formal disciplines would fall into the realm of experimentation and the knowledge we gain from this reasoning should, as a consequence, be regarded as *experiential knowledge*.[24] In light of this, however, the Leibnizian distinction between experiential and rational truths is blurred. As Brentano argues, Mach's use of the notion of experience differs severely from how it is understood in its most usual sense, namely as a collection of sensual perceptions in the memory that leads human beings to general judgment, abstracted from individual situations. According to Brentano, we should simply not speak of experience in the case of *apodictic judgements* because this violates the common understanding of the experiential. If a judgement follows directly from the concepts used in the premises, it simply does not contain experience about the world. Brentano concludes that the concept of experiment should be restricted to the methodological variation of conditions that lead to certain sensations. Within this picture, neither is a chess player solving a puzzle performing an experiment nor a mathematician who investigates the square roots of numbers. Experiential knowledge is thus opposed to knowledge or pure reasoning and Brentano accuses Mach for ignoring this opposition. Furthermore, the notion of experiment should, according to Brentano, not be used for each and every kind of inductive research. Brentano admits that each kind of research contains, as a matter of fact, a certain searching or trial behaviour aimed at new knowledge. He suggests however to confine the notion of experiment to searching activities that involve a variation which makes an observation possible that is needed in order to decide for or against a hypothesized law-like relation that holds between certain facts. In other word, it is the notion of a *crucial experiment* or an *experimentum crucis* in a Baconian sense

[23] Franz Brentano, *Über Ernst Machs 'Erkenntnis und Irrtum'*, Ed. by R. M. Chisholm and J. C. Marek, Amsterdam: Rodopi 1988, p. 81.

[24] Franz Brentano, *Über Ernst Machs 'Erkenntnis und Irrtum'*, loc. cit., p. 80.

that is at the core.[25] Thus, not everyone who searches for knowledge, particularly not someone who simply observes something is considered an experimenter. The astronomer using a telescope to watch the stars or the biologist observing bacteria through his microscope are, within this picture, not experimenting. The notion of experiment is rather restricted to activities that include a methodological variation in the sense of *artificially produced observations* that are used for the purpose of deciding between conflicting hypotheses.

A second point of criticism has the deep connection Mach draws between instincts and experimentation as its topic. Mach's idea of an *instinctive experimentation* is, according to Brentano, a 'contradiction in adiecto'.[26] As he claims, this can easily be seen if we have a closer look at the components of this composite term: 'instinctive' and 'deliberate' are opposite to each other and cannot, therefore, be brought together. For Brentano deliberation and planned action are core elements of scientific experimentation. And instincts, as the counterpart, can in principle not be considered to be inherent in experiments. To put it in a nutshell, 'instinctive experimentation' simply demarks an abuse of the notion of experiment.[27] It is furthermore obvious for Brentano that animals in general do not experiment. As he claims, Mach shows himself as a 'careless anthropomorphist'[28] when ascribing experimentation to animals and, thus, holding that their behaviour meets the relevant criteria. Brentano admits that there is a certain shared ground between humans and other animals. Both are able to gain new knowledge by investigating the world through their bodies. The ability to perform systematic experiments is, however, an exclusively human accomplishment.

Yet another point of criticism concerns Mach's idea that thought experiments and physical experiments are continuous to each other. Brentano does not deny that thought experimentation is of great importance for the sciences, but he emphasizes that this holds only insofar as it is related to sensation and memory. According to Brentano, Mach's derivative understanding of experimentation has also unpleasant consequences on his idea of thought experiment. Mach argues, for instance, that the question as to whether a thought experiment can be completed is dependent on the extent of experience that it presupposes. For Brentano, however, it is *new* experience that is at stake in 'real' experiments, and not, as Mach suggests, experience already made. Furthermore, Brentano claims that Mach, by dissolving the crucial difference between thought and physical experiments, is not able to do justice to the history of the sciences. Thus, the great of success of the modern sciences that rely deeply on the invention of systematic experimentation in contrast to the sciences in Ancient Greece that only knew thought experiment would in Mach's picture be a miracle.

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[25]Franz Brentano, *Über Ernst Machs 'Erkenntnis und Irrtum'*, loc. cit., p. 82. See also Francis Bacon's 'crucial instances' in: *The New Organon*, Ed. By L. Jardine and M. Silverthorne, Cambridge: Cambridge University Press 2000, Book II, Aphorism xxxvi, pp. 159ff.

[26]Franz Brentano, *Über Ernst Machs 'Erkenntnis und Irrtum'*, loc. cit., p.84.

[27]Franz Brentano, *Über Ernst Machs 'Erkenntnis und Irrtum'*, loc. cit., p.89.

[28]Franz Brentano, *Über Ernst Machs 'Erkenntnis und Irrtum'*, loc. cit., p.84.

To summarize, Brentano accuses Mach of three transgressions that result from his extraordinary broad notion of experiment and that can be characterized by three kinds of continuum. First, Mach's theory includes a continuum of inductive and deductive reasoning. Second, he holds that there is a continuum of instinctive experiments and experiments guided by thought. Third, Mach endorses a continuum between thought experiments and physical experiments. In the next section, I shall discuss these *continuum theses* in more detail.

31.4 Three Kinds of Continuum

31.4.1 Inductive vs. Deductive Reasoning

Without any doubt, it is astonishing that Mach considers experimentation the basis of all disciplines and, therefore, also of disciplines that are commonly regarded as basically a priori or deductive such as mathematics. At first glance, Mach's thesis shows similarities to Quine's famous first dogma against empiricism, according to which there is no fundamental difference between analytic and synthetic truths.[29] But one should be careful to not over-interpreting Mach here by ascribing such a radical thesis to him. Although he subsumes both inductive and deductive reasoning under the umbrella term of experimentation, he does not explicitly state that there is no difference between the two of them. He rather states that he aims to bridge the gap between deduction and experiment and this is mainly done by two theses. First, the thesis that the method of thought experiment and therefore the method of variation is the prevalent method of mathematics. And second, the thesis that mathematics as a discipline is ultimately grounded in the sensual world insofar as it can be traced back to counting and measuring of material objects.[30] Either of the two theses is consistent with the view that there still is a fundamental difference both between inductive and deductive reasoning and between empirical and a priori disciplines. That thought experiments do play a crucial role in mathematics is hard to deny. And since thought experiments are continuous with physical experiments within Mach's picture, an opposition of the two kinds of experiments as such cannot be used as the basis for the opposition of experiential and a priori disciplines. But one should not forget that Mach does not claim that thought and physical experiments are *just the same*. Rather he emphasizes some severe differences between the two of them, for example the fact that thought experimentation is not directly confronted with facts in the real world whereas physical experimentation is. Mach's second thesis can be understood us a speculative thesis about the origin of the sciences and the relations between the disciplines. To be sure, by tracing it back to sensations, mathematic

[29]Cf. Willard Van Orman Quine, "Two Dogmas of Empiricism", in: *The Philosophical Review* 60, 1, 1951, pp. 20–43.

[30]Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit., p. 207 ff.

seems, at least *historically* or *etiologically*, an empirical discipline to him. From this however it does not follow that mathematics and the natural sciences do not differ in other ways, for instance, in an *epistemological way*.

To sum up, I do not agree with Brentano's claim that Mach blurs the distinction between inductive and deductive reasoning all together. By subsuming them both under the notion of experiment he rather highlights some similarities between the two kinds of reasoning which are usually neglected. He does not deny that there is any difference at all. Still I think that Brentano's criticism is, at least partly, justified because Mach does not state explicitly which level of argumentation (historical, heuristic, epistemological, or otherwise) his continuum thesis belongs to.

31.4.2 Instinctive Experiments vs. Experiments Guided by Thought

Mach's thesis that there is a kind of 'instinctive experimentation' and that animals like hamster, dogs and horses do experiment may indeed be regarded as unconventional. It could however only be considered a *contradiction in adiecto* if we presuppose a certain understanding of what an experiment is. More precisely, Mach's idea only leads to a contradiction if we regard deliberate action as inherent to experimentation. But we need not to do this. We could, for instance, state that deliberate action in the sense of intentionally producing artificial conditions for an observation needed to test theories is in most cases, especially in paradigm cases in the history of the sciences, an important starting point of experimentation. We could deny though that deliberate action is a *necessary condition* for performing an experiment. In light of this, Mach's idea of an 'instinctive experimentation' is considerably less problematic. By this idea Mach seems to capture the fact that experiments, although they are performed in a highly technologized laboratory environment, do have their roots in a basic behaviour. In this way, Mach could be defended against Brentano's criticism.

However, Mach's continuum of instinctive experiments and experiments guided by thought reveals an inconsistency of his theory. This inconsistency becomes clearer if we have a closer look at his idea of the relation between theory and experiment. In principle, experimentation is, according to him, deeply connected to theory. A hint to this is found in his foreword to the German edition of Pierre Duhem's *La Théorie physique. Son object, sa structure* (in German *Ziel und Struktur der physikalischen Theorien*) in which Mach claims that of Duhem's most important merits is his 'emphasis of the close interdependence, the inseparability of experiment and theory'.[31] In *Erkenntnis und Irrtum* he puts it the following way:

[31] Ernst Mach, „Vorwort zur deutschen Auflage“, in: Pierre Duhem, *Ziel und Struktur der physikalischen Theorien*, Hamburg: Meiner 1998, p. iv.

> The deliberate, autonomous extension of experience through the physical experiment and the systematic observation are *therefore always guided by thoughts*, *and cannot be sharply limited and separated from the thought experiment.*[32]

This emphasise of the intellectual aspect in the sense of being guided by thought and connected to thought experiment threatens to yield an inconsistent picture of experimentation. On the one hand, Mach speaks of ‘instinctive experimentation’ and therefore seems to hold that the method of variation can be applied in a purely instinctive sense, without any preceding intellectual effort. On the other hand, he hints to the indispensible role that thoughts and thought experiments do play in physical experiments.

His first thesis seems, at least in its spirit, to be in accordance with some perspectives on the experiment that have been developed after the New Experimentalism movement. In this context, many philosophers argue that the notion of experiment should not be reduced to its connection to the testing of theories. As an example, Steinle holds that experimentation can be ‘explorative’ in the sense that they serve as a basis for an extensive development of certain scientific concepts.[33] And Krohs points to the fact that new techniques in systems biology lead to a kind of ‘convenience experimentation’ that focuses on the collection of a vast amount of data.[34] These approaches capture the fact that experiments do not always meet the idealized image of theory-guided, crucial experiments, but that they are rather shaped by a variety of other aspects than theory and that they serve different purposes. This understanding is in line with Mach’s emphasis of the role of instinct and habits in experimentation and of his claim that even mere chance can have an important influence on experiments.

Mach’s second thesis, by contrast, goes along with a narrowing of the notion of experiment. The strong connection between reflection and experiment does not allow for an instinctive, or otherwise derivative kind of experimentation. One might be inclined to draw a connection between Mach’s thesis and the idea of a theory ladenness of experiments in a Duhemian sense. However, this interpretation would be far too radical. As we have already seen, one reason for the rejection of such an interpretation is his idea about an instinctive experimentation. Yet another reason is that Mach seemed to be critical about the idea that theories do have a stable and guiding character-an idea that is indispensable for the thesis of a theory ladenness of experiment. This is nicely shown by his famous words that ‘theories are like withered leaves, which drop off after having enabled the organism of science to breathe for a time.’[35]

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[32]Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit., p. 212.

[33]See, for instance, Friedrich Steinle, “Entering New Fields: Exploratory Uses of Experimentation”, in: *Philosophy of Scienc*e 64, 1997, pp. 565–574.

[34]Cf., Ulrich Krohs, „Convenience Experimentation“, in: *Studies in History and Philosophy of Biological and Biomedical Sciences* 43, 1, 2012, pp. 52–57.

[35]Cited after Robert S. Cohen/Raymond J. Seeger (Eds.), *Ernst Mach – Physicist and Philosopher*, Dordrecht: D. Reidel Publishing, 1970, p. 220.

To conclude, Mach's idea of an instinctive experimentation can, in principle, be defended against Brentano's criticism. However, his continuum between instinctive experiments and those guided by thought contains an inconsistency that concerns the relation between experiment and theory or thought in general.

31.4.3 Thought Experiments vs. Physical Experiments

I will now turn to Mach's continuum of thought experiment, on the one hand, and physical experiments, on the other hand. As we have already seen, Mach endorses a certain primacy of thought experiment over physical ones. At least at first glance, this primacy is in conflict with his Sensualism, according to which all knowledge is based on sensual perception.[36] This conflict is, however, only an apparent one if we consider Mach's idea of thought experiment in more detail. According to him, it does not transcend sensual experience. Thus, it is not connected to a certain armchair method that is detached from the sensual world.

To be sure, Mach's remark that also those 'who make projects and pipe dreams, who write novels or poets and create social or technical utopias' can be regarded as experimenters suggests that his notion of thought experiment is extremely broad.[37] By this remark Mach seems to emphasise that poets, novelists and others also use the method of imagined variation in their play of phantasy. At first place, however, Mach wants to establish the method of thought experiment in the (natural) sciences and, in this context, he claims that if, for instance, physicists use thought experiments they usually aim at a deep connection to sensations and do not employ ideas that are essentially new or different from what they actually experience. It is not any kind of variation in the experimenter's phantasy that is relevant for thought experiments in the sciences but rather a *continuous* variation that has sensual experience as its anchor point.

The primacy of thought experience Mach has in mind is furthermore not an *epistemical* one. This becomes most obvious in his reference to Pierre Duhem in a footnote. As Mach states explicitly, Duhem is right in his warning of mistaking thought experiments for physical ones.[38] Thus, he indeed admits that thought experiments are, from an epistemic point of view, far more problematic than physical experiments.

To conclude, although Brentano offers a too restrictive interpretation of Mach's idea of a thought experiment several questions about the continuum of thought and physical experimentation remain indeed unanswered, especially the question as to whether there is a primacy of thought experiments over physical ones.

[36] Cf. Ernst Mach, *Die Analyse der Empfindungen*, Ed. by G. Wolters, Berlin: Xenomoi 2008.

[37] Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit., p. 196.

[38] Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, loc. cit., p. 198, fn 306.

31.5 Conclusion

Mach's characterization of experimentation leads to some inconsistencies that reveal challenges for the philosophy of experiment that are even today, more than 30 years after the initiation of the New Experimentalism pertinent. These challenge concern, among others, the question as to how we should sharp the notion of scientific experiment after having abandoned the far too narrow idea of controlled laboratory activity that is exclusively performed in order to test theoretical hypotheses. Long before the New Experimentalism was born, Mach saw that this narrow concept is not appropriate and tried to give a thorough characterization of experimentation which is attached to the real world and takes into account the historical, contextual, and sometimes even contingent conditions without which scientific experiments cannot be fully understood. However, he created a notion of experiment that is far too broad and, by this, involves certain inconsistencies. Although Mach did not offer a convincing conception of the experiment, his theory should be regarded as a fruitful and, at least for his time, a pretty unconventional way to think about scientific experimentation.

Chapter 32
Mach's Views on Physical Space and Time and Their Grounding in Perceptual Space and Time

Theodore L. Kneupper

Abstract Here are presented the essential features of what Mach considered the four important types or ideas of space and time. These are referred to as 'perceptual,' 'geometrical,' 'physical space and time' and 'mathematical manifolds.' Although the first is foundational, we consider how in Mach's view each further type is in a sense a more general abstraction, freed from particular limiting characteristics of the preceding type. What is most significant is his view of the fourth, in which the most fundamental and essential feature of space is as a relation of immediacy and of time as a relation of mediacy. Some of the important (and often overlooked) implications of this are discussed, along with suggestions regarding their possible relevance to contemporary physics.

Much has been written about Mach's influence on Einstein and his impact on contemporary physics. While this is quite relevant, it strikes me that little attention has been given to what I think are Mach's more fundamental insights that are the basis of his impact on Einstein and others: his views on space and time. Here I will attempt to clarify the substance of those views.[1]

There is a story from India that tells of seven blind men giving seven different descriptions of an elephant as they sought the truth. This is not unlike the attempts among thinkers to disclose the nature of space and time, which because they have the name 'space' or 'time' is often assumed to be accurately describable in one way, or even that they designate only one 'thing.' Mach, however, saw that the meanings of those terms are multiple, and carefully distinguished their diversity. He further

[1]This article is based on a thorough study of Mach's views on space and time in my doctoral dissertation, *Ernst Mach's Views of Space and Time,* (1973, University of Louvain), which examines the development of his views from 1860 to 1916.

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saw that unless those meanings are kept in mind there are likely to arise serious misunderstandings.

Broadly speaking, for Mach space and time are of *four major but related types*. One he referred to as ‘psychological,’ ‘physiological,’ or ‘perceptual.’ The second he called ‘geometrical,’ or more generally ‘metrical.’ The third is ‘physical space and time.’ The fourth is the most abstract, called ‘mathematical manifolds.’

Mach’s first articulation of the central idea of his view was expressed in “Bemerkungen über die Entwicklung der Raumvorstellungen,” published in 1866 early in his professional career. This was the result of his recognition that the then-accepted view, which he had tried to teach 3 years earlier, was fundamentally flawed. He points out:

> I would not publish the following lines if I were not of the opinion that they contain several stimulating thoughts, which in so far as they are more rarely presented, arise out of a simultaneous occupation with physics and psychology.[2]

That is, what he proposed originated from a reflection on how all ideas of space are rooted in the properties of perceptual space, which are the basis of metrical space, which in turn are the basis of our ideas of physical space. Here he focused on space ideas, but the overall principle is later extended to include time. This first attempt to characterize perceptual space was later revised somewhat to reflect a more complete account of perceptual space and time, but the basic insights remain the same.

I will summarize eight important features of perceptual space and time, which are described in Mach’s most mature articulation, *Erkenntnis und Irrtum*.[3]

1. Aspects of both space and time are immediately sensible; that is, there are *space- and time-sensations*. Although immediate experience is a complex whole that undergoes changes in its contents, careful observation discloses components of those complexes. What he called ‘Sinnesempfindungen’ or ‘qualitative sensations’ can be differentiated from spatial and temporal sensations. The latter can further be distinguished or analyzed into the smallest observable components, or ‘*elements*,’ which are primarily locations in the larger spatial and temporal complex.
2. Immediate perception also discloses that space and time elements have *relational* features. For example, the relational structure of a line is immediately perceived as significant, as well as the difference between a straight line, a uniformly curved line, and a more randomly structured line. Similarly, time-elements display relational characteristics that are immediately perceivable.
3. Each sense mode has its own spatial characteristics or ‘space,’ although the sense-modes of smell and taste almost completely lack spatial aspects. That

[2] BER, p. 227.

[3] These are found in the chapters “Der physiologische Raum im Gegensatz zum metrischen,” “Zur Psychologie und natürlichen Entwickelung der Geometrie,” “Zeit und Raum physikalisch betrachtet,” and “Die physiologische Zeit im Gegensatz zur metrischen.” The first three are translated into English, with minor differences, in *Space and Geometry*.

is, there is *visual space*, *tactual space*, *auditory space*, and (or equilibrium) *labyrinth space*. (This is his primary reason for objecting to Kant's view that space is an a priori form of sensibility.)

4. Each of these sense-spaces have their own peculiar *systemic properties* that are based on their relational characteristics. For example, visual space discloses a three-dimensional, bounded, finite field of multiple co-present locations that is anisotropic for various parts (e.g., a right-left, above-below, near-far differentiation). Tactual space of the skin is a closed two-dimensional space of co-present locations that is also anisotropic. Labyrinth-spatiality is quite different from both of these, in that it has no co-locative characteristics, but only directional properties. Auditory space also has its own systemic properties. None of these sensory spaces is Euclidean in structure.
5. However, these sense-spaces are integrated by way of a mechanism Mach called a '*space-register*,' probably correlated with a region of the brain. He concluded that the spatial structure of the space-register is very close to Euclidean in its overall properties.
6. *Perceptual time* displays little difference over the various sense-modes and is present in all of them. But, like space-perception, it has several important relational and systemic features. One is a kind of anisotropy in relation to rhythms (especially salient in hearing), which is based on its initial beat at a different point in the rhythm. Another is the occasional reversal of time-order, as in the case of the 'physician's illusion (where blood is perceived to flow prior to incision).'
7. Mach also found it necessary to postulate a '*time-register*,' centered in the brain, that integrates the features of sensory times with memory and the anticipatory perception of imagination. It is particularly within this register that time has its dominant overall feature of uni-directionality.
8. The *primary function* of both space and time sensory structures is for the *organism's adaptive satisfaction of its needs*. This includes the need for its continuation, its avoidance of pain and its obtaining nourishment and pleasurable sensations. But it also has aesthetic and intellectual needs, which lead to artistic expression and philosophical and scientific inquiry.

In the "Bemerkungen," after considering perceptual space, Mach discusses how geometrical space is a more abstract concept that reflects primarily, but not completely, the characteristics of visual space. Indeed, later he refers to it as 'metric space' and extends the notion to 'metric time.'[4] Central to this idea is the operation of measurement.

The important insight here is that the measuring operation involves a comparison of a physical object with a standard of measure. That is, a space-measurement results in a numerical value that indicates a relationship between the object and the standard. Thus, metrical space is fundamentally relational. This is distinguishable

[4]EI, p. 337 and p. 423.

from the structure that is the focus of space as a system based on these metric relationships, such as is found in the systemic characteristics of geometry. The systemic notion of space is more abstract but founded on this more fundamental metric space relation. Later[5] he points out that although one of the simplest systemic ideas is that of Euclidean geometry, alternative systems can also be formulated, such those of Riemann and Lobachevsky.

From this idea of metric space as essentially founded on the notion of space as a relation between object and standard, he moves further to characterize *physical space*. As he says: "… one could go further in the hierarchy of space–ideas and thus come to the idea whose core insight I would like to call *physical space*."[6] Mach recognized that the generally accepted idea of physical space, as well as physical time, had been that of a 'hyperphysical container' of all objects considered to be material bodies and processes. Space was thought to have Euclidean properties, and time a simple systemic structure. This view was expressed in Newton's discussions of absolute space and time.

However, Mach found Newton's idea to involve serious problems, including the fact that it cannot be connected with what is experienced regarding things in nature. This led him to a radically different idea of physical space and time, based on a new way of defining or characterizing what is usually referred to as 'matter.' Thus he states: "Let us thus think under the term 'matter' a something in which various states can occur. Let us imagine, for the sake of simplicity, a pressure that can become greater or less."[7] This concept does not involve direct appeal to space or time. Matter is a mere something that can be determined with regard to certain properties, which are observable. Later he clarifies this as being by either direct perception or indirectly through instruments. The important point is that the ways in which it is or can be determined are *states*. The example here of *one* observable, pressure, is only illustrative of what is characteristic of a state. In fact, material objects, which include either the more stable forms we think of as 'things' or 'bodies' or the more fluid forms we call 'processes,' are characterized by several factors, including pressure (or force), mass, temperature or heat aspects, electrical aspects, magnetic aspects, and possibly even other aspects. The important point is that a state is something that is *observable* and *variable* in its particular quality or value.

Further, he proposes a major shift in the concern of physics:

Now it appears to me that the fundamental law of force of nature should no more contain spatial relations, but rather ought to express the dependence between the states of matter.[8]

That is, the primary objects observed by the scientist are various bodies and processes, each characterized by its state. Mach here seems to mean that the parameters generally taken as 'spatial' and 'temporal' (x, y, z, and t of equations)

[5]SG, p. 134.

[6]BER, p. 230.

[7]BER, p. 231.

[8]BER, p. 231.

are to be understood as referring to the relational concepts of metric space and time, which are more concrete spatio-temporal concepts. While these are useful, they are not essential for describing what is more fundamental: the states of physical objects and their relationships. Thus, he sets aside the earlier view that considers space and time as 'primary characteristics' of matter.

As he points out:

> The [idea of] physical space that I have in mind (and which contains time in it) is thus nothing other than dependence of the phenomena on one another. A completed physics, which would know this fundamental dependence, would need no special space- and time-considerations, for these would be already exhausted [erschoepft] or included.[9]

Accordingly, what Mach calls 'physical space' seems best understood as more abstract than the traditional 'container' idea. It is fundamentally relational and is a kind of 'mathematical manifold' that might be called 'the physical manifold,' which includes within it the time-relation or physical time. It differs from the Newtonian idea of 'absolute space and time' in three important ways:

1. it does not involve any assumptions regarding the systemic structure of space or time;
2. its features are all based on observable relations; thus, it is not 'metaphysical' and 'senseless' (or 'sinnlos'), as is the case with absolute space and time;
3. its systemic characteristics are dictated primarily by what is found through observations; thus, it can be Euclidean, Riemannian, or Lobachevskian, or indeed any other systemic structure compatible with observations.

Although Mach himself was of the opinion that the observational data of his time were accountable equally well by either Euclidean or non-Euclidean geometries, he considered the Euclidean system preferable because of its greater conceptual simplicity. However, he saw that further observations, particularly on the scale of the very large or very small, might demand a non-Euclidean systemic structure. That is, this idea of physical space and time serves as the basis for a major liberation of scientific thinking to explore radically different conceptual models. Indeed, he concludes the "Bemerkungung" with an interesting suggestion in that direction, that would turn physics and chemistry conceptually upside-down:

> If one has thought till now of physical phenomena, including chemical ones, preferentially as motions, positioning near one another, etc., then one will perhaps not without advantage try to think of motion-phenomena *chemically*, for example. Light is supposed to be an oscillation. We know that chemical reactions can be incited by light. Why could we not think of light as a rapidly alternating beginning chemical separation and combination?[10]

Of course, this is only an example of how science might possibly develop. Whether that would be useful was yet to be determined.

[9] BER, p. 232.

[10] BER, p. 232.

This fundamental insight was later given two somewhat nuanced further characterizations. One is expressed in the third edition of *Analyse der Empfindungen*, where he states that space and time are relations of simultaneity.[11] This at first glance seems puzzling, but can be seen to hold clearly for metric space and time. That is, any measurement involves the comparison of the object measured with the standard. But that comparison can occur only if both are juxtaposed in the same act of observation, which must occur at a given time. That is, the object and the standard must be simultaneously present, so that the measurement is a relation of simultaneity. This holds for both space- and time-measurements.

The second point is Mach's later differentiation between physical space and physical time. This is briefly mentioned in edition 3 of *Analyse* and more fully discussed in EI.[12] The central idea is that *physical time* is fundamentally a *relation of immediacy*, while *physical space* is a *relation of mediacy*. In EI he describes a thought experiment that illustrates the difference between them, which I now summarize:

The *immediacy of the time-relation* is illustrated in a thought-experiment,[13] where the spatial relation is rendered inconsequential. Mach proposes three bodies, u_1, u_2, u_3, identical in all aspects except for temperature, connected with each other in such a way that the conditions of heat-transference are the same for each pair. (See Diagram 1). Further, they have an infinite inner conductivity. Under the Newtonian law of thermal conduction, if the respective initial temperature-differences from the average temperature are V_1, V_2, V_3, and the temperature differences from the average at any time after the initial state are v_1, v_2, v_3, then the law follows:

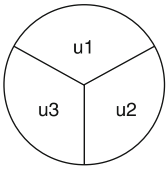

Diagram 1

$$\begin{aligned} v_1 &= V_1 e^{-3kt} \\ v_2 &= V_2 e^{-3kt} \\ v_3 &= V_3 e^{-3kt} \end{aligned} \tag{32.1}$$

It likewise follows that:

$$v_1/V_1 = v_2/V_2 = v_3/V_3 \tag{32.2}$$

[11]"All accurately and clearly recognized relations may be regarded as mutual relations of simultaneity." AS, p. 94.

[12]That space is a relation of mediacy is discussed on pp. 91–92 of AS. This is more fully clarified in the chapter of EI entitled "Zeit und Raum physikalisch betrachtet", pp. 434–439.

[13]EI, pp. 434–5 [426–7]. Unfortunately, the most recent German addition has changed the pagination that was in the original edition without any explanation for that change, no doubt giving rise to needless annoyance for scholars. Here I use the page numbers of the 1906 edition.

Reflecting on this, he finds the *essential characteristic of physical time*. First he notes that the value of the variable t in eq. (32.1) is simply the value of the state of a standard process (in the usual case, that of the earth's position in rotation). This is a matter of *convenience*, since *any* process could be used to characterize the t variable with perhaps other forms for eq. (32.1).

Beyond the conventionality of the form of the equations, however, Mach sees the essential nature of the temporal relation as lying in two aspects. The first is its *one-sensedness*. Eq. (32.1) indicate the fact that in the process concerned, there is only a *decrease in differences.* As he states:

> We must think of each event as determined by differences, if science is to be able to get at it at all. Where no differences are accessible to us, we are also not able to find any determination. But if we imagine for a moment that the differences would increase, we then recognize the incompatibility of this view with most general traits of our world-image, that nowhere are there aimless changes, but that everywhere is disclosed a tendency towards a determined state.[14]

That is, the direction of time as one-sensed lies in the fact that, as in the given illustration, processes are always related so that differences decrease. This generalization is indeed broad, and at first would seem to be controverted by many common experiences, such as those in which the original differences are set up. Mach answers this:

> Indeed, it occurs that certain differences increase, if certain other more important ones decrease in return; but an uncompensated spontaneous increase of *one* difference does not happen.[15]

That is, the cases of difference-increase involve partial compensation by other decreases. This can be stated abstractly: *wherever there occurs an increase of difference of one or a set of variables, there can always be found another variable or variables whose differences decrease*.[16]

[14]EI, pp. 436–42: "Jeden Vorgang, soll die Forschung demselben überhaupt beikommen können, müssen wir uns doch durch irgend welche Unterschiede bestimmt denken. Wo uns keine Unterschiede zugänglich sind, wissen wir auch keine Bestimnmung zu finden. Denken wir uns aber für einen Augenblick, die Unterschiede würden sich vergrössern, so erkennen wir die Unvereinbarkeit dieser Vorstellung mit den gewöhnlichsten Zügen unseres Weitbildes, das nirgends Veränderungen ins Ziellose zeigt, sondern überall ein Streben nach einem bestimmten Zustand verrät."

[15]EI, p. 436: "Zwar kommt es vor, dass gewisse Differenzen sich vergrössern, wenn dafür gewisse andere *gewichtigere* sich verkleinern, allein eine unkompensierte spontane Vergrösserung *einer* Differenz kommt nicht vor."

[16]Mach interjects here that this formulation makes the question of the *heat-death* of the universe quite clear, a point that he had evaluated as 'sinnlos' or scientifically meaningless in CE. For, the universe may be either finite or infinite in extent. But if it is infinite, then there can always be found systems outside any finite (observed) system whose variables of state could supply the necessary difference-decrease, in order to increase the differences in the observed system, or at least to maintain them at a constant level. But for *observation* the universe is finite. By this it is meant that only a limited number of variables can be observed at any time. It is thus impossible to determine by observation whether it is ultimately infinite or finite. Accordingly, no decision can be made, since the limitedness of observation renders it always possible to discover new compensating variables that serve to maintain the status quo. The question of a heat-death can thus in no way be empirically decided, and is therefore a nonsense-problem, a metaphysical question.

In the eq. (32.2) Mach comes to the second point, which is the specifying aspect of physical time:

> Deviations from the average temperature undergo *simultaneous* variations, which are *dependent* on each other and indeed *proportional* to one another in immediate mutual relation of the bodies.[17]

and:

> The determination of variations through the differences of bodies is *mutual*, since no body has a preference over the other; since as in our example, the *one* body receives what the *other* loses.[18]

Thus, eq. (32.2) show the direct *mutual interdependence* of the variables: the value of one determines that of the others. By having eliminated the influence of space through the original conditions of the experiment, and now by eliminating the relationship to processes extrinsic to the process, the nature of the temporal relation more fully expressed in eq. (32.2). *Immediacy* and *mutuality* of determination are the characterizing factors.

Mach then clarifies the essential characteristic of *physical space*. It is a relation of *mediacy*. Continuing illustratively, he proposes a variation in the thought-experiment, which introduce space as a significant factor.[19] (Diagram 2.) Taking four identical bodies with temperature variables u_1, u_2, u_3, u_4, of the same types as before, he joins them in a ring. Where c is the sum of those temperatures, U_1, U_2, U_3, U_4 the initial temperatures, and u_1, u_2, u_3, u_4 are the varying temperatures, he finds the relation[20]:

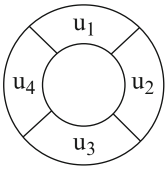

Diagram 2

$$u_1 = \frac{1}{4}\left[c + (U_1 + U_3 - U_2 - U_4)\, e^{-4kt} + 2\,(U_1 - U_3)\; e^{-2kt}\right] \tag{32.3}$$

Analogous equations hold for the other u_i. Eq. (32.3) shows the spatial relation as a matter of introducing a complexity in which *mediately* related objects (here u_i) affect the variable in a way different from the effect of those immediately related to it. In this case, no mutual determination can be found, as was expressed in Eq. (32.2).

[17] EI, p. 435: "Die Abweichungen vom Temperaturmittel erfahren *simultane*, voneinander *abhängige*, and zwar bei *unmittelbarer* Wechselbeziehung der Körper einander *proportionale* Änderungen."

[18] EI, p. 436: "Die Bestimmung der Änderungen durch die Differenzen der Körper ist *gegenseitig*, da kein Körper vor dem andern einen Vorzug hat, da, wie in unserem Beispiel, der *eine* Körper empfängt, was der *andere* verliert."

[19] EI, p. 437.

[20] EI, ibid.

It is this failure of simultaneous mutuality of determination that space brings into the system.

If the system is expanded to more mediating links, the effect is fortified. Mach observes:

> The regular ordering of the four masses in a ring corresponds to a simple, finite, unbounded, linear Riemannian space of four discrete elements. The ring-form has given us the advantage of obtaining greater perspicuity through the application of cyclical permutation. Instead of four masses, we could have considered, without an essential change of the result, a ring of a hundred or even, as Fourier does, a homogeneous ring with continuous distribution of the temperature. We obtain a two-dimensional Riemannian space by filling a thin spherical shell with an arbitrary number of masses arranged in it. By the fiction of suitable conducting connections we could imitate still other spatial arrangements with respect to their physical consequences. The result of our reflection always remains the same. The influence of mediate physical relations is manifested later, and is covered and observed by the immediate relations or by relations mediated through a lesser number of connecting links. *In spatial relations are expressed mediate physical dependencies*.[21]

I need not comment on the extension to more complicated systems. The important point here is that he makes use of the more abstract idea of a mathematical space (referred to as a 'Riemannian space' or 'manifold') as a convenient way of thinking of the more concrete physical spatiality. He clearly avoids confusing or conflating them. One is concerned about the relationships among physical phenomena; the other serves as a more general way of thinking of their relationships. But what is most important is that physical space involves a relation of mediacy. That is, spatially separate phenomena are related only by way of determining phenomena to which they are immediately related.

In this is also contained an insight into the close connection between time and space. For, spatial intermediacy would not arise if the mediately related parts (e.g., u_3 with respect to u_1) were to affect those mediating parts (u_2 and u_4) instantaneously. It is solely by virtue of this mediation that space can be involved in any physical process. That is, only in so far as there is such a mediated determination of one part by another is space *physical*.

We may consider in contrast a world in which the relations of dependence were *all immediate*. There would then be *no physical space*. Here, of course, we must not

[21]EI, P. 439: "Die regelmässige Anordnung der vier Massen in einem Ring entspricht einem einfachsten endlichen unbegrenzten linearen Riemannschen Raum aus vier diskreten Elementen. Die Ringform hat uns den Vorteil geboten, grössere Übersichtlichkeit durch Anwendung der zyklischen Vertauschung zu erreichen. Wir hätten statt vier Massen, ohne wesentliche Änderung des Ergebnisses, deren hundert oder gar, wie Fourier, einen homogenen Ring mit kontinuierlicher anfänglicher Verteilung der Temperatur betrachten können. Einen zweidimensionalen Riemannschen Raum erhalten wir durch Ausfüllung einer dünnen Kugelschale mit den in dieser angeordneten Massen von beliebiger Zahl. Durch die Fiktion passender leitender Verbindungen könnten wir noch andere räumliche Anordnungen in Bezug auf ihre physikalischen Folgen nachahmen. Das Ergebnis unserer Betrachtung bleibt immer dasselbe. Der Einfluss der vermittelten physikalischen Beziehungen äussert sich später, and wird durch die unmittelbaren oder durch eine geringere Zahl von Zwischengliedern vermittelten Beziehungen verdeckt, verwischt. *In dem räumlichen Verhältnissen äussert sich die vermittelte physikalische Abhängigkeit*."

confuse this with Mach's first example, which *abstracts* from spatiality by looking only at the thermal interaction. If he were to consider the matter, say, mechanically, the spatiality of the bodies would enter. In the case where *all* dependencies of mediacy are eliminated, only one object could be found, and in that differenceless world, it follows that nothing could occur. That is, *without physical space, there is no physical time*. The converse also follows, since the elimination of all immediate dependence would be entailed; and without immediate dependence, mediate dependence, or space, would be absurd. Physical space and time are thus co-ordinate relations, although they can be abstractly isolated in the way Mach does here. We may add, finally, that since physical space and time are specific variations of the notion 'dependence,' they are essentially modifications of the most abstract notion of causality (i.e., functional dependence or logical conditionality).

This revolutionary idea of physical space and time is closely connected with what Mach regarded as the fundamental task of physics, which he describes most generally:

> Everything that we can want to know is given by the solution of a problem in mathematical form, by the ascertainment of the functional dependence of the sensational elements on one another. This knowledge exhausts the knowledge of 'reality.[22]

This seems best understood as saying that the aim of science is to describe the functional relationships of the states of what he calls 'matter.'

Now I would like to make some concluding observations. The first is regarding his notion of physical space and time as centering on the relations of 'states that can be expressed as values of variables within an abstract manifold.' He held that states can be ascertained either directly in perception, as in the case of observing what are called 'bodies' or 'processes' like the motions of those bodies, or indirectly, as in radioactive decay or the motion of electromagnetic waves. Although understanding may be aided by way of visualizing them as occurring in some sort of 'containing' space-time, there is an obvious problem with states involving more than three or four dimensions. That is, Mach's view offers a way of freeing scientific thought to think in ways beyond the more traditional ideas of space and time as containers.

Further, it is important to get an accurate understanding of what Mach's proposal actually involves before critiquing it. Some scholars have failed to do this and thus raised spurious objections against his view.[23]

Finally I think it might be very useful to assess whether the further development of modern physics can be more fully accounted for in terms of his proposal. I suggest that the actual empirical discoveries in astronomy, such as gravitational lensing or black holes, may well be accommodated within his view. Even his objections to Einstein's theory do not involve an outright rejection in principle, but only the failure

[22] AS, p. 369.

[23] Some of the more serious failures to do this by critics of Mach seem to be exemplified in the comments of Mario Bunge and Howard Stein. I concur with Gereon Wolters' analysis (in *Mach I, Mach II, Einstein und die Relativitätstheorie*, esp. pp. 70–90) of Stein's misunderstanding of Mach.

of the data gathered prior to his death to give it full confirmation. This may also hold for the discoveries in quantum physics, including its use of atomic and sub-atomic models.

Thus, at least in principle, his view can accommodate types of 'causal' relationships, or more exactly relations of functional dependence, such as various sorts of action-at-a-distance, including gravitation, the 'Mach Principle' or even Bell non-locality. More generally, it accommodates very different types of relationships between states than is traditionally accepted as possible. This in includes the relationship between states of matter that are not only spatially distant, but also the possibility that a later state could determine an earlier state, or even that a 'mental' state could determine a 'physical' state. However, whether such determinations actually hold are dictated solely by what is observed in experience.

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Chapter 33
The Discovery of the Mach Reflection Effect and Its Demonstration in an Auditorium

Peter Krehl and Martin van der Geest

Abstract This paper examines the historical back ground leading to the discovery of the Mach reflection effect and applies original documents from Mach's residue which are kept in the archives of the Ernst-Mach-Institut in Freiburg. Two experimental setups for the generation and demonstration of the Mach reflection effect, incorporating an overhead projector, are described: (i) Mach's historic mechanical shock wave reflection and interaction experiments with soot covered glass plates, performed in 1875. The Mach triple points sharply erase the soot which results in a residual picture of funnel-shaped V-formations. The head-on collision of two shock waves is marked as a narrow line of piled-up soot. (ii) Caltech's hydraulic jump reflection experiments in a shallow ripple tank, performed during World War II. Regular reflection and its transition into a Mach reflection wave. Using a slightly inclined tank and providing a "shoreline" in the middle of the tank, Mach stem propagation slows down to zero when hitting the shore line and, therefore, can be observed "live" without the use of a slow-motion technique.

Keywords Ernst Mach · History of shock wave research · Mach reflection · Gas dynamic/hydraulic analogy

33.1 Introduction

Ernst Mach (1838–1916), a universalist of science in the classical sense and a leading authority of his time in philosophy, physiology and physics, was also a pioneer in fluid dynamics and ballistics. He was the first and foremost who

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F. Stadler (ed.), *Ernst Mach – Life, Work, Influence*, Vienna Circle Institute Yearbook 22, https://doi.org/10.1007/978-3-030-04378-0_33

Fig. 33.1 A little-known portrait of the young Ernst Mach at the age of 23, then appointed *Privatdozent für Physik* at Vienna University, Austro-Hungarian Empire

recognized the characteristics of shock waves and invented various high-speed visualization techniques and shock wave diagnostic methods (Blackmore 1972). Figure 33.1 shows a portrait of the young Ernst Mach.

For many physicists and engineers, the name of Ernst Mach is associated mainly with the Mach number, the ratio of flow speed to acoustic speed which can be less than, equal to or greater than unity according to a steady subsonic, sonic or supersonic flow, respectively. Furthermore, he discovered the occurrence of head waves (or bow waves) which surround a body flying with supersonic speed and which, for example, creates the well-known sonic boom of supersonically traveling aircraft.

However, the Mach reflection effect is certainly his most important contribution to fluid dynamics. Today, more than 115 years since his first conclusions, it now as before remains a phenomenon which is unexpected and fascinating for the newcomer as well as surprising and challenging for the expert because of the continuous discovery of new side effects and the tremendous difficulties in modeling them mathematically. From 1981 a special international symposium has been dedicated exclusively to this effect.[1] Mach reflection is a very basic effect in shock wave physics and can cover all ranges of shock pressures. Although mostly investigated in gases, it exists also in liquids and even in solids, where ultrahigh dynamic pressures can be achieved in very simple arrangements (Fowles and Isbell 1965).

[1]The International Mach Reflection Symposia have been held in Victoria, BC, Canada (1981); Sydney, Australia (1982); Freiburg, FRG and Melbourne, Australia (1983); Tokyo and Sendai, Japan (1984); Menlo Park, CA, U.S.A. (1985); Beer Sheva, Israel (1986); Albuquerque, U.S.A. (1987) and Toronto, Canada (1988).

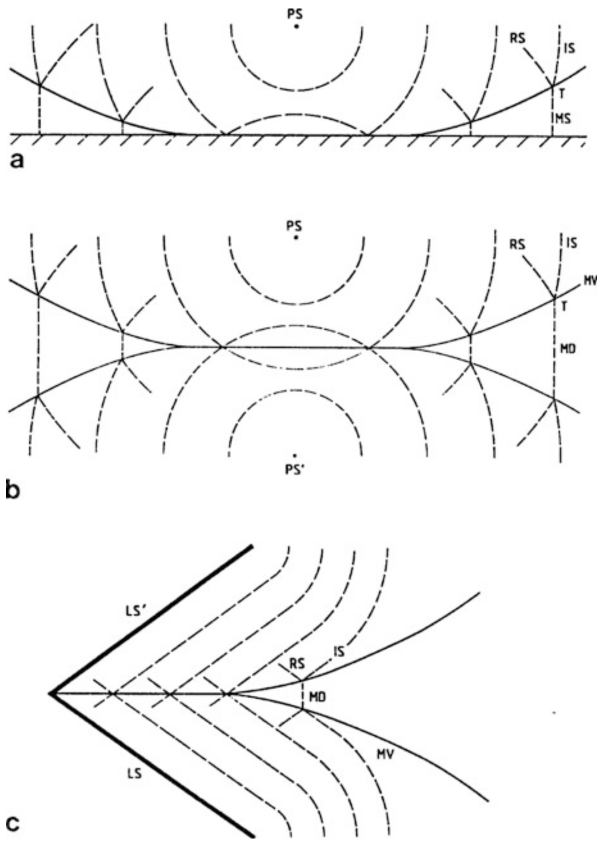

Fig. 33.2 (**a–c**) Different geometrical arrangements to generate Mach reflection: (**a**) reflection of a shock wave at a rigid boundary; (**b**) corresponding analogous setup of two identical and simultaneously triggered point shock sources PS and PS'; and (**c**) oblique interaction of shock waves emerging from two simultaneously exploding linear sources LS and LS'. Broken lines represent instantaneous shock wave patterns at four successive time instants, solid lines the residual soot picture. *IS* incident shock; *RS* reflected shock; *MS* Mach stem; *MD* Mach disk (or "Mach bridge"); *T* triple point; and *MV* Mach-V (or "Mach funnel")

Quite frequently visitors to our institute show a particular interest in the Mach reflection effect, and we can refer to our large collection of photographs on shock propagation and reflection phenomena studied within shock tubes and in the free field, but also in liquids. These pictures, mostly taken in shadowgraph, schlieren or interferometer arrangements with sophisticated and expensive high-speed framing cameras, makes one forget that the era of gas dynamics started with very simple but highly ingenious methods and apparatus. In recent years, already two from our institute (Merzkirch 1970; Reichenbach 1983) have reminded us of this glorious beginning. The present paper follows this line by describing two different types of historic Mach reflection experiments modified by us for demonstration purposes. They are both easy and inexpensive to prepare and appropriate to be shown to a large audience with the aid of an overhead projector.

The Mach reflection effect – in shock wave physics briefly called "Mach effect" – is illustrated in Fig. 33.2a. At sufficiently oblique incidence angles the reflected shock wave no longer meets the incident shock wave directly at the boundary, but rather at a point in the fluid. The two waves join to form a third shock wave extending to the wall. This form of reflection is known as "irregular reflection"

(Courant and Friedrichs 1948). In the beginning of analytical treatment this three-shock configuration was also known as a “λ-configuration” (Courant and Friedrichs 1948), but later-on this designation was rarely used. Today, the third shock is frequently described as the *Mach shock* and, according to the applied geometrical setup, as *Mach stem* and *Mach bridge* (or *Mach disc, Mach disk*). At the triple point, three regions of different pressures and densities join each other in the *Mach triple point.*

Merzkirch (1970) mentioned that the designation “Mach effect” for an irregular shock reflection originated from Seeger in 1944. However, already in his publication on oblique shock reflection, von Neumann (1943) cited a paper by K. Friedrichs entitled “Remarks on the Mach effect” which was presented in 1943 at the Applied Mathematics Panel of the National Defense Research Committee (NDRC). Today it is difficult to state with certainty who coined this designation. Obviously, the originator had a profound knowledge on the history of gas dynamics.

33.2 Shock Reflection Soot Experiments

33.2.1 Historical Remarks on the Mach Reflection Effect

Ernst Mach discovered the reflection effect in 1875 at the Physical Institute of the German University of Prague. At that time, he still had his laboratory at No. 562-1 Obstmarkt 7, a building located in the town center and close to the “Carolineum,” the oldest building of the University. The discovery was favored by the coincidence of the following factors.

First – Mach was basically an experimentalist, and his great success in physical interpretation was based on observation. Consequently, he was fascinated by any new visualization technique. There already existed a remarkable body of dust recording methods for acoustical and electrical phenomena. G.C. Lichtenberg (1742–1799) was the first who in 1777 made visible traces of gliding sparks along insulators by dusting them. E.F. Chladni (1756–1827) discovered in 1787 sound figures of oscillating membranes, and A. Kundt (1839–1894) introduced this method in 1866 to mark standing waves in acoustic resonators. Curious as to the acoustic nature of Kundt’s dust figures, Mach asked his assistant C. Dvorak (1848–1922) to investigate them more closely.

Second – Mach, particularly interested in refraction and reflection of acoustic waves since 1860, had just performed with his assistant A. Fischer physiological-acoustic studies using electric sparks as a source of sound. This combined curiosity in acoustics and electricity continued during his whole life and led to remarkable achievements such as intense electric spark light sources, trigger circuits with tunable microsecond time delays, and high-voltage high-current pulse generators.

Third – At the same time, K. Antolik, professor at Kaschau College in Hungary, published a paper entitled “The gliding of electric sparks” (Antolik 1874). At first experimenting also with dust to mark spark traces, he discovered the suitability of soot by chance. Bringing a small soot-coated glass balloon close to the spark of an influence machine, he noticed a well-marked trace of the spark in the soot. He readily developed a new soot recording technique which was later taken over by Mach who observed an important phenomenon: soot covered glass plates, brought close to crooked electrical discharges, showed complicated V-shaped patterns which, however, disappeared when the air between the plates was evacuated. It is important here to point out the fact that, contrary to dust, only the soot method is capable of recording traces of the triple points as will be shown later in Fig. 33.7. Furthermore, dust is less appropriate in high-voltage arrangements, because charges on the plates, induced by electrostatic influence, can also affect dust transportation.

Fourth – It was Dvorak who brought this paper to Mach's attention. Dvorak repeated Antolik's experiments and demonstrated them at the regular institute's seminars. Here Mach, an expert both in acoustics and electricity, speculated for the first time that the origin of these soot figures was merely caused by an interaction of acoustic waves originating from the electric sparks. At that time, he was not yet conscious of the phenomenon of shock waves which propagate faster than acoustic waves. Later on, Antolik was also invited into Mach's institute and lectured on his work.

Then, only within a few months after Antolik's publication, Mach together with his student Wosyka eagerly verified his discovery by also applying other experimental methods. Already on April 15, 1875, Mach communicated to the Imperial Academy of Sciences of Vienna in a brief note that he and Wosyka had successfully repeated Antolik's experiments, revealing that Antolik's soot pictures are caused by an interference of acoustic waves (Wiener Akad. Anzeiger 10:83). Their final results, submitted for publication on June 10, 1875, are summarized here as follows (E. Mach and Wosyka 1875):

(i) They repeated Antolik's soot experiments, but immersed the glass plates in turpentine. They obtained also the V-formations which, however, were somewhat blurred because the liquid partly dissolved the soot. This proved for the first time the existence of irregular reflection in liquids.
(ii) They used a rectangular plate of transparent glue which had just solidified and hit one corner with a hammer over a piece of wood into which a rectangular cutout had been milled and brought into contact with two edges. Applying an optical setup with crossed polarizers he observed the propagation of mechanical waves emitted from both corners and their mutual interaction. Again, they obtained similar results of funnel-shaped V-formations as obtained in their previous soot experiments. This method was even recommended for demonstration in an auditorium. As a light source they used a heliostat, a plane mirror driven by a clockwork mechanism which reflected sun light into the darkened lecture hall. Today this method – to optically diagnose stress distributions in solids – is called "photoelasticity."
(iii) They also successfully used surface waves for modeling purposes which will be described further in Sect. 3.1.

Although the schlieren method, a considerably more powerful recording method, was already discovered in 1865 by A. Toepler, it was infrequently used by Mach in the beginning because of technical problems such as providing an intense flash light source, an electric delay circuit in the microsecond regime, low sensitivity of available films, *etc*. However, later on it became his favorite method in photographing supersonic projectiles. It is interesting to note that Mach ingeniously concluded the existence of an irregular reflection behavior merely out of soot pictures which can provide only residual traces of the triple points. On the other hand, shock physicists nowadays are accustomed to think more in terms of instantaneous wave patterns such as provided directly by high-speed photo-instrumentation.

We do not know today how Mach himself felt about his discovery. His numerous communication notes with the Vienna Academy as well as his publications reveal that he was also working in 1875 successfully in completely different fields such as optics and physiology. His private notebook of this period also documents that only a minor part of his entries relates to the reflection effect. Certainly, his major research activities were a continuation of previous years, while he was overcome with the discovery of nonlinear reflection phenomena by chance. But after 1875, Mach and his team continued on the soot recording technique and applied it to various problems: mechanical-acoustic effects of electric sparks (Rosicky 1876); measurement of the velocity of shock waves (E. Mach and Sommer 1877; Mach et al. 1878); study of propagation of two- and three-dimensional shock-wave criteria for the occurrence of irregular reflection (Mach 1878), and investigation of the fine structure of the V-formations (E. Mach et al. 1878; E. Mach and Simonides 1879). Wosyka was excluded from the team. The reason was described in a short note dated from 1886 and is now in the Ernst-Mach-Archives. Mach stated that among other things: “In the year 1876 my assistant J. Wosyka was discharged at once from the institute for book stealing. I have replaced the books. I have fallen, because of this behavior of Wosyka who was indebted to me for many things, into an emotional depression which has made me for years incapable of work.” He developed an eye ailment related to high blood pressure which led to migraine headaches (Blackmore 1972).

These publications laid the cornerstones of modern shock wave physics and can be summarized as follows: B. Riemann (1826–1866), professor at Göttingen University, was the first who in 1860 mathematically treated shock waves as waves of finite amplitude and predicted for shock waves a higher propagation velocity than the sound velocity (Riemann 1860). Mach carefully analyzed his first experiments of 1875 and experimentally confirmed Riemann’s very important conclusion that shocks are waves of finite amplitude and propagate faster than sound waves. In the case of an oblique intersection of two shocks, a new secondary wave is generated in the plane of symmetry which has a higher strength and which propagates faster than the component of the primary shocks in the direction of the axis of symmetry. Also, examining the fine structure of the soot lines under a microscope, he concluded that the secondary wave was of greater strength by the fact that the soot inside the two branches of the V-formation was compressed stronger than outside the ‘V’. From simple geometric considerations of the velocity vectors of incident and reflected waves he calculated the starting point of the V-formation in the fluid and found experimental evidence for this. However, the first comprehensive analytical treatment of the Mach effect did not succeed until World War II (von Neumann 1943). Later, Ernst Mach first used a Jamin interferometer to measure the density jump at the front of an aerial shock wave generated by a spark discharge (E. Mach and von Weltrubsky 1878). In the following years, this ambitious diagnostic objective might have initiated the development of the Mach-Zehnder interferometer (L. Mach 1891) which is a more appropriate construction for applications in gas dynamics than the Jamin interferometer.

How was then the echo in the physical community of his time on this remarkable achievement? Theoreticians on nonlinear flow did not pay any attention to his results. Notable contemporary theoreticians on hydrodynamics were e.g. Helmholtz (1821–1894), Hugoniot (1851–1887), Kirchhoff (1824–1887), Lord Rayleigh (1842–1919), and Stokes (1819–1903). There was also hardly any interest from experimentalists. This is in contrast to his next great discovery in 1886, the phenomenon of the bow shock which surrounds a supersonic projectile. First strongly doubted by French experts it was quickly accepted worldwide for its direct practical importance in ballistics. Only Baron Mathias De Waha (1842–1916), an inspector at the Institut Royale, Grand-Duché de Luxembourg (De Waha 1878) and Alois Schuller (1845–1920), professor of experimental physics at the Polytechnicum Budapest, performed similar soot experiments. Schuller had duplicated some of Antolik's and Mach's results, however, using explosives instead of electric sparks. Unfortunately, Schuller did not consider his results to be important enough for publication (E. Mach and Simonides 1879). Even many years after its first application, Mach himself showed a continuous interest in the soot technique and on Antolik's ongoing research. In a letter of May 14, 1884, Antolik describes to Mach further electric spark experiments.[2]

Then Mach's principle method of shock reflection diagnostics, the soot technique, fell into oblivion for more than 60 years until it was rediscovered in the U.S.A. during World War II. The renewed interest arose also from the revival of interest in the Mach reflection effect for military applications, both in the U.S.A. and England, for determining the optimum height of burst of atomic weapons (Reines and von Neumann 1947) and for increasing the efficiency of underwater explosions from multiple charges (Cole 1965), respectively. At that time John von Neumann (1903–1957) developed a theory on oblique reflection of shocks and became highly interested in previous experimental results. He owed his knowledge of Mach's work on the irregular forms of shock collisions to discussions with Col. H. Zornig at the U.S. Army Ordnance Department, in 1941. On von Neumann's suggestion, E.B. Wilson Jr., E. Kennedy and J. Frankl started with Mach's soot technique in the same

[2]This letter is in the possession of the EMI Archives, together with a collection of many other letters which Mach had received during his life from such famous scientists as Boltzmann, Einstein, Helmholtz, Hertz, Planck *etc*. We do not know his replies, but some of them can be found as drafts in his notebooks.

year. However, in the next year, Prof. R.A. Wood (1868–1955), professor emeritus of Johns Hopkins University and then already 74 years old, continued the experiments (von Neumann 1943). Wood, a talented experimentalist and interested in the photography of acoustical phenomena since the turn of the century, improved the original method. Much later, Seeger (1970) published some of the soot pictures from Wood's personal files by courtesy of J. WosykaMandansky, probably a descendant of Mach's student J. Wosyka. Therefore, it seems quite possible that Wosyka had met and consulted Wood personally, thus acting as a link between the discovery of the Mach reflection effect and its rediscovery in the U.S.A.

At the Ernst-Mach-Institut in Freiburg, Germany the soot technique was applied previously for various problems on detonations in gases. Detailed research on the ignition behavior of spherical detonation waves in gas mixtures was carried out, inspired by the works of Soloukhin (1966) in the U.S.S.R. and Strehlow (1968) in the U.S.A.; a review up till 1971 was given by Schultz-Grunow (1971). In these experiments a soot-coated lucite cone was used and positioned with its tip into the center of the explosion in such a way that the axis of symmetry of the cone pointed radially outwards. The spatial distribution of reaction centers from deflagration into detonation is marked on the soot as a parallelogram-type cell structure. Schmolinske (1974) extended this method by applying a combined schlieren/soot technique. The suitability of the soot method was also demonstrated for the visualization of Mach-V formations at special exit geometries of shock tubes (Reichenbach 1983).

33.2.2 Experimental Setup

The soot recording technique, although in principle easy to apply, is not familiar to modern shock physicists. We experienced the practical difficulties when we repeated the historic soot experiments. Many important parameters have not been described in sufficient detail to reproduce the experiments, *e.g.* the method to provide the soot layer homogeneously, the actual size of the soot figures, *etc*. Also, since the total capacity of the Leiden jars and their charging voltage – both influencing the shock strength – were not specified, it is difficult to get an idea of the sensitivity of the soot method. Therefore, in the following paragraphs we depict these experimental parameters in more detail.

The shock waves are produced by a pulse discharge from capacitors. To obtain strong shocks from small electrical energies, the shock propagation is confined to a thin two-dimensional channel formed by a set of parallel glass plates facing the electrodes. A schematic illustration is shown in Fig. 33.3b, a modern version in Fig. 33.3a. A pulse capacitor of approximately 5 nF is charged up to 35–40 kV and discharged via an air spark gap when its self-breakdown voltage is reached. To stabilize its trigger-voltage level independently from the applied electrode geometry on the glass plate, a high-voltage resistor of 2 MΩ is inserted toward ground. Today, any modern high-voltage power supply and capacitor would be suitable.

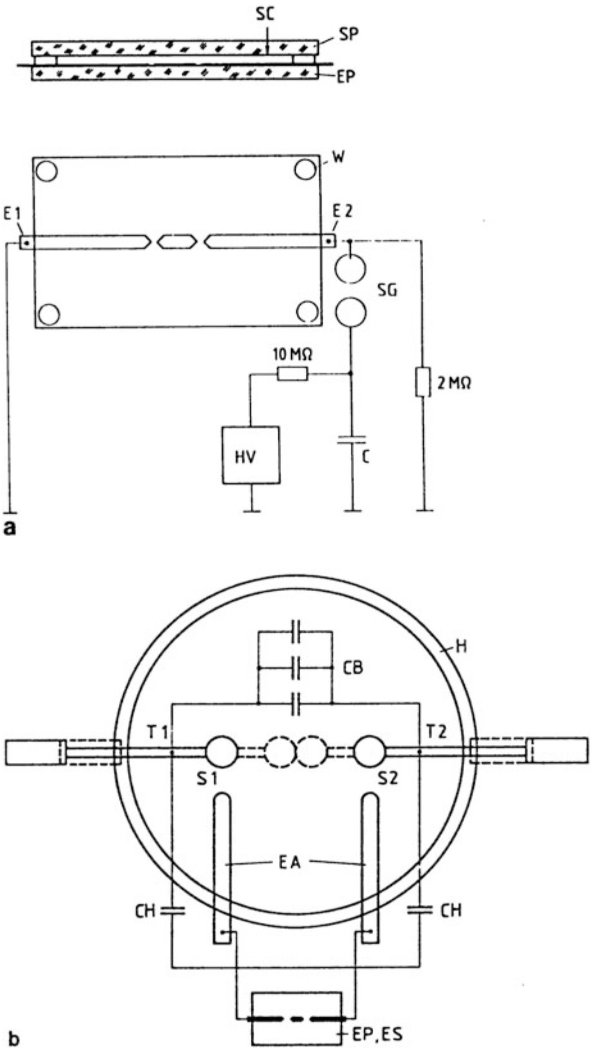

Fig. 33.3 (**a**–**b**) Schematic of the soot experiments: (**a**) modern setup: *C* pulse capacitor, *HV* high-voltage generator, *SG* spark gap, *EP* electrode/soot covered glass plates, *SP* glass plate, *SC* soot coating, *E1* and *E2* copper foil electrodes, *W* washer; and (**b**) historical setup as used by Antolik and Mach: *H* Holtz machine, *CB* additional battery of Leiden jars, *CH* small Leiden jar, *EA* "Einschalt-Apparat" consisting of two isolated mounted telescopic brass rods. Switching occurs between the two air spark gaps *S1* and *S2*. The machine is started with the connection terminals *Tl* and *T2* shortened (broken lines)

Both glass plates are 3-mm thick, have a format $210 \times 150\ \mathrm{mm}^2$ and are separated by 2-mm thick washers at each corner. The electrodes, consisting of a 0.15-mm thick copper foil, are glued on top of the lower glass plate. For cylindrical shock interactions, Fig. 33.2b, each spark is generated between the short gap of two pointed electrodes. Linear shock wave fronts as depicted in Fig. 33.2c can be produced by electric wire explosions. However, a substantial part of the capacitor energy would be needed to evaporate the wire material and only a minor part would be transmitted· into the shock wave. In this regard gliding sparks are more effective, but the discharge path of long sparks is random. To force the gliding spark in following a predetermined path, different methods had been used. Antolik applied a gold paint. Wood (Seeger 1970) drew these lines with a lead pencil. We obtained best results with silver paint, sufficiently thinned with Cyano Solv, both from GC Electronics (Rockford, IL) and applied to the glass plate with a 0.1-mm wide drawing pen. The lower surface of the upper glass plate is coated with soot. The quality of the soot layer is decisive for the resolution efficiency of the soot pictures. Antolik used a stearin-candle, but it is difficult in this way to achieve a homogeneous layer of soot. Rosicky (1876), one of Mach's assistants, improved the quality of the soot layer by using city gas. We tried various methods, including diesel fuel, petroleum, and acetylene gas. We obtained best results by using an acetylene-driven Bunsen burner, operated at 200 kPa and carrying a narrow, $40 \times 2\text{-mm}^2$ nozzle adapter. The top of the flame front should just touch the glass plate. For recording strong shock waves, it is advantageous – prior to exposing the glass plate to the flame – to provide a very thin layer of silicone grease on it by using a rubber roller. This will result in a well-adhered soot layer (Giesel 1990).

Mach and Antolik had used an array of Leiden jars charged up by a Holtz-type influence machine; their historic setup is shown in Fig. 33.3b. The first manually powered high-voltage generator based on friction electricity was invented in 1663 by O. von Guericke (1602–1686). A more effective machine based on the principle of electrostatic influence was invented in 1864 by W. Holtz (1836–1913) in Berlin and independently by A. Toepler (1836–1912) in Riga. Considered as the most advanced and powerful high-voltage generator of its time, the Holtz machine became a widespread instrument. Hundreds were produced, but very few have survived up to today. Leiden jars were the favored high-voltage capacitors at Mach's time. The Leiden (or Kleist) jar was invented in 1745 by P. van Musschenbroek (1692–1761) in Leiden, Holland and, independently, by E.G. von Kleist (1700–1748) in Pomerania, then an eastern province of Germany. In the present example three Leiden jars, each with a capacity of 1.7 nF, have been manufactured from quartz glass beakers 280 mm in height and 140 mm in diameter (such as commonly used in chemistry laboratories). The influence machine incorporates also an "Einschalt-Apparat" (Holtz 1865), a twin air spark gap device representing the air-spark switching device as depicted in Fig. 33.3a. It completely decouples the discharge load galvanically during the charging cycle, an important advantage for experimenting with high voltages. A view of a Holtz influence machine is shown in Fig. 33.4. The two small Leiden jars (each with a capacity of 15 pF) connected to the output terminals are from Leybold Didaktik GmbH (Stuttgart, Germany).

To demonstrate the Mach reflection experiments in an auditorium, an overhead projector may be used. Figure 33.5 shows an overall view of the complete setup. First the lower glass plate is put on the projector to illustrate the applied electrode geometry. Then the electrodes are connected to the discharge circuit, and the opaque, soot covered upper glass plate is laid on top of the lower plate, spaced by four washers. The experiment is started by driving up the Holtz generator. Immediately after discharge the complete soot picture, including the electrode geometry, is directly visible to the audience.

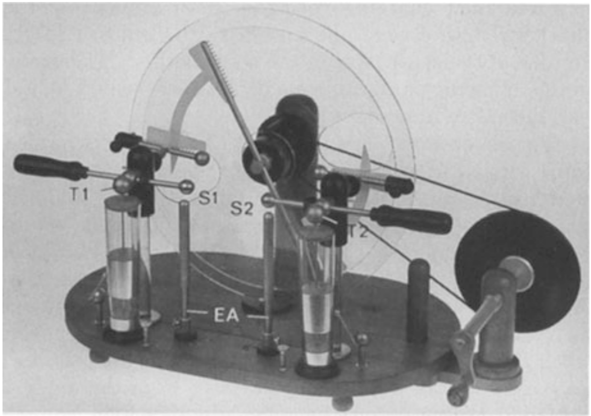

Fig. 33.4 View of EMI's reproduced Holtz influence machine as originally manufactured in 1872 by E. Borchardt, Berlin. Since the Holtz machine is not self-exciting, it has to be started by providing an external charge to one of the paper segments at the stationary glass disk such as by touching it with a hard-rubber bar which has been rubbed before by a woolen cloth

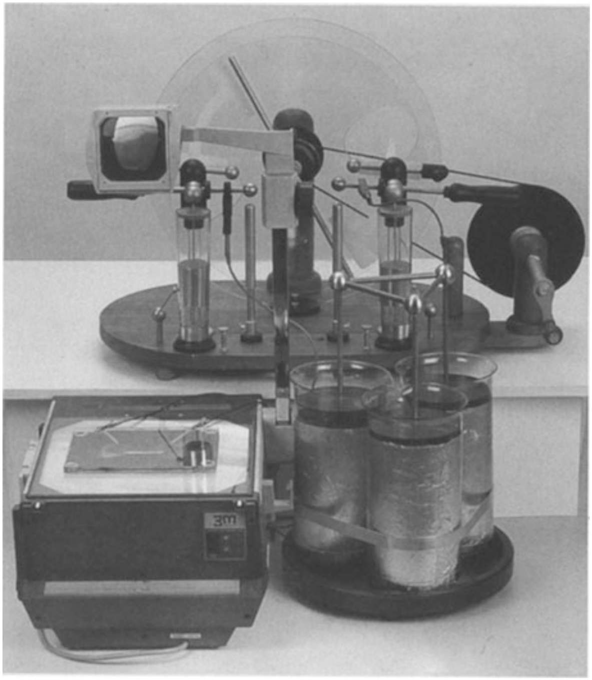

Fig. 33.5 Total setup with overhead projector for demonstration of soot experiments

33.2.3 Antolik's Gliding Spark Soot Experiments

Antolik (1875) had described a large number of soot experiments. In the beginning, he used a setup which consisted only of one glass plate. He glued the electrodes onto the glass plate and covered them with a piece of cardboard, such as a visiting-card. Then he coated the arrangement with soot by holding it over a candle. The cardboard was necessary to isolate the high voltage spark from the semi-conducting soot layer. Later he improved this method by applying a second, upper glass plate which he installed only 2–3 mm apart from the lower, clear glass plate carrying the electrodes. Obviously, this "covering method" as he called it had the advantage that cardboard was no longer necessary and that also the close environment of the sparks was nicely marked in the soot.

In the following, we want to confine our attention to a few typical experiments which are summarized in Fig. 33.6. Generally, gliding sparks along glass surfaces are rarely straight lines, extending from one to the opposite electrode as shown in

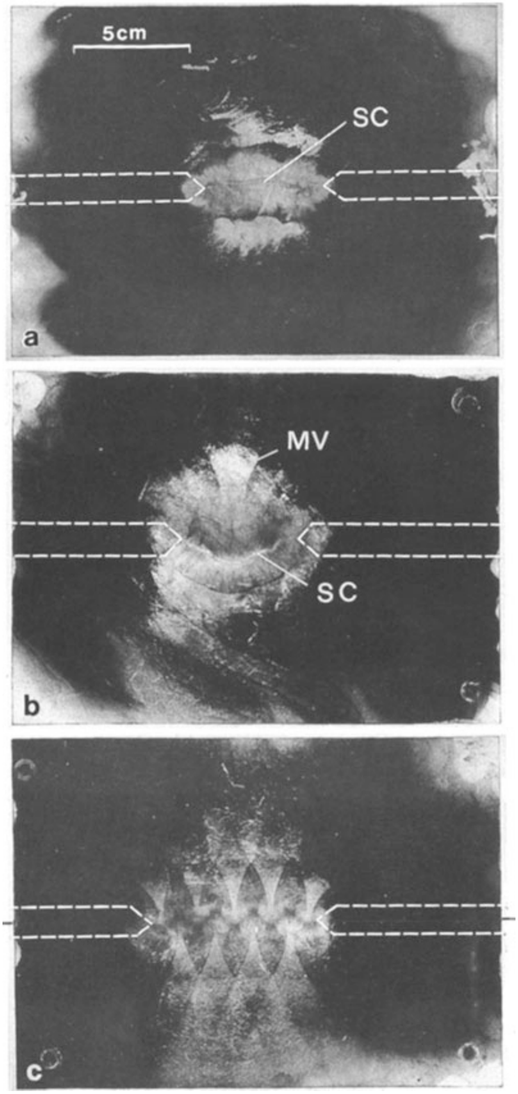

Fig. 33.6 (**a–c**) Duplication of Antolik's soot pictures: (**a**) gliding spark with a straight discharge channel; (**b**) gliding spark with a discharge channel curved at random; and (**c**) a zigzag-guided gliding spark showing a multitude of Mach-V configurations. *El* and *E2* electrodes; *SC* spark channel; *MV* Mach-V (or "Mach funnel")

Fig. 33.6a. Rather, the spark follows the instantaneous inhomogeneities in local conductivity, thus resulting in a random spark trace. In this case, shock waves emerging from such a crooked spark channel interact with each other and can create Mach-Vs as illustrated in Fig. 33.6b.

Antolik produced crooked spark channels artificially by drawing with gold paint a zigzag line on the glass plate, thus forcing the gliding spark to follow this trace. As illustrated in Fig. 33.6c, every straight section of the zigzag-shaped spark channel becomes then a source of a shock wave which, interacting with its neighbors, forms a multitude of funnel-shaped lines. Certainly, this soot picture, which is nice to look at but unexplained by Antolik, inspired Mach to reduce this complicated phenomenon to the essential mechanism by first experimenting with a single V-arrangement of two straight gliding sparks.

33.2.4 Mach's Shock Reflection Soot Experiments

With the soot technique, Mach studied four basic types of shock interaction geometries: (i) Double discharge experiments, Fig. 33.2b; (ii) Oblique interaction of two plane shock waves, Fig. 33.2c; (iii) Head-on collision of a Mach disk with a plane shock wave, Fig. 33.8b; and (iv) Interaction of two Mach-V configurations, Fig. 33.8c.

Although we still retain in our archives some of Mach's original photographs from his ballistics experiments, none of his soot pictures have passed on to us. It seems that in most cases he generated the shock waves by an electric discharge between two closely spaced glass plates. Although wave propagation is then not strictly two-dimensional because of continuous reflections along the plate surfaces, sharply pronounced shock fronts are generated. This is best illustrated in the schlieren photos Fig. 33.7c, d for the example of a double discharge. In Fig. 33.7a, b corresponding pictures were taken with the same electrical and geometrical parameters, but using different recording methods. These also document that the soot funnels truly represent records of the traces of the triple points. However, the dust method only shows that along the middle line of both discharges the superposition of both shocks is somewhat stronger than a single shock, thus sweeping the cork dust further outwards.

A soot picture of the famous Mach funnel for a V spark is shown in Fig. 33.8a. This geometry easily allows one to change the angle of incidence of both shocks which in the close environment of the spark is identical with the angle both spark channels form with each other. Initially, the soot funnel starts from a central line between the two sparks, indicating regular reflection. But at the transition angle into Mach reflection it bifurcates into two lines. This is seen more clearly in Fig. 33.8b, c.

In the configuration of Fig. 33.8a the Mach disk has not marked itself on the soot. However, using another instantaneous wave, colliding head-on with the Mach disk, soot transportation is stopped along a line where the afterflows of both shocks eliminate each other. This line is well marked as a sharp wall of accumulated soot and illustrated in Fig. 33.8b, c for two different spark arrangements. The straightness

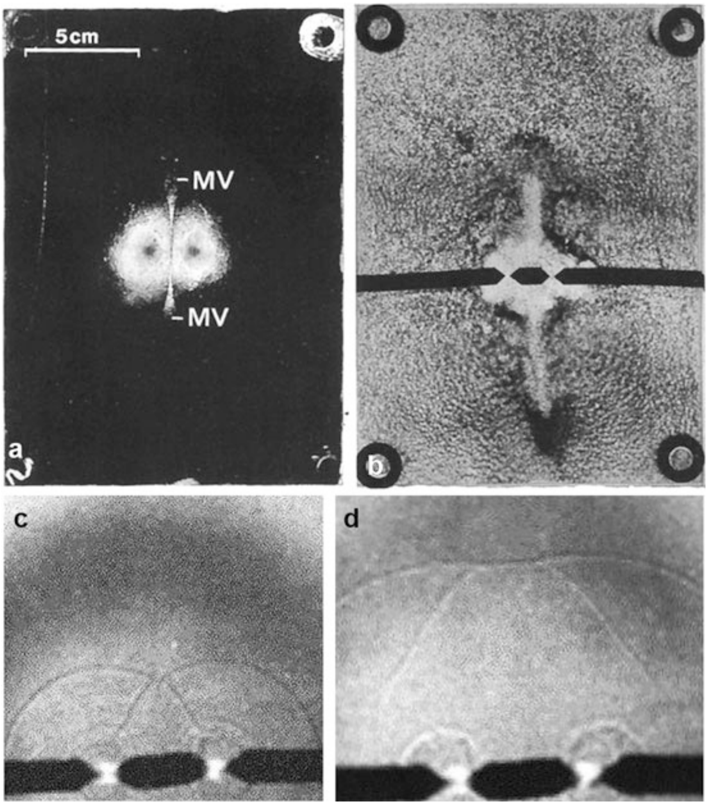

Fig. 33.7 (**a**–**d**) Comparison of different recording methods of Mach reflection but applied on the same geometry according to Figs. 33.2b, 33.3: (**a**) upper glass plate coated with soot on its lower surface; (**b**) lower glass plate covered with cork dust on its upper surface; and (**c, d**) corresponding high-speed schlieren photos of shock wave patterns taken at 30 and 65 μs, respectively, after beginning of discharge. At 30 μs evolution of Mach reflection is still in its infancy and the distance between the two triple points is small, but at 65 μs the Mach disk, a shock wave, is fully developed. Note its almost flat wave front (*see* also Appendix)
Note that in (**c, d**) shock interactions were visualized in a 2-mm air layer using the shadowgraph imaging technique. Since in thin layers differences in refractive index are small, shock fronts and their interaction are only weakly reproduced against the bright background. Therefore, for convenience of the reader, the visibility of shock waves and their interaction into a Mach disk has been improved using subsequent image processing

of this soot wall in the case of a plane, head-on colliding shock wave, Fig. 33.8b, proved to Mach that the Mach disk is also a straight line.

It truly surprised Mach that in the near vicinity of the "V"-shaped gliding spark the soot inside the funnel lines was completely erased, thus creating sharply pronounced boundaries. These lines represent the trajectories of the two triple points which separate an outer region composed by the incident and reflected shocks, and an inner region created by the Mach disk alone. Today we know that, in the inner

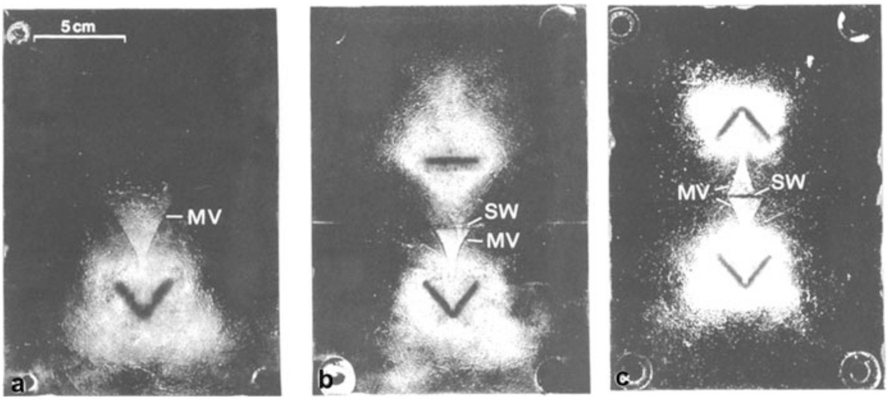

Fig. 33.8 (**a–c**) Duplication of Mach's soot experiments: (**a**) Mach funnel MV, generated by interaction of two shock waves according to Fig. 33.2c; (**b**) Stopping of Mach disk propagation by head-on collision of a plane wave which results in a narrow, straight soot wall SW; and (**c**) Mach disk stopping at two oppositely facing V-sparks

region closely behind the Mach disk, there is also a slipline, extending between the two triple points, which separates the two regions of different density and flow velocity. Principally, at this boundary the velocity vectors have the same direction but different magnitudes. It is quite possible that this behavior leads to micro-vortices which, propagating across the increasing width of the Mach funnel, "mill off" the soot from the glass plate. The afterflow following this slipline sweeps the loose soot off, and finally the Mach funnel becomes then fully visible. However, because of the inertia of the soot particles, this process is slow in comparison to shock propagation. Current experiments at EMI (Krehl and Heilig 1991) indicated that a clear formation of the "V"-branches does not occur until approximately 100 μs after passage of the triple points.

33.3 Regular and Mach Reflection Experiments with Surface Waves

33.3.1 Historical Remarks

Mach and Wosyka (1875) also applied surface waves in liquids to demonstrate irregular reflection. First, they used mercury as a liquid. To store the flow field sweeping over the mercury surface they strewed lycopodium seed on it, a very fine dust. By letting a V-shaped or a zigzag-shaped iron wire fall horizontally onto the mercury surface, they observed wave patterns very similar to the ones obtained in Antolik's soot experiments. They also used milk and syrup instead of mercury and lycopodium, respectively. These successful experiments which Mach had also documented in his notebook as illustrated in Fig. 33.9 and which he published later

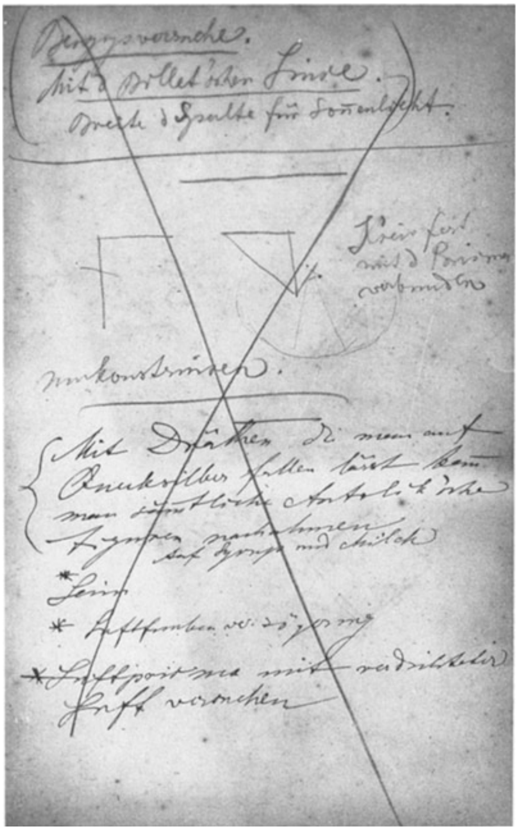

Fig. 33.9 Copy of a page of Mach's notebook No. 7, covering the period Feb. 1 – Aug. 19, 1875

(E. Mach and Wosyka 1875) reveal that he can also be regarded as the spiritual father of modeling the interaction of shock waves by free-surface waves. His notebook No. 7 covered the period from February 7 to August 19, 1875. This entry documents his successful interaction experiments with surface waves and their analogy in respect to Antolik's results: "With wires which one let fall on mercury, all Antolik's figures can be reproduced on syrup and milk glue...", (Mach and Wosyka 1875). – Mach used to cross out those pages in his notebooks which he worked out in his later publications.

At this point, some comments regarding Mach's notebooks might be of interest to the reader: The original notebooks of E. Mach, 65 volumes in all, cover the period 1870–1910: most of them are in the handy format 190 × 120 mm^2 and are stored in the archives of the Ernst-Mach-Institut. They do not represent laboratory notebooks in the modern sense with a detailed record of experimental parameters and results, but rather reflect outlines of scientific ideas, sketches of planned experiments and brief resumes of their results as well as personal notes, letter drafts and philosophical thoughts which he sometimes composed into verses. It is striking that none of the entries bear a date, with the exception of the frontispiece of each notebook on which he wrote the starting date of a new notebook. Therefore, it is not possible to state with certainty the exact date when he discovered the reflection effect.

The analogy between the two-dimensional supersonic flow of a gas and the shooting of a shallow liquid with a free surface – a so-called "hydraulic jump" – was first put on a mathematical basis by Jouguet (1920). Experimental testing on this similarity started in 1936 in Pasadena at the Hydrodynamics Laboratory of the California Institute of Technology (Caltech). Einstein's son, Hans Albert Einstein (Albert Einstein's first son), also participated in this research (Einstein and Baird 1947). A detailed review covering the time period until 1950 is given by Crossley (1949) and Gilmore et al. (1950). At that times it was hoped to model complicated shock wave structures such as the three-shock Mach interaction on a low-cost water table rather than running the tests in a supersonic wind tunnel which requires expensive high-speed diagnostics. The use of a ripple tank to study the interaction of surface waves dates back to Huygens (1629–1695). Its principle suitability to study also the reflection of hydraulic jumps, a non-linear superposition process, could be proved. However, it turned out that the analogy is exact only if the ratio of specific heats of gases, $\gamma = c_p/c_v$, is equal to two. Since for air, the gas of most practical interest, this ratio amounts to 1.4 only, this research method was soon abandoned. Additionally, it was found that just for the most interesting case of strong hydraulic shocks the agreement between theory and experiment is poor, probably caused by the formation of a breaker or roller which results in a curvature of the Mach jump.

Nevertheless, this method, straightforward and inexpensive, proved to be very valuable and illustrative for the basic understanding of irregular reflection phenomena. Therefore, we have resumed it for demonstration purposes and modified it in such a way that – in combination with a usual, commercial overhead projector – shock wave reflection and interaction processes can easily be shown "live" in an auditorium.

It is noteworthy here that Mach-type interactions of hydraulic jumps can also be observed in nature. Probably the earliest document can be found in the book by Vaugham Cornish (1862–1948), a British geographer who during his journeys round the world photographed all different kinds of wave phenomena at sea and by sea-shores, in rivers, waterfalls, whirlpools and canals (Cornish 1910). He observed quite correctly that the curious interaction of the waves of Fig. 33.10 exists only in shallow water and depends on the strength of interacting waves. However, he could not give a satisfying physical explanation of it. Stimulated by his observations, one of us (P.K.) carried out observations at Chesapeake Bay, Virginia. The Mach effect in the case of hydraulic jump interactions can best be observed directly at the shoreline. Since in shallow water the propagation velocity c of a hydraulic jump depends only on gravity g and water depth h, given by the simple equation (Lagrange JL de 1781)

$$c = (gh)^{1/2}$$

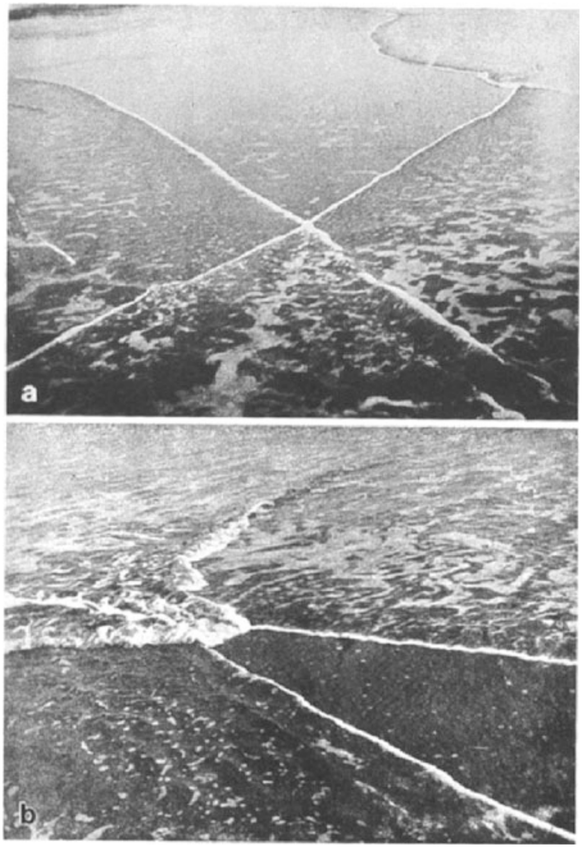

Fig. 33.10 (**a**, **b**) Meeting and crossing of sea waves in very shallow water (Cornish 1910): (**a**) regular reflection; and (**b**) Mach interaction phenomenon

the velocity of any surface wave (such as the Mach stem formed during Mach reflection of a hydraulic jump) slows down to zero when running and heading towards the shoreline. At the moment when the velocity reaches zero, the Mach stem becomes distorted and is immediately followed by its disintegration.

It was this observation which initiated the idea that for demonstration purposes a shallow ripple tank with a slight inclination would be most advantageous. This allows one to slow down reflection phenomena just by setting the "shoreline" into the center of the field of view of an overhead projector. Therefore, it enables the audience to catch and resolve quite clearly the geometry of hydraulic jumps during their propagation and reflection, although the screen magnification – depending on the available light intensity output of the applied projector and normally not exceeding 10 – also magnifies the speed of the actual phenomena in the ripple tank.

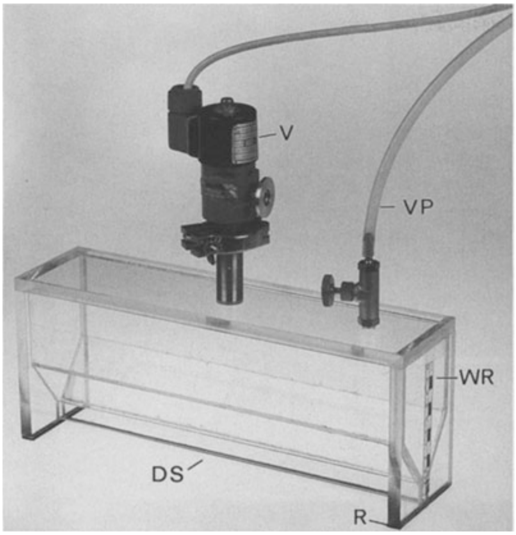

Fig. 33.11 View of the wave generator: *WR* water reservoir; *DS* discharge slot; *R* rubber pad; *V* air inlet valve; *VP* connection to vacuum pump

33.3.2 Experimental Setup

A ripple tank 500 × 350 × 60 mm^3 of 10-mm thick glass has been used. It was positioned directly on the projection window of the viewgraph projector at a slight inclination and filled with about 0.55 1tr of water to provide a "shoreline" in the middle of the tank when the liquid is pumped up to a certain height in the reservoir.

The construction of the wave generator was similar to the one used by Crossley (1949) and is shown in Fig. 33.11. The apparatus extends over the total width of the tank, thus providing wave fronts of the same length. The water is made to rise inside the generator by reducing the pressure by means of a small vacuum pump. An electrically operated high-vacuum valve, Balzers AG, type BPV 43000 (Trübbach, Switzerland), is located at the top of the generator. A 2-mm thick soft rubber ribbon is inserted between the bottom of the wave generator and the ripple tank to avoid undesired mechanical vibration during activation of the electric valve. A uniform, 5-mm wide discharge slot at the bottom of the apparatus provides a uniform wave. To reduce detrimental adhesion effects at low water levels, especially along the "shoreline," a wetting agent such as Agfa Agepon (AgfaGevaert AG, Leverkusen, Germany) was added to the tap water in a concentration of about 0.2% by volume.

The strength of the hydraulic jump released by the generator is determined by the diameter a of the air inlet orifice of the valve, the height b of the discharge slot, the water level c in the ripple tank at the position of the discharge slot, and the height d to which water is pumped up into the reservoir. These main experimental parameters are schematically illustrated in Fig. 33.12. For demonstration purposes a good result – *i.e.* slow and clearly resolvable wave propagation – is obtained for $a = 10$ mm, $b = 10$ mm, $c = 20$ mm, and $d = 45$ mm. Before discharge the "shoreline" is set at a distance $e = 300$ mm apart from the discharge slot, resulting in an inclined water level of 1.9°.

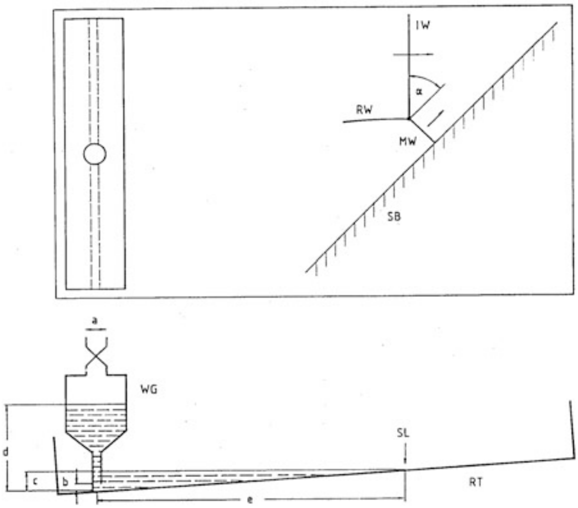

Fig. 33.12 Schematic of hydraulic jump interaction experiments: *WG* wave generator; *RT* ripple tank; *SB* solid boundary; *SL* "shoreline;" *IW* incident wave; *RW* reflected wave; *MW* Mach wave (or "Mach stem"); *a* angle of the incident wave

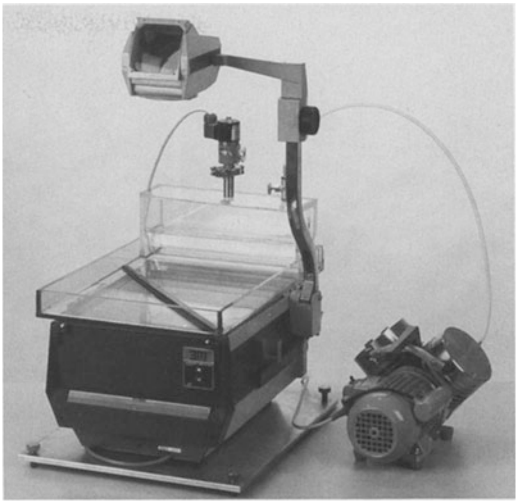

Fig. 33.13 Total setup with overhead projector to demonstrate oblique reflection of hydraulic jumps

33.3.3 Regular and Mach Reflection Experiments at a Solid Boundary

The total setup for demonstration of hydraulic jump interaction experiments is shown in Fig. 33.13. Wave reflection at a rigid boundary is studied by using heavy brass cylinders with a rectangular profile and of different lengths. These are placed on the tank bottom and positioned under different angles in relation to the incident wave front.

Figure 33.14a–d show for two successive time instants the propagation of regular and Mach reflection of a hydraulic jump at a plane solid boundary, respectively. In the case of an angle of incidence of 25°, the reflection remains regular. However,

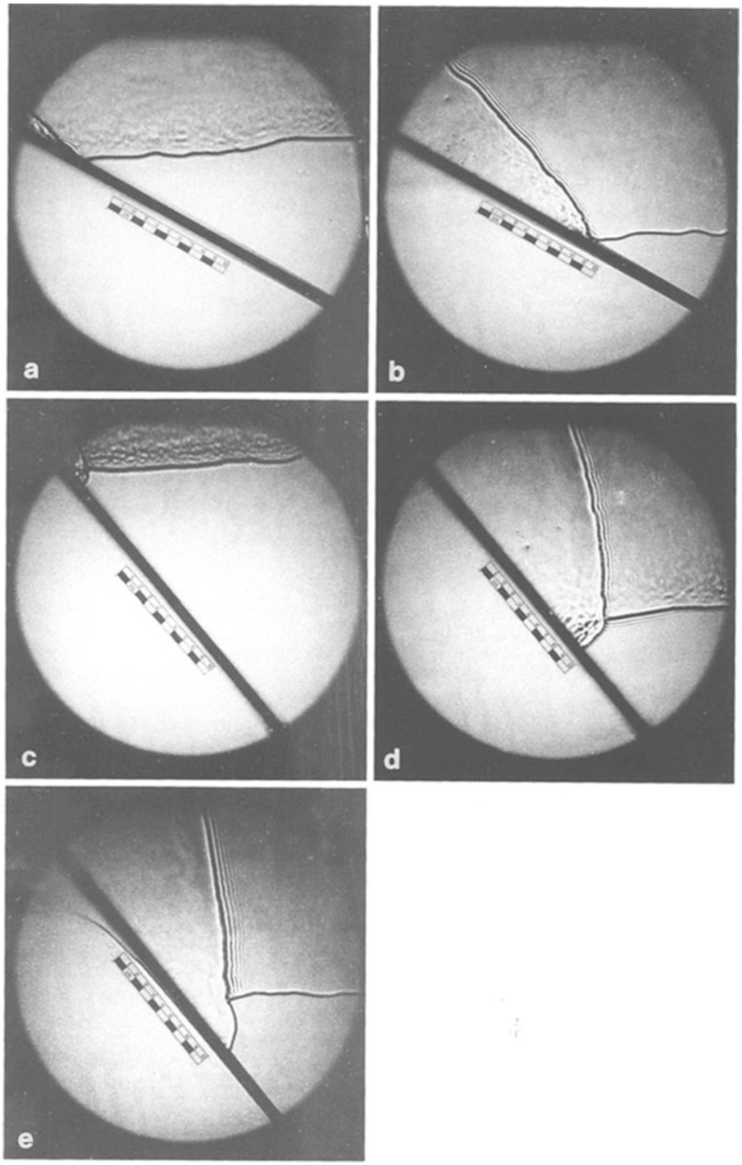

Fig. 33.14 (**a–e**) Oblique reflection of a hydraulic jump at a solid boundary under an angle of incidence α photographed at two successive time instants: (**a, b**) regular reflection at $\alpha = 25°$; and (**c, d**) Mach reflection at $\alpha = 50°$; (**e**) change in geometry of the stagnated Mach stem just before its quick disintegration

when this angle is increased up to 50°, the regular reflection very soon turns into irregular reflection. The increasing extension of the Mach stem with time is clearly visible. When running up the inclined "beach," the Mach stem is slowed down to a complete standstill. At this moment, depicted in Fig. 33.14e, the Mach stem front is no longer perpendicular to the boundary, but rather becomes strongly deformed and immediately begins to dissolve.

Previous experiments at EMI on the interaction of hydraulic jumps using a larger ripple tank and a constant water depth have been documented (Krehl and Grünewald 1978) in a 16-mm movie which shows both in real time and slow motion: (i) propagation of a plane wave; (ii) interaction of two plane waves under oblique incidence; (iii) oblique reflection of a plane wave at a rigid boundary; and (iv) propagation and reflection of a plane wave within straight conical and convex curved nozzles.

Acknowledgements The permission of the Musée Océanographique de Monaco for inspecting their comprehensive collection of publications on sea wave phenomena as well as the support of the Deutsches Museum, München for duplicating their Holtz machine is gratefully acknowledged. The Holtz machine was manufactured at EMI's workshop by M. Fischer and W. Schöpflin.

Appendix

- **Shock interactions in Figs. 7c, d**: Unfortunately, wave configurations in these shadowgraphs, resulting from the symmetric interaction of two weak shock waves propagating in a 1.5-mm thick layer of air, are barely visible in the print. For reader's convenience, magnification and digital image processing has been applied for showing Mach disk evolution more clearly.
- **Jaromir Wosyka** was one of Ernst Mach's students at Prague University (1873–1875) and later one of his auxiliary assistants (1875–1876). Wosyka was discharged in 1876 from the institute for book stealing [according to a note by E. Mach written in 1886 and now kept at the Deutsches Museum, Munich (DMM)]. It appears that Wosyka didn't continue his career in scientific research. The British *Catalogue of Scientific Papers* which lists papers published within the period 1800–1925 only refers to the famous Mach-Wosyka paper.[1]
- **Edgar Bright Wilson, Jr. (1908–1992)**, a U.S. associate professor of physical chemistry at the Dept. of Chemistry of Harvard University who during WWII also worked on the improvement of underwater explosions at Woods Hole, MA, repeated in 1942 the Mach-Wosyka experiments, even prior to Robert W. Wood. He described his results in a technical report.[2]
- **Robert W. Wood (1868–1955)** was a U.S. chemist but later became more interested in physics, and at the University of Berlin (1894–1896) under the influence of the German physicist Heinrich Rubens (1865–1922) he changed

[1] *Sitzungsber. Akad. Wiss. Wien* 72 (II), 44 (1876).

[2] Monthly technical report, prepared under Contract O.E.M.sr334 for Oct. 15th and Nov. 15th, 1942.

permanently to a career in physics. Possibly, during that period he took an interest in the works of August Toepler (1836–1912) who first studied propagating shock waves subjectively using spark stroboscopy,[3] followed by Ernst Mach (1838–1916) who used high-speed schlieren photography.[4] The schlieren technique was used later by Wood to photograph the reflection and refraction of sound waves from surfaces of various shapes.[5] In fluid dynamics the schlieren method became a standard method for visualizing shock waves.

- Wood's expertise on the visualization and photography of sound waves stimulated **John von Neumann (1903–1957)** in 1942 to ask him to repeat the historic Mach-Wosyka experiments. Wood, at that time professor emeritus at Johns Hopkins University (JHU), studied Mach reflection in more detail: he used not only the soot technique of Károly Antolik (1843–1905), thereby making more than 50 soot plates (with the aid of William D. Kennedy and J. Frankl), but also applied the Toepler schlieren method. In this report, Wood coined the terms *Mach bridge*, *Mach funnel, and Mach V* which are still in use today. Wood used pencil lines on ground glass as spark-guides instead of metalized threads as used by Wilson Jr. and associates.[6]
- **Raymond J. Seeger (1906–1992)** was a U.S. physicist at the U.S. National Science Foundation who during WWII had joined John von Neumann and John G. Kirkwood (1907–1959) to study shock wave phenomena. In 1944, Philip C. Keenan and Raymond J. Seeger coined the name *Mach reflection* for the irregular reflection of shock waves.[7] In 1970, Seeger reviewed U.S. experiments on Mach reflection carried out during WWII [see ref. *Seeger RJ (*1970*)* in the above paper]. Why Seeger reproduced in his article Wood's photographs with the addendum ("courtesy of J. Wosyka Mandansky") is still an enigma. Does this name refer to Mach's student or to an offspring? It is little probable that Wood had contacted J. Wosyka in 1942 for obtaining information on some experimental parameters such as the initially stored electrical energy and the dimensions of the used gliding spark configurations – valuable data for reproducing the historic experiments which were not included in the Mach-Wosyka paper. At that time J. Wosyka, born in the early1850s, would have been at the age of about 90.
- **Residues of Mach/Wosyka-type experiments in terms of smoked glass plates.** The original plates are not kept at DMM in its Ernst-Mach Collection.[8] According to ref. 9 of Seeger's paper cited above, Wood's smoked glass plates are

[3] *Pogg. Ann. Phys. Chem.* 131, 180 (1867).

[4] *Sitzungsber. Akad. Wiss*. Wien 98 (II), 1333 (1899).

[5] *Phil. Mag*. 48 (V), 218 (1899).

[6] A preliminary version of wood's OSRD report is kept at Johns Hopkins University (JHU) in the M.S. Eisenhower (MSE) Library, Special Collections, Baltimore, MD. Private communication by Jim Stimpert, archivist at MSE Library.

[7] Explosives Research Rept. No. 15, Navy Dept. BuOrd, Washington, DC (1944).

[8] Private communication by Dr. Matthias Röschner, Deutsches Museum München (DMM), Germany.

kept at the Rowland Physics Laboratory. It was later reorganized into JHU's Rowland Department of Physics & Astronomy, and Wood's residues were moved to JHU's MSE Library. However, his smoked glass plates could not be located there.[9] But it is quite possible that they still exist somewhere at the Physics Dept. which had kept its own informal archive. Residues of Krehl's Mach-Wosyka experiments, demonstrated in 1992 at the Mach Reflection Symposium in Freiburg, Germany and consisting of sets of soot-covered glass plates combined with glass plates provided with different gliding-charge configurations, are now kept at the European Center for the History of Physics (Dr. Peter M. Schuster), Pöllau Castle, Austria.

- **Optimum height of burst (HOB)**. It is now common knowledge that "the Mach effect was actually used in the bombing of Hiroshima, that is, in determining the position of the atomic bomb best suited for optimum damage" [Seeger RJ (1970)].

In 1944, then the United States still being at war with Germany and Japan, the British mathematical physicist William G. Penney (1909–1991) gave in his classified memorandum "The Height of Burst of the Gadget" a warning that a height of burst (HOB) of an atomic bomb as low as 500 ft. and a yield of 1 kt TNT equivalent may be required which was in contrast with earlier opinions made in December 1944 by Bernard Waldman (1913–1986) and Norman F. Ramsey (1915–2011) who considered a HOB of 1500–2000 ft. and a yield of 10 kt. Penney also pointed out a significant difference in the blast resisting characteristics of German *vs.* Japanese towns.[10]

The so-called "Hight-Of-Burst (HOB) problem" was apparently first discussed in the open literature by Samuel Glasstone (1897–1986), author of the book *The Effects of Nuclear Weapons*.[11] In section 3.28 of his book, he wrote: "Since the Mach stem is nearly vertically, the accompanying blast wave is traveling in a horizontal direction at the surface, and the transient winds are approximately parallel to the ground. Thus, in the Mach region, the blast forces on aboveground structures and other objects are directed nearly horizontally, so that vertical surfaces are loaded more intensely than horizontal surfaces." His published HOB diagrams – *i.e.*, plots of HOBs *vs.* distance from ground zero with peak overpressure as a parameter – allowed one for the first time to quickly calculate the optimum HOB for a given energy yield of a nuclear explosion.

- **The mechanism of soot removal under irregular oblique shock interaction** is still an enigma and not yet fully understood. Already Ernst Mach was surprised about the double-line fine structure of his recorded V-configurations. Based upon this curious phenomenon, Antoni K. Oppenheim (1915–2008), a professor at

[9] Private communication by J. Stimpert, JHU's MSE Library.

[10] W.G. Penney: *The height of burst of the gadget*, see http://blog.nuclearsecrecy.com/document-list/

[11] U.S. Govt. Print. Off., Wash., DC (1957, 1962, 1977); ISSBN 9781258793555.

Berkeley University, speculated that since the flow behind the Mach stem is locally subsonic, while the flow behind the reflected shock is supersonic, this gives rise to a vortex of concentrated high-temperature gases acting as a "rotating stylus" and from the soot layer milling out the trace of its path.[12] However, microscopic fluid dynamic studies of the triple point and its close environment, carried out in the 1990s at EMI and using single-shot subnanosecond flash photography, revealed no such turbulence structures.[13]

Japanese and U.S. researchers explained the soot track formation using classical fluid mechanics of near-wall flow in a viscous gas. Based upon numerical simulations of Mach reflection, they proposed that the soot tracks depend largely on variations in the direction and magnitude of the shear stress created by the boundary layer adjacent to the soot layer.[14]

- **Origin of the term *Mach reflection***. Possibly even prior to Keenan and Seeger (*see* above), the term "Mach reflection" might have originated from **Herman Zornig (1888–1973)** who during WWII was director of the U.S. Ballistic Research Laboratory (BRL). As the Assistant Military Attaché assigned to the U.S. Embassy in Berlin from 1927 to 1929, Zornig applied and was accepted to the Technische Hochschule (TH) at Berlin-Charlottenburg. Meeting the tuition expenses out of his own pocket, he studied ballistics under several of the leading German scientists in the fields of interior and exterior ballistics, such as Prof. C.J. Cranz (1858–1945) and Hubert Schardin (1902–1965) as well as organic and inorganic chemistry. In the late 1920s, Cranz and Schardin first visualized cinematographically "Mach reflection" – quite possibly eye-witnessed by Zornig.[15]
- **Establishment of EMI**. In 1941, Schardin, a German physicist and former Ph.D student and assistant (1926–1936) of Prof. Cranz, became director (1936) of the Department of Technical Physics & Ballistics at the *Technische Akademie der Luftwaffe (TAL)* in Berlin-Gatow and full professor (1941) at the TH Berlin. After WWII he founded the German-French *Laboratoire de Recherches Techniques de Saint-Louis* (Saint-Louis, France) – from 1959 *Institut Saint-Louis (ISL)* – and became its first director (1946–1965). Schardin was honorary professor at the German Universities of Freiburg (1947) and Cologne (1965). He established two departments of applied physics in Weil am Rhein, and at the University of Freiburg (1949), which, 10 years later, merged into the *Ernst-Mach-Institut (EMI)* at Freiburg, a subsidiary research institute of the Fraunhofer-Gesellschaft (FhG) with headquarters in Munich. Schardin became EMI's first director (1959–1965).

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[12] A.K. Oppenheim: *Introduction to gas dynamics of explosions.* Springer, Vienna *etc.* (1970), pp. 27-29.

[13] P. Krehl and S Engemann, unpublished results.

[14] ICCES 4 (1), 41 (2007).

[15] *Z. Phys*. 56, 147-183 (1929).

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Chapter 34
Ernst Mach's Geometry of Solids

Klaus Robering

Abstract The present article first places Mach's consideration about space and geometry into the context of the discussion of these issues in the nineteenth and early twentieth century and then proposes three interpretations of Mach's thesis, put forward in chapter XXI of his *Knowledge and Error*, that the problem of measuring the volumes of material bodies is the origin of geometry. According to the first of these interpretations, Mach's thesis is an assertion about the historical origin of the science of geometry. Alternatively, one may understand Mach as suggesting that our geometric theorizing is best understood by relating it to our handling of material bodies and our interest in their volumes. Finally, Mach's thesis may be conceived as asserting that the most appropriate form of geometry would be a metric geometry of the volumes of solids. The article concludes with a discussion of objections raised by Brentano against both Mach's thesis of the priority of the measurement of volumes and his conception of bodies as complexes as sensations.

Mach's Concerns with Geometry

Mach is among the first authors carefully distinguishing between different notions of space: the "physiological spaces that different senses embrace" (Mach 1976, p. 254/341),[1] "physical space" (ibid., p. 349/447) as the object of natural science, and the abstract spaces of modern geometry, which Mach—in a slightly ironic and skeptical tone—calls "the creations of the metageometricians" (ibid., p. 251/338,

[1]Page numbers separated by a slash refer to the English translation (first number) of a work originally written in German and to the German original (second number).

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my translation).[2] All these different spaces are the topic of chapters XX–XXII and XXIV of Mach's *Knowledge and Error* (Mach 1976).[3] The present article is mainly concerned with Mach's treatment of geometry and space in chapter XXI of this book.[4] The title of that chapter—"On the psychology and natural development of geometry"—aptly characterizes its content: in accordance with the general aim of the book, chapter XXI attempts to show how the science of geometry develops, on the basis of man's physical and mental constitution, in the interaction with her/his environment. For Mach, this coincides with showing how our "spatial image of the world" (Mach 1976, p. 264/353) emerges; hence he implicitly identifies geometry with the description of that spatial image.[5]

Furthermore, it is obvious from Sects. 16–18 that Mach often is thinking of Euclidean geometry when he is talking about "geometry" *simpliciter*. For him, Euclidean geometry is the most obvious and economic way to describe physical reality. There is, however, an extensive discussion of non-Euclidean geometries in chapter XXII of *Knowledge and Error* at the end of which (Mach 1976, p. 322/415) Mach concludes that "[w]e are able [. . .] to represent the facts of spatial observation with all possible precision by both Euclidean geometry and the geometries of Lobachevsky and Riemann". But he states that physicists have not found any "reason for departing from the assumption [. . .] of Euclidean geometry" (ibid.), which was probably still correct for the year 1905 when the first edition of his book appeared.[6]

In the following, I provide an analysis of Mach's account of geometry. First, I describe the historical context which provides the background for both the specific formulation of his research question and the method by which he hopes to answer it. In Sect. 34, I shall explain what I conceive to be Mach's main thesis, and in Sect. 34 I shall be concerned with two objections against his approach to geometry.

[2]The wording of the German original is "den Gebilden der Metamathematiker" (plural, dative case) where the English translation just has "space of metageometry" which is more neutral and grammatically singular.

[3]There is no chapter numbering in the German original; it has been added in the English edition. Chapter XXIII deals exclusively with time; chapter XXIV with "Space and Time Physically Considered". Visual space and the perception of movement are also treated in chapters VI and VII of Mach's *Analysis of Sensation* (Mach 1959).

[4]This chapter has been originally published in 1902 as an article in the journal *The Monist* (vol. 12, no. 4, pp. 481–515). The article version of the text had been translated from Mach's manuscript by Thomas J. McCormack and was included with some marginal changes into Erwin N. Hiebert's 1976 English edition of *Knowledge and Error*.

[5]This is one of the many issues of Mach's conception of geometry which has been severely criticized by Brentano. According to Brentano (1988, p. 126), the investigation of our spatial image of the world is the task of empirical disciplines as astronomy and geography rather than that of geometry, which science is concerned with the relationships between spatial magnitudes.

[6]However, the situation already changed three years later when Minkowski suggested his four-dimensional affine geometry for the special theory of relativity in 1908. Even more radical departures from the Euclidean scheme followed soon within the general theory of relativity.

Debates on Space in the Nineteenth Century

The philosophical problem which Mach attempts to answer in ch. XXI of *Knowledge and Error* is that of the epistemological status of geometry. The problem whether geometrical knowledge is based on the formal structure of our intuitive faculty, as Kant thought, or rather derives from experience was a hotly debated topic in the whole nineteenth century and the first decades of the 20th. This discussion comprises several "sub-debates" one of which is the nativist-empiricist dispute concerning the nature of visual space perception in which Helmholtz and Hering have been the main opponents.[7] In this dispute, Helmholtz employs the Kantian terms *intuition*, *representation*, *perception*, and *sensation*; but uses them in a way deviating from that of Kant. Unlike Kant, for whom both sensations and intuitions are special kinds of perceptions ("Perceptionen") which in turn are a species of representations ("Vorstellungen"; cf. Kant 2007, p. 314/249f = B 377), von Helmholtz (1924, III, p. 10f/609) draws a sharp distinction between these categories. He reserves the term *representation* for such an "image of visual objects which is retained in the memory, without being accompanied by any present sense-impressions [sinnlichen Empfindungen]." Immediate perceptions, on the other hand, do not comprise any "element whatever that is not the result of direct sensations;" ibid. Intuitions occupy the position in between: an intuition of an object comprises both sensual sensations relating to it and traces of memory. Sensations are the effects of stimulations of the nervous systems "by external agents of various kinds"; (von Helmholtz 1924, II, p. 2/231). For Kant, sensations are the "matter" of (at least our human) intuitions whereas space and time constitute their form; cf. Kant (2007, p. 82/65 = B 59f). This distinction between formal and material components of intuitions is missing from Helmholtz' conceptual scheme.[8] Hence the question immediately arises where the spatial and temporal features of an intuition may come from: do they derive from special sensations co-present with the intuition or rather from those of its components which result from memory and learning from previous experience; or are they, finally, due to (an interaction of) both? Since it depends upon our innate constitution which sensations we can have at all, theories adopting the first possibility are called "nativistic" by Helmholtz, whereas theories following the second option are "empiricist". The third possibility is not considered by him, who—as is well-known—opts for empiricism.

[7]For a detailed account of the debate cf. Turner's (1933).—In a note to Brentano's investigations concerning space, time and continuum (Brentano 1976, p. 229, Fn. 131), Kastil ascribes the origin of the labels *empiricist* ("empiristisch") and *nativist* to Helmholtz by referring to the 2nd edition of the latter's *Treatise on Physiological Optics*; cf. von Helmholtz (1924, III, p. 10/608f). The English translation of this work is based on the posthumous three-volume third German edition from 1910. That edition, in turn, is a revised reprint of the first edition from 1867 supplemented by appendices by the editors Allvar Gullstrand, Johannes von Kries, and Willibald Nagel.

[8]More precisely, "matter" vanishes completely in Helmholtz' conceptual framework since he views "our sensations as regards their qualities just as signs whose nature completely depends upon our organization", von Helmholtz (1924, p. 586).

Whereas Helmholtz defines the notion of a sensation in physiological terms, Hering (1879, p. 344f) provides a phenomenological account of this notion. He first distinguishes "visual space" ("Sehraum") with its "things-as-seen" ("Sehdinge") from physical space and the things inhabiting it. Then he explains: "The stuff out of which the things-as-seen consist are the visual sensations;" (Hering 1879, p. 345). The setting sun as a thing-as-seen "may be called a circular, yellow-red sensation;" ibid. Three consequences of this are immediate. First, Hering's visual sensation are neither in the eye nor in the brain or in the mind. We see the setting sun, but "[...] nobody sees the sun in his eye or in his head;" ibid. Secondly, the setting sun is circular; thus it has spatial properties. Hering rejects the idea of a "pure" sensation as a "shapeless and un-spatial something;" ibid. Hence, thirdly, one cannot, as Kant did for his empirical intuitions, draw a distinction between form and matter. Both its circular shape and its yellow-red color are just features of the setting sun as a thing-as-seen.[9]

Mach has been Hering's colleague at the University of Prague for 25 years and positive references to Hering's work abound in Mach's writing; cf., e.g., Mach (1959, pp. viif/VIIf, 57/101, 68/114, 81/139) and Mach (1976, pp. 254/341, 257/346, 259/349) and, especially, the long footnote in *The Analysis of Sensations* (Mach (1959, p. 27f/22, Fn. 1) commenting on Hering's example with the rising sun cited in the previous paragraph. Furthermore, Mach frequently speaks of "spatial sensations" or "sensations of space"—e.g., Mach (1976, pp. 254f/342, 257ff/ 345ff, 264/353, 267/356, 291/383))—while there exist no such sensation for a strict empiricist á la Helmholtz. He agrees even with the further going assumption of Hering and James, "that every sensation has a certain spatiality," cf. Mach (1976, p. 254/341). For Mach, such spatial sensations are a necessary presupposition for geometry: "[j]ust as without sensations of heat there would have been no theory of heat, so also there would be no geometry without sensations of space;" Mach (1976, p. 265/353).

Though Mach thus seems to be in complete agreement with the nativist position, Brentano, who in the dispute takes the part of the nativists, nevertheless does not recognize him as a fellow combatant in the quarrel: "Although Ernst Mach conceives of himself as a nativist of a special coloring, I do not consider him as truly belonging to the nativists," (Brentano 1976, p. 171). Brentano extends the empirism-nativism dichotomy to a trichotomy by adding "anoetism" (Brentano 1976, p. 175) as a

[9]Both Hering and Helmholtz dismiss the Kantian distinction between form and matter. But whereas Helmholtz eliminates the spatial features of intuitions and turns their qualitative features into formal ones (cf. Footnote 8 above), Hering—conversely—turns them into just another species of material components. Hence von Kries, in an appendix to Helmholtz' *Physiological Optics* (von Helmholtz 1924, III, p. 641) is completely right when he declares it absurd "to identify the views that Helmholtz opposed, that is, so-called nativism, with the apriority of Kant." Kant recognizes "a fundamental distinction between the spatial (and temporal) determinations of our sensations and their qualitative or intensive determinations;" ibid. p. 640. But Hering "wipes out this distinction and places the spatial determinations exactly on a par with others;" ibid. Helmholtz himself, however, conceives of Hering's nativism as standing in the Kantian tradition; cf. von Helmholtz (1924, III, p. 36/613).

third position. Anoetists claim that we do not possess any adequate conception of space at all since the concept of space is beset with conceptual difficulties or even inconsistencies. Mach is (besides, e.g., Boltzmann and Poincaré) reckoned among the anoetists by Brentano because "that what he calls 'physiological space' does not correspond to the true concept of space, since that requires continuity in three dimensions;" (Brentano 1976, p. 171). Mach's physiological space, however, is—according to Brentano—not continuous but rather "composed out of a finite number of qualities;" (Brentano 1976, p. 171f). Probably, Brentano is alluding here to the chapter on "The continuum" in *The Principles of Heat*. There Mach explains that a continuum is a mere "ideal construct" which, since it embraces an infinity of items, cannot be given by the senses; Mach (1923, p. 73/71). In Chapter XX of *Knowledge and Error* Mach, referring to the cited chapter in his book on the theory of heat, remarks that continuity "need not be real for either space", the geometrical and the physical, and that it is assumed "for the sake of convenience" only, Mach (1976, p. 256/343f).

Brentano might have had yet another reason for assigning Mach to the anoteists rather than to the nativist as indicated by the reserved phrase "that what he calls 'physiological space"', by which Brentano dissociates himself from Mach. Actually, it is not quite clear what Mach means by *the* physiological space in distinction from the *various* physiological spaces of the different senses. The very first sentence of Chapter XX of *Error and Knowledge* (Mach 1976, p. 251/337) seems to equate physiological space with the space of intuition. In a later section of the same chapter, however, he defines physiological space as a set of "places in the brain". These places correspond to points of physical space and they are the centers at which the memory images of those bodily movements are localized which, respectively, have the associated point of physical space as its goal. "Spatial sensations would correspond to the organ sensations of these places," (Mach 1976, p. 260/349). An "organ sensation" is that component of a sensation which is not due to the quality of the stimulus causing the sensation but which is entirely determined by the organ's "own individuality"; Mach (1976, p. 257/345). This doctrine of spatial perception is somehow speculative as Mach himself seems to admit by the sentence introducing the section in which he sets forth his ideas: "We may imagine spatial perception physiologically founded as follows ...," (ibid.). The verb *imagine* seem to suggest that the considerations following are a tentative description rather than a definitive account.[10]

[10]Mach's association between points of outer space and places of the brain reminds of the Gestalt psychologists' principle of isomorphism according to which "[...] the organization of experience and the underlying physiological facts have the same structure," (Köhler 1922, p. 301). For Mach, the structural similarity between physiological and geometrical space is restricted to their topology; cf. Mach (1976, p. 256/344) and he considers this insufficient for upholding (a bio-physiological version of) Kant's thesis of the apriority of space. The thesis that only the topological properties of intuitive space are a priori is put forward by Carnap in his Ph.D. thesis; cf. Carnap (1922, pp. 62ff).

Solids and the Foundations of Geometry

The same method which Mach uses in his epistemological considerations of mechanics is also applied by him in his quest for the sources of our spatial knowledge. Dingler, in his little monograph on Mach's philosophy (Dingler 1924, p. 24ff), aptly characterizes this method as "historic", "biological", and "psychological". Mach recognizes our biological needs as the ultimate origins of the science of geometry: as biological beings, we are—and have to be—interested in the physical bodies of our environment. Among the many geometric properties of a solid, one is of prime biological importance: "the volume of the body, is, all other things being the same, proportional to its capacity for satisfying our needs, and possesses consequently a biological import," (Mach 1976, p. 265/354). Given thus the biological importance of spatial knowledge, we may assume that our senses have adapted to directly receive geometric information and that hence some pieces of that information are fixed by our senses and their physiology. For Mach, for instance, "[a] straight line is primarily a unique concrete image characterized by physiological properties" (Mach 1976, p. 285/376), and "[t]he plane, like the straight line, is physiologically characterized by its simplicity" (Mach 1976, p. 278/369) by appearing the same in all its parts. Here Mach agrees with the nativists by assuming that our spatial knowledge directly depends on our sensations. Sensations, however, are not enough. Humans learn from their practical experiences with physical bodies and thus "a spatial image of the world is created, at first instinctively, then in the practical arts, and finally scientifically, in the form of geometry," (Mach 1976, p. 264/351). By accepting the role of experience and learning, Mach approaches the empiricists and takes a position intermediate between the two factions of the debate described in the previous section. But he also points out a third factor in the historic process of the development of our spatial knowledge. In its final, "scientific" phase consciously adopted conventions which allow for the succinct formulation of a theory play a role, too. As we already have seen above (p. 475), for Mach, the assumption of continuity is just such a convention.

By emphasizing the importance of solids for the development of geometry, Mach takes a similar stance concerning the foundations of this science as the nineteenth century's founders of non-Euclidean geometry Bolyai and Lobachevsky. Especially the latter's work, which has been available to Mach by Friedrich Engel's German translation (Lobachevsky 1898), is discussed in Chapter XXII of *Knowledge and Error*. Both Bolyai and Lobachevsky propose reformulations of the foundations of geometry which start from the concept of a solid. Though, however, Mach is acquainted with their views of the conceptual basis of geometry, he does not refer to them when he, repeatedly, emphasizes the importance of experiences with rigid bodies for the development of geometry but rather invokes the authority of Leibniz, who had developed similar ideas long before[11] and has been a source of inspiration for Mach in several other respects, too; cf. Mach (1976, pp. 279f/370f, 297/369, Fn. 1).

Real, physical bodies are, however, not the objects of geometry. The geometric notion of a solid derives from our experiences with physical bodies by the processes of "schematization and conceptual idealization;" (Mach 1976, p. 280/371). This process is driven by our striving for an "economical representation of the actual" (Mach 1959, p. 49/40). Which traits of physical bodies are kept in this process—rather than eliminated by idealization—is a practical and, ultimately, a biological issue. As we have just seen, the volume of solids is of primary biological importance and is thus a matter of concern before other geometric features of physical bodies attract attention: "The volume of a body is instinctively taken into account as representing the quantity of its material properties, and so comes to form an object of contention long before its geometric properties receive anything approaching to profound consideration," (Mach 1976, p. 268/358). Hence according to Mach, geometry is originally metric geometry concerned with the comparison of solids with respect to their volumes.[12]

I shall call the thesis that our practical concern with bodies and their volumes is prior to other geometric endeavors *Mach's priority thesis*. The thesis may be understood in (at least) three different ways. Firstly, it may be conceived as a historic hypothesis about the emergence of geometric thinking. This may be called the *historic* priority thesis. The historic thesis is at odds with the common historic narrative that geometry developed from the ancient Egypts' measurement of areas used for agriculture and flooded by the annual rise of the Nile. That there must have been a serious and extensive concern with volume, too, already in very ancient times (ca. 3200/3100 B.C) is nevertheless confirmed by archaeological excavations of plenty of shards of receptacles stemming from the Sumerian city of Uruk. The containers to which those shards belong are all of approximately the same volume which corresponds to half of the portion of barley given, according to later documents, as a daily ration to the workers associated with big households; cf. Damerow et al. (2004, p. 50f).

Secondly, the priority thesis may be interpreted as asserting that (much of) our geometric theorizing can be understood—and, perhaps, even justified—by relating it to our practical concerns involving solids. Let us call this the *hermeneutic* priority thesis. It bears some resemblance to Paul Lorenzen's project of a "protogeometry" which seeks for a foundation of geometry in practical space-related activities; cf., e.g., Lorenzen (1984). This program has been inspired by the doctrines of Hugo Dingler, who thus may have functioned as a "link" between Mach and Lorenzen.

[11] Cf., e.g., Leibniz explanation: "Erit enim qui arbitretur corporis notionem priorem esse notione superfici et lineae, tanquam corporis terminorum, nec per se subsistentium, et has corporis sectione cognosci," (Leibniz 1849, p. 199) ("The notion of a body will have to be considered to be prior to those of a surface and a line which as the boundaries of the body, not as something subsisting by itself, are recognized by a dissection of the body.").

[12] Hjelmslev's (1922, p. 4) position resembles that of Mach: "Die Erfahrungsgeometrie muß mit metrischen Grundlagen (Eigenschaften des festen Körpers) anfangen [Experience-based geometry has to begin with metric foundations (properties of the rigid body)]." However, in the passage just cited, Hjelmslev definitely suggests what will be called the "axiomatic thesis" below (p. 478).

Many affirmative reference to Mach can be found in Dingler's 1911 book on applied geometry (Dingler 1911). In that book (Dingler 1911, p. 21/22), Dingler also points to Mach's mention of the "three-plate-procedure" ("Drei-Platten-Verfahren") for the technical production of plane surfaces by alternatively rubbing two of three bodies together, cf. *Knowledge and Error* (Mach 1976, p. 278f/369f). This procedure—or rather: the geometric idea behind it; namely, the characterization of the plane by its specific inner symmetry[13]—plays an important role in Dingler's and Lorenzen's (Lorenzen 1984, p. 36f) approaches to geometry as well as in Hjelmslev's (1922, p. 3) geometry or reality ("Geometrie der Wirklichkeit").

Finally, the priority thesis may be understood as a proposal for a more systematic axiomatic exposition of geometry. It is well-known that Euclidean geometry may be axiomatized by extending the axiom system for metric spaces by some further postulates; cf., e.g., Blumenthal's (1980, ch. VII) axiomatization of planar Euclidean geometry. Given such formal systems, one would expect a formalization of Mach's approach to geometry to contain two things: (1) a set of axioms formulating the basic laws for the notion of volume in the same way as the three axioms for metric spaces characterize the notion of distance between points; and (2) additional axioms which render the spatial structure Euclidean as do, in the 2-dimensional case, the axioms which Blumenthal (1980, p. 156) added to those of a metric space. I shall call this understanding of the priority thesis the *axiomatic* thesis.

In most parts of ch. XXI of *Knowledge and Error* where the priority thesis is at issue, it is obvious that Mach then is considering the historic or the hermeneutic thesis. However, there are also passages which seem to indicate that Mach propagates the axiomatic thesis. Brentano at least seems to have understood Mach in this way.

Problems for Mach's Program

Brentano, in a series of critical comments on Mach's *Knowledge and Error* (Brentano 1988), interprets him as holding the axiomatic priority thesis when saying that Mach believes to have shown that any geometric determination is based upon a measurement of volumes.[14] A measure function for the volume of solids assigns the same number to solids with the same volume. The definition of such a function thus requires a criterion for the sameness of volume. Brentano argues, *contra* Mach, that any such criterion will rely upon prior measurements of the surfaces, edges, and angles of the solids to be compared. According to him, the only alternative method for testing solids for equality is trying to make them coincident by superimposing them. This, however, is impossible because of the impenetrability of solids.[15]

[13] Mach (Mach 1976, p. 279f/370) ascribes this idea to Leibniz.

[14] Mach "glaubt [...] bewiesen zu haben, daß jede geometrische Bestimmung auf eine Volumenmessung zurückgeht," (Brentano 1988, p. 134).

[15] "Durch Ineinanderschiebung konnte die Gleichheit aber auch nicht konstatiert werden, da die Körper undurchdringlich sind," (Brentano 1988, p. 134).—Here Brentano alludes to Euclid's fourth axiom that "[t]hings which coincide with one another are equal to one another." This axiom

As it stands, Brentano's argument does not hit its target since impenetrability is a property of physical bodies rather than of the ideal ones of geometry. Only the latter are of concern in the axiomatic priority thesis, however. As regards the hermeneutic priority thesis, it is not difficult to find practical procedures for comparing physical solids with respect to their volumes. Hölder (1900, p. 18), who might have been an inspiration for Mach[16] surmises that the notion of volume has been achieved by practical experiences made in the measurement of liquids in everyday life and explains, anticipating Mach, that from this concept one may derive that of the area of a surface.[17] These remarks suggest a method to compare the volumes of physical solids: one fills two equal glass vessels with the same amount of water and dunks the solids into the liquid in order to check whether the water levels in the two vessels still coincide or one of them is higher than the other. One has to admit, however, that this check involves a comparison of lengths though not a measurement of them in the full meaning of that word.

Though Brentano's objection against Mach's priority thesis cannot be uphold if "solid" is understood as "physical solid", he is nevertheless justified in requiring a criterion for the assignment of numbers to geometric solids in the measurement of their volumes. Congruence, of course, is a sufficient criterion for the identity of volume.[18] Felix Hausdorff, in his celebrated book on the *Basics of Set Theory* (Hausdorff 1914, 400), suggests to declare two solids congruent if they can be pointwise mapped onto each other by a bijection which conserves distances between points. This stipulation makes use of the notion of distance between points and is therefore at odds with Mach's priority thesis. In order to fully vindicate the axiomatic understanding of that thesis, one would still have to show that the notion of distance between points can be defined in terms of the notion of volume. But even if we succeeded in this, a serious problem arises as soon as we complement the requirement that congruent solids should have the same volume by two rather plausible additional postulates, namely: (1) that a cube whose edge has length 1 should also have this volume and (2) that the volume of a complex solid consisting of two non-overlapping parts should equal the sum of the volumes of these parts. Using a construction which was one of the inspirations giving rise to Banach and

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legitimates the method of superposition which is used twice by Euclid in order to show the congruence of two triangles by moving one of them in such a way upon the other that the two figures coincide.

[16] Hölder's little book, containing his inaugural lecture held in 1899 at the University of Leipzig, is cited twice in ch. XXI of *Knowledge and Error*, cf. Mach (1976, p. 296, Fn. 4/360, Fn. 1, p. 298, Fn. 38/387, Fn. 1).

[17] "Man kann den Inhalt bei Körpern als einen Erfahrungsbegriff ansehen, der aus dem Gebrauch der Hohlmasse bei Flüssigkeiten abgezogen ist, und von dieser Seite kann man dann auch zum Inhalt ebener Flächen gelangen." The importance of our experiences with liquids for the development of the notion of volume has also been emphasized by Lorenzen (1984, p. 21).

[18] There is a further problem involved here, namely: how to account for the identity of volume of non-congruent solids. The strategy applied for the corresponding problem of equal areas of two non-congruent polygons is, very roughly, to dissect non-congruent polygons of the same area into the same number of pairwise congruent triangles. It is known, however, that the three-dimensional analogue of this strategy does not work.

Tarski's (1924) famous "paradoxical" result concerning the decomposition of a ball into congruent parts, Hausdorff (1914, p. 402ff)[19] shows that there cannot be a function assigning the same volume to congruent solids and which, at the same time, fulfills both postulates (1) and (2).

Conclusion

Should we thus conclude then that the axiomatic priority thesis fails? Such a conclusion would be rash. Hausdorff's result concerns sets of points and it is by no means obvious whether such sets are adequate for modelling solids. Even if they are, one can still argue that those results only show that not each set of points can be conceived of as a (model of a) solid. Mach (1976, p. 264/354) himself defines solids (bodies) as "intricate and intimate complexes of other sensations with space-sensations."[20] Brentano (1988, p. 130) criticizes this explanation as mistaken for two reasons. (1) A solid does not consist of sensations; and (2) every sensation is, as Mach himself has admitted, already intimately connected with a sensation of space.[21] Thus this intimate connection is psychologically prior to the constitution of bodies. Brentano's first objection merely insists on a certain understanding of the relationship between elements and complexes which aligns this relation to that obtaining between the physical parts of a solid and the solid as a whole. The second objection overlooks the possibility of spatial sensations—e.g., "gestalt-sensations"—which contribute to the constitution of solids without belonging to those spatial sensations which "are intimately connected" with other, non-spatial elementary sensation entering into that process.

Hence it seems possible to defend Mach's explanation of the notion of a solid as a complex of sensations against Brentano's objection. Furthermore, solids need not be sets of pointlike sensations: neither is it necessary to equate Machean "complexes" with sets—rather than with, e.g., a mereological sums—nor must sensation be pointlike. Thus it may be possible to defend Mach also against objections based on Hausdorff's result. On the other hand, this result provides a constraint for any notion of a "complex" which is suitable for a more precise and formal explication of Mach's specific concept of a solid as a complex of sensations. Whatever notion is ultimately chosen for this purpose, it must admit for the definition of a suitable measure function for the volumes of those complexes which are solids.

[19]This section has been omitted in John R. Aumann's selective English translation of Hausdorff's book from 1957.

[20]This echoes Mach's explanation in *The Analysis of Sensations* (Mach 1959, p. 29/23): "Bodies do not produce sensations, but complexes of elements (complexes of sensations) make up bodies."

[21]"[...] zweitens hat Mach [...] auch gelehrt, daß jede Sensation auf innigste mit einer Raumempfindung verbunden sei."

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Part V
Mach and Pragmatism

Chapter 35
Empiricism or Pragmatism? Ernst Mach's Ideas in America 1890–1910

Erik C. Banks

Abstract Ernst Mach's philosophical ideas were warmly received in America, which already had a pragmatist tradition close to Machian empiricism and budding schools of philosophy, psychology, and physics more or free of the neo-Kantian influences which were a strong academic competitor to the spread of empiricism in Europe. The founding pragmatists Charles Sanders Peirce and William James engaged directly with Mach and Paul Carus, the editor of the *Monist* and publisher of the Open Court press actively translated and published Mach's works for the American public. A generation later when members of the Vienna Circle sought Academic posts in elite American universities, the ground was well prepared for their arrival as Holton and Stadler have described. Beneath the surface however, the American reaction to Mach was not one of naïve admiration but fairly staunch criticism, which Mach himself appreciated and welcomed. Peirce was highly critical of Mach's mechanics in a review and Peirce famously described Mach's empiricism as akin to riding a horse to death. In some ways, Peirce himself had anticipated aspects of Mach's views on mind and body, a surprising discovery I made recently. Even Carus, who declared himself an admirer, was highly critical of Mach's theory of economy of thought. James, too, who admired Mach greatly, had major disagreements with Mach on so-called sensations of innervation in psychology, and although's James' own radical empiricist essays owed much to Mach's neutral monist ideas in the *Analysis*, James broke away from what he saw as Mach's excessive physical reductionism, rejecting the monism about nature that was Mach's trademark. In short Mach's ideas acted as a stimulus to American thinkers, but they had their own tradition and they were able to resist his authority and contribute in reverse to Mach's own refinement of his positions.

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Introduction

Ernst Mach's influence on American thought was certainly very great and has already been documented at some length by John Blackmore (1973), Gerald Holton (1992) and Friedrich Stadler (2001) among others. Mach, who had considered emigrating in his teens, and who called America the "land of my deepest longing" saw the New World as a fertile ground for the elimination of metaphysical and historical baggage in philosophy and science, as he said in a foreword to his "Antimetaphysical Remarks" published in the very first issue of the *Monist* in 1890: "The time seems ripe for the overthrow of all metaphysical philosophies. I contribute this article in the confidence that America is the place where new views will be most fully developed."

I will take it as established that there were some natural affinities between Mach and American thinkers, and focus instead on differences. In fact, the American reaction was surprisingly critical. I focus on the period of 1890–1910 and specifically on the tension between American pragmatism and Machian empiricism. The main figures of my story are Paul Carus the editor of the *Monist* and a philosopher in his own right, Charles Sanders Peirce and William James, the New American Realist movement, and a surprising case of "parallel evolution" in the work of the Cincinnati lawyer and judge J.B. Stallo. In presenting Mach's views, I refer the reader to my in-depth studies of his philosophy and science (Banks 2003, 2014).

Paul Carus

Paul Carus (1852–1919) was born and educated in Germany and was a student of Hermann Grassmann. He emigrated to America where he became involved with the Open Court publishing company in LaSalle IL, near Chicago, and began editing the journal the *Monist*. Carus was crucial in getting Mach's works translated and making them available for the American reading public. The translations, most by Thomas McCormack, are readable and accurate and even preserve some of Mach's characteristic locutions.

Carus stayed in regular contact with Mach from the late 1880s onward and visited him in Prague in 1893 and in Vienna in 1907. He also made repeated, persistent attempts to clarify Mach's philosophy of science in various articles for the *Monist* and published some of Mach's replies from his correspondence. Carus, a trained philosopher, was a monist himself and the author of a self-styled "religion of science" with the formal, Eleatic Oneness of Nature substituting for a religious ideal. He also made a serious attempt to criticize Mach in the spirit of reaching a deeper understanding. This criticism concerned two main things:

1. The nature of Mach's neutral elements-cum-sensations
2. The status of abstract forms, concepts, theories and the formal "unity of science" vis a vis Mach's ideas about the Economy of Thought.

Mach is of course known for his "neutral monist" view of sensation, in which the same element, a sensation of blue, is also a physical event under a different set of physical variations (Mach 1959 orig. 1886). The question remains: is every physical element also a sensation, making Mach a kind of sensationalist even about physics? Mach's critics, like Vladimir Lenin, thought so, although James and Russell, and the American Realists, did not fall for this misreading at all. It must be said that although Mach said sensations were elements first and sensations second, and pointed to the existence of unsensed sensations in other minds and physical objects (for which see Banks 2003) he was often very unclear, using the word "sensation" when he seems to have meant "element." In a 1893 piece, Carus recalls the meeting in Prague when this question of words came to the fore:

> When several months ago I met Professor Mach in Prague . . . he assented to my speaking of scientific terms as abstracts . . . But when I proposed that the term 'sensation' also was according to my terminology an abstract term presenting one feature of reality only and excluding other features, Professor Mach took exception to it, saying that he understands by sensation reality itself. If, as Professor Mach uses the term, sensation is another name for reality, the main difference between our views appears to be removed." (Carus 1893, p. 299)

I think Mach is finally admitting that sensation is just his term for the really existing concrete natural elements, whether or not they are individual sensations. The term sensation is, in short, a metaphysical term for the individual events that concretely exist in nature, *some* of which are human sensations. With the admission that Mach's elements are actually more than *mere* human sensations, the debate over words seems to have dissolved to Carus' satisfaction.

Carus also wanted to know what Mach thought about formal laws and abstract theories in science. Were they really just economical devices and aids to memory rather than true forms inherent in nature? He wrote:

> While I have no objection to Mach's description of science as an economy of thought, I would hesitate to say that it is sufficient as a definition, because science is a correct (or adequate) description of facts in their essential features. Exactness, correctness, adequacy, truth, or whatever you may call it is the main thing and comprehensiveness comes in second as a natural consequence whenever the essential features have been rightly understood. I try to explain why . . . there is a feature in experience itself that justifies the formulation of theories . . . the purely formal is not merely a matter of method, it is not purely subjective, but must be a feature of the objective world. It explains why there are uniformities. (Carus 1906, pp. 336–337)

Thus, Carus can accept some kind of "second order" economy of thought that seeks to unify the greatest number of empirical laws under the fewest theoretical laws and principles, but rejects the idea that the formal or lawlike side of nature is itself a mere product of the economy of thought. Carus (a student of Hermann Grassmann who advanced a whole theory of abstract form in the beginning of his *Ausdehnungslehre*) emphasized the need for all laws to harmonize essentially into one, which mere economy could not guarantee, and would even perhaps discourage. Many others did as well, including Charles Sanders Peirce, seeing Mach's philosophy as totally inadequate to explain the importance of formal abstract concepts and how they seem to model the real, formal aspect of nature.

What *Was* Mach's Economy of Thought?

Economy of thought is a very deep issue in Mach's philosophy and requires extensive explanation. The short answer to Carus is that Mach *did* of course recognize the role of mathematical form in nature, and did emphasize that individual elements are mathematical functions of each other (perhaps relating their intensity) and are thus bound together in functional complexes. Unlike in Hume's philosophy, elements cannot occur *except* in relations with others, although the form the functional relation takes cannot be anticipated a priori, nor is the form possessed of any a priori certainty beyond that given by experience, as Kant would have it. Objects and egos are but crude aggregates or agglomerations of elements that are constantly changing: the functions that were really behind these objects all along take on this role of the "real objects," as Mach emphasized in the *Analysis of Sensations*. They could, for example, be temporarily closed systems of elements united by a function, f(a,b,c) = 0, an example Mach used often. The conservation of energy is, in Mach's view, simply a way of stating "the mutual (functional) dependence of phenomena on each other," which is certainly a formal principle. He stuck to this idea from the *History and Root of the Principle of the Conservation of Energy* (1872) all the way to his most mature scientific works, stating it again and again as a kind of musical coda to each of them.

However, Mach was also very clear that many of the most basic scientific concepts, especially these, are probably abstractions or even falsifications of direct concrete experience: absolutely enduring objects, frictionless planes and perfect spheres, but also absolutely repeatable, cyclic events, exact symmetries, and especially the spatio-temporal form of objects and processes which he felt was a superficial way of understanding the underlying reality of elements and functions described above and ceded too much ground to mathematics and to our psychological processes of visualization ("metaphysics").

Especially in his essay "On the Economical Nature of Physical Inquiry" of 1882 (contained in Mach 1895) Mach's basic skepticism about these perfect, smoothly-machined, concepts of physics is undeniable. Is there such a thing as perfect cyclical repetition, or symmetry, or do we simply demand that events take that form convenient for our understanding and the application of mathematics to nature? If I read him right in my 2003 book (pp. 131–134), Mach even considered the idea of making the second law of thermodynamics (for irreversible processes) foundational because of the impossibility of perfect cyclical repetition in nature, rejecting both the cyclical Carnot process and even the conservation of energy as abstractions.

Notice the inversion of Kant's synthetic a priori principles of natural science. Kant had insisted that if a concept, or judgment involving concepts, or a principle for forming judgments, was sine qua non for any scientific inquiry into experience, e.g., ideas of number, degree, conservation, sequence, the concept also had an epistemic a priori necessity and made science possible. Mach pulled up that argument by the roots and cast basic doubt on the epistemic foundation of those Kantian principles while still admitting their a priori status in the order of our thinking about nature, or the historical course of ideas in their development. These ideas have an a priori status in our thinking or methodology or history of a discipline like mechanics, but this does not mean they rest on a more certain foundation than experience or economical idealization. They may even be *more* suspect because they are unexamined. We may be forced to assume certain ideas in order to think or experience events, and they will appear to take an a priori position in the logical order *relative* to other ideas, but not absolutely so. As in much else, one can see quite clearly here how Mach's ideas have evolved directly from his criticism of Kant's synthetic a priori principles of natural science. (He is actually quite close to Nietzsche here, a connection that has interested several recent scholars including Pietro Gori.)

However it is also true (this is a point Michael Stöltzner emphasizes) that Mach said the scientist may discover real patterns or "the same great facts" stretching over many domains of inquiry, as long as these principles are said to rest upon experience alone. So as abstractions they can make infinite claims about future experience and be true generalities on one hand but they only rest upon finite evidence or cases and can be overthrown in the future. This is what I think Mach meant by saying that in an evidentiary, and even an ontological sense, there is no law of refraction only those cases of refraction that instantiate the law. A better example would be his use of potentials as effective general abstractions, while emphasizing that only potential *differences* (expressed in forces, or equilibrium of forces) are concretely real (for which see Banks 2003).

It is not widely known that Mach used abstract principles and laws often and thought the abstract phenomenological laws of thermodynamics could be an example of laws of great generality, completely independent of what domain of physics they are realized in, hence his hostility to the idea of basing thermodynamics on mechanics and not the more fundamental excluded perpetual motion principle, which he believed, in turn, evinced a general law of causality or functional dependence of phenomena on each other, as he says in his 1872 Treatise on the *Conservation of Energy*. (Mach 1910, orig. 1872)

It is also true that for Mach "nature forms one whole" a remark which delighted Carus as well as puzzling him. This means that there is actually a formal "coherence of nature" principle operating alongside Mach's injunction to consider only concrete elements and cases as really existing and the fact that "nature is but once given." I think this overall formal coherence is the order of functional connections between events for Mach, not the order of economical abstractions. In so far as economical abstractions do hold as real regularities they depend upon the deeper order of functional connections among the elements. If not, then the economical abstraction may be a simple aid to memory or a provisional device for talking about objects or other semi-permanent complexes, founded in biological need or ease of visualization.

Even if real regularities are reached, nothing whatever indicates which laws should be sub-ordered to which, or which laws truly run the deepest, and here another second order notion of economy comes into play. There are a few candidates for the ultimate abstract laws, great facts like the laws of thermodynamics and the law of least action. Why these basic laws hold is "unintelligible" but they are unintelligibilities with which we have become so historically familiar that we have ceased to see them as unintelligible. If other laws took their place, it could be these laws could then be explained, but only the assumption of further unintelligibilities (Mach 1910 orig. 1872, pp. 55–56). There are, in fact, two prominent examples in Mach's work of trying to flip or invert the order of principles to arrive at a new scheme:

1. Principle of inertia, statics for dynamics. Mach inverted the order of Newton's laws deriving the principle of inertia from the principle that forces induce accelerations, the logical converse of which is no net external forces = no accelerations, so when forces cancel for example in a dynamical equilibrium the result is no acceleration, so rest or uniform motion. As Mach also emphasized, D'Alembert's principle deduced statics from dynamics, by interpreting accelerations as inertial forces balancing the effective forces on a mechanical system. Again statics, which seemed more fundamental than dynamics, is actually less fundamental when their roles are inverted.
2. Mechanics and thermodynamics. While most scientists sought an explanation of thermodynamics from mechanical principles, Mach, again, sought to invert the explanation, using thermodynamic and electrostatic analogies (of potential functions and potential levels) to interpret the deeper meaning of mechanical laws (masses being analogous to charges and quantities of heat and distances, or velocities, as analogous to temperature or voltage). Could thermodynamical concepts be prior to mechanical ones? (Parenthetically, it is interesting to think here of DeBroglie's conjecture that Planck's constant h suggests a fundamental unit of entropy, not further reducible to a mechanical explanation of disordered motion. If so, then mechanics is actually a manifestation of thermodynamics, not the other way around.)

As Mach said, "where we stop," or which regularities we logically deduce from which is a sort of economical decision and will indeed revolve around questions of parsimony of assumptions, or even convenience, or historical acceptability and continuity with the past. It is in the sorting out of these patterns or overall "super laws" or great facts that the economy of thought is really applied by Mach.

It is well known that Mach wanted to disrupt the convenient assumption of basing physics on mechanics, which he regarded as a historically and psychologically conditioned conception, based on the fact that we are most comfortable with mechanical experiences of bodies moving in space and time and find these things easier to visualize and describe mathematically. This in no way indicates that mechanical ideas really do run deepest, merely that we *make them do so* relative to our other possible orderings of laws. It can therefore happen that some laws come to *appear* a priori because of the relative deductive position they assume relative to other laws. Some laws that lie very deep or high in the order, such as principles of symmetry and conservation, may even seem a priori to all others as Kant held. But again, for Mach this relative position of laws, or priority with respect to each other, does not give them any extra necessity or *evidentiary* weight as it does for

Kant. Even the most abstract postulates still rest for their *evidence* upon experience and not on any prior notion of formal unity and structure of nature. This is a very important point.

Consider one of Mach's famous examples, the transitivity of mass. One would think that transitivity is so basic or bedrock a property that any bona fide physical property would be guaranteed to have it a priori. Mach however in his definition of mass imagined three masses on a frictionless ring colliding by impact. Mass A collides with mass B which collides with C and then C collides with A again. We think the transfer of momentum and energy is a priori certain to be transitive, but there is no actual guarantee of this and it does not follow logically; it must be explicitly assumed as a *further* fact, in addition to other facts. It is a very clever insight and was deployed by Mach not to demolish abstraction or form but to deny form any extra a priori evidentiary power in science. I believe Mach could well be given credit for a philosophical breakthrough here, destroying Kant's ideal of what he called "synthetic a priori principles of pure natural science." According to Mach there simply is no such thing.

So to sum up, Carus thought the formal reality of nature was somehow out there to be discovered as a fact; Mach accepted the reality of form but always grounded it, both ontologically, and in an evidentiary sense, in experience, i.e., the concrete behavior of the elements in functional relationships that are likewise empirical.

Charles Sanders Peirce

Peirce (1839–1914) was the son of the mathematician Benjamin Peirce and was himself a practicing scientist and a prominent logician. Peirce worked in astronomy, measuring the brightness of stars and in geodesy, mapping the gravitational field of the earth for the U.S. Coast Survey, at the time the premier scientific institution in America. Peirce was actively involved in philosophy as evidenced by his two best known papers written for the *Journal of Speculative Philosophy*, the "Questions Concerning Certain Faculties Claimed for Man" and "Some Consequences of Four Incapacities" both in 1868. He also attended meetings of the so-called Metaphysical Club in Cambridge, Mass and it was here in 1872 that he read a paper William James later remembered as containing the germ of what became American Pragmatism, probably containing points from his later papers on the "Fixation of Belief" of 1877 and "How to Make Our Ideas Clear" of 1878.

In Peirce's first set of papers in the 1860s, he attacks Descartes, critiques the idea of an innate power of introspection and develops the idea that self-consciousness arises as an induction from experience and is not a logically prior notion underlying experience. There are Machian themes here. Even the distinctions between so called outer and inner sensation is inferred, not given, and one might say that for Peirce experience is a kind of neutral field which we learn to divide up into subject and object, inner and outer, sensation and form, by remembering and mastering the variations we find in experience. Even sensation itself, the momentary present experience, is not immediately present to the mind for Peirce but has to be abstracted by considering shorter and shorter durations.

Peirce clearly anticipated aspects of Mach's and James's later neutral monism. I have assumed that Mach was the main influence on James through the Analysis of Sensations (Banks 2003, 2014), but Peirce's neutralism may well have been an independent line of influence.

For Peirce, all results drawn from experience are strictly speaking inductive and follow from the application of various inductive and hypothetical methods of reasoning—a hodge-podge subject philosophers still call (a bit confusingly) "inductive logic." Peirce conducted a lifelong study of inductive-hypothetical methods in science and in philosophy and this led him more or less directly to what we now call American Pragmatism.

What *is* Pragmatism and how does it differ from Machian empiricism? A maxim often taken to define pragmatism is that two concepts that have exactly the same practical applications and consequences for science have no reason to be distinguished, despite the fact that the concepts may yet be metaphysically different. Peirce offers as an example the vector representing both force and the accelerating particle in "How to Make Our Ideas Clear." For Peirce, the idea that there is a further metaphysical distinction to make between force and the accelerative effects of force expressed in motion is a pseudoproblem. As yet, it isn't particularly clear how this would differ from empiricist verificationism or the underdetermination of theories by empirical evidence. Mach said such things about non-testable differences as well, but he took a different view of this example, claiming that Newton's second law is not a mere tautology but an important *empirical* law linking the presence of a force to the manifestation of accelerating masses. A force, for Mach, is an equalization of some existing potential difference, for example the potential energy of a body raised against gravity. In that sense, one can compare natural potential differences to each other and there is no reason why, for example, potential differences in height might not have equalized according to Fourier's law instead of Newton's (whereby differences of temperature "potential" are equalized by the "velocities" of heat flow). Or third and higher derivatives of position for that matter. Evidently an impractical metaphysical question for one person may well be regarded as empirically meaningful for another!

Pragmatism however, as Peirce understood it, is rather the idea that a priori philosophical theory of knowledge (as in Descartes or Kant) should be replaced by the inductive-hypothetical methods of the working scientist. Science is not a body of results and assumptions but a working method and scientific truth is nothing but the results our best methods can deliver over time leading to belief and confidence. Hence Peirce's often ridiculed idea that truth is the "ideal end of an infinite scientific inquiry." Hilary Putnam, following Paul Feyerabend, later attacked this view calling it "method fetishism." The fatal flaw of the view of course is that it assumes we already possess the correct methods of investigation and need only apply them infinitely many times.

I see this essential link between truth and method as the basic cornerstone of pragmatism in America, not the so-called "pragmatic maxim." And it does perhaps reflect a sort of scientific optimism very much in line with Peirce that the right methods will deliver the goods eventually, not through pure a priori thought, or synthetic a priori first principles (with which Mach would have agreed). In more recent times, American philosophers like Davidson and Putnam offered sophisticated variations on this Peircean idea that truth is inseparably linked somehow to our best rational methods for discovering truth, while remaining a method-dependent, and method transcendent ideal of sorts. Davidson for example links truth with intentionality and rational decision theory. The political philosopher John Rawls likewise defines justice as the outcome of a "fair process."

Peirce reviewed Mach's *Science of Mechanics* in 1893 for the *Nation* magazine (Peirce 1893) and we can see here exactly what he thought of Mach's views. Peirce took issue with Mach's historico-conceptual criticism, his economy of thought, and what he perceptively saw as Mach's imposing his own empiricist-nominalist metaphysics on science while claiming all the while to be "metaphysics free."

Elsewhere, Peirce said: "Dr. Mach who has one of the best faults a philosopher of science can have, that of riding his horse to death, does just this with his principle of the economy of thought" (Peirce 1931 p. 122). Peirce's critique of economy seems to be two fold: 1. Abstraction and generalization from individual experiences to abstract laws and concepts, is not merely for the purposes of book-keeping or economy, to replace a list of experiences with a single heading. The abstraction, the discovery of laws and applicable concepts, is actually the *goal* of inquiry and not simply to catalogue sensations, but because the laws and concepts are provisionally true (in the pragmatist sense of "following from our best methods"): there are precise natural laws and objects like atoms which can be guessed at and even concluded as a result of an inductive-hypothetical inquiry. 2. The individual, vanishingly brief, sensation is an abstraction as much as any other and "is known to us only inferentially."

Regarding Peirce's point that the element is an abstraction, Mach was also quite clear that the elements are provisional and can always be divided further, so they are by no means immediately given to individual knowers. Yet even in the complex way in which they are given, they are concretely real and not an abstraction, this is probably why Mach resisted Carus on that point. But Peirce was right to say that the neutral elements are a genuine metaphysical assumption although Mach would not have admitted it, until pushed by Carus to do so.

There is one other criticism Peirce makes and this has to do with Mach's rather dim view of official, codified scientific methods and his belief that those methods are based upon pre-scientific biologically or evolutionary instincts, for permanence, for repetition, for clear psychological visualization, human "intelligibility" in other words. Mach is the forerunner of today's philosophical naturalists who see science itself in the context of human evolution and brain science. Also, in making non-rational instinct the precursor of high sounding ideas of permanence, conservation and symmetry, Mach is close to Nietzsche as pointed out above.

Peirce points out sharply that Mach's view of inquiry is too passive, too one-sided, as experience imposes itself upon the human mind and accommodates thoughts to experience and thoughts to each other. Peirce disagreed very strongly with this. For him, hypothetical and inductive methods are *active*, based upon norms of reason, similar to those of deductive logic, and are *not* founded upon human psychology or pre-rational behavior. Abstraction is part of that essential process Peirce called abduction, where general hypotheses are essentially guessed and then tied to the experiences the guess would allow you to predict. They cannot be directly "induced" from a multitude of experience themselves. Mach might have agreed: he didn't think much of induction in science either and emphasized the role of abstract thought experiments (such as excluded perpetual motion and the role it played in Stevinus' chain argument, or the role of reversible Carnot engines in thermodynamics). These are certainly not inductions from experience. It's also clear however that however abstract principles are *arrived at*, they do not really "go beyond experience" in their evidence for Mach. They have no special Kantian synthetic a priori certainty qua abstract principles or norms, and the same goes for maxims of inquiry. As a fallibilist, Peirce might have agreed with that as well.

But Mach would never have shared Peirce's all too American optimism in the success of scientific methods in delivering results in the long run. Mach it is true made many studies of the different pathways of inquiry, historical and conceptual, in *Knowledge and Error* (1905) most notably, when he returned to Vienna to take up the Chair of History and Philosophy of the Inductive Sciences (a forerunner to our "HPS" programs of today). But, as Mach often emphasizes, the same methods that lead to knowledge *also* lead to error and there is no guarantee which will be the result, besides success. At the end of the day therefore Mach was *not* a pragmatist; he was still an empiricist who saw experience as the external arbiter of both truth and methods.

William James

Mach and James were both professionally engaged in sense psychology and physiology in the 1880s. James was writing his two-volume *Principles of Psychology* (1890–1) and, after a stint in university administration, Mach was putting the final touches on the *Analysis of Sensations* (1886) which was the culmination of work dating back to the early 1860s. These two figures met personally in 1882 in Prague for a conversation that must have been delightful (for both accounts, see Hentschel and Blackmore 1985 and Thiele 1978).

It is clear that James's version of Pragmatism was too much for Mach, as it would have perhaps relativized truth not only to scientific methods, as with Peirce, but still more general methods and interests, so much so as to admit pseudoscience, or "Spiritualismus und Schwärmerei." (Hentschel and Blackmore 1985, 63). Mach avoided the issue, merely suggesting to James he needed to read the book again and think about it some more. In James' defense, his pluralism of methods and of pragmatic truth is usually misconstrued; James did *not* claim to put all methods on the same footing or to embrace epistemic or cultural relativism about truth. Different methods will deliver different goals and objects, but they are not all equal in what they deliver. It also may be that for James, truth itself is many sided and not a monistic coherent structure, for which more below.

I suggest the real Mach-James connection should be sought in James' developing Radical Empiricism and not really in James' Pragmatism at all, hence Mach's tepid response to the latter. We have a letter from James to Mach (of 1902) in which he describes a new philosophy he is working up before his students, which will soon become the Radical Empiricist essays.

> I am now trying to build up before my students a sort of elementary description of the construction of the world as built up out of 'pure experiences' related to each other in various ways, which are also definite experiences in their turn. There is no logical difficulty in such a description to my mind but the genetic questions concerning it are hard to answer. I wish you could hear how frequently your name gets mentioned and your books referred to. (Thiele, p. 173)

Note: the word "pure experience" is a literal translation of *reine Erfahrung*, which was Richard Avenarius' term for neutral sensation in the *Kritik der reinen Erfahrung*. Aside from the term, which may simply have caught James' fancy as an inveterate word-collector, I can't see much else here. James knew Avenarius personally as well, but the relation to Mach seems much closer than to Avenarius's rather complex system.

Common to James and Mach is the idea that sensations, colors for example, are *real* facts about events occurring in the nervous system, and should be treated as neither exclusively mental, nor as physical, events, at least not in the customary sense of 'physical' which excludes experiences as "secondary qualities." Mach reached these views in the 1870s having shrugged off idealist, phenomenalist and monadic (Herbartian) views. James' road to the neutrality thesis is much less well understood.

In the 1890 *Psychology*, James considers a view called the "mind dust" theory, attributable to many different authors including W.K. Clifford. "Mind dust" is a compositional panpsychist theory in which each material object contains a grain of sentience or protosentience, such that when the grains combine physically into organisms they also combine mentally into experiences and minds. So the human experience of seeing blue comes together somehow out of various proto-experiences which sum up to blue somehow in the human nervous system. In the *Psychology*, James strongly rejects "mind dust" on the grounds that simply putting the materials of proto-sentience together would not assemble a mind any more that the thoughts of several people on the street can be combined into a mind or a team. Summing separate elements would not achieve the unity they achieve in consciousness, James thought. Moreover, each ego seems to be separate from all the others and fundamentally "unsummable" in some way with others.

However, by the Radical Empiricist Essay "Does Consciousness Exist" in 1904, James says that, just like Mach 20 years before, that he abandons this idea of consciousness fundamentally enveloping and segmented off our experiences. The blue one sees is also a physical event in the nervous system and would remain blue even if the other various functions of the mind, like memory, association, and reflex did not bind it in the context of a conscious experience. In place of the unified ego we have a collection of various functional connections ultimately realized in the brain and its activities, perhaps more like the mathematical composition of functions one inside another f(g(x)).

Mach of course had represented this view in psychology for many years and applied it to the phenomena of the Mach Bands, depth perception, and in his own rejection of Helmholtz's vague unconscious inferences, in which Mach sees simply an innate reflex or evolutionary mechanism requiring no conscious thought and which, in fact, undergird acts of consciousness when they seem complex enough and unified enough to be designated as such. The collection of innate reflexes make up the functional conscious ego, not vice versa.

James was also in open revolt against Brentano and the mysterious "intentional" acts which separated experience from the physical realm. In James' American Psychological Association address "The Knowing of Things Together" of 1895 later published under the title "The Tigers in India," Brentano's doctrine of intentional inexistence is under direct attack. Here James defends a causal theory of knowledge *and* error, before Mach's book of that name appeared in 1905, in which intentional and representational links between mind and object are replaced by purely causal links which have no necessary relation to their objects but purely natural ones, including those that lead us astray when we make errors. James famously says later in "A World of Pure Experience" that purely external links between a mental image of Memorial Hall and the real Hall are what establish the ability of a picture to be about the hall or even to be similar to the Hall. Or in another famous example from "Does 'Consciousness' Exist?" James points out that a pure experience of a fire and a mental image of licking orange tongues of flickering light are both real experiences taken in themselves. It is only the external causal power of the one experience to "burn real sticks" and the link of the other with a fever or illness, or burning only mental sticks perhaps, that establishes the difference between the two. I have written on Jamesian direct realism elsewhere (Banks 2014) which I feel to be his most unique contribution to philosophy.

So, with the ego gone and the pure experience freed from any permanent association with the mental, there was nothing to prevent James from joining Mach and becoming what Russell later called a "neutral monist." Indeed in my 2003 and 2014 books I argued for a Mach-James-Russell "movement" in neutral monism in the early twentieth century extending to today's neutral monists in the philosophy of mind, including the present author (and see also Stubenberg 2016). But this is not the end of James' evolution, there is also a problematic "next phase" which took him away from Machian monism for good and toward pluralism.

James' Next Phase

Machian elements and James's pure experiences both exhibit power or force, just like physical events do. This explains why they are functionally related to each other since the elements simply are concrete manifestations of power in events and affect one another as such, thus concretely grounding the functional relations in real causal relations (see also Banks 2014). For Mach this seems to have been a kind of triviality long known to physics, but for James, the concrete "concatenated" structure of reality was a further mystery to be understood by contemplating the workings of our own experience directly, or what he called "mental work," to accompany the "energetic" work that bits of pure experience exert in their physical variations (an idea he picked up from Wilhelm Ostwald and the energetics movement and their theory of sensation as "forceful mental energy"). (James 1977 p. 181, Banks 2003 Chapter Nine). Of mental work James says:

> Wherever the seat of real causality is, as ultimately known 'for true' (in nerve processes if you will that cause our feelings of activity as well as the movements which these seem to prompt), a philosophy of pure experience can consider the real causation as no other nature of thing than that which even in our most erroneous experiences appears to be at work. Exactly what appears there is what we mean by working, though we may later come to learn that working was not exactly there. Sustaining, persevering, striving, paying with effort as we go, hanging on, and finally achieving our intention—this is action, this is effectuation in the only shape in which, by a pure experience philosophy, the whereabouts of it anywhere can be discussed. Here is creation in its first intention, here is causality at work. (James 1977, 289)

James added to this a note that he was not contradicting his earlier writing in "Does 'Consciousness' Exist?" where he spoke of two orderings of pure experience, a mental ordering by psychological association and memory and a physical "energetic" ordering. The mental work is real but mental activity trains operate "by other parts of their nature than those that energize physically." (James 1977, p. 285n). However, unlike the physical work, for which we consult motions and external effects, the "mental work" is presented to us directly in the phenomena of our own minds and open for direct inspection. For Mach this would have been fine as long as it is acknowledged that both sorts of work are ultimately to be unified in one set of elements and variations, not two mutually exclusive sets in a sort of extended or enhanced "physics of the future" that includes psychology as a subdomain. But James clearly would have none of it. Indeed, in a notebook fragment published by Gerald Myers, James says there is *no possible unified view*:

> Apropos of my *reine Erfahrung*! Isn't the difficulty of a simple smooth scheme uniting the subjective and the objective due after all to the pluralistic constitution of things? Everything is many-directional, many-dimensional, in its external relations; and after pursuing one line of direction from it, you have to go back and start in a new dimension if you wish to bring in other objects related to it, different from those which lay in the original direction. No one point of view or attitude commands everything at once in a synthetic scheme. Yet all things are continuous through the mediation of the fact that each of them is contiguous to some other or others.

> To be more concrete, a sensible "experience" of mine, say this book written on by this pen, leads in one dimension into the world of matter, paper-mills, etc., in the other into that psychologic life of mine of which it is an affection. Both sets of associates are contiguous with it, yet one set must be dropped out of sight if the other is to be followed. They decline to make one universe in the absolute sense of something that can be embraced by one individual stroke of apprehension (Myers 1986, 326).

Gerald Meyers devotes a long endnote to this question, himself referencing Ralph Barton Perry's famous study of James:

> According to Mach's theory, sensations are neutral elements from which both mind and body are constructed. As Perry noted, Mach envisaged a construction modeled on physics. Perry described Mach's theory and James's response to it thus: "We find him defining the domain of psychology as the dependence of the sensations or elements on the central nervous system. 'Decidedly not,' remarked James in his copy of Mach's *Analyse der Empfindungen*, for this could only mean the reduction of psychology, through psychophysics, to physics; while for James psychology had its own categories, scientifically as authoritative as those of physics and metaphysically more fundamental." (Myers 1986, 569 n)

It would seem, then, that James' pluralism and his disunity of nature finally separates him from Machian monism once and for all and that this was his final position.

Ralph Barton Perry and the American Realists

The American Realists were a group of Professors at elite American universities deeply influenced by both Mach and James. The group included Ralph Barton Perry, Edwin B. Holt, William P. Montague, Walter B. Pitkin, W.T. Marvin and E.G. Spaulding. In 1910 they published their "Program and First Platform of Six Realists" in the *Journal of Philosophy, Psychology and Scientific Methods* (Perry et al. 1910). Each man wrote his own set of "bullet points" and they then signed a statement that each version was designed to fit under a general umbrella.

The Six Realists all defend a Machian theory of the neutral elements and are clear that these will include elements that are not human sensations, the latter being a subset of the former. Perry saw Mach's neutral monism as the crucial breakthrough to a realistic (*not* phenomenalistic) view of sensation and to one neutral order of elements. According to Perry, "Mach's book the *Analysis of Sensations* deserves to be numbered among the classics of realism." (Perry 1925, 79).

As Perry points out, however, the "functions" of Mach's view are to be replaced by the new mathematical logic, especially the logic of relations, in order to provide a formal structure for the elements. Perry claims that Mach's naturalistic and economical view of functional connections was insufficient to account for the formal mathematical side of nature (this issue again) and yet he (Perry) holds back from any sort of Platonic realism. (Perry 1925, 83)

> While Mach's statement of the theory is correct in principle, it is colored by the author's naturalistic predilections. He neglects the logical aspect of knowledge. Physical and psychical complexes have in common not only sensible qualities, but also certain more fundamental formal relationships, such as implication, order, causation, time, and the like. These relations in their purity can be discovered only by carrying analysis beyond the bounds of sensible discrimination. They require, in short, logical analysis. (Perry 1925, 311)

Perry also breaks with James's late pluralism. He and the other realists emphasize the Machian idea that the ego is a construction or a subset of relations within the larger set of relations of the natural elements. They also reject the privacy of mental experience, insisting that the sensation-elements are "open to all" no different from any other elements of nature. Perry also states that introspection is not to be the primary method of investigation of the mental, but rather the investigation of the mental relations themselves, and these should not be treated as if they are "hidden from view." This strongly foreshadows the American behaviorist movement.

However, in yet another meaning of "realism," Perry explains that because the sensation is also at the same time a physical element or event, it is possible to imagine that a perceived object extends all the way into the knower's consciousness, as on James' theory of direct, non-representative, perception. Bertrand Russell commented on this aspect of neutral monism as well in 1914, saying that Mach (and James) had performed "a service to philosophy" in explaining how part of external objects could be directly perceived in the mind as sensations (Russell 1984, pp. 31, 22). Yet it is also possible to group the mind-independent elements into a mind-external object, making representative, or indirect realism, true as well depending on which elements of the object we wish to emphasize. Perry points out the elegance of this solution to the problem of perception, in effect allowing for both direct and indirect realism.

J.B. Stallo: A Case of "Parallel Evolution"

In closing, I would like to mention J.B Stallo, who was born in Germany and emigrated to Cincinnati to pursue a career in law and to further his independent scientific studies. Stallo's *The Concepts and Theories of Modern Physics* (1882/1960) was a penetrating philosophical examination of the mechanical natural philosophy of atomistic matter and motion and Stallo himself uses the term "metaphysics" to describe this view and to declare his own "anti-metaphysical" position. Stallo even uses the word "metaphysics" in the psycho-physiological and historical sense of Mach, that is the unwarranted use of biological and psychological imagery and misleading visualization in natural science as well as historically conditioned ideas. For Stallo, just as for Mach, "metaphysical" does *not* mean that which is abstract, or hypothetical, or beyond direct verification. It means something completely different than what this term later meant in verificationist logical positivism. Stallo is the American thinker closest to Mach the physicist and critic of physics, although it is not a case of influence so much as parallel development. Was it ultimately Stallo more than the pragmatists who most convinced Mach that the American "soil" was ready for his ideas to take root, as indeed they did with the emigration of the logical positivists in the following generation?

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Chapter 36
Mach, Jerusalem and Pragmatism

Thomas Uebel

Abstract Ernst Mach's positivism, it is argued in this paper, may be regarded as a version of pragmatist philosophy of science. Already James's biographer Perry detected such tendencies in Mach and this is confirmed here by close attention to Mach's early works, esp. *History and Root of the Principle of the Conservation of Energy* and *The Science of Mechanics*. Both Mach's principle of the economy of thought and his principle of scientific significance are shown to bear out his pragmatism. A similar conclusion is shown to hold for the philosophy of Wilhelm Jerusalem already long before he became the translator of James's *Pragmatism* into German. But while Jerusalem early on relied perhaps even more than Mach on evolutionary theory for promptings of pragmatist insights, he soon too linked them, as Mach had all along, to broadly sociological observations concerning the condition of human cognition.

Introduction

In the fall of 1882 William James, then still working mainly in psychology, visited Ernst Mach, already well-known as an experimental physicist, in Prague and they thereafter remained in occasional correspondence. Precisely 25 years later, late in 1907, the book *Pragmatism. A New Name for some Old Ways of Thinking* by James, now a philosopher, was published in German translation by the Viennese pedagogue, psychologist and philosopher Wilhelm Jerusalem who henceforth allied himself with the pragmatist movement and became its foremost defender in Germany and Austria. Jerusalem had become a personal friend of Mach's since Mach's return to Vienna in 1895 and had been in correspondence about psychological questions with James since 1900. Mach for his part also guardedly expressed sympathy for James's

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Pragmatism. With that positive attitude he and Jerusalem were part of a very small minority in the German-language discussions about pragmatism in the years before WW1.[1]

What I want to do in this paper is to explore whether Mach and Jerusalem can be said to have offered a pragmatist account of human knowledge and philosophy before and independently of James (or Peirce) and how Jerusalem built on this basis so that his later apparent conversion to pragmatism was in fact a "re-branding" of his own already fully formed philosophy. Demonstrating the existence of such a home-grown pragmatism has significant consequences for our view of later twentieth century philosophy of science. It allows us to better recognize a similar tendency in thinkers never shy to declare their intellectual debt to Mach and often still today belittled as hapless, befuddled positivists—like Mach himself.[2] But here I'll stick to Mach with Jerusalem as additional illustration.

A word also on the concept of pragmatism. Just what precisely was meant by this "ism" was already in dispute between the founders of American pragmatism and it has been a flexible term ever since, but Hilary Putnam once gave a useful characterization that can serve us here. Pragmatism rejects scepticism about human knowledge but fully embraces fallibilism, it rejects unbridgeable dichotemies and it accepts the "primacy of practice" in demanding that human ideation be suitably grounded in experience to be held trustworthy.[3] In short, pragmatism deeply distrusts eternal verities and stresses the human authorship in all cognitive endeavours. There are numerous further differences between Mach and James and other pragmatists that I do not wish to deny, but it is in Putnam's fairly minimal sense that I wish to explore Mach's pragmatism here.[4]

The Pragmatism in Mach's Positivism

That Mach's supposed phenomenalism was in fact a thorough-going epistemological naturalism was convincingly argued by Rudolf Haller a generation ago (1988). It should not be too surprising then to learn that Mach's philosophy also was deeply pragmatist in outlook.

[1]On the German reception of pragmatism see Oehler (1977), Joas (1992), Dahms (1992), Ferrari (2006), Uebel (2014). For the different reception of pragmatism in France and Italy see Ferrari (2013).

[2]For the role of pragmatist elements in Rudolf Carnap's thought early and late see Carus (2007) and in his mature philosophy see Richardson (2007); for the role of pragmatism in the later thought of Philipp Frank see Uebel (2011) and in the earlier thought of Frank, Hans Hahn and Otto Neurath see Uebel (2015).

[3]See Putnam (1994). Note that this characterization says nothing about metaphysics and, likewise, does not proscribe all dichotemies and allows for variation in how they are bridged. For a good overview of pragmatism see Hookway (2008/2013).

[4]It is in this minimalist sense too that some of Mach's heirs in Vienna continue his pragmatism.

Mach as a "Forerunner" of James

That his personal acquaintance with Mach on the occasion of his visit to Prague in 1882 left a lasting impression of his "pure intellectual genius" on James is well-known.[5] But James's first biographer also wrote:

> From Mach, James had learned something of what he knew about the history of science, and he had readily accepted his view of the biological and economic function of scientific concepts. That was in the early days. In his insistence on the practical motives of knowledge, James had now [ca. 1907, TU] gone so far that he could obtain from Mach only the sense of a somewhat lagging support: 'W.J., but not emphatic enough,' he wrote in the margin of his copy of Mach's *Erkenntnis and Irrtum*. The latter's acknowledgement of *Pragmatism* was brief and somewhat perfunctory: 'I have read the book through hurriedly from beginning to end with great interest, in order to study it again later. Although I am by my training a scientist and not at all a philosopher, nevertheless I stand very close to pragmatism in my way of thinking, without ever having used that name. By following out his line the unprofitable differences between philosophers and scientists could be resolved.' (Perry 1936, p. 463)

Perry's judgement that Mach provided only lagging support needs to be qualified a little bit, but overall it is borne out in his correspondence, albeit not with James.[6] What I wish to stress here is that Mach's support of James's pragmatism extended only to what pertained to the understanding of science.

Mach did not at all care for James's metaphysical-theological flights of fancy. This is shown in his correspondence with the Danish physicist Anton Thomsen. Recalling James's visit in Prague some 20 years later, Mach returned, as it were, James's compliment, but also gave a sober assessment of James's philosophy:

> I cannot think of anyone with whom I was able to discuss matters as well and as fruitfully despite the divergence in our views. He opposed me nearly in everything and yet I gained in nearly everything from his objections .... The main focus of his work lies certainly in his excellent psychology. I cannot quite agree with his pragmatism ["nicht ganz befreunden"]. 'We must not drop the concept of God because it promises us too much.' That is a dangerous argument.[7]

Of course, even this selective appreciation left Mach still far more favourably disposed towards James's pragmatism than most academics in Germany were at the time. (In this they differed from their colleagues in France and Italy where a very positive reception of James had been taking place.)[8]

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[5] See the often-quoted letter to his wife, 2 November 1882, e.g. in Thiele (1978, p. 169).

[6] Perry also noted about Mach that "his last work approached closely to the pragmatist position" (Perry 1936, p. 588); presumably he meant *Erkenntnis und Irrtum* of 1905. Note also that in 1903 Mach had dedicated the third edition of his *Popular Scientific Lectures*, containing seven new essays, to William James and retained the dedication for the fourth edition in 1910.

[7] Mach to his Danish colleague Anton Thomsen, 21 January 1911, in Blackmore and Hentschel (1985, p. 86; trans. TU). In a letter of 4 September 1909 Mach remarked to Thomsen, after praising James's *Principles of Psychology* (1890): "That James tends towards passionate enthusiasm [*Schwärmerei*] and spiritism has to be weighed against his other achievements." (Ibid., p. 63)

[8] See Ferrarri (2014).

Perry's summary of James's reception in German-speaking Europe also made the following point:

> Although Ernst Mach was an important forerunner of pragmatism, while Simmel and Ostwald were greeted by James as allies, pragmatism gained only a light foothold in Germany, and that mainly in Austria! Even these three philosophers just mentioned accepted it as an interpretation of method in the physical or social sciences rather than as a philosophy. (1936, pp. 579–80)[9]

Here I want to ask: once we discount James's metaphysics, what remains of pragmatism as regards science is concerned, that had not already been developed by his "forerunner" Mach?

To see why one might think that what Mach's philosophy of science amounts to is what might be called "scientific pragmatism", let's consider further what Perry called Mach's "view of the biological and economic function of scientific concepts" (which James imbibed from him).[10] That view can be seen condensed, for instance, in the final sentence of the opening chapter, "Introductory Remarks: Antimetaphysical", of his *Contributions to the analysis of Sensation*s (which James knew very well): "No point of view has absolute, *permanent* validity. Each has importance only for some given end." (1886/1897, p. 26)

The Historical-Critical Method: Enlightenment Anti-metaphysics

To understand the pragmatist nature of Mach's philosophy of science, however, we must consider not so much his *Analysis of Sensation*s—which rather sees him classified, misleadingly but very widely so, as a phenomenalist positivist—but the more philosophical chapters of his historical works, *The Science of Mechanics* of 1883 and related essays, *Principles of the Theory of Heat* of 1896, and, of course, his *Knowledge and Error* of 1905.[11] The very aim of all of Mach's histories was philosophical in a sense of laying bare the epistemological principles in accordance with which the different branches of physics developed. This aim, he was very clear, connected him to the Enlightenment. As Mach put it in the Preface to the first edition of *The Science of Mechanics*, its "enlightening tendency" was

[9]A correction is needed here: James did not mention Simmel in *Pragmatism*, but Jerusalem did in his "Translator's Preface" (1908c, p. v); for the relevance of Simmel for Jerusalem see Uebel (2012).

[10]Mach repeatedly declines being bracketed with philosophers (e.g. 1886/1897, p. vii) but—whether like his later admirer Otto Neurath—he liked the association or not, his reflections on science simply do count as philosophical by all normal standards.

[11]See Mach (1882/1943, 1883/1960, Ch. 4, Sect. 4, 1884/1943, 1896/1986, Chs. 25–34, 1905/1976, passim).

"anti-metaphysical" (1883/1960, p. xxii).[12] So enlightenment for him meant laying bare these epistemological principles and that meant exposing as unnecessary and unwarranted all sorts of metaphysical assumptions.

It is also important to remember that the basic conception of Mach's thinking about science was long in place when his major historical works were written. It was laid down very clearly in his *History and Root of the Principle of the Conservation of Energy* published in 1872.[13] From it we can glean the kind of thinker and the kind of thinking that so impressed James on his visit to Prague.

Already in this early work his methodology was "historical-critical" (to use the subtitles of both his *Science of Mechanics* and *Principles of the Theory of Heat*) though he did not yet use the term. And while Mach may have borrowed the name of his method from the hermeneutic tradition of bible criticism (as Don Howard once pointed out), the point of his use of this method was not, of course, the restoration of divine revelation beneath the human distortions accrued over centuries, but the dismantling of metaphysical illusions about human experience. (In the light of Mach's own theory of elements, of course, we may think that we can detect a similar mythology of pure origin, but let's hold our critical horses for a moment.)

The point of the method was philosophical self-clarification: "There is only one way to enlightenment: historical studies." (1872/1911, p. 16) Moreover, Mach derived from this application a far-reaching diagnosis that speaks to the roots of the ignorance to which our enthrallment to metaphysics is owed: "We are accustomed to call concepts metaphysical, if we have forgotten how we reached them." (Ibid., p. 17) Mach called ideas "metaphysical" that have become absolutized: "if from history we learned nothing else but the variability of views, it would be invaluable." To excise metaphysics then is an eminently practical affair: "Whoever knows only one view or one form of a view does not believe that another has ever stood in its place, or that another will ever succeed it: he neither doubts nor tests." (Ibid.)

This practical point Mach himself felt was important enough to be repeated many years later, in the Introduction to the *Principles of the Theory of Heat*.[14] But both

[12]The English translation obscures Mach's historical side-taking by speaking merely of "clearing up ideas" to get rid of "metaphysical obscurities".

[13]Mach himself dated it to the early 1860s; see (1883/1960, p. 591)

[14]"Historical studies are a very essential part of a scientific education. They acquaint us with other problems, other hypotheses, and other modes of viewing things, as well as with the facts under conditions of their origin, growth and eventual decay. Under the pressure of other facts which formerly stood in the foreground other notions than those obtaining today were formed, other problems arose and found their solutions, only to make way in their turn for the new ones that were to come after them. Once we have accustomed ourselves to regard our conceptions as merely a means for the attainment of definite ends, we shall not find it difficult to perform, in the given case, the necessary transformation in our own thought.

A view, of which the origin and development lie bare before us, ranks in familiarity with one that we have personally and consciously acquired and of whose growth we possess a very distinct memory. It is never invested with that immobility and authority which those ideas possess that are imparted to us ready formed. We change our personally acquired views far more easily." (1896/1986, p. 5) the diagnosis of the root of metaphysical illusion and the pragmatic point of concern with history were already clearly cast into relief in this early work (the beginnings of which, Mach told readers, date back some further 10 years). History had the task of making us aware of the constructed nature of human concepts and the constructive task of human knowledge. Thus Mach urged in a most memorable phrase: “Let us not let go of the guiding hand of history. History has made all; history can alter all.” (Ibid., p. 18)

The Principle of the Economy of Thought and the Economy of Science

Not surprisingly then, already in this early work Mach concluded about scientific theories in general that they operate according to a principle of mental economy:

> If all individual facts—all the individual phenomena knowledge of which we desire—were immediately accessible to us, a science would never have arisen. Because the mental power, the memory, of the individual is limited, the material must be arranged. ... [a] ‘law’ has not in the least more real value than the aggregate of the individual facts. Its value for us lies merely in the convenience of its use: it has an economical value. (Ibid., pp. 54–55)

In terms borrowed from his friend, the political economist Emanuel Herrmann, Mach believed that “science faces a problem of economy or thrift” (ibid., p. 88, trans. altered).[15] Science operated within a practical context where it was constrained by what’s thinkable and doable with the resources at hand. To render comprehensible the otherwise incomprehensible multitude of phenomena was precisely its task. And still before the task of economic systematization came that of economical description.

As has often been remarked, economies can be effected in different ways. Applying this insight to theoretical thought, Mach was concerned therefore to stress that arriving by analysis at simpler elements must not be misunderstood as a different kind of achievement than it was.

> Besides this collection of as many facts as possible in a synoptical form, natural science has yet another problem which is also economical in nature. It has to resolve the more complicated facts into as few and as simple ones as possible. This we call explaining. These simplest facts, to which we reduce the more complicated ones, are always unintelligible in themselves, that is to say, they are not further resolvable. ... Now it is only, on the one hand, an economical question, and, on the other, a question of taste, at what unintelligibilities we stop. People usually deceive themselves in thinking that they have reduced the unintelligible to the intelligible. Understanding consists in analysis alone; and people usually reduce uncommon unintelligibilities to common ones. They always get, finally, to ... propositions which must follow from intuition and, therefore, are not further intelligible. (Ibid., pp. 55–56)

[15] On Herrmann, see Haller (1986).

To see in this only Mach's well-known anti-realism does not do justice to the radicalism of his thinking. Mach was clearly aware that conceiving of explanation as reduction to the familiar may avoid appeal to noumena beyond the ken of human understanding, but also that such a reduction ran the risk of misrepresenting what had been achieved cognitively. That such reductions of complex phenomena into simpler ones always proceed by means of conventional choices forced upon him the conclusion that what we consider to be basic elements must not be considered metaphysical ultimates. Rather, the very familiarity of these simplest notions betokens our ignorance of their true natures of their referents. Analysis provided understanding alright, but this understanding exhibited neither the depth nor the irrevisability which apriorist metaphysicians sought to endow their own intuitions with.

Importantly, moreover, not any old unintelligibilities were admissible for Mach, but only those that remain within reach of empirical investigation.

> The ultimate unintelligibilties on which science is founded must be facts, or, if they are hypotheses, must be capable of becoming facts. If the hypotheses are so chosen that their subject can never appeal to the senses and therefore also can never be tested, as is the case with the mechanical molecular theory, the investigator has done more than science, whose aim is facts, requires of him—and this work of supererogation is an evil. (Ibid.)

Clearly, already in play in this early work was a non-specified criterion of scientific significance. (More on this presently.) But, to be sure, here we also touch on Mach's objection to the atomic theory as he understood it, namely as a metaphysical ultimate, and which he rejected as beyond testability.[16] Let me simply note that what Mach said here also should apply to his own later theory of elements in his *Analysis of Sensation* (which, as it happens, was also foreshadowed in this early work).[17] Accordingly, his so-called "neutral monism" is not to be regarded as a metaphysics as with Russell, but an attempt at deflationism that seeks to redirect our attention from unanswerable questions to practical ones about the role of the concepts in our knowledge of the world. In other words, the "incomplete conception of the world" toleration of which Mach recommended to scientists (1883/1960, p. 559) is incomplete not only because the work of science remains unfinished and its results fallible, but also, importantly, because we must abstain from claims of the true nature of the basic elements of that conception, indeed banish altogether the very idea of things in themselves and rest content with what they do for us.[18]

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[16] In his 1882 Vienna lecture he stated: "The atom must remain a tool for representing phenomena, like the functions of mathematics." (1882/1943, p. 207).

[17] What he called "phenomena" (1872/1911, p. 61) were his later "elements", e.g. (1882/1943, pp. 208–210).

[18] To be sure, Mach sometimes speaks in a seemingly more dogmatic tone, as in the paragraph of *The Science of Mechanics* beginning with "Nature is composed of sensations as its elements." and ending with "Properly speaking, the world is not composed of 'things' as its elements, but of colors, tones, pressures, spaces, times, in short what ordinarily we call individual sensations" (1883/1960, p. 579). A deflationist reading has to read "nature" and "world" here as indexed to the scientific perspective. (Likewise with the claim "There is no cause nor effect in nature; nature has

So Mach concluded:

> In the investigation of nature, we always and alone have to do with the finding of the best and the simplest rules for the derivation of the phenomena from one another. One fundamental fact is not at all more intelligible than another: the choice of fundamental facts is a matter of convenience, history and custom. (Ibid., p. 57)

Our choice of fundamental facts then is conventional—"a matter of convenience, history and custom"—and as such is legitimate and neither capable nor in need of deeper explanation, as long as the prescription of testability is observed for them. With this conventionalist empiricism Mach early on distinguished his own position from that of most contemporaries (including that of his later friend and admirer Jerusalem).

The Evolutionary Dimension of the Economy of Thought

By the time that James visited him in Prague, some 10 years after the publication of *History and Root*, Mach had further broadened the horizon of his historical-critical inquiries and deepened them, as the lecture "On the Economic Nature of Physical Inquiry" given earlier that year to the Imperial Academy of Sciences in Vienna makes clear. To be sure, the principle of the economy of thought stood in the foreground. As he put in sect. IV of chapter 4 of the then soon to be published *The Science of Mechanics* into which that lecture material was worked: "In the reproduction of facts in thought, we never reproduce the facts in full, but only that side of them which is important to us, moved to this directly or indirectly by a *practical interest*. Our reproductions are invariably abstractions." (1883/1960, pp. 578–579, emphasis added). As before, the focus of this interest-relativity was pragmatically determined. But now it was the evolutionary origin of this interest-relativity—"the homely beginnings of science" as he put it in the lecture (1882/1943, p. 189)—that Mach began to stress.

To better understand the development of science and its epistemology, he now sought "to consider the growth of natural knowledge in the light of the theory of evolution. For knowledge, too, is a product of organic nature." (1884/1943, p. 217).

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but an individual existence; nature simply is" (ibid., p. 580).) And the translation "Only in the mind, therefore, does the mutual dependence of certain features exist" (1882/1943, p. 199) misleads for "the mind" replaces a demonstrative pronoun standing for "our schematic imitation". Whether the merely deflationary intention can be upheld by his theory of elements is another matter, of course, but see Haller (1980) for a sympathetic anti-phenomenalist reading that also stresses the only hypothetical character of the economical descriptions aimed for. It may also be stressed that Mach's elements are not Tractarian atoms: "Experience shows us the elements as dependent on one another." (1910/1992, p. 118)

Or, as he later summarised it in the opening sentence of *Knowledge and Error*: "Scientific thought arises out of ordinary thought, and so completes the continuous series of biological development that begins with the first simple manifestation of life." (1905/1976, p. 1, trans. altered). But already his 1882 lecture briefly sketched these "homely beginnings": "Man acquires his first knowledge of nature half-consciously and automatically, from an instinctive habit of mimicking and forecasting facts in thought, of supplementing sluggish experience with the swift wings of thought, at first only for his material welfare." (1882/1943, pp. 189–190) Mach fully recognized that the emergence of science possessed a socio-historical dimension, adding yet another dimension of economy:

> The first real beginnings of science appear in society, particularly in the manual arts, where the necessity for the communication of experience arises. Here, where some new discovery is to be described and related, the compulsion is first felt of clearly defining in consciousness the important and essential features of that discovery ... The aim of instruction is simply the saving of experience; the labor of one man is made to take the place of that of another. (Ibid., p. 191)

The demands that the social nature of knowledge acquisition imposed were themselves reflected in the economy of thought. As Mach put it soon after:

> It is the object of science to replace, or *save*, experiences, by the reproduction and anticipation of facts in thought. Memory is handier than experience and often answers to the same purpose. This economical office of science, which fills its whole life, is apparent at first glance; and with its full recognition all mysticism in science disappears. Science is communicated by instruction, in order that one man may profit by the experience of another and be spared the trouble of accumulating it for himself; and thus to spare posterity, the experiences of whole generations are stored up in libraries. (1883/1960, p. 577, orig. emphasis)[19]

Being evolutionary in origin the principle of economy of thought extended to the material means of representation as much as to its content. Mach explored both.

To begin with the means of scientific representation, language was the "instrument" of the communication of scientific results across individuals and entire generations and was "itself an economical contrivance" (ibid., p. 578). For instance, Mach claims, "[t]he first and oldest words are names of 'things'" even though "[t]he thing is an abstraction, the name a symbol, for a compound of elements from whose changes we abstract. The reason we assign a single word to a whole compound is that we need to suggest all the constituent sensations at once." (Ibid., p. 579) "The whole affair", Mach summarises, "is a mere affair of economy. In the reproduction of facts, we begin with the more durable and familiar compounds and supplements these later with the unusual by way of corrections." (Ibid.)

[19]Compare: "To save the labor of instruction and of acquisition, concise, abridged description is sought.... By communication, the experience of many persons, individually acquired at first, is collected in one." (1882/1943, p. 193)

In terms of the content of our representations, the principle of economy can be traced throughout the development of science, both in specific doctrines and general features of theory formation. Concerning the principles of the determination of laws of nature Mach thus gave an evolutionary-economical rendition of Hume's critique of the idea of causation as necessary connection (1883/1960, p. 581) and later provided a dissolution of the nominalism-realism dispute (1896/1986, p. 383). As regards the notion of law itself, Mach wrote of his favourite example: "[I]n nature there is no law of refraction, only different cases of refraction. The law of refraction is a concise compendious rule, devised by us for the mental reconstruction of a fact ..." (1883/1960, p. 582; cf. 1882/1943, p. 193; 1884/1943, p. 231; 1896/1986, p. 357) In sum: "Science itself ... may be regarded as a minimal problem, consisting of the completest possible representation of facts with the *least possible expenditure of thought*." (1883/1960, p. 586, orig. emphasis)[20]

So whatever the practical purposes of inquiry may be that set the parameters of convenience now, to this day all cognition and science bore the traces, deep in its conceptual make-up, of this origin. "In the economical schematism of science lie both its strength and its weakness. Facts are always represented at a sacrifice of completeness and never with greater precision than fits the need of the moment." (1882/1943, p. 206) For Mach, some sense of "the incongruence between thought and experience" (ibid.) was bound to remain, however much we might narrow the gap between the two. After all: "Nature exists only once. Our schematic mental imitation alone produces like events." (Ibid., p. 199).

These then were the ideas that Mach was likely to impart to anyone who listened in 1882. Now James, who, as Gerald Holton stressed, studied Mach's *Science of Mechanics* closely in the years after his visit to Prague as well as his *Analysis of Sensations*—his copies are marked up heavily—clearly made Mach's perspective his own.[21] And no doubt James was reminded of this after Mach had sent him a copy of the second edition of in *Principles of the Theory of Heat* in 1900 when he read it 2 years later.[22] There Mach wrote:

> The character and course of development of science becomes more intelligible if we keep in mind the fact that science has sprung from the needs of practical life, from provision for the future, from techniques. ... The investigator strives for the removal of intellectual discomfort; he seeks a *releasing thought*. The technician wishes to overcome a practical discomfort; he seeks a *releasing construction*. Any other distinction between discovery and invention can scarcely be made. (1896/1986, p. 407, orig. emphases)

The extent to which Mach's "positivism" was indeed a "pragmatism" as far as science was concerned can hardly be rendered plainer. As far as scientific method was concerned, it seems, James's pragmatism had little to add here.

[20] "The goal ... is the simplest and most economical abstract expression of facts." (1882/1943, 207)

[21] See Holton (1992/1993, p. 10–11) and Ryan (1989).

[22] See the letter from James to Mach of 17 June 1902 in Thiele (1978, p. 171).

The Principle of Scientific Significance

If all the above still sounds a bit too general to convince readers of the "pragmatic" nature of Mach's philosophy of science, then consider that as part of his general naturalistic approach Mach also formulated a maxim for scientific reasoning that has a good claim of being placed next to what James called "Peirce's principle". Back in *The Science of Mechanics* Mach had written:

> The function of science, as we take it, is to replace experience. Thus, on the one hand, science must remain in the province of experience, but, on the other, must hasten beyond it, constantly expecting confirmation, constantly expecting the reverse. *Where neither confirmation nor refutation is possible, science is not concerned*. (1883/1960, pp. 586–587, emphasis added)

Compare now Peirce's principle in "How to Make Our Ideas Clear":

> Consider what effects, which might conceivably have practical bearings, we conceive the object of our conception to have. Then, our conception of those effects is the whole of our conception of the object (Peirce 1878/1992, p. 132).

Now neither Peirce nor Mach mentions statements, let alone propositions. But the process by which science is distinguished by Mach—that it is possible to test its claims—is, broadly speaking, what taking account of "practical bearings" involves. There is then a deep affinity—ideationally. Chronologically, Peirce clearly predates Mach, but there are no indications that Mach ever read Peirce. Nor does the latter's principle seem to have been on James's mind at the time he visited Mach.[23] (When James himself put it to work he "pushed this method to such extremes as must tend to give us pause", Peirce once remarked (1902).)[24] In *Pragmatism* James's paraphrase of the principle from 1898 was repeated:

> To attain perfect clearness in our thoughts of an object, then, we need only consider what conceivable effects of a practical kind the object may involve—what sensation we are to expect from it, and what reactions we must prepare. Our conception of these effects, whether immediate or remote, is then for us the whole of our conception of the object, so far as that conception has positive significance at all. (1907/1991, pp. 23–24; compare 1898/1963, p. 13)

The difference between Peirce's and James's understanding of the principle has variously been described as logical v. psychological, non-individualistic (concerned with general consequences) v. individualistic (concerned with particular consequences), and as applying to scientific concepts v. all concepts.[25] But we need not

[23] In his *Pragmatism* James himself said that Peirce's principle "lay entirely unnoticed by any one for twenty years" (1907/1963, p. 24) until he "brought it forward again" in a paper of his own of 1898.

[24] In consequence Peirce sought to distinguish his own understanding of the principle by calling the resultant doctrine "'pragmaticism' which is ugly enough to be safe from kidnappers" (1905/1958, 186). Likewise Dewey criticized James's *Pragmatism* in his (1908).

[25] See Wiener and Peirce in editorial preface to Peirce (1905/1958) and Dewey in (1925). For a clear comparison of Peirce and James see Hookway (2008/2013).

go into these differences here or even those between the pragmatic maxims and what I call Mach's principle of scientific significance. What matters now is wherein they all agree. Mach's maxim for scientific theorizing specifies in logical terms Peirce's "practical bearings we conceive the object of our conception to have" and James "conceivable effects of a practical kind [an] object may involve—what sensation we are to expect from it, and what reactions we must prepare". All three agree that only differences that make a discernible difference matter for only they can make a difference to how we deal with the world and the challenges it presents to us.

It is this tying of significance or meaning to the possibility of human action and intervention in the world that renders all three criteria pragmatist. This is by no means a coincidence. It is as characteristic of the pragmatism of Peirce as of James that belief is regarded not as primarily a vehicle of representation of how the world is independently of what our concerns may be. Peirce called belief "a habit which will determine our actions" (1877/1923, p. 15) and, more carefully, attributed to it "just three properties. First, it is something that we are aware of; second, it appeases the irritation of doubt; and, third, it involves the establishment in our nature of a rule of action, or, say for short, a habit." (1878/1923, p. 41) As James put it, beliefs are "rules for action" (1898/1963, p. 12). How can they be that? Beliefs, as Peirce and James understand them, involve, indeed *set up* expectations about how things will be.

Mach had a different terminology, but aimed at similar reorientation of thought about thought. Old-school, he spoke of judgements but defined them as "not a matter of belief but naive feelings. It is rather that belief, doubt, unbelief, rest on judgements about agreement or disagreement between often very complicated sets of judgements." (1905/1976, p. 90 n. 14) For Mach, belief was a higher-order, metatheoretical concept and phenomenon. What mattered was, ultimately, how the overall informational state of an organism was prepared for new experience—whether that was conscious or not was not important—and that, for him, was a matter of judgment. And to do that judgment too set up expectations. Thus he could decree:

> A judgement ... that we find appropriate to the physical or mental finding to which it relates, we call correct and see knowledge in it.... Knowledge is invariably a mental experience directly or indirectly beneficial to us.... Knowledge and error flow from the same mental sources, only success can tell the one from the other. (1905/1976, 83–84)

Again, this largely agrees with Peirce's "truth, which is distinguished from falsehood simply by this, that if acted on it will carry us to the point we aim at and not astray" (1877/1923, p. 31)—and both of their pronouncements are about as suggestive and as vague as James's famous and notorious talk of the "cash value of truth".

In sum, Mach's principle of scientific significance and the entire conception of knowledge underlying it was deeply pragmatist. Without even mentioning it he rejected scepticism and embraced fallibilism, he rejected the dualism of mind and body and he most clearly accepted, as we just saw, the primacy of practice. Mach's naturalism also was a form of pragmatism.

Wilhelm Jerusalem's Pragmatism

Wilhelm Jerusalem is not much read today, but was a notable figure in the intellectual life of turn-of-the-century Vienna until his death in 1923.[26] Remembered, if at all, for his advocacy of the cause of American pragmatism, he also made significant contributions to the psychology and the sociology of his day. Here I can only point out the continuity of his views before and after his declaration of allegiance to American pragmatism.

Jerusalem's "Conversion" to Pragmatism

What is noteworthy is Jerusalem's own "conversion" to pragmatism. According to his own account**,** his prior work played a crucial role, in particular *Der kritische Idealismus und die reine Logik* of 1905, a strongly polemical intervention in the psychologism-dispute then raging in, even dominating German philosophy. (This was a wide-ranging *Streit* which concerned both the specific doctrine that the laws of logic and arithmetic are ultimately of an empirical nature and the more general issue of the proper method of philosophical inquiry; in addition it provided the occasion for the final disciplinary separation of psychology from philosophy.)[27] It was precisely Jerusalem's opposition to a priori philosophising in that book that prompted the English pragmatist F.C.S. Schiller in a review (1906) to comment on his proximity to pragmatism. This led Jerusalem to inquire about this movement with James with whom he already had been in correspondence about psychological matters since 1900.[28] Ultimately James's answer led to Jerusalem becoming James's translator.[29]

Consider Jerusalem's pronouncements on truth that had attracted Schiller's attention:

> Truth ... is created only by the function of judgement.... In judgement human beings of the most primitive level of development only adopt a stance, however. This adoption of a stance consists in the actions which are prompted by the interpretation of a perceived process. If the measures taken on the basis of that interpretation prove to be beneficial for life, biologically useful, then the interpretation was right; if they prove to be superfluous or even detrimental then the interpretation was wrong.... The valuation which action is accorded due to the benefit or detriment it brings with it, this valuation and nothing else is the origin of the concepts *true* and *false*. (1905, p. 162)

[26]For a biography and comprehensive treatment of his views see Eckstein (1935), for a recent overview and analysis of his contribution to the sociology of knowledge see Uebel (2012).

[27]See Kusch (1995).

[28]The correspondence was started when Jerusalem sent him a copy of his *Die Urtheilsfunction* (1895) and James "acknowledged its importance and his measure of agreement with it" Perry (1936, p. 580).

[29]See Jerusalem (1925, pp. 32–33).

So far, so (proto-) pragmatic and anti-Platonistic: no judgement, no truth.[30] Jerusalem went on:

> Soon the function of judgement proves so valuable and beneficial for life that it is exercised even where there is no immediate employment of its interpretation. We pass judgements in advance for later, as it were, and store the results of the interpretations made in our memory .... This brings with it a change in the meaning of the concept of truth. A judgement is true in the first stage of development only in so far as it prompts us immediately to undertake measures that are useful and beneficial for life. As soon as we begin to judge for storage, however, this meaning becomes a broader one .... Purely theoretical, highly objective judgement is thus itself a product of the instinct of preservation, indeed one of its most valuable and significant products .... Such judgements are in fact possible—as proved by the emergence and development of science. There research into the laws governing physical and psychological processes is undertaken without concern for practical gain. Even if the results of these investigations in the end are destined to make the life of humanity safer, richer and more pleasurable, the individual researcher can contribute to this last and highest aim only by proceeding strictly objectively. (Ibid., pp. 168–169)

Given that he later on often had to deny the common charge that pragmatism was unable to account for objective truth, it is notable that Jerusalem already here did not deny "purely theoretical" truth but stated: "It is possible for us to think theoretically, but first we had to learn to do so." (Ibid., p. 170)[31] We may note also that Jerusalem in his own philosophy anticipated the pragmatists' rejection of correspondence truth as a philosophical primitive as much as their rejection of a priori theorising and its replacement by reflections on human cognitive capacities in their evolutionary role. Just those were the ideas, after all, that Jerusalem foregrounded in the pragmatism he defended ever since 1907.[32] As his "Translator's Preface" stressed: pragmatism was primarily a method of inquiry, not a system of philosophical propositions (1908c, p. iv).

What these quotations from the pre-pragmatist Jerusalem make evident is that when he did become a pragmatist, he really did not have to change his views at all—all he had to do was re-label them and advertise, as he did, his own evolutionary-historical elaborations of their theory of truth and its embedding in the overall socio-cultural development of mankind as "supplementations" (ibid., p. vi). Accordingly, when in presenting pragmatism he asserted that "[f]or pragmatists, there is no such thing as a purely theoretical truth the content of which would never be practically discernible anywhere" (1908a, pp. 138), the critical emphasis lay on the concept of a *discernible* difference. By contrast, objective truth had consequences that were discernible.

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[30] In these passages Jerusalem also called upon similar ideas in (Simmel 1900, pp. 58–66), which built on ideas first expressed in (Simmel 1895). In later years, however, Simmel was critical of pragmatism: see Ferrari (2006).

[31] Later, in his own Preface to *Pragmatism*, Jerusalem gently suggested that James's remarks on truth needed to be recalibrated.

[32] See Jerusalem (1908a, b, 1909a, 1910, 1913).

Jerusalem's Evolutionary Psychology

So what prompted Jerusalem to develop his own proto-pragmatism even prior to learning of James's? A large part was played by his own research into the psychology of cognition which over the years morphed into evolutionary social psychology, but another was undoubtedly played by Mach's ideas as communicated personally and through his publications. In his Preface to his translation of James, Jerusalem explicitly noted that Mach's principle of the economy of thought and "especially his conception of natural law as a delimitation of expectation and generally his entire biologically grounded approach to science ... stood very close to pragmatism." (1908c, pp. vi–vii)[33] But the independence of Jerusalem's pragmatism from James's is also well shown by his own efforts to account for the social factor in individual development and the process of civilization.

Jerusalem's genetic-biological perspective on knowledge produced a distinctive psychology that opposed Herbart's psychology (still dominant in Austria in the second half of the nineteenth century) according to which mental life was accounted for solely in terms of representations and their interplay. Not only did feeling and volition need separate investigation, additions were also required on the cognitive side: an active psychological mechanism that imposed a certain structure on the cognized material as well as social mechanisms to operate alongside it. For Jerusalem, a pre-linguistic stage operating with "typical ideas" (said to picture biologically significant features of objects) was followed by a stage of primitive concept use (by means of one-word-sentences) and finally by a properly judgmental stage. This stage saw the operation of a constructive principle Jerusalem claimed to have been the first to have properly understood, the "basic judgement function" (*fundamentale Apperception*). It consisted in interpreting every happening as separated into the two elements of a "centre of force" and an "expression of force" such that the centre of force has ascribed to it a "will" that wills the expression in question. "By separating the root [one-word-phrases] into subject and object we form, structure and objectivize the process at issue. Only then do we begin to interpret it in a way that is conducive to our own nature so as to comprehend and master it intellectually." (1902, p. 107) Originally formulated in his 1888 *Textbook of Empirical Psychology*, this schema and its principle received repeated elaborations in later work.[34]

[33]For his part, Mach mentioned "the nearness" of his views to those of Jerusalem in *Der kritische Idealismus* in the Preface to the second edition of his *Erkenntnis und Irrtum* (1905/1976, p. xxxv; cf. ibid., p. 83) and credited it to their shared biological-evolutionary perspective. Mach also contributed a paper to a Festschrift for Jerusalem with an affectionate preface recalling "the time when you used to visit me in the evenings so as to allow this recluse to participate in the events of the world, especially the philosophical ones" (1915, p. 154).

[34]See also Jerusalem (1895, passim), (1899, pp. 77–80), (1902, pp. 89–91), (1909b/1925, pp. 142–143).

A central concept for Jerusalem in his attempt to understand the cognitive development of individuals and human intellectual development from prehistory onwards—from the use of typical ideas to the provisional endpoint so far at which stood precisely the concept of theoretical truth we saw him outline above—was that of "*Verdichtung*" ("solidification").[35] This concept was first used in this theoretical capacity by Moritz Lazarus, the originator of a version of *Völkerpsychologie* which aimed to provide both a psychology of social life and a theory of socio-cultural evolution.[36] For Lazarus *Verdichtung* was central, first as denoting the phenomenon of conscious effort becoming a stable disposition (as in individual learning), then using different forms of *Verdichtungen* to account for all sorts of social and cultural phenomena.

> We must distinguish between two types of the solidification of thought. One is individualistic, subjective, such that the solidified product of thought emerges from one's own efforts, one's own slow process of solidification. The other is universal, objective, such that it is only the result of a historical process that is taken into one's mind. The former shows the culture of the individual, the latter the public culture of an age. (1862/2005, p. 35)

In *Verdichtung* in the objective sense the intellectual labour of past generations is laid down in concepts or seemingly self-evident judgements or in firm customs reflecting a certain moral standard attained by previous generations, or even in works of art. Lazarus gave no specific account of how the advance made by personal *Verdichtung* was translated into the objective *Verdichtungen* of definitions, platitudes and expected behaviours. Significantly so, however, he did point for this to language as a means of communication and education and to the "creation of organs of the solidification of thought", of consciously fashioned concepts, through the intervention of scientist, moral thinkers and artists in everyday life (ibid., pp. 32–33).

Notably the term "*Verdichtung*" also appears in Mach's 1882 lecture which we already noted, aptly in connection with Mach's favourite example of the economy of science.[37]

> No human mind could comprehend all the individual cases of refraction. But knowing the index of refraction for the two media presented, and the familiar law of the sines, we can easily reproduce or fill out in thought every conceivable case of refraction. The advantage here consists in the disburdening of the memory; an end immensely furthered by the written preservation of the natural constants. More than this comprehensive and condensed (*verdichtet*) report about facts is not contained in a natural law of this sort. (1882/1986, p. 193)

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[35]Literally meaning "thickening", "increase of density" and "compression" in technical contexts and "condensation" in figural contexts, the translators of Ludwik Fleck who twice quoted the term from Jerusalem used "consolidation" (1935/1979, pp. 47, 172), while the translators of Freud who also used the term used "condensation"; see Laplanche and Pontalis (1967/1980, p. 83).

[36]See Köhnke (2005). The characterisation of *Völkerpsychologie* given here—which restores it against much misrepresentation of varying sorts—is his.

[37]The term *Verdichtung* does not, however, appear in Section 4.4 of Mach (1882), which is dedicated to the same topic, the economy of science, though the process and result designated by it is very well described there.

Other phenomena dealt with by Mach under the heading of the economy of thought also exemplified *Verdichtung* but did not use the term, e.g.: "By communication, the experience of many persons, individually acquired at first, is collected in one." (1882/1943, p. 193) Whether Mach adopted the term "*Verdichtung*" from Lazarus is unclear—others did.[38] Yet others seem to have adopted it from Mach.[39] Jerusalem's review of the German edition of *Popular Scientific Lectures* (containing Mach's address) also picked up on Mach's use of the term—he reported Mach's claim that "[w]e make use of the work of earlier generations and condense [*verdichten*] it in our concepts and formulas" (1897/1905, p. 188; cf. 1916/1925, p. 208)—but he himself had already employed the term in application to the formation of concepts and credited it to Lazarus.[40] What Mach and Jerusalem appear to have added, independently, to the use of Lazarus's concept was the explicitly evolutionary setting and especially its pragmatic dimension. Moreover, Jerusalem sought to elaborate the social processes involved elucidating their pragmatic character.

Jerusalem's Sociology of Cognition

Soziale Verdichtung, social solidification, became the central concept of what some describe as Jerusalem's sociology of knowledge, others as his social psychology. In any case it was central to his account of the "economy of mental life" (1902, p. 99), much of which covered the same ground as Mach's economy of thought but focussed on the early stages of cognitive development and provided an evolutionary account of the emergence of the epistemic concept of objective truth. Social solidification involves something like social reinforcement or, as Jerusalem once put it, "reciprocal fortification" (1909b/1925, p. 144). It different ways it represents the social factor that, Jerusalem argued, was active in all stages of the cognitive development of individuals and collectives, but especially early on. Social solidification creates and sustains intersubjective agreement in all of the ways which Lazarus had specified for *Verdichtung* in the objective sense: via language in concept-formation, via common-sensification of once notable affirmations, and via norm-formation for social behaviour. What brings about the social solidification of ideas of how things are or should be may be a more or less reasonable agreement with others in a group but it may also be coercive. But unlike intersubjective

[38]Simmel too used the term, albeit in writings of his not mentioned by Jerusalem, and without mentioning Lazarus; for Simmel's relation to Lazarus see Köhnke (1990).

[39]For instance by Friedrich Adler in his German translation of Duhem's *La théorie physique, son object et sa structure* which has him speaking, with reference to Mach, of "laws being condensed (*verdichtet*) in theories" (1906/1978, p. 24).

[40]See Jerusalem (1895, p. 150). In his later translation of James's *Pragmatism*, Jerusalem used the term "*verdichtet*" for "funded" as in "funded truths" and "experience funded" (1907/1994, pp. 142, 148, 170).

agreement, the concept of objective truth comes into view only once the evolution of cognitive development has entered the individualistic stage. Only then can coercive forces of social solidification be broken.

> Human thought begins with social solidifications and only the emergence from the herd, only the formation of independent personalities by social differentiation, leads beyond social solidifications to the objective knowledge of facts and laws. The social factor must be accompanied by the individualistic one if true knowledge is to develop. . . . Independent human beings strive to rid themselves of the ties of social solidification. They do not want to believe traditional opinions about things but want to get to know the things themselves. They direct knowledge to what is objective. 'True' no longer is what is believed by all, but what has been established by careful observation and measurement of things. . . . The place of the intersubjective criterion of truth, which consists in the agreement with fellow thinkers, is taken by the objective criterion of the fulfillment of predictions. (Ibid., pp. 149–150)

Jerusalem recognised that the process of social solidification and the search for truth can conflict. This made it "necessary that the traditional concepts of a science must be revised from time to time" (ibid., p. 145). However, Jerusalem did not regard as correct the objection that objective truth therefore had become independent of social processes.

> Truth is always a guide for human action. That is why the social factor retains its importance. An individual researcher may have discovered a new truth independently and all by himself, he may have proved incontrovertibly its objective validity by confirmed predictions. However, truth can become an effective force only by being recognised and translated into action. Even objective truths must become 'socially solidified' if they are to attain constancy and effectiveness. (Ibid., p. 150; cf. ibid., p. 152)

It was not the task of social solidification to separate truth from falsehood, but to make beliefs causally effective by being shared—whatever their truth value. This role social solidification still held in science itself whose social nature Jerusalem fully recognized (ibid., p. 141).

Jerusalem's use of the concept of social solidification illustrates, I believe, the independent nature of his pragmatism. In it he saw a set of mechanisms that allowed him to explain in somewhat greater detail how the demands of the economy of thought were realized without requiring undue efforts of each single individual and how thereby the primacy of practice in cognition was enforced throughout an entire population and culture.

Conclusion

I should add that despite the similarity between them that I was concerned to document, it must not be thought that I intended to portray the philosophies of Mach and Jerusalem as identical. Unlike Mach, Jerusalem was not repelled by James's metaphysics even though he did not endorse it. Indeed, Jerusalem, in a review of the second German edition of *Analysis of Sensations* voiced his dissent from Mach's theory of elements, stating that "[w]e shall always need a little bit of anthropocentrism and a little bit of metaphysics to build the world" (1900/1905, p. 202).[41] That said, the deeply pragmatic nature of both of their philosophies of knowledge should be evident.

Nor should it be thought, I repeat, that either of Mach's or Jerusalem 's philosophies were identical with those of the American pragmatists. Their differences from James's version—Mach's rejection of any metaphysical or theological speculation on account of what works psychologically for an individual and Jerusalem's insistence on the need for and possibility of the attainment of objective truth—should be clear. But neither must the difference between Mach (and perhaps even Jerusalem) and Peirce be overlooked.[42] Peirce objected strongly to Mach's nominalism. Peirce agreed with Mach's principle of economy in principle but held that he went "altogether too far. For he allows thought no other value than that of economizing experiences. This cannot for an instance be admitted. Sensation, to my thinking, has no value whatever except as a vehicle for thought," (1934, pp. 419–420). Despite the apparent misunderstanding (Mach's sensation were not altogether thoughtless) again the difference is clear. But short of some invidious essentialism that goes against how pragmatism has always been understood—which did not then and does not now preclude substantial quarrels among its protagonists—surely neither disagreement disqualifies them from being "pragmatists enough".

To conclude, let me briefly revisit Putnam's characterization. Clearly, neither Mach nor Jerusalem thought scepticism worth much attention and equally clearly, both accepted fallibilism. And while neither rejected all dichotemies, both rejected some with decisive vehemence: Mach that of mind and body, Jerusalem that of individualism and collectivism, and both that of apriori and aposteriori knowledge. Finally, both clearly accepted the primacy of practice. I conclude that, Austria had native pragmatists and that their pragmatism was home-grown.

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[41] By contrast, Mach stressed to the end that abductive reasoning does not legitimate switching into talk of entities of an entirely different category: "The conceptual compilation of facts is certainly what makes a compendious natural science possible, since without it an endless, immense, scarcely usable number of facts would exist. But it does not follow from this that the conceptual system must include *much more* or something *wholly different* from the individual facts of sensation accounted for; it still includes them, only ordered, only ordered perspicuously." (1910/1992, pp. 123–124, orig. emphasis, trans. altered).

[42] For Peirce's criticism of Mach see also Erik Banks's contribution to this volume.

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Chapter 37
What Does it Mean to Orient Oneself in Science? On Ernst Mach's Pragmatic Epistemology

Pietro Gori

Abstract The paper aims to investigate some aspects of Ernst Mach's epistemology in the light of the problem of human orientation in relation to the world (Weltorientierung), which is a main topic of Western philosophy since Kant. As will be argued, Mach has been concerned with that problem, insofar as he developed an original pragmatist epistemology. In order to support my argument, I firstly investigate whether Mach defended a nominalist or a realist account of knowledge and compare his view to those elaborated by other pragmatist thinkers, such as W. James, H. Vaihinger and H. Poincaré. Secondly, the question of what does it mean, for Mach, to orient ourselves in science is addressed. Finally, it will be argued that, although Mach tried to keep his epistemology restricted to a mere operational and economical account of science, that question involves the wider plane of practical philosophy.

Introduction

At the present time, Ernst Mach's contribution to contemporary epistemology is too often neglected in the philosophical studies. Although his name appears in several writings published by influential philosophers from the twentieth century, and during the last decades some scholars dealt with Mach's legacy, he is still sometimes considered as a secondary thinker, that is, an author who contributed to the development of some interesting ideas, but whose merits are not so relevant that he should be thoroughly studied. On the contrary, Mach's role in the contemporary cultural history is quite important, and it is possible to say of the people who

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nowadays pay little attention to him what Einstein, a hundred years ago, wrote of the opponents of Mach – that they "scarcely know how much of Mach's way of thinking they have absorbed, so to say, with their mother's milk."[1]

Aim of the present paper is to shed light on Ernst Mach's role in the history of thought, from a somewhat "untraditional" point of view. The guiding lines of the research, indeed, do not come from special studies in epistemology or in the history of the philosophy of science, but rather from an investigation carried on by the German scholar Werner Stegmaier, who focused on the topic of "orientation" as characteristic feature of modern and contemporary Western philosophical culture. In his main work on that issue (*Philosophie der Orientierung,* 2008) Stegmaier scarcely deals with the philosophy of science, and is rather more concerned with questions that – only apparently – are related to a different field of study. Nevertheless, as will be shown, this is a fertile perspective for studying Mach, since it helps contextualize his investigation in the cultural debate of the final decades of the nineteenth century, thus showing some elements that otherwise would remain hidden. With no intention of pretending that Mach was someone that he himself always refused to be – i.e., a philosopher – this paper aims to stress the *philosophical relevance* of some outcomes of Mach's investigations, and to show that they are consistent with particular issues that pertain to modern and contemporary philosophy.

In what follows it will be argued that Mach belonged to the thematic path outlined by Stegmaier and, furthermore, that he gave an original contribution to that path by developing a pragmatic epistemology. In order to properly contextualise the paper, two premises will be needed. Section 37.2 will therefore be devoted to explain (a) what is the *Philosophy of orientation*; (b) which definition of "pragmatism" will be adopted in this paper; finally, (c) what pragmatism has to do with the problem of orientation in philosophy.

Orientierung and Pragmatism

Werner Stegmaier's *Philosophie der Orientierung* (2008) offers a thorough study of the meaning and use of the notion of "orientation" in modern and contemporary philosophy. According to Stegmaier, that notion played an important role in Western philosophical culture, for it is related with some issues debated since the late-eighteenth century (particularly in Germany). Furthermore, Stegmaier stresses that the German word *Orientierung* is recent and that its use in philosophy dates more or less two and a half centuries. That term has of course first a topographical meaning (it actually means "to look at orient", that is, "to find the east"), but

[1] Albert Einstein, "Ernst Mach", eng. trans. in: John Blackmore (ed.), *Ernst Mach – A Deeper Look*, Dordrecht/Boston/London: Kluwer 1992, pp. 154–159, p. 155.

it can be used in many senses, in order to describe attitudes, beliefs, ideologies, etc. In general, *Orientierung* means "the capacity of finding our way in a specific situation [*Leistung, sich in einer Situation zurechtzufinden*] and adopting solutions that allow us to have that situation in control."[2] This definition can be applied to several different fields, that is to say, orientation is not only a matter for theoretical investigation, but rather involves issues that also pertain to pragmatic (or practical) research, Ethics and Morality.[3]

The origin of the philosophical meaning of the notion of *Orientierung* in the German-speaking world can be traced back to Immanuel Kant. As Stegmaier argues, it is in Kant's writing *What Does it Mean, to Orient Oneself in Thinking?* (1786) that one finds a philosophically relevant use of the verbal form "to orient oneself".[4] With that text, Kant contributed to a debate on Belief and Reason (*Glauben* and *Vernunft*) by adopting the idea of orientation as a pivotal concept connecting those notions. In Kant, *sich orientieren* can be seen as a type of make-believe which is presupposed in any activity of Reason and, therefore, is involved in the actual *critique* of the Reason itself.[5] Leaving aside the details of Kant's 1786 text for that would lead us far beyond the aims of the present paper, it is worth remembering the general problem that Kant was facing. That is, the problem of human knowledge and the value of make-believe, a problem that strongly influenced modern and contemporary philosophy, for it led to the heated topic of relativism (not to mention nihilism), which has been widely debated during the second half of the nineteenth century.

The importance of the notion of orientation in and for philosophy can be found in the idea that "to find our way" in the world is a fundamental necessity of the human being. *Orientierung*, therefore, lies at the basis of any questioning, of any *posing problem* itself, and it is so deeply rooted in our approach to reality that, on 1872, the German thinker Julius Baumann (that will be also mentioned in Sec. 37.3 of the present paper) adopted the newly coined word *Weltorientierung* as a synonymous of "philosophy".[6] To put it briefly, the idea is that, at any level of his activity (theoretical, practical, etc.) the human being has to do with a potential disorientation, for contemporary philosophers questioned the actual existence of the reference points of our world description and interpretation. From that viewpoint one can interpret the several forms of relationship of the human being with the external world as attempts to *provide means for the orientation*. These forms include religion, art, and ethics – but also science, which should not be seen as separated from the general philosophical thought (as nowadays sometimes happens).

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[2] Werner Stegmaier, *Philosophie der Orientierung*, Berlin/Boston: De Gruyter 2008, p. 2.

[3] *Ibid.*, p. 5.

[4] *Ibid.*, p. 78.

[5] *Ibid.*, p. 88.

[6] See Julius Baumann, *Philosophie als Orientirung über die Welt*, Leipzig: Hirzel 1872, and Werner Stegmaier, *Philosophie der Orientierung* cit. p. 111–12.

In his reconstruction of the presence of the theme of orientation in philosophy, Stegmaier indeed devotes some sections to the role that *signs* (*Zeichen*) play in our relationship with the world, and focuses especially on logic and scientific thought. For him, concepts, names, and logical notions, all have a fundamental symbolic value, and can therefore be seen as means for an orientation in the specific fields to which they pertain, but also as tools for finding our way in the world in a broader sense.[7] That view of course implies a new consideration of science, whose aim has not to be seen as to provide an actual *knowledge* of reality, but only to *manage* it and predict its development as well as possible. The very notion of *truth*, thus, acquires a quite different meaning from the one that was taught by the old schools of philosophy. According to Stegmaier, truth becomes a kind of regulative idea, an ideal objective of research: as he argues, "truth is the escape point [*Fluchtpunkt*] of scientific orientation, the point towards which she is oriented."[8]

The meaning of what above stated will be clearer when Ernst Mach's position will be taken into account (Sects. 37.3 and 37.4). As for now, let us consider the second premise of this paper, that is, pragmatism. In what follows, pragmatism will be considered from a broad point of view, as an inclusive philosophical research program. In particular, pragmatism can be seen as a peculiar *reaction to the problem of the meaning of ideas and truth*, that is, as a strategy for dealing with a disorientation which is epistemological as much as practical. As argued by William James in the chapter of *The Meaning of Truth* titled *Humanism and Truth*, pragmatism arises from the development of modern epistemology and faces the relativism implied in "the break-down which the last fifty years have brought about in the older notions of scientific truth."[9] According to James, the "multiplication of theories" in the second half of the nineteenth century led to a sceptic view of the value of scientific laws and concepts; as a result, these laws and concepts should be treated only as "conceptual shorthand, true so far as they are useful but not farther."[10] In order to avoid that scepticism and any kind of epistemological nihilism, it is necessary to find a way to manage relativism and, if possible, also to make it productive. That was the aim of several epistemologies that have been developed during the late-nineteenth and the early-twentieth century, research programs that shared a positive attitude towards the relativism above mentioned and that worked out comparable methods for determining the value of ideas with no truth-value. As Christophe Bouriau recently argued, these methods are pragmatic at their very core, insofar as they are grounded on the belief "that from the positive

[7] *Ibid.*, pp. 507 ff.

[8] *Ibid.*, p. 519.

[9] William James, *The Meaning of Truth. A Sequel to "Pragmatism"*, London: Longmans, Green & c. 1909, p. 57.

[10] *Ibid.*, p. 58. See also this excerpt from 1904: "Thus has arisen the pragmatism of Pearson in England, of Mach in Austria, and of the somewhat more reluctant Poincaré in France, all of whom say that our sciences are but *Denkmittel* – 'true' in no other sense that of yelding a conceptual shorthand, economical for our descriptions" (James, *Collected Essays and Reviews*, ed. Perry, New York 1920, p. 449–450).

practical implications of certain ideas, the value of these ideas may be determined, such implications being conceived in terms of operational convenience and of fruitfulness."[11]

As final preliminary remark, it is worth noting that pragmatism, thus conceived, is deeply concerned with several fundamental features of the "philosophy of orientation". From a general point of view, indeed, pragmatism contributed to contemporary philosophy by focusing on the problem of providing means for finding our way in the world, thus facing the same disorientation Stegmaier talks about in his volume. Moreover, pragmatism considers as a primary criterion for evaluating ideas and theories precisely their operational fruitfulness *as means for describing and managing the world* – that is to say, for orientation. Finally, the most important pragmatist thinkers (e.g. Peirce and James) have been concerned with the specific topics of *signs* and – in particular – *truth*, and the outcomes of their reflections are consistent with Stegmaier's argument.

The Task of Philosophical and Scientific Thought

Given these premises, it is now possible to address the question: What does Mach have to do with the "philosophy of orientation"? As will be argued, more than one can imagine.

In talking about scientific knowledge, Ernst Mach is especially as much as explicitly concerned with the problem of orientation. In the final section of the first chapter of the *Analysis of Sensations*, for example, he states that "the biological task of science is to provide the fully developed human individual with as perfect means of orientating himself as possible [*eine möglichst vollstandige Orientirung*]."[12] Some years later, in a paper on *Sensory Elements and Scientific Concepts* (1910), Mach sums up his view on the elements and their "dependence upon a complex of elements which includes one's own body," and then argues: "Only in so far as we establish the *dependence of the elements on one another* and *explore* those connections, whose stability is determined by the elements, can we orient

[11] Christophe Bouriau, "Vaihinger and Poincaré: An Original Pragmatism?", in: Michael Heidelberger and Gregor Schiemann (eds.), *The Significance of the Hypothetical in the Natural Sciences*, Berlin: de Gruyter 2009, pp. 221–250, p. 248. James was well aware of the existence of these epistemologies, and in fact he considered pragmatism as "a new name for some old ways of thinking," as we read in the title of his 1907 book. The definition presented by Bouriau aims to include Hans Vaihinger's *Fictionalism* and Henri Poincaré's *Conventionalism* among those ways of thinking, but one can also add to them Ferdinand Schiller's *Humanism* and Ernst Mach's *Empiriocriticism*.

[12] Ernst Mach, *The Analysis of Sensations and the Relation of the Physical to the Psychical*, eng. trans. Chicago/London: Open Court 1914, p. 37.

ourselves in the world [*in der Welt orientieren*]."[13] These excerpts already show that Mach adopted the terminology that pertains to the thematic field investigated by Stegmaier, that is to say, Mach uses the term *Orientierung* with a meaning that is not topographical, and he does so with regard to an intellectual activity of the highest level. Moreover, Mach proves to be concerned with the same fundamental problem that characterizes modern and contemporary Western culture and that gives philosophical value to the theme of orientation: namely, the lack of absolute and unchanging reference points (that is, *truths*) of human knowledge.

If one wants to explore the possibility of relating Mach with the *Philosophie der Orientierung*, the most interesting textual evidence can be found in the first chapter of *Knowledge and Error* (1905). That chapter is devoted to *Philosophical and Scientific Thought*, and in its opening sections Mach presents some observations on human knowledge from an evolutionary point of view. In the fourth paragraph, Mach deals with scientific thought (*wissenschaftliche Denken*), which, in his view, "presents itself in two seemingly different forms: as philosophy and as specialist research." Then, Mach argues:

> The philosopher seeks to orient himself as completely and comprehensively as possible [*sucht eine möglichst vollständige, weltumfassende Orientierung*] in relation to the totality of facts, which necessarily involves him in building on material borrowed from the special sciences. The special scientist is at first concerned only with finding his way [*um Orientierung und Übersicht ... zu tun*] about a smaller area of facts. Since, however, facts are always somewhat arbitrarily and forcibly defined with a view to the momentary intellectual aim, these boundary lines are constantly shifting as scientific thought advances: in the end the scientist too comes to see that the results of all other special enquiries must be taken into account, for the sake of orientation [*Orientierung*] in his own field. Clearly in this way special enquirers also collectively aim at *a total picture* [*eine Weltorientierung*] through amalgamation of all special fields. Since this is at best imperfectly attainable, this effort leads to more or less covert borrowings from philosophical thought. The ultimate end of all research is thus the same.[14]

In this excerpt Mach talks again of "orientation" as task of both philosophers and special scientists, and uses the German word *Orientierung* as he did in other writings. Nevertheless, the passage contains something more, namely a hidden reference that is fundamental for the aim of the present paper. At the end of the quoted excerpt, Mach talks of the "total picture" that the special enquirers collectively aim at gaining. In the original German version of *Knowledge and Error*, Mach uses the word *Weltorientierung* (italics by Mach), a term that appears only here in his whole writing. This isolated case cannot be by chance, and in fact it is revealing. As mentioned in the previous section of this paper, the word *Weltorientierung* first appeared in the German speaking world in Julius Baumann's

[13]Ernst Mach, "Sensory Elements and Scientific Concepts", in: John Blackmore (ed.), *Ernst Mach* cit., pp. 118–126, p. 119. The same view of the relationship between the elements can be found in the first chapter of the *Analysis of Sensations*, § 15, just before Mach's observation on human orientation through science.

[14]Ernst Mach, *Knowledge and Error*, eng. trans. Dordrecht/Boston: Reidel 1976, pp. 2–3.

book *Philosophie als Orientirung über die Welt*. Baumann is an author scarcely known in modern times, but that at the end of the nineteenth century played his part in the philosophical debate.[15] If one looks at the pages of Baumann's book where that word appears, it is easy to see that the questions there explored are exactly the same as those Mach deals with in the above quoted passage from *Knowledge and Error.*

Baumann, indeed, talks of *Weltorientierung* in the preface of his 1872 book. In that text, Baumann defends the idea that philosophy actually *means* "general orientation in the world through thought."[16] Moreover, Baumann argues that philosophy gains an important aid from scientific thought (*wissenschaftliche Nachdenken*), and he then deals with the relationship between scientific philosophy and the special sciences.[17] For Baumann, the only difference between philosophical and scientific thought concerns the limits of their application. While philosophy aims to reach a general and universal knowledge, each special science deals with a limited portion of the world, and can therefore only gain an orientation that will be restricted to these portions ("*wir haben in ihnen blos Orientierungen über einzelne Theile der Welt*").[18] Of course, if we collect the outcomes of all the special sciences, the result will be a general overview of the world. In other words: "Each science, if separated from the others, provides us with a limited orientation in the world [*ein Stück Weltorientierung*], while all the sciences taken together can provide us with a complete orientation [*die Ganze Weltorientierung*]."[19] What the orientation provided by the special sciences lacks is the general and universal perspective that pertains only to philosophy, which, in Baumann's view, remains at the very edge of the pyramid of human knowledge.

As above suggested, there is a striking similarity between Baumann's and Mach's texts. Both the authors deal with the relationship between philosophy and special sciences, that they both consider as an expression of scientific thought in general. Moreover, the task that both Baumann and Mach attribute to these disciplines is also the same – namely, to provide man with a general orientation in the world (*Weltorientierung*). Thus, although there is no actual proof that Mach read Baumann's 1872 book (unfortunately, the text does not appear among Mach's documents stored at the *Deutsches Museum* in Munich), there are good reasons in support of the idea that *Philosophie als Orientirung über die Welt* is the hidden

[15]Baumann also wrote a paper on Mach which first appeared in the *Archiv für Systematische Philosophie* (1898, pp. 44–64) and that has been later included in his book *Deutsche und Außerdeutsche Philosophie der letzten Jahrzehnte* (1903). On 1899, the paper – titled *Über Ernst Mach's Philosophische Ansichten* – received some critical remarks by Hans Kleinpeter, to which Baumann replied the same year ("Ist Mach von mir Mißverstanden worden?", in: *Archiv für Systematische Philosophie*, 1899, pp. 367–369).

[16]Julius Baumann, *Philosophie* cit., p. 1.

[17]*Ibid.*, pp. 12 ff.

[18]*Ibid.*, p. 18.

[19]*Ibid.*, pp. 18–19.

reference of the quoted passage from *Knowledge and Error*. Moreover, it can be argued that Mach's concerning with orientation in and through science should not be seen as a minor topic of his epistemological investigation.

Pragmatic Epistemology

What has been considered above supports the idea that Mach belongs to that section of the history of Western culture and philosophy outlined by Stegmaier's *Philosophie der Orientierung*.[20] This idea is corroborated by the fact that Mach gave an original contribution to that history, that contribution consisting in the value and function Mach attributed to scientific concepts – which are the actual *means of orientation*. An investigation on Mach's view of scientific concepts will therefore answer the question: *What does it mean, for Mach, to orient oneself in (and through) science?*

To address that question allows us to define what can be called "Mach's pragmatism". An investigation of the nature and role of scientific concepts and theories, and, consequently, of the meaning of scientific "truths", actually pertains to the research program that arose during the second half of the nineteenth century and to which William James gave a collective name. As known, James has been particularly influenced by Mach in developing his own form of pragmatism. The overlapping of Mach's views on psychology and epistemology with those defended by James has been stressed by authors who personally knew Mach (e.g. Hans Kleinpeter and Philipp Frank),[21] and during the last decades studies have been devoted to that topic, in order to show the "state of elective – but also selective – affinity" that characterized the relationship between Mach and James.[22] James's considerable number of annotations in his private copies of works such as *Analysis of Sensations* and *Knowledge and Error* demonstrates his interest in Mach's investigations, and reveal the former's attempt to indicate similarities between Mach's views and his own position or current interest.[23] As Gerald Holton concludes, "James's copies of Mach's book graphically demonstrate the intense impression they made on him

[20]Incidentally, it is worth noting that Stegmaier only mentions Mach in a footnote devoted to the internal ear (Ohrlabyrinth) and the physiological capacity of orientation (Orientierungsempfindungen). See Stegmaier, op. cit., p. 37 n. 5.

[21]See Hans Kleinpeter, "Der Pragmatismus im Lichte der Machschen Erkenntnislehre," in: *Wissenschaftliche Rundschau* 1912; Id., *Der Phänomenalismus. Eine naturwissenschaftliche Weltauffassung*, Leipzig: Barth 1913; Philipp Frank, "Was bedeuten die gegenwartigen physikalischen Theorien fur die allgemeine Erkenntnislehre?", in: *Erkenntnis*, I/1930–1931, pp. 126–157.

[22]Gerald Holton, "Ernst Mach and the Fortunes of Positivism in America", in: *Isis* 83/1, 1992, pp. 27–60, p. 34.

[23]See Holton, *op. cit.*, pp. 35–6 and Judith Ryan, "American Pragmatism, Viennese Psychology", in: *Raritan* 8, 1989, pp. 45–55.

during the period in which he was engaged in writing his own major works."[24] That impression is particularly evident in James's *Pragmatism*, where the debt to Mach is explicitly mentioned.[25] In general, it is possible to say that jamesian pragmatism is deeply grounded on machian basis, and that is why Mach himself, in a famous letter he sent to James on June 28, 1907, admitted: "Although I am by my entire training a scientist and not at all a philosopher, nevertheless I stand very close to pragmatism in my ways of thinking, without ever having used that name."[26]

Ralph Perry stated that "from Mach, James had learned something of what he knew about the history of science, and he had readily accepted his view of the biological [evolutionary] and economic function of scientific concepts."[27] Both these elements are fundamental features of Mach's pragmatic epistemology that can be found at the origin of his idea that science provides "the fully developed human individual with as perfect means of orientating himself as possible".[28] In *Knowledge and Error*, Mach argues that concepts are mental constructs produced by a process of abstraction, thought symbols that "enable man to classify the real."[29] According to him, "concepts [are] so valuable and useful for science, [for] they can represent and symbolize in thoughts large areas of fact. The purpose of concepts is to allow us to find our way in the bewildering tangle of fact [*in der verwirrenden Verwicklung der Tatsachen sich zurecht zu finden*]."[30] It is easy to see that Mach is in total agreement with the perspective of a *Philosophie der Orientierung*. "The capacity of finding our way [*zurecht finden*] in a specific situation" is actually the definition of *Orientierung* (see above, Sect. 37.2), and in dealing with concepts Mach focuses on the same symbolic value that Stegmaier stresses, when he talks about the role and function of *signs* in the scientific discourse. Nevertheless, as mentioned above, Mach's view of the scientific concepts presents some original features that can be stressed by making reference to other writings where he deals with that same topic.

It is well-known that Mach defended an evolutionary conception of knowledge, according to which science is the final product of an intellectual development. Within that framework, concepts are but "mental symbols for groups of sensations – symbols that do not exist outside our thought".[31] Therefore, in Mach's view, scientific concepts do not *correspond* to external reality, that is to say, they do not describe reality as it is *in itself*. The anti-realistic picture that can be drawn from

[24] Holton, *op. cit.*, p. 36.

[25] See e.g. William James, *Pragmatism. A New Name for some Old Ways of thinking*, London: Longmans, Green & C. 1907, pp. 57 and 190.

[26] Joachim Thiele, *Wissenschaftliche Kommunikation. Die Korrespondenz Ernst Machs*, Kastellaun: Henn 1978, p. 175.

[27] Ralph Barton Perry, *The Thought and Character of William James,* Boston: Little, Brown 1936, p. 463 (as quoted in Gerald Holton*, op. cit.*, p. 33).

[28] Mach, *The Analysis of Sensations* cit., 37.

[29] Mach, *Knowledge and Error* cit. p. 93.

[30] *Ibid.*, p. 98.

[31] Mach, *Popular Scientific Lectures*, eng. trans. Chicago: Open Court 1897, p. 201.

Mach's statements on the economical nature of physical inquiry – that is, the idea that the name we give to a group of properties is nothing "more than a compendious economical symbol" – is mitigated by his famous view of the adaptation of thoughts to facts and of thoughts to one another.[32] If literally applied to epistemology, the Darwinian model suggests that thoughts are shaped accordingly to external reality, whose general features could therefore be inferred from the attributes of thoughts themselves. This *hypothetical realism* is a kind of "third way" between realism and anti-realism, and helps dealing with an issue that, in Mach, is not always so clear.[33] However, this latter dichotomy can be addressed in a different way, which is precisely what I think Mach did.

Concepts, according to Mach, are a creation of human thought whose relationship with facts cannot be neglected. Therefore, concepts are not a product of pure imagination, but at the same time they do not just reflect the external world. The original contribution of Mach to that topic consists in leaving aside the *content* of scientific concepts (the portion of reality they should describe), and to look, instead, at the *practical role* they play, at the *activity* they represent. As Mach states in *The Principles of the Theory of Heat*, "the strict definition of a concept and, in case it is familiar, even the name of the concept is a stimulus to a precisely determined though often complicated, testing, comparing or constructing *activity* whose result, in most cases perceptible by the senses, is a term in the extension of the concept."[34] For what concerns physics, in particular, concepts can be seen as "instructions for building", while "facts are the results of building".[35] Moreover, in Mach's view "the concept is not a finished idea, but body of directions for testing some actually existing idea with respect to certain properties, or of constructing some idea from given properties. The definition of the concept, or the name of the concept, releases a definite activity, a definite reaction, which has a definite result."[36]

This is a pure pragmatic epistemology. The value of a concept is not judged on the basis of what that concept represents or describes, but rather by looking at what it *produces*, that is, at *the effects of the reaction the concept releases*. This idea can be found in Mach's very definition of "knowledge" and "error". As James sums up in some marginalia at the end of Chapter 7 of his personal copy of the 1905 edition of

[32] See Mach, *Popular Scientific Lectures* cit., chapter 10, and Ernst Mach, *Principles of the Theory of Heat*, eng. trans. Dordrecht/Boston: Reidel, chapter 25.

[33] Supporters of hypothetical realism are, for example, Donald Campbell and Konrad Lorenz. See on this Michael Bradie, "Assessing Evolutionary Epistemology", in: *Biology and Philosophy* 1, 1986, pp. 401–459. It is worth noting that Campbell mentioned Mach in his seminal essay "Evolutionary Epistemology" (in: Paul Schilpp (ed.), *The Philosophy of Karl R. Popper*, LaSalle: Open Court, pp. 412–463). There are several elements, indeed, to consider Mach as a forerunner of the research program outlined by Campbell; among them, Mach's idea that the Darwinian theory of development can be applied to thoughts as much as to organisms (see e.g. *Principles of the Theory of Heat* cit., p. 351).

[34] Mach, *Principles of the Theory of Heat* cit., p. 369.

[35] *Ibid.*, p. 370.

[36] *Ibid.*, p. 381.

Erkenntnis und Irrtum, "error in Mach's eyes has the exclusively practical meaning of a concept that leads to disappointment in expectation. *Täuschung* [deception] leads to *Enttäuschung* [disappointment], *Wahrheit* [truth] to *Bestätigung* [confirmation]."[37] The only difference, therefore, lies in the result of each evaluation, which proves (or denies) the actual *operational convenience* and *fruitfulness* of a conception in guiding our expectations. As Mach argues in his late paper on *Sensory elements and Scientific Concepts*, "whether our expectation is satisfied (. . .) or is disappointed, in both cases the value of the concept will be determined by testing."[38]

Mach's view is consistent with the thematic lines presented in the first section of this paper. As many other thinkers from the second half of the nineteenth century, Mach is concerned with a conception of human knowledge that is quite different from the traditional one, and that, by rejecting the idea that our thoughts correspond to external reality, leads to a mere *relativistic* view of "truth". Given that concepts and theories cannot be judged by looking at their actual content, and that man *needs* some principles of evaluation in order to keep on pursuing scientific research, Mach explores the same possibility other pragmatist thinkers of his time took into account and focuses on the *practical consequences* of ideas. As above stated, the main aim of all this is to provide man with principles of *orientation in the world*.

For what concerns the actual *orientation* that, in Mach's view, scientific concepts provide us, some hints can be found in the final chapter of *Knowledge and Error* devoted to *Sense and Value of the Laws of Nature.* In that text, Mach contrasts the usual opinion "that the laws of nature are rules, which processes in nature *must* obey," with the idea that these laws are only the result of an abstraction from natural processes, that is to say, "our intuition and our concepts *alone prescribe* laws to nature."[39] That view clearly limits the normative value of the laws of nature. According to Mach, their value rests on their role of "restrictions that under the guidance of our experience we prescribe to our expectations," a role that stresses the biological importance of these laws, which is coherent with the general evolutionary conception of science defended by Mach.[40] What is worth noting, for the aim of the present paper, is that Mach's dealing with that topic is related with the theme of orientation. Indeed, Mach argues that the "laws of nature are a product of our *psychological* need to find our way about [*zurecht finden*] in nature, so that we do not stand estranged and baffled in front of natural processes."[41] Furthermore, he stresses that they must be considered only as the most recent "attempt at orientation

[37]Excerpt quoted in Hiebert's *Introduction* to Mach, *Knowledge and Error*, op. cit. p. XXVI. James's copy of *Erkenntnis und Irrtum* is conserved in the Houghton Library of Harvard University. See also Mach, *Knowledge and Error* cit., p. 84: "Knowledge and error flow from the same mental sources, only success can tell the one from the other. A clearly recognized error, by way of corrective, can benefit knowledge just as a positive piece of knowledge can."

[38]Mach, *Sensory Elements* cit. p. 123.

[39]Mach, *Knowledge and Error* cit. p. 351.

[40]*Ibid.*, pp. 351–2.

[41]*Ibid.*, p. 354.

[*Orientierungsversuch*]" produced by our "current state of culture".[42] According to Mach, the main urge of scientific research at the beginning of the twentieth century is "to minimize mental effort, to attain economy, continuity, constancy, and as general a scope as possible for profitably applying the rules set up."[43] The value of scientific laws and theories thus lies in their practical efficacy, in their operational fruitfulness as economical tools for dealing with the hitherto accumulated individual findings. "Natural science," continues Mach, "may be viewed as a kind of collection of instruments [*Instrumentsammlung*] for the intellectual completion of any partially given facts or for the restriction, as far as may be, of expectations in future cases."[44] As above considered with reference to the distinction between "knowledge" and "error," what is fundamental in Mach's epistemology is the role of expectations. The laws of nature are, in his view, "merely subjective prescriptions for an observer's expectations to which reality need not conform,"[45] and their value can only be judged *pragmatically*, by looking whether those expectations are finally met or disappointed. Therefore, the role of scientific laws as instruments for finding our way about in the natural world is far from being normative. "A proposition in natural science always has a merely hypothetical sense,"[46] and, as Mach concludes, "science has developed into the factor that is biologically and culturally the most beneficial" for she replaces "tentative and unconscious adaptation by a faster variety that is fully conscious and methodical."[47] However, that does not mean that the laws that science abstracts from the natural processes can be seen as *norms* from which those processes cannot deviate. On the contrary, in Mach's view, the role science plays in human orientation lies in her capability of providing men with working hypotheses, with concepts that are merely mental constructs and human devices for testing some existing idea and fruitfully guiding our expectations. That is, precisely, Mach's pragmatic epistemology.

[42] *Ibid*.

[43] *Ibid.*, pp. 354–5.

[44] *Ibid.*, pp. 355–6.

[45] *Ibid.*, p. 358.

[46] *Ibid.*, p. 356.

[47] *Ibid.*, p. 361.

Chapter 38
"The Most Artistic Lesson I Ever Heard" – A Contribution to the Reflection on a Comment Made by William James Regarding a Lesson by Ernst Mach

Mariana Valente

Abstract On November the 2nd 1882, William James visited Ernst Mach in Prague, and attended one of his lectures. The conversation with Mach and the lecture were marking events for James. James was also very interested in Hermann von Helmholtz's ideas and he attended also one of his lessons. However that lesson had not such a marking effect on James. Based on Mach's and Helmholtz's lectures for the general public I propose a reflection on the defining traits that made the said event "the most artistic lesson [James] ever heard". We shall remark, namely, on the imaginative joy contained in Mach's texts, which appear to embody some of James' key ideas on Education. To evaluate these writings as regard the 'artistic lesson', we shall turn to William James's *Talks to Teachers on Psychology and Education* (1892) and to Alfred Whitehead's "The Aims of Education" (1929), as well as to some contemporary thinkers.

Keywords Artistic lesson · To experiment · Imagination · Sensibility · Imaginative joy

The Question

A number of researchers in science education have returned to the pedagogical insights contained in the writings by Ernst Mach, elaborating on them and using them as new values (M. Matthews, M. Euler, K. and H. Siemsen, among others).

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I propose to address a comment made by William James[1] in two letters: one addressed to his wife on November 2, 1882, and the other to Carl Stumpf, regarding a lesson by Ernst Mach, which James referred to as "the most artistic lesson I ever heard".[2] These comments aroused my curiosity about the possible merits of Ernst Mach's lessons, which had so strongly impressed James.

In 1882 while travelling in Europe, William James met with Hermann von Helmholtz and Ernst Mach and attended their lectures. Both Helmholtz and Mach researched scientific fields that interested James very much (Physiology, Psychophysics, Physics).

Another comment made in the letters to his wife about a conversation he had had with Mach shows James's enthusiasm:

> I don't think anyone ever gave me so strong an impression of pure intellectual genius. He apparently has read everything and thought about everything and has an absolute simplicity of manner and winningness of smile when his face lights up, that are charming. (Jeremy Bernstein, 1986, p. VII)

These observations help us explore the necessary conditions for an "artistic lesson". On the one hand, having "read everything and thought about everything" stimulates the imagination and the sensibility if they are experiences in the Jamesian sense, which they are indeed. On the other hand, the empathy conveyed by Mach's manner and smile shows his particular way of relating to others, and to what he read and thought.

According to Max Planck (2014), Helmholtz's lessons were not remarkable experiences. James stresses this in the letter addressed to Carl Stumpf, cited by Herbert (1976, p. XIII): "Helmholtz... gave me the very worst lecture I ever heard in my life except one". Notwithstanding, Helmholtz was an erudite scholar. Helmholtz's and Mach's education was influenced largely by the same authors. Both are inter-disciplinarians, a feature that is clearly visible in their popular scientific lectures. So what made them so different as teachers?

We shall address this aspect by revisiting some of the writings by Helmholtz and by Mach, particularly the lectures given to the general public, because these reveal the two scholars' views on Knowledge and Nature.

To evaluate these writings with regard to the 'artistic lesson', we shall turn to William James's Talks to Teachers on Psychology and Education (1899) and to Alfred Whitehead's "The Aims of Education" (1957, first edition 1929).

[1]H. Siemsen and K. Siemsen have addressed this issue from a different perspective from the one we will present.

[2]I first came across this comment in a footnote to the first chapter of Holton's book "Science and Anti-Science" (1993, p. 45). Erwin Herbert (1976) in his Introduction to Mach's work "knowledge and Error" mentions the comment made by William James in a letter addressed to the philosopher Carl Stumpf. He is said to have used the expression "beautiful lesson" in the letter addressed to his wife.

Hemholtz and Mach's Worldviews Expressed in Their Popular Scientific Lectures – Some Contrasts

The conferences delivered by Helmholtz between 1853 and 1892 and by Mach between 1864 and 1898, to non-specialised audiences, were filled with references to objects, experiments and pictures. The proceedings of Mach's conferences that I am using were translated and re-edited by McCormack in 1986, while those by Helmholtz, that I am using, were collated and published in 1995 by science historian David Cahan.

In one of his writings, Mach states that "the subject-matter of the natural sciences should be made familiar by means of pictures and experiments before a profounder and reasoned grasp of these subjects is attempted" (p. 365). In these texts we detect the "signs of times" - the nineteenth century - through the topics that were addressed and the experiments that were conducted and presented; many references are made to the nature of scientific knowledge and although the authors have very different views on the matter they both share a "concrete" rather than an abstract approach in these lectures. Mach's texts stresses the importance of being aware of our fixed habits of thought, and how important it is to enrich these habits through streams of consciousness in our relationship with the world. Mach is constantly driven by the multiplication of perspectives. The educational value of these texts has been addressed by different authors, maybe more often about Mach's texts than Helmholtz's. Music, literature and painting are important for both scientists and although their emphasis on each of these fields may differ, they bear witness to the extensive culture of the two authors. We do not aim to deepen the analysis of these texts but rather to highlight some of the thoughts they express, which will enable us to highlight the relevant differences that have potential implications on their ways of teaching.

In his work "An autobiographical sketch", Helmholtz writes (last lecture before his retirement, 1891, p. 384)[3]:

> As I became bigger and stronger I went about with my father and my schoolfellows a great deal in the neighbourhood of my native town, Potsdam, and I acquired a great love of Nature. This is perhaps the reason why the first fragments of physics which I learned in the Gymnasium engrossed me much more closely than purely geometrical and algebraical studies. Here there was a copious and multifarious region, with the mighty fullness of Nature, to be brought under the dominion of a mentally apprehended law. And, in fact, that which first fascinated me was the intellectual mastery over Nature, which at first confronts us as so unfamiliar, by the logical force of law. But this, of course, soon led to the recognition that *knowledge of natural processes was the magical key which places ascendency over Nature in the hands of its possessor*. (I am responsible for italic sentence)

[3]I'm using the date of the lectures to emphasize his place in Helmholtz's life. All the pages are in reference with David Cahan's edition.

These words were written by Helmholtz at the age of 70 and they convey a world view that places "the Intellectual Mastery over Nature" at the top of the ladder, whereas in Mach's writings we find the joy of thinking and discovering, through the simplest gesture in our relationship with the world. We find a fine example of this in Mach's book "Kultur und Mechanik" with illustrations by his son: "The touch of hands and feet triggers a number of sensations. The small cylindrical piece of wood under our hand, a disc-shaped stone held between thumb and forefinger make us experience the rich feeling of rolling motion "(pp. 26–27), and from this experience Mach leads us to the invention of the "fixed axis". Here we are not confronted with "the intellectual mastery over nature" but rather in a kind of enaction between man and the world (Fig. 38.1).

If we read other texts by Helmholtz we will become aware of a man-nature order. In fact, let's take a look at this excerpt from a beautiful text on the "Physiological causes of harmony in music" (1857, pp. 46,75):

> Ladies and gentlemen, - In the native town of Beethoven, the mightiest among the heroes of harmony, no subject seemed to me better adapted for a popular audience than music itself. Following, therefore, the direction of my researches during the last few years, I will endeavour to explain to you what physics and physiology have to say regarding the most cherished art of the Rhenish land – music and musical relations. (. . .)
>
> Thus both harmony and disharmony alternately urge and moderate the flow of tones, while the mind sees in their immaterial motion an image of its own perpetually streaming thoughts and moods. Just as in the rolling ocean, this movement, rhythmically repeated, and yet ever varying, rivets our attention and hurries us along. *But whereas in the sea, blind physical forces alone are at work, and hence the final impression on the spectator's mind is nothing but solitude – in a musical work of art the movement follows the outflow of the artist's own emotions*. (I am responsible for italic sentences)

Does the flow between "the so called lifeless world" and man –lead to a feeling of loneliness? In Mach's case this stream is always filled by emotion and by an "imaginative joy". Man is Nature.

In another conference, by Helmholtz, about "The Interaction of Natural Forces", there are very inspiring passages for the introduction of the concept of work that I often use in teacher training contexts. The following excerpt of this text

Fig. 38.1 "The small cylindrical piece of wood under our hand"

reflects the idea of the need for a dull effort in order to reach some fruition in the learning process. Indeed, Helmholtz wrote: "I must conduct you a portion of the way – as short as possible – over the uninviting field of mathematico-mechanical ideas, in order to bring you to a point of view from which a more rewarding prospect will open" (p. 20). But what follows may not be bleak; it feels barren to Helmholtz because he only feels enjoyment in moments of "intellectual mastery over nature". His is a world view centred on the preference for the universals: "you see how, starting from considerations based on the immediate practical interests of technical work, we have been led up to a universal law (. . .)" (p. 125). To understand, "a natural phenomenon in physical science" implies being able to explain it as follows: "tracing it back to the ultimate forces which are concerned in its production and its maintenance" (p. 12). In contrast, Mach feels pleasure from the start as in the example of "the small cylindrical piece of wood under our hand". Mach's idea of understanding a phenomenon is to learn to establish relevant and appropriate connections (sophistication of causality, a methodological continuity between common sense and scientific explanation). It is therefore necessary to multiply perspectives and experiences. "Things (that) at home are passed by unnoticed, delight us when abroad, though they may appear in only slightly different forms" (p. 224). In educational terms we need to provoke the experience of "foreign" perspective, as Mach does so well, especially using "the growth of science".

As far as Mach is concerned one needs to focus on what is new in any learning situation. This is a very important notion in science education nowadays and very important in Whitehead's thinking.

> *Every motive that prompts and stimulates us to modify and transform our thoughts, proceeds from what is new, uncommon, and not understood.* Novelty excites wonder in persons whose fixed habits of thought are shaken and disarranged by what they see.[4] (I am responsible for the italic sentences)

He thus suggests a common learning methodology to different areas of knowledge:

> *It is through change of circumstances that the natural philosopher learns.* This process, however, is by no means confined to the investigator of nature. The historian, the philosopher, the jurist, the mathematician, the artist, the aesthetician, all illuminate and unfold their ideas by producing, from the rich treasures of memory, similar yet different cases; thus they observe and experiment in their thoughts.[5] (I am responsible for italic sentence)

He further states that "the extension of experience always involves a transformation of our ideas".[6] Let us recall the beautiful image of the very simple experiment[7]: to roll a small stick under one hand. We detect Mach's fertile sensitivity, awareness and imagination.

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[4] Ibid., p. 224.

[5] Ibid., p. 230.

[6] Ibid., p. 229.

[7] Op.cit. p. 338.

Learning science involves developing an interest in the phenomenon and changing contents of consciousness which is something Mach does very well. Streams of consciousness are associated with the experience of the world and of culture. He praises the journey as a physical experience infused by what has been lived and recorded. "What an immense portion of the life of other men is reflected in ourselves; their joys, their affections, their happiness and misery!".[8] His experience of the physical world was always influenced by a live historical culture.

Some short passages provide us with what promises to be a very inspiring and up to date way of teaching, which helps us foster a more ecological relationship with the world:

> We cannot mark out in hard and fast lines the science of the future, but we can foresee that the rigid walls which now divide man from the world will gradually disappear; that human beings will not only confront each other, but also the entire organic and so called lifeless world, with less selfishness and with livelier sympathy.[9]

Given my contemporaneity, these fragments are in line with much of my readings, namely the works by Martha Nussbaum and Michel Serres. In her book "Poetic Justice - The Literary Imagination and Public Life "(1997, french translation 2015), Nussbaum leads us to new perspectives through the reading of romances. Serres in "Le Gaucher Boiteux. Puissance de la Pensée "(2015) recalls that he always rejected a pedagogy that separates between Humanities and Sciences, but these days he deeply regrets the separation, in the training of engineers, of the practical and technological side of education from the scientific training, and concludes:

> un second concordat pédagogique devrait enseigner aux futurs ingénieurs l'ancienneté colossale et l'exquise fragilité des habitats où ils auront à installer leurs activités. Je rêve que le Muséum d'histoire naturelle redevieenne le centre du Quartier Latin (p. 216).

To turn the Museum of Natural History into the centre of the "Quartier Latin" could be a sentence written by Mach, had he been alive.

Sensibility, Imagination, and the Habits of the Heart and the Mind

In 1892, William James delivered a series of conferences dedicated to teachers that were edited for the first time in 1899 in book format, *Talks to Teachers on Psychology*.

In his first lecture to teachers, "Psychology and the Art of Teaching", James warns his audience that Psychology can only provide boundaries for the practice of Pedagogy and that they should not expect Psychology to guarantee the success

[8] p. 234, op.cit. p. 337.

[9] Ibid., p. 213.

of pedagogical approaches. Psychology is a science that formulates general laws whereas Pedagogy is an art and as such emphasizes the concrete. Varying and even diverging pathways can inhabit the same boundaries. The success of those pathways depends on the “inventive mind”, a kind of “génie personnel” – an aspect also stressed by Whitehead when he wrote about the conditions a teacher needs in order to attain the necessary “stage of romance”. One way to achieve the development of this “génie personnel” could be to “read everything and think about everything”. We can well imagine James’s feeling for the important quality of “inventive mind” in his experiences during Mach’s and Helmholtz’s lectures. The theme was the same, they had similar cultures and yet they delivered such different lessons!

According to James[10]:

> you must simply work your pupil into such a state of interest in what you are going to teach him that every other object of attention is banished from his mind; then reveal it to him so impressively that he will remember the occasion to his dying day.

And he concludes: “divination and perception, not psychological pedagogies (...) are the only helpers here”.[11] In his French translation, Bernard Jolibert (1996) equates the terms “divination and perception” with “imagination and sensibility”, thus expressing their contemporary meaning.

Whitehead also believes that the creative phase is an essential element in the learning process. Whitehead maintains that all actions intent on educating should be capable of nourishing the stage of romance (with romance, precision, and generalization representing the stages of “rhythmic claims”). He writes: “Without the adventure of romance, at the best you get inert knowledge without initiative, and at the worst you get contempt of ideas - without knowledge”.[12]

George Allan (2012, p. 14) wrote the following about Whitehead’s romance concept:

> it involves not only apprehension, appreciation, and interest but also their *iteration until they become habits of the heart and mind* (...). We are becoming used to asking questions and seeking new experiences, imagining novel possibilities and ferreting out their implications (I am responsible for italic sentence)

Émile Boutroux (1910, cited by Henry Bergson in *Creative Mind*, 2007, p. 223) testifies to the nature of James’s pedagogy in his strong relation with life and, in this sense, his key concept is “to experiment” meaning “not coldly to observe a thing happening outside us, but to undergo, to feel within oneself, to live oneself this or that manner of being”.

This might well be what James encountered in Mach’s lesson. Mach himself refers to learning for life: “The best that we have learned, that which has remained with us for life, outlived the test of examination”.[13]

[10] p. 4, op.cit. p. 340.

[11] Ibid., p. 4.

[12] p. 33, op.cit. p. 336.

[13] p. 368, op.cit. p. 337.

We quote Whitehead not just for his expertise but rather to remind us of the words that are not new to us but which we need to continue to nurture: “there can be no mental development without interest. Interest is the *sine qua non* for attention and apprehension”.[14] And this interest is generated during the romance stage that should remain as the background for the precision stage. Hence,

> romance is not dead, and it is the art of teaching to foster it amidst definite application to appointed task (. . .). The organism will not absorb the fruits of the task unless its powers of apprehension are kept fresh by romance.[15]

One difference between Helmholtz and Mach is that for Mach the stage of precision needs the background of romance, hereby stressing the importance of what is “new, uncommon and not understood”; another difference concerns the relationship Man-Nature.

According to Whitehead College Education should culminate in the enjoyment of generalization, a kind of romance disciplined by accuracy in the stage of precision. But such is not the case, as he wrote: “In my work at universities I have been much struck by the paralysis of thought induced in pupils by the aimless accumulation of precise knowledge, inert and unutilised”.[16] Whitehead acknowledged that it is not easy to keep the flame of romance alive. “Having read everything and thought about everything” did help.

The Imaginative Joy in Mach’s Writings

We shall give some simple examples of Mach’s imaginative joy in Nature, gathered from his above mentioned lectures. Mach’s lectures convey lively learning experiences.

According to Helmholtz, as we have seen, the enjoyment of knowledge awaits us after an arduous journey, whereas for Mach the pleasure of connections, present from the beginning, puts us in touch with experiential moments of inventive joy in nature.

Between the two views ‘our love for nature is inventive’ (Mach), and ‘our love for nature derives from intellectual mastery over it’ (Helmholtz), we shall find substance to characterise their traits as teachers, and to be able to imagine the “artistic lesson”. We shall focus on the latter aspect.

“Our love for nature is inventive” can be perceived through the different perspectives when contemplating the development of science. Mach is inventive and can surprise us through unexpected comparisons that he develops in these and other texts.

[14] p. 31, op.cit. p. 336.

[15] Ibid., p. 34.

[16] Ibid., p. 37.

For example, in his text about the forms of liquids Mach provides many elements, about what is uncommon, strange and stimulating, that derive from his knowledge about the "growth of science" and from his critical thinking:

> Liquids have no form of their own! No, not for the superficial observer. But persons who have observed that a raindrop is round and never angular, will not be disposed to accept this dogma so unconditionally[17] (p. 3)

In this text, as in others of this collection, he goes from one experiment to another one, progressing along the interweaving skills of the experimenter and the "acts" of nature (nature acts [. . .] as "covetous tailor"). We could say that he practices a modern "natureculture" perspective.

Then the unexpected happens: we are flying to the moon:

> Statues and 'plaster' casts of syrup are undoubtedly things of fancy, even on the moon, but maple-syrup would flow so slowly there that we could easily build a maple-syrup man on the moon, for the fun of the thing, just as our children here build snow-men.[18]

Now is time to return to earth and to the joy of experimenting, transforming our thoughts and perspectives. This journey is very inventive and a good source of inspiration for teachers, through the multiple connections contained in it.

Let's have a glimpse of another one that I like very much: "Why has man two eyes?" I emphasise his taste for objects and pictures, in particular for photography (Mach was born a year before the invention of photography and his life was very marked by this invention) and for stereoscopic photography.[19] The beautiful stereoscopic objects were in fashion at that time (Fig. 38.2).

The experience of walking in a forest adds value to these experiments with objects. In this text a man with his two eyes is an element of nature capable of developing an awareness of the value of his experiences. But there's also humour and a lot of enjoyment in this text. Mach writes that if he had the ability to write novels his hero would be the cockchafer:

> the hero of my novel would be a cockchafer, venturing forth in his fifth year for the first time with his newly grown wings into the light, free air. Truly it could do no harm if man would thus throw off his inherited and acquired narrowness of mind by making himself acquainted with the worldview of allied creatures[20]

This is the meaning of placing the Museum of Natural History in the centre of the "Quartier Latin".

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[17] The page number is always in reference with op.cit. p. 337.

[18] Ibid., p. 4.

[19] "But the stereoscope accomplishes still more than this. It can visualize things for us which never see equal clearness in real objects (. . .). For example, if we photograph a machine stereoscopically (. . .). I have employed this method for obtaining transparent stereoscopic views of anatomical structures" (ibid. 74). William James uses the metaphor of stereoscopic view in his Talks to Teachers.

[20] Ibid., p. 86.

Fig. 38.2 Stereoscope belonging to the collection of teaching instruments of the secondary School André de Gouveia, Évora. Photograph taken by manuel Ribeiro. Courtesy Project "Ciência na Cidade de Évora", (2006–2008)

This is to lead us to new perspectives through narratives about very different ways of life, as Nussbaum proposes.

One aspect that I would like to highlight is how Mach, in these lectures, uses the History of Science. It is not the history by today's Historians of Science but rather an instrument of comparison, of development of flexible rather than dogmatic thinking habits and, with all his "génie personel", an instrument of imagination and joy that enriches our worldview.

Mach – An Artistic and Inspiring Teacher

We can appreciate how during his stay in Prague Mach influenced his students, through Emilie Těšínská's research (2010). Some of them followed educational or technical careers related with physics. The text below transcribes the testimony of a student, V. Novák who describes the "ways" of a unique professor:

> Many of Mach's experiments, namely from mechanics and optics, were original and very educational. The clean copies of Mach's lectures, which I drew up immediately afterwards, while they were still fresh in my memory, remain a valuable memento of my university studies. (. . .) *Mach's disquisitions, which were preceded by a historical introduction supplemented by appropriate philosophical commentary, were original*. They pointed to the frailty and inconsistency of basic physics concepts according to historical development, namely experimental concepts, and were a testimony to the great pedagogical talent of the lecturer. [...] *Mach accompanied his lectures with beautiful experiments, which he performed himself*. (. . .) Mach adjusted many of the experiments for subjective observation, where the observers had to exchange places. These were often the best experiments, which he left, until after the hall emptied, for the few most science-hungry.

> During the experiments, we admired his dexterity and speed and how he was able to easily help himself in the case of improvisation. (p. 83, I am responsible for italic sentences)

We emphasise the originality acknowledged by his students (about his use of history and philosophy), we emphasise the "beautiful experiments" and we emphasise the delicate and adept gestures, both in the manipulation of objects and in the communication with his students, which stimulate the transformation of thought. The need felt by this teacher and Mach's former student to write down everything learned in class, and his claim that these notes are the memory of important moments of his passage through University, is almost a testimony of James's opinion that the teacher must be able to develop in the student an interest he will remember forever.

Mach's texts show us also how he captures, from colleagues of other areas, concepts that he will integrate in his thinking. We come across his "sense of beauty": "every day the physicist is confronted in his workshop with the most beautiful vibrating figures, with the phenomena of polarisation, and with images of diffraction".[21]

His texts are still very inspiring and employ words in an uncommon way. For instance, I always like to use this formulation with my students: "Soon after we have accustomed ourselves to the fact that light added to light increases its intensity, we suddenly come across a case of total darkness produced by this cause".[22]

Which images did he use out of the many that he produced or looked for their production, in particular photographs? What were the experimental devices the handling of which James watched? Was it the beautiful machine Mach designed for the study of waves that was shown at the world exhibition in Vienna in 1873? Pure speculation. But we can imagine him trying to surprise and "to work his pupil into such a state of interest in what you are going to teach him that every other object of attention is banished from his mind" as James put it in his *Talks to Teachers*. According to Whitehead, "Inventive genius requires pleasurable mental activity as a condition for its vigorous exercise". A lesson should be a time of art, not of real life, as Boris Groys wrote in the catalogue for the installation "A Model Scenario of the Flying Classroom", by the German artist Martin Honert, inspired by Kästner's novel, *The Flying Classroom*" (Venice Biennale of 1995). I could find here a good metaphor for the ingredients of an artistic class. The tangible, the imagination, the change of perspective, the contact with novelty are all contained within the metaphor of the Flying Classroom, where students fly in space and in time, and return to the classroom. We can imagine them as Mach's students (Fig. 38.3).

I shall conclude saying that we should not forget what may be the most important part: "it is up to him (teacher) to elicit the enthusiasm by resonance from his own personality,[23] and create the environment of a larger

[21] p. 90, op.cit. p. 337.

[22] Ibid., p. 194.

[23] Ending on a personal remark: this text results from the elaboration of a presentation at Ernst Mach Centenary Conference at Vienna (2016). During its production I experienced a singular sensation that I would like to share here because of its Machian and Whiteheadian aspect. While

Fig. 38.3 Martin Honert, *A Model Scenario of the Flying Classroom*, 1995. Acrylic on wood, polystyrene and epoxy resin, Twelve elements: 157 1/2 × 236 1/4 × 157 1/2 inches overall 400 × 600 × 400 cm overall. © Martin Honert, Courtesy Matthew Marks Gallery

knowledge and a firmer purpose".[24] I use these Whitehead's words that reflect what James felt in class and in the conversation with Ernst Mach and which might have inspired him to formulate the concept "The tact of teaching".

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trying to pick strong and illustrative examples of Mach's singularity I happened to be working in the countryside, where I live, with the windows open. Someone started preparing the soil and I heard the hoe working the soil with a certain rhythm. The consciousness of this pace was a pleasure that has filled my spirit. Rhythm and resonance have been the background of my views which were inspired by Whitehead.

[24] p. 40, op.cit. p. 336.

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Part VI
Mach, Didactics, and Pedagogy

Chapter 39
Mach's Educational Theory and Practice

Michael R. Matthews

Abstract Ernst Mach (1838–1916) was one of the great philosopher-scientists in the late nineteenth and early twentieth centuries. He was among the first to deal systematically with the contribution that the history and philosophy of science can make to science education. His teaching was the occasion to unite pedagogical, psychological, philosophical and scientific concerns. His ideas on education are scattered throughout his books, textbooks and journal articles. However, there are three lectures where he explicitly addressed pedagogical issues. – 'On Instruction in the Classics and the Mathematico-Physical Sciences' (Mach, On instruction in the classics and the sciences. In his *Popular scientific lectures*. Open Court Publishing Company, La Salle, pp 338–374, 1886/1986), 'On Instruction in Heat Theory', and 'On the Psychological and Logical Moment in Scientific Instruction' (1890). As well as intellectual and practical interests in education, Mach had a notable Enlightenment-inspired political involvement in educational reform. Mach's relative neglect by English-speaking science educators is unfortunate.

Mach's life in Habsburg Austria, his commitment to the Enlightenment tradition, his philosophy of science, his phenomenalism, his psychology, and his historical studies – are all important for understanding his views on education; all are important for what might be called his educational theory and practice. Mach championed a new Austrian school system with the creation of the new *Einheitsschule* where integrated education in the humanities and the sciences could occur; he promoted new methods of teaching based on psychological research on concept acquisition; and he advocated the restructuring of science curricula based on history of the sciences and informed by philosophy of the sciences.

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Mach had the characteristic Enlightenment broad-view of science education: it encompassed both formal and informal education; it was subsumed under the category of the 'popularisation of science'. In 1866, during his first university appointment at Graz, he wrote:

> Once a part of science belongs to the [research] literature, a second task remains, which is to popularize it, if possible. This second task also has its importance, but it is a difficult one. It has its importance, because – regardless of the distribution of knowledge that increases its value – it is not unimportant either for the further development of science itself how much knowledge has been disseminated into the public. The difficulty is to know the soil very well in which one wants to plant the knowledge. (In Siemsen 2014, pp. 2336–37)

He recognises that the growth of scientific knowledge, of future research, is dependent on the popularisation or spread of extant knowledge. At the time, and even subsequently, this was a rarely acknowledged dependency: scientific research in laboratories depends directly and indirectly on science teaching in classrooms.[1]

Mach did not write any book titled *Educational Theory and Practice* however his ideas on the social function of schools, on curriculum and on pedagogy can be discerned from four sources: his historical books that in part arose from his own teaching, including his out-of-school teaching; the many textbooks he wrote for students; articles that he published in the pedagogy journal he co-founded; and the explicitly educational essays he published. The first of these latter educational essays – 'On Instruction in the Classics and the Mathematico-Physical Sciences' (Mach 1886/1986) – is his most systematic treatment of education in general and science education in particular.[2] His other pedagogical papers are: 'On Instruction in Heat Theory', and 'On the Psychological and Logical Moment in Scientific Instruction' (Mach 1890/2016), in volumes one and four respectively of his *Zeitschrift*. The last paper is his most detailed account of how psychologically-informed pedagogy should proceed.

Mach's Textbooks

Mach the physicist and philosopher wrote eight university textbooks that went through 20 editions, and many translations.[3] These numerous and much-used textbooks reveal a good deal of his understanding of education as they all had their

[1] Direct dependency means ensuring enrolments in university undergraduate and graduate science programmes; indirect dependency means support of the general population for funding and provision of such research. James Conant was forthright in arguing these dependencies in the USA after the Second War (Conant 1947).

[2] The essay was originally prepared for a 1881 conference of Austrian scientists discussing the subject of science instruction in schools. It was subsequently expanded and delivered before the 1886 Congress of Delegates of German College Teachers. Mach took the occasion to decry the stranglehold of Classics on university entrance, and to argue that the lauded cultural and humanistic goals of Classical education can equally be gained by good historically and philosophically informed science education.

[3] For publication details and history of these textbooks, see Blackmore et al. (2001b).

origin as texts for courses he was teaching. His Prague teaching (1867–95) was mainly to medical and pharmaceutical students. He took an historical approach to all topics in his experimental physics courses; this same approach was accordingly mirrored in the popular textbooks that he wrote on the course topics: *Compendium of Physics for Medical Students* (1863), *Optical-Acoustical Investigations* (1873), *Doppler's Theory of Tone and Colour Change* (1874) and *Theory of Motor Sensations* (1875). In 1891 he published two university physics textbooks. And his popular historical studies – Energy (Mach 1872/1911), Mechanics (Mach 1893/1974), Heat (Mach 1900/1986), Optics (Mach 1926/1953), and essays on mathematics (Mach 1903/1943) – were used by both university students and faculty. The texts provided a psychologically-based and philosophically-informed historical introduction to the different fields of science.

Given the number of textbooks Mach wrote and their wide adoption in German lands, it is not surprising that most of the major European contributors to late nineteenth and early twentieth-century physics mention their debt to his texts. In Einstein's memorable words:

> The fact is that Mach through his historical and critical writings in which he followed the development of the individual sciences with so much love and traced historical details into the inner sanctum of the brain [*Gehirnstübchens*] of path-breaking scientists has had a great influence on our generation of natural scientists. I even believe that the people who consider themselves opponents of Mach, scarcely know how much of Mach's way of thinking they have absorbed, so to say, with their mother's milk. (Einstein 1916/1992, pp. 154–55)

Machian Education

Although Mach did not bequeath any systematic and detailed 'theory of education' or any 'pedagogy manual' nevertheless his textbooks, educational essays and reports of his teaching, suffice to identify features of a 'Machian' approach to teaching and learning. These features are: a historically-informed or 'heuristic' method; experiential and manipulative ('hands-on') learning; thought experimentation; liberal, coherent and limited curriculum; elaboration of philosophical content; directly or indirectly teaching the nature of science.

Historical or Heuristic Method

The most notable feature of Machian education is that history informs the curricula and classroom pedagogy. This commitment to history arose from Mach's own early investigations of psycho-physics and sensory physiology. In an autobiographical essay, he comments that:

> The teaching itself led [me] to the opinion that the historical presentation of material was the simplest and the most understandable. Such general conceptual connections revealed the economic motives of cognitive theory and the conception of science as part of a general

> phenomenon of life and development, a view which finally rounded out [my] biological and economic epistemology . . . . Since then I have remained as loyal as possible to the historical way of proceeding [*Gange*] in giving lectures. (Mach 1913/1992, pp. 24–25)

Pierre Duhem followed Mach in this regard:

> The legitimate, sure, and fruitful method of preparing a student to receive a physical hypothesis is the historical method . . . that is the best way, surely even the only way, to give those studying physics a correct and clear view of the very complex and living organisation of this science. (Duhem 1906/1954, p. 268)

For Mach, the 'historical method' did not mean teaching the history of science; rather he advocated thoughtful, laboratory-based teaching and demonstrations, with students engaged in solving problems and puzzles. This was a form of Inquiry Teaching, but it was guided inquiry with history providing the background or puzzles for inquiry; children's natural curiosity about nature – shadows, tides, magnification, animal behaviour, and so on – can all be connected to people and episodes in the history of science.

Mach was the first to identify educational and social benefits of the historical approach to science teaching. Such benefits that have repeatedly been appealed to by educators, and they can be listed as[4]:

(i) *Easy beginnings*. Replicating the historical progression of a science means that subject matters start simple, are manageable and can to some degree be grasped. The simple pendulum before compound pendulum; the composition of air before photosynthesis; Volta's pile before lithium batteries, etc.
(ii) *Practice in theorising*. Student theorising or hypothesising about historical material or phenomena that they themselves can experience, and then testing these conjectures in practice, can show the centrality of theorising for science. What factors affect the period of a pendulum? Is it sunlight or heat or both that are necessary for photosynthesis?
(iii) *Connectivity*. Following through historical thread of developments in a subject or about a topic can show the interconnection of science with philosophical, social, cultural and religious traditions. The dependence of pendulum physics first on geometry, then calculus; the utilisation of pendulum movement in timekeeping and so solving the longitude problem, etc.
(iv) *Epistemological development*. Over time and with different content, historical approaches can contribute to a more sophisticated scientific, personal and general epistemology; students can become familiar with the basic epistemological questions of: how do we know that some claim is true, and how do we judge one claim as more justified than another? This competence is important inside and outside of the classroom. How do 'accidents' or 'impediments' bear on claims about laws of pendulum motion?

[4] Arguments and evidences for an historically informed and grounded curriculum and pedagogy are outlined in Matthews (2015, Chap. 4).

(v) *Sense of tradition*. The historical approach when repeated from subject to subject, and topic to topic, gives students a sense and appreciation of science as a living social tradition that is in lively interaction with its culture and society; and in which each generation or epoch benefits from those that preceded it.

Optics as an Example of Heuristic Teaching

Mach's final major work was his book *The Principles of Physical Optics: An Historical and Philosophical Treatment* (Mach 1926/1953). It is an immensely detailed 320-page book with 279 diagrams and scores of footnotes and citations beginning with Euclid in Greek and working through every major contributor – in Latin, French, German and English – to the science of optics. The material had been the basis of his lectures and experiments in the first year of appointment in Prague (1867). The manuscript and Prefaces were largely completed by 1913 but on account of the outbreak of war, and the further deterioration in his own already crushing and debilitating medical condition (Blackmore 1972, p.180), finalisation and publication did not happen till after his death in 1916, with the English translation appearing in 1926.

The purposes of this chapter are well served by drawing attention to a 1926 review of the book's English translation that made special mention of its treatment of polarisation:

> A feature of the book that deserves special praise is its treatment of polarization and double refraction . . . .. the present writer has encouraged optics students to begin the study of these subjects with the simplest apparatus and natural crystals, such as were available to the early workers. In this way they obtain a thorough acquaintance with the principal features of the subject . . . thus by easy stages the properties of uniaxial crystals become familiar ..[The book] in addition describes many beautiful experiments which will be new to the majority of readers. (Martin 1926/1992, p. 70)

Mach devotes two chapters to polarisation, chapters X and XII (60 pages), and he notes:

> As we have seen, great difficulties had to be overcome before the nature of polarization could be thoroughly explained. This was, no doubt, the reason why workers of such renown worked on this problem, and the cause of the tardy nature of its solution. It would thus be worth our while to go into these difficulties. (Mach 1926/1953, p. 204)

His university teaching of the topic is guided by the memory of how hopeless was his school introduction to the subject:

> It was while attending grammar school (gymnasium) that I first heard of the transverse vibrations of which light must consist. This view made a very strange, phantastic, and unsympathetic impression on me, without my knowing the actual cause. When I tried, with the aid of memory, to obtain a clearer view of the matter, I had to confess that I felt instinctively the impossibility of transverse vibrations in so readily movable (displaceable) a medium as air, and thus more so for the ether, which I considered must be more rarefied and easily displaceable. (Mach 1926/1953, pp. 204–05)

For Mach it was by experimentally working through debates, experiments and achievements in the history of the subject that the 'strange, phantastic, and unsympathetic impressions' were rendered intelligible. He begins with Erasmus Bartholinus' 1670 description, in Latin, of the rotating double images of objects seen through Icelandic spar. And turns then to Huygens account, 20 years later in French, of the polarisation phenomena in his *Treatise on Light* (Huygens 1690/1945). Predictably Mach says that Newton makes progress beyond Huygens because he:

> takes care to proceed along the lines of the views expressed at the beginning of the *Optics*. In experimental science, namely, little regard is to be paid to hypotheses, and the invention of obscure qualities for each phenomenon in particular is not to be encouraged. (Mach 1926/1953, p. 189)

Where Huygens held to light rays being uniform, Newton allowed them to be asymmetrical; the ray properties in one direction were different from those in the ray perpendicular to it. By apt and simple manipulation of light through different adjacent 'Island' crystals, Newton showed that the polarisation property was in the light prior to its entry into the crystal, it was not manufactured by the crystal but rather selected by the crystal (Newton 1730/1979, pp. 354–366).

Through the 60 pages, Mach continues his account of the experimental history of polarisation, identifying the new experimentally-manipulated phenomena and the hypotheses and their refinements tested against the phenomena. He draws a typically Machian methodological lesson:

> It is one question, what actual property of light it is that makes itself evident in polarization, and quite a different one, whether this property may be (mechanically) explained or further reduced. The fact that these two questions have not always been clearly distinguished has often had a retarding action on the progress of optics. (Mach 1926/1953, p. 205)

Experiential and Experimental Teaching

Although a pre-eminent theorist, and concerned with economy of thought in education, Mach firmly believed that abstractions in the science classroom should, as Hegel said of philosophy, take flight only at dusk: 'Young students should not be spoiled by premature abstraction, but should be made acquainted with their material from living pictures of it before they are made to work with it by purely ratiocinative methods' (Mach 1886/1986, p. 4). Mach constantly returned to this basic defect of pedagogy: the confusing of the logical structure of a discipline with the structuring of its pedagogical presentation. In his lectures in *Space and Geometry* he observes:

> Great inquirers, even in recent times, have been misled into following Euclid's example in the presentation of the results of their inquiries, and so into actually concealing their methods of investigation to the great detriment of science. (Mach 1903/1943, p. 113).

Mach develops this point at length in his 'Psychological and Logical Moment' essay published in his co-edited pedagogy journal *Zeitschrift für den physikalischen und chemischen Unterricht* (*Journal of Instruction in Physics and Chemistry*, 1890, vol.4 pp. 1–5)[5] where he says:

> The generally prevalent overrating of the logical moment in relation to the psychological – also when one completely disregards the abnormal outgrowth of it completely – meets us often enough. It probably derives from the time when the elements of Euclid were seen as a model of scientific method. (Mach 1890/2016)

Mach is a philosopher and wants students ultimately to appreciate the logical structure of disciplines, meaning the relational structure of concepts, generalisations and laws within disciplines.[6] However Mach's pedagogical point is:

> It nevertheless seems to be clear that the order of the concepts can only occur when and to the extent that concepts are gained in the first place. (Mach 1890/2016)

And this gaining of concepts is a psychological process that begins with and requires tactile and visual experience, not just reading. Putting the logical before the psychological means:

> what at best can be the end of the activity, one wants to begin with. This procedure – the counter-image of the historical way of development – I can only consider as mistaken. (Mach 1890/2016)

Further:

> Also the solution of a problem, if it is to be valued and understood, needs to be prepared psychologically. Even the obscurity, the discrepancy, which comes before the solution of the problem, should be felt. The solution should not appear ready, before the problem has appeared, but rather become gradually. Thereby it also becomes clear that not every produced sentence can and should be indefeasible from the point of view of the resolved problem. Here applies in detail what has been stated about the application of teaching in general. (Mach 1890/2016)

The substitution of words for experience that Mach laments has been a constant source of complaint in science teaching from Mach's time to the present. John Bradley, at the University of Hull is a Mach enthusiast who wrote a PhD thesis and subsequent book on Mach's philosophy of science (Bradley 1971). The book begins:

> My interest in Mach arose out of a lecture on the lever given to freshmen at Cambridge in 1927 by the late Alexander Wood. He advised his students to read Mach, and I have been doing so ever since. (Bradley 1971, p. vii)

[5]The journal is available on the web. It was the second ever science pedagogy journal, the first being *Zeitschrift für mathematischen und naturwissenschaflichen Unterricht* which began publication in 1870 and was edited by J.C.V. Hoffmann, a secondary school teacher in the Saxony mining town of Freiberg. (Thanks to Kathryn Olesko for this information.)

[6]He of course says that a discipline has no fixed, immutable structure; with the choice of different fundaments or primitives, a new disciplinary structure is created, but nevertheless this also has a conceptual structure which ultimately needs be grasped.

Bradley railed against the dominance of theory in school science programmes. The influence of his early reading of Mach is seen in a 1935 article on ‘Atomism in the School Certificate’ (Bradley 1936). Thirty years later he wrote:

> The young people of this country come hopefully to school asking for the bread of experience; we give them the stones of atomic models. (Bradley 1964, 45, p. 366)

His belief was that children should not be exposed to atomic models, or much other theory, until the final school years; theory should be X-rated. The NSF programmes of the USA were in his sights:

> By returning from the far country [USA] with its painted Jezebels of atomic models to the homeland and pure gospel of Armstrong, the teaching of chemistry could be immensely improved without the expenditure of a penny. Indeed money could be saved, because sulphuric acid is cheaper than models of models of models. (Bradley 1964, 45, p. 366)

Thought Experiments

A special feature of Mach’s view of science education was his advocacy of thought experimentation (*Gedankenexperimente*).[7] He said of this that ‘Experimenting in thought is important not only for the professional inquirer, but also for mental development as such’, not only the student but ‘the teacher gains immeasurably by this method’ (Mach 1896/1976, p. 143). Thought experiments enabled the teacher to know what grasp students had on the fundamental concepts of a discipline. At a simple level ‘The method of letting people guess the outcome of an experimental arrangement has didactic value too’ (Mach 1905/1976, p. 142).

It is noteworthy that each edition of his *Zeitschrift* carried thought experiments for his readers to perform. For instance, he asks, what is expected to happen to a beaker of water in equilibrium on a balance when a suspended mass is lowered into it? Or in another issue, what happens when a stoppered bottle with a fly on its base is in equilibrium on a balance and then the fly takes off? These examples are of thought experiments of an anticipatory type: the actual experiment can be performed. Mach wanted such thought experimentation to be part and parcel of physics education. The ‘experiments’ engage the mind, and they reveal what a student believes about the relevant concepts being investigated. He believed that the exercise of creative imagination was another way of bridging the gap between humanities and the sciences: ‘The planner, the builder of castles in the air, the novelist, the author of social and technological utopias is experimenting with thought’ (Mach 1896/1976, p. 136). Their utilisation does require that teachers know about them; that teachers have some training in the history and philosophy of the subject they are teaching.

[7]Mach’s views on thought experiments are most thoroughly developed in *Knowledge and Error* (Mach 1905/1976, Chap. XI).

Thought experiments were not only important for pedagogy. They were not merely a way of finding out about students' knowledge and grasp of concepts; rather they latched onto a fundamental feature of science: the centrality of idealisation and abstraction in scientific practice. Surveying the history of science, Mach notes how often experimenters have to refine procedures and apparatus so as to minimise or remove 'impediments' and 'accidents', to use Galileo's terminology.[8] He notes that:

> Physically, such a process is often impossible to carry out, so that we may speak of it as an idealization or abstraction. (Mach 1896/1976, p. 140)

And goes on to say that Newton's law of inertia was discovered by abstraction, so too Kirchhoff's notion of the perfect black body, Carnot's absolute insulator, and most other laws of physics. Further:

> All general physical concepts and laws, the concept of a ray, the laws of dioptics, Boyle's law and so on are obtained by idealization (Mach 1896/1976, p. 140)

Mach's advocacy of thought experiment did not take the education world by storm. In the late nineteenth century, science was not much taught, and where it was, imagination, hypothesizing and creative thought were not much valued. Einstein, who was to place thought experiments upon the centre stage of modern physics, made the oft-quoted remark about his own schooling that: 'after I passed the final examination, I found the consideration of any scientific problems distasteful to me for an entire year', and 'It is, in fact, nothing short of a miracle that the modern methods of instruction have not entirely strangled the holy curiosity of inquiry' (Schilpp 1951, p. 17). Einstein of course thanked Mach for opening his mind to the possibility of novel ways to conceptualise physics and for 'legitimising' creative thought in science. Concerning his special theory of relativity, he says:

> The type of critical reasoning which was required for the discovery of this central point was decisively furthered, in my case, especially by the reading of ... Ernst Mach's philosophical writings. (Schilpp 1951, p. 53)

Liberal Curricula

Mach refused to identify 'liberal education' with 'classical education'. He said the latter, in part, needs to meet 'the general wants of the times', and clearly the classical curriculum did not do so (Mach 1886/1986, p. 371). Consequently: 'A truly liberal education is unquestionably very rare' (Mach 1886/1986, p. 371). And further:

> The *schools* can hardly offer such; at best they can only bring home to the student the necessity of it. It is, then, his business to acquire, as best he can, a more or less liberal education. (ibid.)

[8] On Galileo and idealization see Koertge (1977) and McMullin (1985).

Machian science curricula are found in present-day Liberal Education programmes where specialisation is avoided, intra-disciplinary and inter-disciplinary connections are stressed, philosophical content is developed, ethical and moral dimensions are high-lighted, and so on.[9] Mach thought a thinned-out curriculum, taught in what might now be called a historical-investigative or heuristic manner, gave the best chance of realising a satisfactory liberal education:

> every young student could come into living contact with and pursue to their ultimate logical consequences merely a *few* mathematical or scientific discoveries. Such selections would be mainly and naturally associated with selections from the great scientific classics. A few powerful and lucid ideas could thus be made to take root in the mind and receive thorough elaboration. (Mach 1886/1986, p. 368)

Using reference material from the web and well-documented texts this Machian goal is reachable.[10]

Mach saw bloated curricula as an obstacle to education. For him the central aims of education were to promote knowledge and understanding of appropriate topics across a range of disciplines, to improve reasoning, to encourage imagination, and to advance autonomous or independent thinking. An over-stuffed curriculum, and much more so, teaching for the test of such a curriculum, frustrated these aims:

> I know nothing more terrible than the poor creatures who have learned too much. What they have acquired is a spider's web of thoughts too weak to furnish sure supports, but complicated enough to produce confusion. ... It is not necessary that all the matter that is offered in schools should be learned. ... How can the mind thrive when matter is heaped on matter, and new materials piled constantly on old, undigested materials? (Mach 1886/1986, p. 367)

And for Mach:

> It seems also unnecessary that all branches should be treated at school, and that exactly the same studies should be pursued in all schools .... Uniforms are excellent for soldiers, but they will not fit heads ... A certain amount of liberty in the choice of studies must be introduced in the upper classes (Mach 1886/1986, pp. 367, 369, 370)

One hundred years later these laments are still being voiced about the US 'one mile wide and one inch deep' curricula. The present telephone-directory sized *Next Generation Science Standards* (NRC 2013) with all its sequenced 'cross-cutting' concepts, embedded in 'The Common Core' with national, uniform high-stakes testing – does nothing to abate this concern, only strengthens it.

Mach was writing about late nineteenth-century Austrian education, which was dramatically unequal, illiberal, hidebound, clerically dominated and verging on fossilized. But just as he refused to grant 'timelessness' to metaphysics in science,

[9]There is a large literature on the theory and practice of liberal education, sometimes called 'general' or 'humanistic' education. See at least Bantock (1981, Chap. 4) Peters (1966, Chaps. 1 and 2), Schwab (1949/1978, 1950/1978) and contributions to Kirby and van der Wende (2016).

[10]For texts see Holton (1952/2001). For historical texts and experiments that can be utilised in classes, see Kuehn (2014, 2015). For the philosophical contexts and implications of these episodes in the history of science see Weinert (2005).

it would be un-Machian to just carry over Mach's diagnoses and remedies for his own time to contemporary education. Yet his solution to the educational ills of his period was democratic and not without current merit:

> But the path is marked out for us; the will of the people must acquire and exert upon our school legislation a greater and more powerful influence. Furthermore, the questions at issue must be publicly and candidly discussed that the views of the people may be clarified. (Mach 1886/1986, pp. 374)

Philosophy in Science Teaching

For Mach, the teaching of science, or any discipline at all, went hand-in-hand with teaching the philosophy of the discipline. For a student to understand the discipline and its claims, they had to appreciate the methodology, epistemology, ontology and related ethics and goals of the discipline; know how it came to make its claims and how these claims were substantiated; to appreciate the role of internal and external factors in the process of substantiation. Acquiring such philosophical understanding of a discipline meant attending to its history. And this held whether the discipline was science, mathematics, economics, psychology, history, theology or anything else. An example of Mach's 'philosophy of the discipline' concern is:

> I led [during doctoral examinations in Vienna, 1895–1898] candidates into a conversation on general, and even the most general, questions of their special field. I recommended to philologists that they study the writings of philosophers of speech, to historians cultural history and prehistory, and mathematicians and natural scientists normally Mill and Jevons. It often became evident that the candidates did not know the philosophical writings of their own special fields. They were usually very thankful for my suggestions about future study. (Blackmore 1972, p. 139)

For Mach, philosophy was in the weft and warp of science (and indeed of all subjects being taught). Philosophical reflection does not have to be imported into science teaching, it is already there in the textbook, laboratory and classroom; it just needs to be recognised and elaborated. Otto Blüh, the Machian refugee, physicist and pedagogue, stated this well in the Preface to his physics textbook:

> This book further offers the student the opportunity of becoming acquainted with the historical and cultural relations of physics, in the belief that the education of a scientist can be advanced most effectively by giving a significant place to the philosophical, social, and moral implication of physical science *within* the physics curriculum rather than through supplementary so-called humanistic and social studies. Such course work or reading, valuable in itself, will make its mark on the scientist's intellectual and cultural development only if it is intimately related to his scientific studies proper. (Blüh and Elder 1955, p. vii)

At a most basic level any text or scientific discussion will contain terms such as 'law', 'theory', 'model', 'explanation', 'causation,' 'truth,' 'knowledge', 'hypothesis', 'confirmation', 'observation', 'evidence', 'refutation', 'idealisation', 'time', 'space', 'fields', 'species', 'proof', 'evidence', 'mass', and so on. Philosophy begins when students and teachers slow down the science lesson and ask what these terms mean and what the conditions are for their correct use. Students and teachers can be encouraged to ask the philosopher's standard questions: What do you mean by ____? And, how do you know ___? of all these concepts. The chapters in any 'Introduction to Philosophy of Science' textbook will all deal with all of these topics and teachers should be encouraged, indeed they should feel obligated, to read and engage with such texts.

Philosophy is a part of all of science, and this is especially obvious in Newtonian theory, a staple of all science classrooms.[11] Mach had the greatest respect for the genius of Newton, for his 'intellectual greatness' (Mach 1893/1974, p. 304), and excused his failure to deeply appraise the foundations of his 'system of the world' because: 'He that has to acquire a new point of view naturally cannot possess it so securely from the beginning as they that receive it unlaboriously from him' (Mach 1893/1974, pp. 304–05). But Mach says that after two hundred years the situation is different and Newton might well have expected those following him to more closely attend to, scrutinize, and philosophise about the foundations of the system they were 'unlaboriously' receiving.

This is not just a task for philosophers; Mach saw that the task can begin in science classrooms whenever the Newtonian system (or Einsteinian, Darwinian, Mendelian) is taught. But this rarely happens. Herbert Goldstein, in his popular *Classical Mechanics* book, lays out the standard procedure:

> Basic to any presentation of mechanics are a number of fundamental physical concepts, such as space, time, simultaneity, mass, and force . . . . For the most part, however, these concepts will not be analysed critically here; rather, they will be assumed as undefined terms whose meanings are familiar to the reader. (Goldstein 1950/1980, in Assis and Zylbersztajn 2010, p. 143)

Mach might say 'familiar, but not understood'; and further would note the missed opportunity to encourage students to put their toe in the philosophical water. The opportunity for basic philosophical engagement is everywhere in science, but is everywhere put off – 'later, later, later'. At best this deferment goes on to postgraduate years, but usually 'later' does not come even then.

Mach's view on the place of philosophy in science education is clearly seen in the writings and teaching of Philipp Frank, the Viennese physicist who studied in Mach's department, who often expressed his great debt to Mach, and who was a founding member of the 'Mach Circle' in Vienna, and was one of the foundational Positivists in twentieth century philosophy. He is an instantiation of Machian educational ideals.[12] Peter Bergmann went to Vienna in 1933 as an 18 year-old Jewish refugee from Berlin, and subsequently recalled how:

[11] Russell Norwood Hanson (1965) provides a nice exposition of this point; Arnold Arons (1988) gives an indication of what physics teachers can do about the situation.

[12] Some of Frank's education essays are Frank (1950b, c). For the life and publications of Frank see Blackmore et al. 2001a, b, Chap. 3) and Stadler (2001, pp. 631–36); also Thomas Kuhn's interview of Frank (Frank 1962/2001).

> In this overheated and jittery atmosphere there was one fatherly figure who represented all that was best at the University, Philipp Frank. ... He would encourage all of us students, and he gave us the feeling of a wide-open intellectual window, open to things that happened in and out of physics, and open to things that happened outside of the country as well. Philipp Frank saw to it that there was close contact with philosophy of science ... with experimental physics ... and with pure mathematics. (Blackmore et al. 2001a, b, p. 69)

Twenty years later, Jeremy Bernstein gave the following account of Frank's Harvard classes:

> Professor Frank spoke to us – 'lecture' would be too formal a term – for about an hour .. followed by a second hour of discussion. Nothing pleased him more than sharp disagreement with his own points of view in these discussions .... I think that all of us who attended these classes were constantly awed, although this was never Professor Frank's intention, by his almost incredible erudition. He seemed to have read and digested the great philosophical, literary and scientific works in an enormous variety of languages. He once told me that he had studied Arabic, as a young student, in order to be able to read the great texts in that language. ... This vast general culture was also worn instinctively, without pretense, and with the same mastery that characterized his scientific cultivation. (Blackmore et al. 2001a, b, p. 71)

These complimentary reflections of Frank, perhaps not surprisingly, mirror those of Mach made by William James in 1882 and cited at the beginning of the chapter.

Mach knew that science developed in conjunction with philosophy, being both influenced by it and in turn influencing it; thus all his historical studies illuminated this connection.[13] Frank was more explicit about its educational consequences, saying:

> Equally, students of science and philosophy should learn exactly what were the issues between Descartes and Newton, and between Newton and Leibnitz. From these disputes has arisen what we now call the classical physics of the nineteenth century, which until today has been the basis of the training in science [required] to get into colleges of engineering or liberal arts. To grasp these issues would help them to understand our present science as a dynamic living being. (Frank 1950a, b, c, pp. 279–280)

Such broad, philosophically-informed teaching enables students to appreciate the engagement of science with philosophical systems, religion and political ideology. For Frank:

> There is no better way to understand the philosophic basis of political and religious creeds than by their connection with science ... the influence of political and religious trends on the choice of these symbols [metaphysics of science] should by no means be minimized, as is often done in presentation of the philosophy of science. (Frank 1950a, b, c, p. 281)

[13]There are numerous works on the interdependence of science and philosophy. See at least d'Espagnat (2006), Trusted (1991), Wartofsky (1968) and Weinert (2005). Some texts and commentary are provided in Matthews (1989).

It barely needs stating that these accounts of Frank's pedagogy are at odds with the view of positivists as dogmatic, over-bearing, pupil-ignoring, adherents of the 'banking' or 'fill-them-up' view of teaching so popular in education circles.[14]

Nearly 50 years ago Israel Scheffler outlined the contribution that philosophy can make to education, and did so in terms that echoed much of what Mach had written:

> I have outlined four main efforts through which philosophies-of might contribute to education: (1) the analytic description of forms of thought represented by teaching subjects; (2) the evaluation and criticism of such forms of thought; (3) the analysis of specific materials so as to systematize and exhibit them as exemplifications of forms of thought; and (4) the interpretation of particular exemplifications in terms accessible to the novice. (Scheffler 1973, p. 40)

Comparable things were stated in a 1981 review of the place of philosophy of science in British science-teacher education:

> This more philosophical background which is being advocated for teachers would, it is believed, enable them to handle their science teaching in a more informed and versatile manner and to be in a more effective position to help their pupils build up the coherent picture of science – appropriate to age and ability – which is so often lacking. (Manuel 1981, p. 771)

In recent decades there has been a good deal of writing and research on the contribution of history and philosophy of science (HPS) to science teaching.[15] One part of this contribution has been the recognition of the connection of science to other academic and cultural fields. This is constantly pointed to in Mach's historical works. One part of the contribution of HPS to teachers' and educators' understanding is to connect topics within particular scientific disciplines; to connect the disciplines of science with each other; to connect the sciences generally with other disciplines such as mathematics, philosophy, literature, psychology, history, technology, economics, and theology; and finally, to display the interconnections between science and components of culture – the arts, ethics, religion, politics. All of this is obvious in Mach's work, and is developed in more detail by Frank and other contributors to the Machian tradition.

At the same time there has been a concerted effort by researchers and curriculum writers to include Nature of Science (NOS) in science programmes.[16] One problem has been that because HPS is so little taught in graduate education programmes, this NOS research frequently underestimates the complexity of the HPS issues and debates, and presents a too simplified account of the issues. One especially deleterious effect of this underestimation, the more so when it becomes hubris,[17] is

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[14]The disjunction between the reality of positivist-inspired pedagogy and its current educational image is discussed in Matthews (2004, 2015 pp. 43–45).

[15]See at least Matthews (2015) and contributions to the three-volume Matthews (2014).

[16]For guides to the arguments and literature see Erduran and Dagher (2014) and Hodson (2014).

[17]One egregious example is the causal announcement that 'constructivism is the most mature epistemological commitment' (Roth and Roychoudhury 1994, p. 28). This labels at least half of the international philosophy of science community, the 'realist' half, immature.

the presenting of deeply controversial issues in HPS as settled, and so producing numbered lists that purport to capture the nature of science, and going on to have such lists taught catechism-like in school classes and teacher-education programmes. The learning of such lists benefits no one, especially when they appear in national and provincial curricula and become required learning for high-stakes exams.[18]

Conclusion

Mach's Enlightenment-informed approach to education, characterised by Reformism, knowledge-seeking, Experientialism and Liberalism can be championed without commitment to his Phenomenalism. The last was the core of all his scientific and philosophical work, yet his theory of education and his pedagogical style can survive without it. Mach's pedagogical advice was fairly simple:

- Begin instruction with concrete materials and familiarize students with the phenomena discussed.
- Teach a little, but teach it well.
- Be guided by the historical order of development of a subject.
- Aim for understanding and comprehension of the subject matter.
- Tailor teaching to the intellectual level and capacity of students.
- Address the philosophical dimensions and questions that arise in all science teaching.
- Show that just as individual ideas can be improved, so also scientific ideas have constantly been, and will continue to be, overhauled and improved.
- Engage the mind of the learner.

But each needs, in the present time, the kind of historical, philosophical and educational elaboration, and where necessary qualification, that Mach provided for his own late nineteenth-century Austrian circumstance.

Being a Realist is no bar to being a Machian in either the theory or practice of education. But thoughtful realism does require coming to terms with Mach's own phenomenalist arguments that he so comprehensively advanced. Science teachers have endless opportunity to do this. Whenever 'attraction at a distance', 'magnetic fields', 'electron shells', 'inertial mass', 'atomic models' are mentioned, aspects of the phenomenalist/realist debate can be introduced. So much else of what Mach values as philosophy, and that is so much a part of science – good experimental design, logical thinking, justified connection of evidence to conclusions, values – is quite independent of his phenomenalism and warrants attention by teachers.

[18] Having modest goals for NOS teaching is advocated in Matthews (1998). The benefits of moving educational discussion from nature of science to features of science are outlined in Matthews (2011) where it is argued that the latter formulation invites discussion and elaboration of multiple features of science in the way that NOS terminology, and associated assessment, does not.

A great pity is that there is so little opportunity in any country's science teacher-education programmes, or even graduate education programmes, to learn from the life, work and writings of Mach. The history and philosophy of science is not a part of these programmes and neither is the history of science education. With both HPS and history of education missing, Mach does not appear in pre-service or graduate education programmes that are dominated by other supposedly more practical concerns. But in education, as in science, there is nothing so practical as a good theory, and Mach provides one. His theory can in principle be elaborated, revised and criticised. It is an orientation and guide to education and pedagogy that rewards engagement.

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Chapter 40
Transforming Thinking: Can Mach's Pedagogy Be Replicated?

Hayo Siemsen and Karl Hayo Siemsen

Abstract In his obituary on Mach, Einstein, (*Physikalische Zeitschrift*, 1916) asked, "It is difficult – and perhaps also not very important – to answer the question: "What has Mach taught, which was principally new relative to Bacon and Hume?" Mach's teaching had such an influence on people like Einstein that it fundamentally changed their way of thinking. Is this effect reproducible, and if so, how? For answering this question, one needs to research into the historical-genetic origins of Mach's erkenntnis-theory and its difference to other erkenntnis-theories, namely Platonism and Pythagoreanism. Mach's empirical-genetic erkenntnis-theory is the only one consistent with the requirements of evolutionary theory, especially regarding psychology and pedagogy.

Einstein's Question: Can Mach's Influence Be Replicated?[1]

In his obituary on Mach, Einstein (1916) asked, "It is difficult – and perhaps also not very important – to answer the question: "What has Mach taught, which was principally new relative to Bacon and Hume?" More precisely, the question is not what was "new", but what was "different" in Mach's teaching. Mach's teaching had

[1] Initial remark: for brevity reasons, many detail quotations and methodological remarks have been omitted. They can mostly be found in the other articles of the author, as well as many of the factual details on which some of the – perhaps initially surprising – statements are based. The ideas presented here concern ideas and ways of Mach's thinking that have been largely neglected. Telling all the largely unresearched background would be impossible in one article.

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such an influence on people like Einstein that it fundamentally changed their way of thinking. It enabled Einstein to develop a transformative physical theory: relativity theory.

Einstein analyzed in detail what exactly it was that Mach had taught which made Einstein think differently (although he missed some intuitive part from his youth, see Sterrett 1998). Still he could not answer, why it was different or what exactly was different about it relative to teachings from others before. If the teaching would have been the same like Bacon and Hume, people could simply have read Bacon and Hume and have the same ideas as Einstein had. But this was not the case. Therefore, – contrary to Einstein's intuition – the question of what is different in Mach's teachings[2] is important, though maybe difficult to answer.

According to Einstein's analysis in his obituary, Mach's approach made concepts, such as space and time "flexible". Einstein could thus transform the Newtonian perspective on fundamental concepts for physics (see Siemsen 2017e). For Newton, space and time are separate and there is a relativistic space and time as well as the metaphysical *a priori* of an absolute time and space.[3] Mach showed the empirical inconsistencies in this conceptualization. To eliminate the inconsistency, he transformed relative and absolute space and time into the relativistic *concept of spacetime*.

Einstein transformed this Machian concept of spacetime into a physical theory consistent with other fundamental concepts with which space and time are related. One thereby changes fundamental dimensions/properties of the gestalts of "time", "space", "motion" and "objects". As these concepts have intensive relations to other concepts, such as "observer", "universe", "matter", etc., they need to be adapted to

[2]Many people have asked the question, what was different in Mach's thinking regarding physics. But this question is not specific enough. It was not Mach who developed relativity theory and quantum physics. Mach changed the thinking of the people who did. So, to get a meaningful answer to why these developments happen and how, one has to ask, what it was in Mach's teaching that enabled others to develop such ideas. Then, one can ask – like Einstein did – if one can replicate this transformative effect on the science of physics in maybe any area of knowledge.

[3]Newton intuitively adopted these concepts. Space and time were conceptually separated by Parmenides. Plato established Parmenides' view as standard and introduced the separation of absolute ideas and sensual (relative) ideas. Aristotle made this metaphysical theory of his teacher into a more physical (less religious) theory by keeping the separation of space and time and separating each into universal form and factual (relative) application. This Platonist theory of Aristotle was then kept as a theoretical basis for Descartes, Newton, Kant, etc.

This theory and its arbitrary metaphysical separations were already criticized in Presocratic times and by Alexander of Aphrodisias (see Siemsen 2017c; Kessler 2011). After the fall of the Roman Empire, it was first criticized by the Oxford calculators after more of the partly lost classical scientific literature became available again, especially the more empirical works of Aristotle, but also Alexander of Aphrodisias. The criticism on the inconsistencies in the Platonist Aristotle was repeated by Gauss, probably in their tradition (see Siemsen 2017d). Beneke had probably discussed this with Gauss in Goettingen, where Hegel had driven him into exile. Beneke (with a brief hint to Gauss) then used the same criticism on Kant's concept of space and time (Kant adopted it from Newton, see Siemsen 2017a) that Mach later applied to Newton. Mach then also (co-) found the "inner ear", the labyrinthine organ for space perception. Thereby, contrary to Platonist/Descartian/Newtonian/Kantian assumptions, space is not innate/*a priori*, but sensually perceived. Geometrical concepts are gestalts from these sensual elements.

the transformations of their conceptual relatives. The new theory has to integrate the new observations and additionally has to be made as consistent as possible as a whole/gestalt.[4]

Einstein then generalized his experience of the transformative effect of Machian teaching. He observed that Mach had had the same influence on other physicists, even if they were not consciously aware of it. Defending Mach against Planck's attack, Einstein (Blackmore and Hentschel 1985) wrote in a letter to Mach that all physicists of his generation have "imbibed Mach with their *mother's milk*". In his obituary, Einstein (1916) repeated the observation, "It is fact that Mach, through his historico-critical studies in which he follows the becoming of the singular sciences with so much love, and in which he follows the – for their area groundbreaking – researchers into their mental snuggery [*Gehirnstübchen* . . .], *has had a great influence on our generation of natural scientists*."

Mach also had such a transformative effect on other persons.[5] If Mach's influence in physics involved at least dozens of eminent[6] people according to Einstein's observations, central ideas of hundreds of scientists from diverse areas can be traced to Mach's "teachings" (see Siemsen 2014). New areas were formed and old areas transformed.

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[4] Why did Mach not do this himself? Probably because the answers provided by Einstein and Planck did not satisfy him. For Mach, they are like interims answers, which contain new unanswered questions, such as empirical/*erkenntnis*-psychological questions regarding the relation to the senses (physics far away from the daily experience of our senses results in a "bizarreness" dimension of theories). On the one hand, according to Mach's *erkenntnis*-theory, each theory is only temporary. On the other hand, each theory tends to cement this interim view in the long run more than is helpful for the scientific process. It is probably this effect that Mach criticized in Newton that he feared happening again for a new theory. Thereby, Mach saw his role more in the methodological process than in the product (thus his *Erkenntnis und Irrtum*, Mach 1905/1906).

[5] Some of the inventors of important scientific concepts inspired by Mach's teaching: Mautner developed linguistic theory, Otto Neurath the ISOTYPES, von Ehrenfels/Max Wertheimer the Gestalt psychology, Richard Semon (1923) the Mneme, Alfred Binet the Mental Orthopedics (Siemsen et al. 2017), Robert Oppenheimer the Exploratorium science museum, Catharine Stern (1953) the Structural Arithmetic, Georgescu-Roegen the environmental economics, Kaarle Kurki-Suonio the science education in Finland, Martin Cernohorsky many eminent persons in Czech society (scientists, politicians, entrepreneurs, see Siemsen 2011c) or Robert Musil wrote his dissertation on Mach and received the Nobel Prize for literature. Many more less known examples of the effects of Mach's transformative teaching can for instance be found in the late books of Blackmore et al. (2009, 2010a, b; see Siemsen 2011b).

[6] Einstein's "generation" seems focused on the more eminent Nobel laureates, etc. Here the transformative effect can be traced in detail (see also Siemsen 2014). Mach's teaching influence furthermore involved hundreds of people from academia. One could also count the millions of students who read Mach's school books in physics (Hohenester 1988). As there was no OECD PISA comparison, any transformative effects on thinking cannot be traced. Nevertheless, from the effects of Mach-type teaching by Kurki-Suonio and in specific schools, exponential teaching effects are probable (see Siemsen 2011a; see Drucker 1979, or Herdan-Zuckmayer, 1979/1983, for a detailed exemplary account, though they might be partly due to the influence of Beneke via Avenarius, Schwarzwald and Dittes, see Siemsen and Reschke 2013). The intellectual dominance of German speaking physicists can thus only be regarded as a small part of what resulted from Mach's teaching.

Einstein's question is therefore, if this wholesale transformation can be repeated. Is it consistently replicable as a "teaching"/learning method? If so, there might be other historical cases, where one can observe similar effects. If one analyzes such cases systematically, one could identify, what is central for such a generic pedagogical method and what is specific for the case of Mach and need not be replicated. One could apply the cases to other, similar cases in order to find why they did not have the same effect. From this, a general method of transformative teaching could be developed.

Mach and the Implications of Evolutionary Theory on Human Knowledge

Four years after Charles Darwin had published his Origin of the Species in 1859, Mach was probably the first to write on the implications of evolutionary theory regarding human knowledge[7] and scientific knowledge as part of it. Evolutionary theory already had a long tradition before Darwin, from Thales and Anaximander, via Heraclitos, Aristotle and Alexander of Aphrodisias, Linnaeus, Monboddo, Buffon, Cabanis, Erasmus Darwin, Meiners or Lamarck, Wallace and Spencer. Already knowing the works of some of these and others, Mach was not surprised about Darwin's book and could immediately apply the central idea to human and scientific knowledge.

Evolutionary theory (understood in a general, not only Darwinian sense) has two important corollaries: evolution is a continuous and therefore gradual process, and it does not have a "goal". It is a process of adaptation and transformation. Species are interims products of this process which can only be understood by its time dimension. Hands have developed when a "fish" moved from the water to the land and "pushed" itself with its frontal fins. Thereby, humans can still do pushups. The number of fingers humans have, the number of bones in each finder can already be observed in the fins of this "fish". If one only looks at a human hand without this background knowledge, it looks like a miracle. But with evolutionary theory, there is no need for such an ad-hoc hypothesis anymore. As humans, we have an "inner fish" (Shubin 2008/2009).

The human hand is less adapted to swimming in water and hanging on trees, but much more to complex gripping and handling tasks involving tools and changing environments. Thus, one cannot say that one type of hand is better than another, just as one cannot say that a hammer is better than a screwdriver. Therefore, Darwin criticized the tree-metaphor for depicting evolutionary processes – for instance used by Ernst Haeckel – as inherently misleading. Darwin suggested to use the shape of an anemone or bush instead of a tree as an anemone has no "top", but an equal

[7] Mach had a more general concept of knowledge, where knowledge is a general property of all of nature.

height of different branches. This is also used in modern taxonomical depictions of the evolutionary process. Unfortunately, the tree gestalt is still prevalent in many less informed popularizations and therefore integrally in the concepts of many people, including eminent scientists, even biologists.

Boethius made use of an iconic tree image for visualizing ideas from Porphyrios. Porphyrios synthesized ideas from Aristotle and Plato, from biology and logic in order to make a "logical" *scala naturae*.[8] He adopted the idea of a natural hierarchy, *scala naturae* and ideal ideas from Plato. There was a natural hierarchy of biology interrelated with a natural hierarchy of conceptual development. For Porphyrios, the rational thought of Platonist philosophers was ideal, godly.

As Plato described in his *Republic*, Platonist philosophers are trained to look over the shoulder of god at the blueprints on his table and copy these blueprints (the ladder to the shoulder is rational thinking). These copies are thereby directly from the original and ideal. They can then be taught to those not trained how to find the godly spyhole. As the ideas are ideal, they should be accepted by everybody as absolute laws, not to be changed by a jota (they can only be degraded). Thereby, all knowledge needs to be fixed as rigidly as possible.[9] Plato therefore "optimizes" education so that it prevents understanding at all costs (see Siemsen 2017b; Popper 1944/1980, vol. I, p. 189). Boethius was regarded as *the* authoritative figure by the Christian monasteries, which served as the main libraries after the disintegration of the Roman empire. Therefore, his books were used as standard literature over centuries.

There are thus two concepts of knowledge: One from Pythagoras, Parmenides and Plato in which knowledge is revealed, philosophized-forth or otherwise transmitted from God/the gods. The other concept is evolutionary in which scientific knowledge is a part of human knowledge developed further for specific purposes. The first concept of knowledge is absolute and ideal, the second is adaptive and transformative. Error is an integral part of knowledge as the knowledge of today can

[8]Logical empiricism in a way is a more modern version of Porphyrios' synthesis of Platonist/Pythagorean "logical naturalism", as will be shown later. The important similarity is not that logic and nature are combined, but that logic comes before empiry, while in evolutionary theory it has to be a genetic result of it. The genetic process/order is distorted.

[9]Parmenides in his poem, which is considered the foundation of logic, already takes this anti-evolutionary approach in his distinction between "what-is" and "what-is-not". He lets "the goddess" proclaim, "So it has to be either total and whole or not at all. Even the power of proof will not allow that something will appear besides what-is-not; thereby Dike has not loosened her fetters and did not allow it to come-to-be or perish, but she holds it tight" (Gemelli Martiano 2013, p. 21).

Dike is the ancient Greek personification of judgement. Logic therefore, right from its beginning, is tied to a concept of knowledge that is fixed and religious, founded in belief, not in science. This is probably the reason why logicists had and still have a hard time in consistently integrating an evolutionary concept of knowledge. As Beneke (1842) has already described in detail, linking logic and a creationist concept of knowledge is not necessary. It is an arbitrary synthesis. Like in biology, some genes are transmitted, because they are close to some highly advantageous genes on the string of DNA, even if the effect of the genes is disadvantageous for survival.

be the error of tomorrow. The first concept depends on a specific belief in Plato's or Pythagoras' God/Parmenides' goddess. This is not shared by everybody and the "revelations" cannot be observed and scrutinized by everybody. This approach is unscientific in this respect.

Furthermore, the first concept needs to make an epistemological cut in order to distinguish the ideal knowledge only revealed to humans to the knowledge obviously observable in animal behavior. The second concept of knowledge develops knowledge as one gradual process of "adapting the thoughts to the facts and the thoughts to each other" (Mach 1905/1906) from the senses to abstract mathematical or logical theorems. In the following, the first concept of knowledge will be called "metaphysical", while the second is "empirical".[10]

The Origin of Science and Its Pedagogy

Thales and His Pedagogy

The most exemplary case of transformative teaching can probably be made about the very origin of science by Thales. Like Mach, Thales was a "natural scientist" (cosmologist, astronomer), an engineer, a mathematician (geometer) and – a teacher. Like Mach, he was theoretical and practical. He is especially known for building models for helping others to understand his ideas. The most unusual stories exclusively attributed to him by the doxographic commentators are about his unusual transformative "teachings" by "sensual" gestalt models, i.e. (haptic) and acts (enactive).[11]

Thales was seemingly teaching mathematics with wooden models. For instance, he demonstrated a theorem that is attributed to him, namely that a circle is bisected by all its diameters (the circle is split it in half), haptically by making a circle out of wood and cutting it in half. By turning this model around the center of the circle, it serves as an empirical proof of the theorem. Seeing the model, the theorem becomes intuitively evident.

Thales then probably used the same method with a three-dimensional wooden sphere. This is indirectly known, because he allegedly made the first hemispheric model with a wooden sphere (assumably cut in half like his circle and later hemispheric models are). On this hemi-sphere, others later painted the stars from outside (Woehrle 2009, TH 74). Archimedes developed a more sophisticated version of the model. He donated it to an Apollon temple, where one could buy copies. Thales used the model for making mathematical proofs "touchable" and thereby intuitive (haptic). He then used the same model for visualizing his cosmological

[10]The concept of what is "empirical" thereby also transforms empirically. The usages here already hint in this direction.

[11]See Cole (2000) for the usage of these concepts from Jerome Bruner.

model of a spherical universe.[12] Physics and mathematics thus became "one" in one model.[13] Such a transdisciplinary and "practical theory"[14] use of ideas is typical for the approach of Thales.

Thales' pedagogy was so sophisticated that he could even "teach" a donkey to change its behavior by making specific experiences. He often used transformative concepts. For instance, he criticized tyrants by slyly stating that he was surprised to meet one on a journey that was of old age (implying that tyrants tend to be murdered early, because of their reckless behavior; his city Miletus was ruled by a tyrant at this time). When addressed if he had meant the statement in such a way, he claimed to have stated it only about sailors, attributing the tyrant version to somebody else. Thales was also well-versed in politics and government. Thales had a profound influence on the thinking of the students he had. Many if not all the various later traditions of the Presocratics can be traced to him.[15] Like Mach, he seemingly inspired many new ways of thinking in different directions.

Pythagoras and His Mixing of Science and Religion

Also Pythagoras allegedly had been a student of Thales, albeit only for a very brief time. It still seems perfectly possible that Thales had a transformative idea on the scientific ideas of Pythagoras, such as his mathematics and cosmology. In such a way, Mach had a profound effect on the thinking of some of his students, even if they had met him only briefly (for instance in the cases of Fritz Mautner, Wilhelm Jerusalem or Heinrich Gomperz).

But Pythagoras was equally influenced by mystery cults, such as those from Delphi, Crete, Thracia (the Apollon tradition of Hyperborea) or Egypt. These cults and temples preserved many "scientific" ideas that were dedicated to them (like the

[12] It is not clear, if the model only showed the sphere of the stars from the model or the sphere and the universe as well. Only late in his life, Thales was able to measure the approximate distance of the sun by measuring how often the sun fitted into the half-sphere it made around the earth. Thereby, it was due to his student Anaximander to write about the new consistent cosmological model derived from this knowledge (as basically no original texts have survived from both of them, it is difficult to distinguish their models and the development of them by the secondary doxographic sources). Anaximander then used the "cut-open" world sphere as a basis for drawing the first world-map as part of this model.

[13] This is also observable for the Oxford Calculators.

[14] The concept of "practical theory" was developed by the gestalt theorist Kurt Lewin on the basis of Mach's *erkenntnis*-theory.

[15] In this, like with Mach, one can observe that the gestalts necessary for this way of thinking are not easily replicated or reinvented independently. A genetic analysis is thereby possible, but also necessary. The pedagogical element, that the fundamental ideas of the teacher will reappear as basic gestalts in the ideas of the student, is often overlooked in the historical analysis. This is also a requirement of gradual evolution in the area of human culture. As Mach noted, ideas do not fall from heaven, they only grow on fertile fields.

aphorism "know yourself" in Delphi, or the spherical hemisphere model mentioned beforehand). One could be taught these ideas, but only if one would become an initiate. It was thus a synthesis of religion, myths and science. One would have to go through an initiation period with tests and afterwards one had to promise not to make the initiation rites/"scientific" knowledge public.

Pythagoras thereby introduced a rigorous initiation time for his students (including 5 years of silence) and prohibited the publication of the "proofs" and central ideas he taught the initiated/esoteric Pythagoreans/"*mathematikoi*" (learners). All those not initiated had to stay behind a veil where they could only hear their teacher. These uninitiated/exoteric Pythagorists/"*akusmatikoi*" (listeners) were supposed to concentrate on the "*akusmata*" they were told, i.e. the world is such-and-such, so-and-so you should behave. These *akusmata* were "unproven"[16] statements to be memorized as perfectly as possible, not understood. They were to be adhered to by the *akusmatikoi* like laws as they allegedly came directly from the gods.

Akusmata tended to be enigmatic and have double-meanings, a second for the initiated. For instance, the *akusmata* "don't eat beans" meant a dietary requirement for the *akusmatikoi*. For the initiated, it reminded them to avoid and frustrate attempts into the political direction of democracy. Political positions in democratically governed cities were often allotted by beans (in order to reduce lobbyism and vote-buying).

Pythagoras thus subordinated his scientific knowledge to religious beliefs, which served as *a priori* assumptions. Mathematical objects were the basis of the harmony of the world. They were ideal and physical. The experiential world could be derived by extrapolating from them. The Pythagoreans even invented a "counter-earth", hidden from us by a central fire[17] in the universe (not the sun, but the seat of the gods). The invention of the counter-earth was necessary, because the number of planets was nine, but the ideal number for the Pythagoreans was ten. Johannes Kepler initially searched for planets on mathematically ideal, "harmonious" tracks, until he was frustrated by the fruitless attempts to force Tycho Brahe's empirical data into a Pythagorean/Platonist frame.

Pythagoreans believed that the soul was transmigrating from one body to another (metempsychosis). The "quality" of the next body was judged depending on one's behavior in life. If one implemented all of Pythagoras' laws, one would go to "the isle of the blessed" and sit at the table of the gods. Otherwise, one could also be born the next time as an animal. Xenophanes allegedly made fun of Pythagoras

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[16]The Pythagoreans believed that all experience could be traced back to numbers by a chain of proofs. Mathematical objects were thus ideal entities. They were also physical. The world was number (see Hermann 2004).

[17]The cosmological model of Anaximander and probably Thales before him included a sphere of fire around the sphere of the stars. The sun, moon and stars were holes in the inner sphere, through which one could see the light of this fire-sphere. For somebody used to Thales/Anaximander cosmology the Pythagorean cosmology is not very different. It involves some more observational knowledge from later times, though, such as seeing the planets as objects fundamentally differing from the stars.

by telling the story that Pythagoras had intervened in favor of a dog that was beaten. Pythagoras told that he had recognized the voice of a deceased friend in the whelping of the dog.

The assumption of metempsychosis has two important corollaries: As the body is obviously associated with sensual perception, the soul needs its thinking separate from the senses to take thinking and memory with it when it leaves the body after death. Because of their religious beliefs, Pythagoreans require an epistemological cut between the senses and "optimal thinking". Optimal thinking for them is reason (*logos*). Reason and initiation provide access to what the soul knew before it entered into a new body. The faculty of reason provides the proofs from which the world can be developed metaphysically. It is thus prior to empiry. The separation of reason and the senses by an epistemological cut has also an *erkenntnis*-theoretical corollary: *Erkenntnis*-theory is required to use different tools for the two parts. *Erkenntnis*-psychology can observe the body and the senses. *Erkenntnis*-logic is the tool for optimizing ideal reason.

Contrary to Platonists, Pythagoreans are open to the development of new ideas. Natural numbers are infinite, so the world is infinite and knowledge is infinite. Once knowledge and laws are found and proven, it tends to be fixed.

The second corollary is the concept of time. Contrary to Plato later on, Pythagoras has a positive idea about time. The soul can develop over time, although there can also be a degradation process.

Pythagoreans and Politics

Pythagoras had a "fast-track" access into the esoteric community for people who brought with them wealth, political power or special skills. These were the *politikoi* or administrators. This practice of Pythagoras had two corollaries: It made some of the *mathematikoi* jealous, who had to go through the normal procedure. Furthermore, it showed the inconsistency of his religious beliefs. God's laws have to be the same for everybody. Everybody has to be judged on the same basis. Having money, power or skills, often inheriting them from one's parent's, has nothing to do with leading a good life in the sense that Pythagoras taught.

It seems that Hippasus of Metapontium, who was a *politikoi* and *mathematikoi*, saw such inconsistencies and inspired a revolt against the political ambitions of the Pythagoreans. He broke the secrecy by letting internal secrets (such as the anti-democratic meaning on the prohibition of the beans) slip to political critics. He also published a secret mathematical theorem. For the latter, he was allegedly drowned by his brethren.

By the revolt, most of the political/inner-circle Pythagoreans were killed in a fire laid to the house where they met. The mathematical tradition of the surviving Pythagoreans is thereby mainly from the Hippasus group, i.e. more open to publishing and democratic ideas.

Plato – himself an enemy of democracy – took over many of the initial (non-Hippasean) fundamental ideas from Pythagoras and the Pythagoreans, although he adapted them and developed them further. Especially the Pythagorean education system is directly copied in Plato's Republic. The laws of the Republic are derived from God by an oligarchy of philosophers. The philosopher-king is modeled after Pythagoras, whom his students saw as a god. The majority of students are indoctrinated as exoterics, made to follow the godly laws without understanding or being taught the reasons for them. Mathematics is used for separating the esoterics and exoterics early on by the sieve of rigorous testing.[18] The main goal for Pythagoras as well as for Plato is to gain political power to which religion is *de facto* submitted. Religion thus serves only as smokescreen for hiding the real (priority) goals.

But besides Pythagoras, there was a second main source of fundamental ideas/gestalts from which Plato drew, which was Parmenides. Parmenides had learned from a Pythagorean and himself came from the tradition of a medical initiatory cult.[19] He laid the basis of logic by making a *tertium-non-datur* distinction of "what is" and "what-is-not". This distinction abstracts from the time dimension ("what-is" according to the laws divined by the goddess in Parmenides' poem does not come-to-be nor perishes). It is thereby inconsistent with evolutionary theory (see later). This concept was ideal for Plato as he wanted to prevent any development in his Republic at all costs.

Plato's Political Agenda for Psychology and Pedagogy

Plato's Pedagogy

The ancient Greek education, especially in Athens, became divided into two "levels". The *gymnastike* and *mousike* remained the "basic" education. This basic education probably derived from older cultural strata of the "Old Danube Culture" traditions and was thus partly immune against the metaphysical takeover attempts of Isocrates and Plato (see Siemsen 2017a, b, c, d, e, f, g, h).

[18] Probably also the ratio of passing the *mathematikoi*/"mathematics" test is similar: about 10–20% tend to be regarded as understanding mathematics by their teachers nowadays (assuming with Popper that today's education system is essentially Platonist, see later). If one takes the initial mathematics tests at universities (with about 65% failure rate, at least in Germany), only a small fraction of students (less than 10%) pass Pythagoras'/Plato's hurdle and can actually begin to study. The rest are sieved out at different levels beforehand. If taught with a Machian empirical-genetic pedagogy, in principle all (i.e. 100%) can pass, i.e. understand mathematics (see Siemsen, K.H. et al. 2014).

[19] *Katabasis* probably derived as a sub-tradition from Asclepios dealing with the treatment of the soul. This psychological function of medicine was taken over by the initiatory cults after Hippocrates split psychophysiological medicine and focused on dealing with the physiology only.

By formalizing the teaching sophists (wise men) provided further to basic education, Isocrates introduced a "higher-level" education of *paideia.*[20] It was supposed to make philosophers of everybody, i.e. everybody who could afford it. Systematic *paideia* was aimed mainly at rhetoric as a means of being able to speak skillfully and beautifully for the public offices of the *polis*.

Plato adopted and expanded Isocrates' system to make his Academy the "standard" in philosophy education and his ideas and interpretations the standard in philosophy. Plato's dialogs always try to show that he (in the guise of Socrates) is the further development of the main philosophical ideas at the times. Plato appears as the great synthesis. Thus, he was able to harness Western education for his political and social goals as described in his *Republic* and *Laws* (see Siemsen 2017a, b, c, d, e, f, g, h). Learning in Plato's *Republic* is specifically meant to enforce social conformity, making thinking as rigid as possible. Thereby, Plato wants to prevent understanding and any further development (degradation in Plato's view) of supposedly "ideal ideas".[21]

Intuitive methods are used in Plato's *paideia*, but only for introducing rigidity/conformity of behavior with a pain-pleasure psychology. This is done through an autocratic concept of "virtue". The most virtuous is to think and do like the polis/nation/ruler/leader wants.

> I maintain that the earliest sensations that a child feels in infancy are of pleasure and pain, and this is the route by which virtue and vice first enter the soul. (But for a man to acquire good judgment and unshakable correct opinions, however late in life, is a matter of good luck.) [. . .] I call 'education' the initial acquisition of virtue by the child, when the feelings

[20]This was seemingly influenced by observations of the Spartan system of *paideia*, i.e. their system of selecting and educating soldiers (see Jaeger 1933/1959, I: pp. 378). In Plato's *Laws*, an Athenian discusses education with a Spartan. The Athenian admires the military quality of the Spartan soldiers, but criticizes the inability of the Spartan system to also produce effective administrators.

[21]Plato explicitly describes the motive of God/*demiurgos*/craftsman, who makes a copy of his ideal world (i.e. the ideally moving universe). But the copy is slightly faulty. Humans are faulty copies. These mistakes accumulate over time. Evolution/history is thus a "devolution" process in which everything degrades, especially human society. His *Republic* is the idea that by reintroducing the initial perfect ideas and deliberately preventing any change, one can keep the ideal, or at least as close to it as possible. For this, any changes in ideas or any new ideas have to be prevented by education/*paideia*.

In the analysis of Popper, Plato implicitly wants to reinstate the power his family once had/his own power (see Popper 1944/1980 in his *The Open Society and Its Enemies* for a detailed analysis of this hypothesis). The aristocracy in Athens lost their political primacy to the democratic culture/form of government. The Spartans even subdued Athens with the help of the old aristocratic elites like Plato's. But through their puppet government from the old elite and even with Socrates' and Plato's students as tyrants, they were not able to prevent democracy for more than a few years.

In as much as this plan against democracy failed, Plato sees the only possibility in destroying the whole culture in order to rebuild an autocratic utopia with philosophers and a philosopher king as an oligarchy (which is supposedly staffed by Plato's friends and relations as he envisions). He was very successful with this goal. Unfortunately, he still is until today. As Popper already noted, Plato's pedagogy still dominates Western Culture and continues to create existential trouble for democracy (see Siemsen 2017a, b, c, d, e, f, g, h). The goal of preventing any new ideas also implies the prevention of science and technology as Mach noted against Planck (see Siemsen 2010).

> of pleasure and affection, pain and hatred, that well up in his soul are channeled in the right courses before he can understand the reason why. Then when he does understand, his reasons and his emotions agree in telling him that he has been properly trained by inculcation of appropriate habits. Virtue is this general concord of reason and emotion. But there is one element you could isolate in any account you give, and this is the correct formation of our feelings of pleasure and pain, which makes us hate what we ought to hate from first to last, and love what we ought to love. [. . .] Education then is a matter of correctly disciplined feelings of pleasure and pain. (Plato, *Laws* 2.653)

Understanding is explicitly prevented. The child is supposed to be indoctrinated "before it can understand the reason why". The adult is then already indoctrinated from childhood (otherwise eliminated or coerced with a similar method). Conformity to the lawgiver/leader is the main goal of education: "It looks as though our rulers will have to make considerable use of falsehood and deception for the benefit of those they rule. And we said that all such falsehoods are useful as a form of drug." (Plato, *Republic* 5.459c).

Plato's Psychology

For *paideia*, Plato's tools of indoctrination are stick and carrot.

> [Each of us living beings] possesses within himself a pair of witless and mutually antagonistic advisers, which we call pleasure and pain [. . .]; the anticipation of pain is called 'fear', and the anticipation of the opposite is called 'confidence'. Over and against all these we have 'calculation', by which we judge the relative merits of pleasure and pain, and when this is expressed as a public decision of a state, it receives the title 'law'. (Plato, *Laws* 1.644-5)

This is justified by being the law of the gods (packaged charmingly into a metaphor to make it sound less threatening).

> [Thereby, we are] puppets of the gods. [. . .] We have these emotions in us, which act like cords or strings and tug us about; they work in opposition, and tug against each other to make us perform actions that are opposed correspondingly; back and forth we go across the boundary line where vice and virtue meet. One of these dragging forces [. . .] demands our constant obedience, and this is the one we have to hang on to, come what may; the pull of the other cords we must resist. This cord, which is golden and holy, transmits the power of 'calculation', a power which in a state is called the public law . . . ; being golden, it is pliant, while the others, whose composition resembles a variety of other substances, are tough and inflexible. The force exerted by law is excellent and one should always co-operate with it, because although 'calculation' is a noble thing, it is gentle, not violent, and its efforts need assistants, so that the gold in us may prevail over the other substances. [The individual] must digest the truth about these forces that pull him, and act on it in his life; the state must get an account of it either from one of the gods or from the [expert philosopher trained in observing god's ideal ideas/the master blueprint], and incorporate it in the form of a law [. . .]. (Plato, *Laws* 1.644-5)

Plato's psychology of learning, is designed[22] to introduce the hierarchy of his Republic. Education is a sieving-out process to find the ideal warriors and bureaucrats, i.e. those best for the task and least likely to rebel. The philosopher-leaders/oligarchs are pre-selected from the aristocracy. Between Plato's presupposed classes in society there is downward, but little upward mobility in his *Republic*). The ideal city for Plato is an oligarchy[23] of "true philosophers" with a philosopher king who acts as lawgiver and censor of knowledge (*Republic*, 534c-539 or 378a). "Until philosophers rule as kings or those who are now called kings and leading men genuinely and adequately philosophize, that is, until political power and [Platonist] philosophy entirely coincide, [. . .] cities will have no rest from evils, nor I think will the human race." (Plato, *Republic* 5.473c-d).

In order to make people worship the "golden and holy" law and neglect their supposedly hedonistic "advice from pleasure and pain", Plato's psychology is designed for despising the senses. In this, he follows Pythagoras and "resolves" Heraclitos' criticism of flux: According to Aristotle (*Metaphysics*, Book I, 987a30–987b10, see also Book XIII, 1078b7–32) in a rare direct criticism[24] of his former teacher, Plato followed the Pythagoreans in most respects, but believed in the,

> Heraclitean doctrines (that all sensible things are ever in a state of flux and there is no knowledge about them), these views he held even in later years. Plato [inspired by Socrates, who held that a universal] definition could not be a definition of any sensible thing, as they were always changing. Things of the other [non-sensible] sort, then, he called Ideas, and sensible things, he said, were apart from these, and were all called after these; for the multitude of things which have the same name as the Forms exist by participation in it. Only the name 'participation' was new; for the Pythagoreans say that things exist by imitation of numbers, and Plato says they exist by participation, changing the name. But what the participation or the imitation of the Forms could be they left an open question.

Plato probably sensed this later problem and developed his tripartite psychology partly in response to it: The philosopher turns away from the sensualistic body and concentrates on the soul, especially the part of reason. Here the epistemological cut between "lowly" senses and "ideal" reason is introduced metaphysically, i.e. by religious argument. Plato's "reality" is apart from the senses and contrary to evolutionary theory:

> [. . .] The soul is most like the divine, deathless, intelligible, uniform, indissoluble, always the same as itself, whereas the body is most like that which is human, mortal, multiform, unintelligible, soluble and never consistently the same. (Plato *Phaedo* 80)

[22] Plato leaves nothing to chance. All his concepts, even the seemingly most unimportant are carefully adapted for leading into a mental frame/cage of concepts. "Getting out" of Plato's famous cave thus does not lead into freedom of thought, but into mental imprisonment. The cage is carefully made from rubber so that one does not notice its limitations too much until one gets used to it (see Siemsen 2017a, b, c, d, e, f, g, h).

[23] Plato defines "oligarchy" only as an oligarchy of wealth, while the ideal philosophers live in a kind of commune "sharing everything" like the Pythagoreans.

[24] Aristotle criticizes Plato's ideal ideas, but adopts them in a down-scaled version of universal forms.

> When then does the soul grasp the truth? For whenever it attempts to examine anything with the body, it is clearly deceived by it. Is it not in reasoning if anywhere that any reality becomes clear to the soul? And indeed the soul reasons best when none of these senses troubles it, neither hearing nor sight, nor pain nor pleasure, but when it is most by itself, taking leave of the body and as far as possible having no contact or association with it in its search for reality. (Plato, *Phaedo* 64–65)

From the three souls Plato postulates in the *Republic,*[25] one deals with the senses (appetite, depicted as a many-headed savage beast), one is godly (reason, depicted as human herdsman) and in order to resolve the gap, there is a third, which moderates between the two when necessary (spirit, depicted as a lion). The herdsman is supposed to make the lion his friend and obedient servant (like the warrior in the *Republic*), while taming the multi-headed beast and keeping it at bay.

Reality for Plato is "perceived" by neglecting the senses as much as possible. Thus, pure metaphysics makes the "clearest reality". It then comes as no surprise that many Neoplatonist philosophical "realisms" seem quite unrealistic for an empirically minded person.

Plato (especially in *Theaetetus*, but also *Meno*) needs a strict differentiation between his (metaphysical) ideal, godly ideas and the (empirical) sensual elements. His psychology is based on a *scala naturae*. Animals have a sensual intellect, while humans have sensual elements as well as "rational" ideal ideas from God. The latter are supposedly best known to the philosophers. Psychology for Plato has the main role of translating between those two worlds, the one of metaphysics and the empirical.[26] For keeping younger aspirants away from power and to have time for controlling their formation, Plato (like Pythagoras before him) invents an elaborate system of training. One can thus only become a full philosopher beyond the age of 50.[27]

Empirically, "rational" thinking in the sense of Plato only appears in people who have been trained in Platonist method. It cannot be observed in children or adults who have not received Platonist training. Their thinking is "ratiomorph",

[25] For a detailed analysis on the development of Plato's psychology, see Siemsen (2017e).

[26] As Plato readers will know, Plato is of course too clever to describe a world without sensual experience. But he chooses his examples not empirically, i.e. selectively according to his political purposes. Already his student Aristotle indirectly criticized Plato for this. Heraclitus (Kahn 1979, fragment XXV) invented the term of "*kakotechnie*", i.e. the technique/art of doing evil, by Pythagoras for applying knowledge for indirect manipulation explicitly against the interests and motives of the learner (from whom Plato adopted it). Popper called this Plato's "charm" or magic. What Plato states openly and also what he states indirectly are not what he means. His intention, like the intention of the Pythagoreans, was to keep the real motives as hidden as possible, but distinguishable/knowable for the initiated. Parmenides used this method to initiate logic (which is still based on his "magic"). Later Isocrates was an expert at this hiding-motives approach optimized by rhetorical smokescreening.

[27] The system reminds one of the academic system in some countries (like in Germany) of becoming full professor. Even Pythagoras' five years of silence for becoming a member of his inner circle (*mathematikoi* instead of *akusmatikoi*) is still mirrored by the five years one tends to need for a doctoral study.

as the gestalt psychologist Egon Brunswick called it. It might look like it is rational in some aspects, but only superficially (see also Beneke 1835, 1836/1842). Empirically, thinking develops quite differently (learning becomes exponential instead of linear; gestalts/concepts once learnt, one does not forget for a lifetime), if not "disturbed" by Platonist *paideia*. This has been shown in over 30 cases (see Siemsen 2014, for instance for Finland until 2006 in Siemsen 2011a, b, c) and theoretically elaborated by Friedrich Eduard Beneke (1835, 1836/1842). The effect is reproducible. The Platonism in people can be transformed by teaching them a different *erkenntnis*-theory. This is basically what Mach tried to achieve.

Einstein's Examples: Hume and Bacon

Can Plato's influence also be observed in the "Empiricist" tradition? Einstein in his obituary compared Mach's ideas to those of Hume and Bacon. Mach also saw his intellectual influences in Hume and Berkeley. Einstein late in his life regarded the strongest philosophical influences on him to have been "by Hume and Mach, though with Mach I do not remember how anymore" (Speziali 1972).

Francis Bacon took his main ideas from his namesake predecessor Roger Bacon (see Gaukroger 2001). Roger Bacon already introduced a more empirical psychology/*erkenntnis*-theory from Aristotle (*de Anima*) into mathematics and physics (*physis*),[28] adopted from his teacher Grosseteste and other Oxford Calculators (see Siemsen 2017d, on the Oxford Calculators and their relation to Humanism). The empirical-genetic[29] *erkenntnis*-theory of the Oxford Calculators led to a new assessment of the concept of what is empirical by Bacon. Like the humanists, he demanded science/philosophy to be productive, criticizing the "barrenness" of scholasticism.

Locke then adopted a more empirical-genetic psychology from the Oxford Calculators by the inspiration of Spinoza. Locke criticized the Platonist ideal ideas, stripped the ideas off their religious "gaudy robes" and submitted them to a genetic process. But Locke kept some "metaphysical fungus" in the form of *a priori* (i.e. innate) "mental faculties", such as will, rationality or consciousness and especially Plato's psychology of pain and pleasure:

[28]The calculators used more the Greek natural philosophy concept of *physis* and mathematics (like from Thales and Anaximander), where there is no strong Platonist division between the two, because of a common *erkenntnis*-psychology as the basis. In this philosophy, the physical and the mathematical are two perspectives which can be methodologically combined into a common process (like walking on two legs as Mach suggested).

[29]Empirical-genetic is used in order to include what Mach called the "economy" of thoughts/processes. The "origin" (*archae*) makes a larger part of the process in a gestalt (about 70% according already to Aristotle). "Genetic" emphasizes this "spacetime" process view in the empirical/sensual approach.

"Our maker, who, designing the preservation of our being, has annexed pain to the application of many things to our bodies, to warn us of the harm that they will do, and as advices to withdraw from them" (Locke 1690/2014, Ch. 7, p. 123). Pain and pleasure are meant by God "to excite us to these actions of thinking and motion [without them] we should neither stir our bodies, nor employ our minds" (Locke 1690/2014, Ch. 7, pp. 122–3). Also for Locke, like for Plato, God plays puppeteer with humans with pain and pleasure as his strings. The Scottish Empiricists took their psychology from Locke, i.e. the empirical/evolutionary part and the metaphysical/Platonist part. John Stuart Mill – unwillingly – even based his supposedly empiricist Utilitarianism on Plato's anti-empirical pain-pleasure psychology. This Platonist cuckoo-egg is still featuring quite prominent in Empiricism even today.

Empirically, pain-pleasure psychology is an artifact. Pain and pleasure are properties of some psychological processes, not all (see Beneke 1833/1861/1877). They are results of historical adaptive evolutionary processes, which humans are not necessarily bound to in their current adaptive environment. These processes might be directly or indirectly linked to other processes, where pain and pleasure are coincidental. Such processes require a different analysis for their correlations instead of a Platonist label that does not fit.[30] The assumption of pain-pleasure as the psychological basis instead of one partial phenomenon thus leads to largely false interpretations.

A pain-pleasure psychology leads to errors in pedagogy. Learning is only little correlated with positive and negative feelings. For instance, a learner can have the concept that effective learning must be difficult. The more the muscles are tensed when slotting-in numbers into formula, the more one has done for the maths exam. What one can empirically measure in terms of understanding from such a "learning" is mainly that the mistakes are trained so that afterwards, it becomes more difficult to avoid them.

Similarly, gambling machines or certain computer games use the points-collecting psychology.[31] The more points are collected in such games, the better the player feels. Often some digits are added to the number for increasing the effect. The correlation between the points and what is learnt "for life" is rather limited.[32] What

[30]As Jerome Bruner (2004) observed in retrospect, the most important factor in the behavior of his rats in a maze was not the food as motivator. Instead, the behavior of the rats depended upon his daughter playing with the rat beforehand or not. Unfortunately, he did not publish this observation at the time, because he feared that this empirical result would hurt the metaphysical ideology of his fellow Behaviorists too much for his own good. The gestalt psychologist Wertheimer had already observed (only half-jokingly) that the Behaviorist rats from German professors were rather deep thinkers, pondering long before entering their maze, while the US American rats were pragmatic like their professors and tended to go for their maze task without much ado. In terms of pain and pleasure, the maze tasks were similar.

[31]This effect has become even a management tool under the label of "gamification". The management pulls the Platonist strings by immediately rewarding or punishing the behavior of the employees with allotting points. The idea is not new, but adapted from piece-work pay.

[32]Such computer games often do not have the function of learning, but of relaxing because of their ability to distract. But this distraction can also become a waste of time. Computer- or boardgames

is learnt is mostly, how to optimize the game. Learning in terms of understanding has to be observed and evaluated in very different, more meaningful categories than pleasure and pain.

Hume took his main ideas/*erkenntnis*-psychology from Locke (see Siemsen 2017a) and the "Scottish enlightenment" tradition (Broadie 2001/2011). He also adopts the Platonist concept of pain and pleasure. Coming thus back to Einstein's question, what Mach taught different from Hume and Bacon? He "carved out" the empirical aspects in the *erkenntnis*-theory further, reducing the Platonist influence by replacing Plato's metaphysical psychology with the empirical psychology of Beneke (see Siemsen 2017e).

Mach's "set" of concepts/manifold/conceptual fabric[33] is thus the most empirical-genetic (apart maybe from Beneke, but his concepts are less accessible, though more genetic than Mach's in some aspects). Based on empirical pedagogy, Mach's set of concepts furthermore replaces Platonist pedagogy with an empirically effective pedagogy. Empirical pedagogy enables learning instead of hindering it (see for instance Mach 1890, translated by Siemsen, in print). Everybody can learn everything as already Petrus Ramus and Comenius understood it. No elite decides what should be learnt, guarding it with an unnecessarily complicated process for increasing the costs and time of learning.

Bacon and Hume transformed the thoughts of many people, but only for a limited set of concepts. Mach enlarged this effect in his teachings. As Einstein in his article tacitly suggested, the effect can still be enlarged further, if the concepts are made more empirical-genetic.

How can this transformation of thoughts be achieved? Mach suggested an *erkenntnis*-theoretical distinction, which helps in the initial analysis: the distinction between what is empirical (empiry) and what is metaphysical (metaphysics). The processes are "the adaptation of the thoughts to the facts and the thoughts to each other". Both processes have empirical and metaphysical aspects, which need to be distinguished. The main issue is to identify the superfluous or even empirically false metaphysics, such as Plato's concepts and their hypostases. Mach himself acknowledged that he still retained some of these, but he was not sure where. Otherwise he would have worked on eliminating them.

Like for Mach, Bacon and Hume, even the most empirically oriented scientists have a problem to disengage themselves in all aspects from the over-arching 2400-

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can instead be used as sophisticated learning tools, especially when combined with gestalt theory, gestalt pedagogy and an *erkenntnis*-theory that makes the intuitions from the games explicit and analogously applicable to other areas, such as mathematics (see Siemsen 2017d).

[33]Plato has a "frame" of concepts, which is designed to keep thinking within it. Mach suggested the concept of a conceptual manifold. Mathematically, one could describe such a manifold as a set, which is probably closest to popular understanding. Wittenberg (1957) uses the concept of "*Begriffsgefuege*", i.e. conceptual fabric. Mach and Wittenberg stress the aspect of the structure of the relations between the concepts. A "set" seems empirically more open to adaptations.

year-old Platonist metaphysical framework,[34] which dominates *erkenntnis*-theory in all of science (see Siemsen 2017b). Especially the psychology and the pedagogy are affected by this problem. The limited and Plato-tailored psychology inadvertedly introduces the fundament of Platonist conceptual rigidity. The pedagogy is the tool to implement and perpetuate it in such a way that nobody notices (see Siemsen 2017b, on the details of how this is done by "charm", see also Popper, 1944/1980, with more examples on the same question).

Plato's Use of Charm and Rhetoric

For changing fundamental concepts in a manifold of concepts, one needs to change not only the meaning of the concepts in question, but also their relation to other concepts and their meanings as well. When one teaches such a change, the effectiveness in terms of conceptual transformation in the learners depend on the process. The gestalts change according to how the set is taught, rather than how a specific concept in it is changed. This rigidity effect (see Luchins and Luchins 1959) is deliberately strengthened in Platonist conceptual frameworks. In an empirical-genetic set, it is low to non-existent. Here the concepts are meant to adapt and transform, not to rigidly stay "ideal".

Thus, Plato's combination is so good that all the Western World has fallen for Plato's charm. The most brilliant minds of Plato's Academy were involved in this effort. They employed the most sophisticated rhetorics of Isocrates' approach, which deliberately hides very different goals in such a way that everybody thinks of them as their own. By this elaborate charm, Plato's metaphysical ideas are often misinterpreted as Aristotle's empiry. Throughout the centuries, people tended to criticize Aristotle or praise him for ideas, which can first be found in Plato. Already Alexander of Aphrodisias tried to mark and avoid this confusion, which has riddled many controversies, such as between scholasticism and humanism (see Kessler 2011).

The problem of such "Aristotelian" pseudo-debates between factual and artifactual empiry[35] tends to obscure the fundamental issues. These are enwrapped by higher-level concepts and concepts from other areas. From an *erkenntnis*-theoretical

[34] It is a fundamental "feature" of this framework, that it disguises metaphysics as being empirical. Thus, all "realist" approaches are metaphysical and have "nothing to do with the world", only superficially, seen from an empirical-genetic perspective (see also Siemsen 2017e).

[35] In echocardiography, for example, today there are detailed imaging of inner physiological processes, such as blood flows, etc. Physicians new to this field first must learn that there are structures visible on the screen, which "exist" only because of the "interpretation" of the software, but have no correlate in the body. Also, physiological structures not observable on the screen might cause problems. Such "artifacts" are a result of the programmers using the most probable "interpretation" for the software, like humans use in their gestalts the most probable/suggestive/currently associated interpretation.

perspective, much of these problems can be reduced to the Platonist ideas hidden in them. What is labeled by Platonists as empirical can be an artifact. This problem can for example be observed in the case of the Vienna Circle and its relation to Mach. As there is more hidden Platonism involved, the conceptual problem is even more pronounced than in the cases of Mach, Bacon and Hume.

The Pythagoreanism in Austrian Philosophy[36]

For Rudolf Haller et al. (1994, p. 65), probably the most knowledgeable expert on Austrian Philosophy, "Scientificness, basic empirical attitude and the explicit continuation of certain teachings of Bolzano [are characteristic for belonging to Austrian Philosophy]." Haller thereby reduced Austrian Philosophy to three basic constituents. Probably one can be more reductionist and say that Austrian philosophy is Pythagorean[37] (Hippasus style), while Prussian "official"[38] philosophy is Platonist.[39]

Mach and Austrian Philosophy

Haller's basic constituents are mainly chosen to delineate Austrian vs. German/Platonist Prussian philosophy. His description fits all main Austrian philosophers; but one only part way, namely Mach. Mach did not continue certain teachings of Bolzano, neither explicitly nor implicitly, he continued the empirical-

[36] This can still be regarded a recent hypothesis that needs further research. There are of course also Platonist elements in Austrian Philosophy and psychology, but relative to the situation in Prussia and the "state" philosophers supported by the Prussian government, such as Kant, Herbart or Hegel, Platonism is much more dominant in Germany. The differentiation nevertheless requires a detailed analysis, which would be too long for this article. It has to be reserved for future articles, while here only few exemplary cases and areas can be described.

[37] Heinrich Gomperz even organized a discussion circle as "Sokratiker-Kreis" in which he took the role of the Pythagorean Simmias (Stadler 1994).

[38] Beneke taught empirical philosophy in Berlin, but he had to go into exile by decree of the Prussian ministry on behalf of his "colleague" Hegel. When Beneke was tacitly allowed to return, he was not paid for lecturing (though he was obliged to pay the fee for the professor's widows fund).

[39] These are mainly Kant and Hegel at the times. It is probably interesting to note that Bolzano has already criticized Kant and Hegel, while Popper criticized Plato and Hegel. Popper's criticism of Hegel is mainly the same as Bolzano's (of using only rhetoric without philosophical substance). Popper's criticism of Plato in his *The Open Society and Its Enemies* is more substantial than the Hegel critique. He was probably heavily influenced in his perception of Plato by Heinrich and his father Theodor Gomperz.

genetic teachings of Beneke.[40] Mach's concept of knowledge is not and-summative (Pythagorean mathematical), but adaptive and transformative (evolutionary, see Mach 1883/1888). Contrary to Bolzano, Popper or Carnap, Mach's concept of truth is not binary, but like his concept of knowledge (*Erkenntnis und Irrtum* as one evolutionary process, like two sides of a coin).

Mach shares with the other Austrian philosophers the scientificness and basic empirical attitude, but for Mach, empiry comes first, not second. Empiry constitutes Mach's basic scientific attitude. He made this quite clear in his dispute with Planck (Siemsen 2010). All Pythagoreans and Platonists regard their "first principles" as *a priori* to empiry. Thereby, they introduce an epistemological cut between the senses and the higher-level thinking, which supposedly leads to the "first principles".[41]

This epistemological cut is fundamentally inconsistent with evolutionary theory and its gradual process. The cut is required only for the religious assumption of a soul separable from the body. Empirically, such a separation is not generally observable. It depends on personal religious beliefs, not shared by many others. Scientifically, this can therefore be only held as private belief, not as a generalizable scientific concept.[42] If Austrian philosophers regard Scientificness as their main attitude, why do they use a religious belief *a priori* and contrary to a larger part of science?

Furthermore, the concept of what is empirical is different for Mach than for Bolzano, Brentano, Husserl, Gomperz, Popper, Schlick or Carnap. As they introduce logic before empiry, they observe the "adaptation of the facts to the thoughts and the thoughts to these part-metaphysical artifacts". This produces circularities in their arguments (see Beneke 1842, or Wittenberg 1957, pp. 279).

One can observe this for instance concerning their insistence of separating psychological and logical analysis. Logic and *erkenntnis*-logic are used for analyzing and optimizing rational thought. Rational thought is used for analyzing logic, coming to the conclusion that the separation of logic and psychology is necessary. An *erkenntnis*-psychological analysis shows that Parmenides distinction between what-is vs. what-is-not requires the assumption of the *tertium-non-datur*.

[40]See also the letters between Mach and Brentano (Thiele 1978). They know that their *erkenntnis*-theories are different, although they respect each other's views. Mach was asked to take the chair at the University of Vienna, which was strongly associated with Brentano. Brentano took his *erkenntnis*-theory from Bolzano.

[41]As Beneke (1842) analyzed *erkenntnis*-psychologically in detail, this process is quite different from the simplifying assumptions of Pythagoras and Plato.

[42]The defense of rational/logical thinking by Bolzano, Husserl, Popper, Carnap and others, even sacrificing empirical necessities for their understanding of *logos*, is thereby not a sign of a scientific attitude, but the opposite in two respects: taking one understanding of a concept as absolute without reflecting why and putting religious beliefs *a priori* before science. Already Aristotle was more careful with the concept-relation of "logos and error". Mach uses the concept of *logos* as adaptive and transformative *erkenntnis*, not as absolutistically judging rationality (see also William James 1884/1912). Pythagoreans can be very pragmatic in many details, much more than Platonists, but also dogmatic in their fundamentals (see Siemsen 2017h for a detailed analysis regarding the example of Popper).

The *tertium-non-datur* is a convention as the intuitionists argued. One can state the same for the true-false dichotomy of Pythagoras.[43] These conventions are basic for nearly all logical concepts and logical thinking. But they are introduced genetically earlier than rational analysis can start without psychology, i.e. only with logic. Thus, important logical and mathematical premises are hidden in the "evidence" and "web of meanings" of the basic concepts from which mathematicians and logicians start (*Bedeutungsgewebe*, Wittenberg 1957, p. 36). Logic is thereby applied to itself, based "evidently" on its own assumptions. By excluding *erkenntnis*-psychology *a priori*, it becomes "solipsistic": observing all others, but only being observed by itself.

It is then not surprising that logicians often assume logic being innate in humans. They start their analysis in the middle of the process of gestalt/concept formation, when basic logical ideas have already been introduced. The assumption of innateness is based on circularity.

Without psychology, there is no tool for making the earlier assumptions explicit and criticizing the logic-reason circularity. There is also no *erkenntnis*-theoretically consistent tool for observing "logic" and "reason" as concepts (see Kaila's criticism of Carnap's *Aufbau* below). Although they are central, they remain on the shaky basis of being "evident" (Frege's "solid stone" foundation that – as Weyl argued – evaporated into mist together with the whole tower built on it). "The real foundational problem about statements regarding our existence and our knowledge is not in getting to "fitting" [true] views about the world. [The problem is] first of all an *erkenntnis*-theoretical reflection on the way of the validity of our process of knowledge." (Wittenberg 1957, p. 214).

These examples of differences between fundamental concepts of Mach and the other Austrian Philosophers may suffice to show that Mach had a different *erkenntnis*-theory. It is different from Pythagoreanism, but also from Platonism and even from British Empiricism.

Bolzano's Pythagoreanism

Austrian Philosophy thus – according to Haller – genetically starts with Bolzano. Bolzano uses Pythagorean *erkenntnis*-theory and many of their basic assumptions.[44] As he is quite liberal in his use of mathematics and the publication of proofs, he seems to be connected to the Hippasus' tradition.

[43] It is somewhat surprising that it was formalism that did away with the assumption that truth is a necessary concept for mathematical systems (Wittenberg 1957, p. 299).

[44] The genetic origin of this still needs to be researched. Bolzano's origins in Bohemia with its link to the Oxford Calculators via Hus or Bolzano's family origins in Italy might provide some hints. Also, a connection to the historians and mathematicians in Goettingen (Meiners, Gauss) might be possible.

Bolzano writes his largest book about *Wissenschaftslehre* (the teaching of science). It is the book that Pythagoras never wrote. In principle, it is a first version of Carnap's *Aufbau* (see below). Logic (*logos*/reason) is used in a wider sense than by Parmenides. It is a basis for science and scientific knowledge.

For Bolzano, as for the Pythagoreans, knowledge is truth. Empirical knowledge is possible, but in flux and therefore not reliable. It only becomes reliable, when derived metaphysically by chains of proofs from mathematical elementary principles, i.e. natural numbers. Truth for Bolzano is clear-cut, absolute and and-summative, like natural numbers: "[...] If all human truths were united in a single book, [this would be called] the sum of human knowledge" (Bolzano 1837, p. 3). Popper has the same Pythagorean concept of truth. He distinguishes between probabilistic truth and the Platonist "similar to truth" concept. He does not have an evolutionary/transformative concept of truth.

This is only a fraction of total possible knowledge (Pythagorean knowledge is truth-based and thereby fixed, but can be developed further; knowledge is additive as proofs can be built on each other, but less adaptive and transformative). Bolzano's book is the "metabook" about such a book of knowledge. Human knowledge is described by theorems and proofs (similar to Carnap's approach). It is probably not surprising that Bolzano is the originator of the mathematical concept of "set". He developed the basis for Cantor's set theory.

Bolzano has an epistemological cut between the mental and the "physical" world of the senses (in Mach's sense, seeing is psychophysical). The "mental" for Bolzano means only reason and metaphysical ideas, not other psychological processes and empirical ideas.

The Origin of Austrian Erkenntnis-Theory

Mach acquired his empirical-genetic *erkenntnis*-theory from reading Beneke in the library of his father when he was fourteen. The other Austrian Philosophers together with many Austrian students acquired their Pythagoreanism probably in high school at a similar age through Robert Zimmermann. Zimmermann was a student of Bolzano (inheriting his papers), who wrote the school book on psychology and philosophy. The book was used for a long time as standard in the Austro-Hungarian Empire *Empirische Psychologie fuer Obergymnasien* (empirical psychology for high schools).[45] Zimmermann (1852, p. vii) makes explicit use of Beneke, but

[45]Mach wrote similar schoolbooks for physics. These were in use over decades in German-speaking states. The books introduced his adaptive and transformative concepts to, what Einstein's (1916) called his "generation of physicists" heavily influenced by Mach. Mach published some of his popular science articles in newspapers. Zimmermann wrote an article about the need of teaching empirical psychology in schools for a newspaper. Because of this, the Austrian ministry of education introduced such courses and asked Zimmermann to write a schoolbook on the topic.

especially of Bolzano. He seemingly avoids many of the direct Kantians (except for Herbart whom he defended against Hegel).

Thus, with "empirical psychology", Zimmermann has a "basic empirical attitude", but makes the fundamental metaphysical assumption that the soul is "simple" and separate from the body. He assumes innate faculties, like Locke. These faculties lead to the already previously described epistemological cut between "reason" and the senses (Zimmermann 1852, p. 41). Innate concepts from reason are "activated" by the right input from the senses. Such concepts are logical or mathematical and considered "simple" such as "and". "And" (i.e. "+") is "activated" by having several conceptualizations in the soul at the same time. The soul acts thus like a calculator/computer.

Austrian Philosophy: The Affinity to and Misunderstanding of Mach

As Beneke was heavily attacked by the Prussian Platonists of the times, i.e. Hegel as well as Herbart, it is surprising that Mach seems to have been well-received in general by Austrian Pythagoreanism. It seems that Hippasus' Pythagoreanism is less aggressive and in some aspects quite affine to the empirical-genetic *erkenntnis*-theory of Mach.

Mach was the *erkenntnis*-theoretical father-figure of the Vienna Circle (organized in the *Verein Ernst Mach*). Heinrich Gomperz mentions in his autobiography that Mach was one of the central figures for him and his father in their lives (Haller et al. 1994). Nevertheless, in many central aspects, they did not accept and often did not understand Mach's ideas. This not-understanding leads to obvious inconsistencies, which in turn seem to be deliberately overlooked (see Siemsen 2017h).

Also, because of the overlooking and the assumption that the inconsistencies are evident/apodictic/"uncontradicted",[46] no arguments are provided. If any arguments are provided, they are emotional and do not bear scientific scrutiny (e.g. Frege's and Husserl's arguments for the psychologism accusation are today deemed as rather "thin", relative to the deformative impact this had on psychology and science in general, see below). It seems as if there were unnamed thought-taboos. This is a problem of the Mach reception until today.

The book was in use over a long time and thus influenced many generations of Austrian high-school students.

[46]Gomperz quoted in Haller et al. (1994, p.61). It is somewhat puzzling that Gomperz sees the most disputed philosophical question of the time as "uncontradicted" (*unwidersprochen*). It is doubly puzzling, as Frege based his main discussion regarding the separation of psychology and logic on attacking Mill. Gomperz's father was known for being the translator of Mill's works into German. Why did Gomperz relapse to Platonist psychology when he often before used Mach's? Why did he not defend Mill, siding instead with the Platonist Frege? Similar inner inconsistencies can be observed in Popper (see Siemsen 2017h). But then, Popper had learned from Gomperz.

The Metaphysics of the Vienna Circle: Carnap's Aufbau and Kaila's Criticism

The "first" Vienna Circle was established by Hahn, Neurath, etc. in the succession of Mach's transformative lectures on *erkenntnis*-theory (Mach's book *Erkenntnis und Irrtum* covers just one chapter of the lecture; the whole lecture probably needs to be reproduced sometime). The idea was to continue Mach's ideas. But the "second" Vienna Circle was not only influenced by Mach, it took a broader approach. Several of its members had also studied with Planck and Frege. Planck had attacked Mach with Platonist elitism. Later he eliminated Mach's influence among physicists and physical thinking through the political influence he was provided by the National Socialists (see Siemsen 2010).

Frege had influenced Husserl to instigate the Psychologism debate. The accusation of psychologism against people holding professorial positions in philosophy was aimed at preserving the Platonist philosophers against the psychologically oriented, more empirical-genetic philosophers influenced by Beneke and Mach (see also Kusch 1996 and Siemsen 2017a; the accusation of psychologism was first launched against Beneke, see Siemsen 2017f). Through Russell pointing out a logical inconsistency (paradox) in Frege's approach, Frege, like Carnap, later took a different direction. But that was too late for the empirical philosophers, who mostly took refuge in practical psychology. According to Kusch's (1996) analysis, this was also the end of theoretical psychology until today. *De facto*, the Platonist philosophers used the "psychologism" argument in order to get rid of the philosophers with a different approach.

Although Mach's teachings transformed many ideas of his successors, the implicit Platonism and Pythagoreanism remained hidden in many concepts. It "sprouted"[47] as metaphysical fungus as soon as the attention was not focused on Mach anymore. Such an *erkenntnis*-psychological "jojo"-effect can for instance be observed for the Vienna Circle.

Which *erkenntnis*-theory is used, either Pythagorean, Platonist, or empirical-genetic, can be observed most fundamentally regarding the question, which psychology is used. The gestalt concept used by the gestalt psychologists was elaborated by Beneke and Mach. In various forms, it has a long tradition in empirical-genetic psychology, going back to the Presocratics (see Siemsen 2017c, also Kessler 2011 for the time from Alexander of Aphrodisias $\sim$ 200 AD onwards).

The gestalt psychologist Eino Kaila was influenced by Mach early in his life (see Siemsen 2011a). He acquired gestalt psychology, which he tested empirically in a project in Vienna with Charlotte Buehler regarding facial recognition of infants. He established gestalt psychology in Finland so that later Kurki-Suonio was able to centrally integrate gestalt psychology in his "didactical physics" courses (his

[47] Mach (1896/1923/1987).

teachers say that they are not teaching physics, but "concepts", i.e. gestalts, see also Kurki-Suonio 2011).

Kaila gave the Vienna Circle the label of "logical empiricism". Logic comes before empiry, which is genetically false, i.e. inconsistent with evolutionary theory. Kaila (1930) criticized logical empiricism, exemplified in Carnap's *Aufbau*, for this empirical inconsistency:

> However, Carnap believes that his assumption that the 'cross-sections of the stream of experience' are utterly simple qualia agrees with the views of modern psychology, in particular Gestalt theory. He seems to assume that the rejection of the doctrine that experiences are composed of 'mental elements' of some kind or another is equivalent to the statement that–apart from all 'conceptual elaborations'–they are unstructured total impressions (without original internal manifold of their own). [...] After all the construction theory itself is surely based on concepts which cannot have arisen according to the quasi-analytic schema–e.g., the concept of the past, without which this method would not be applicable. This implies that the quasi-analytic formation of concepts is only one among many others. What is more, this kind of concept formation is such as is possible only on a relatively high level of the actual cognitive process. [...] The theory absolutizes this method and introduces it epistemologically too soon, whereby the theory gets entangled in inner contradictions ...

It is basically the same evolutionary criticism on Parmenidean/Platonist logicism that one can already find in Beneke, Clifford and Mach. Carnap's version, though, it is slightly different as it applies not so much to Platonism, but to Pythagoreanism.

Kaila in principle criticizes Carnap for assuming that sensual elements or qualia are not only the starting point of a genetic enquiry into their gestalts/internal manifolds, as adaptation of the thoughts to the facts. Carnap takes the qualia as directly and purely empirical. The thoughts *are* the facts. Logico-mathematical concepts are real, without psychology, i.e. without an evolutionary adaptation process in-between (see Hermann 2004). Thereby, Carnap excludes evolution and explicit psychology in a typical Pythagorean manner. If everything can be proven from some first mathematico-logical principle, all is explained. For this, Carnap introduces an arbitrary Pythagorean epistemological cut in the gradual genetic process. The result of concept formation is "defined" as starting point. From this "starting point", logical concept formation is introduced.

Furthermore, as also Wittenberg (1957) pointed out in general for logic and formalism, neither logic nor Wittgensteinian language theory can be consistently applied in such a way. It is the area of *erkenntnis*-theory. The application of the Platonist logic of Carnap is circular. It introduces its own assumptions into the initial conceptual reduction/abstraction before it analyzes them. Furthermore, its tools and goals are inadequate for the task. The goals require elaborated, relatively stable and clarified concepts, which is not the case for the more fluxual pre-scientific concepts/gestalts. Many of the concepts are even pre-linguistic.

After Kaila's gestalt criticism on Carnap's *Aufbau*, Carnap needed a new psychology. Instead of taking a less Pythagorean/more sophisticated version of Gestalt psychology as Kaila had suggested, Carnap's friend Neurath had the intuition that Behaviorism must be empirical, because it comes from Empiricism. Therefore, he promotes that the Vienna Circle exclusively uses Behaviorist psychology (see

Stadler 1997, p. 292). But Behaviorism is a psychology based on the Platonist pain/pleasure dichotomy.

Carnap (1967) later notices the mistake.[48] In the foreword of the English translation of the *Aufbau*, he draws links to Wertheimer and gestalt psychology. He concludes that he should have started the *Aufbau* from Mach's sensual (psychophysical) elements.[49] Actually, he would have been even more consistent, if he had started from Beneke's empirical psychology (Beneke 1833/1861/1877).

Mach's Image Today and the Exemplary Case of the Vienna Circle

The origin of the Vienna Circle were the empirical-genetic ideas of Ernst Mach. Like with Einstein, these ideas became intuitive with time, part of the scientific "mother's milk". As a result, the ideas the Vienna Circle was studying were less and less inspired by Mach and thereby less and less with empirical-genetic *erkenntnis*-theory. The gaps were taken over/filled with metaphysical/Platonist ideas.

Thus, the "fight" of the left and right-wing Vienna Circle members is mainly a fight of metaphysical ideas versus metaphysical ideas. It is perhaps strange to draw this conclusion as the main "goal" of the Vienna Circle was supposedly fighting metaphysics because of Mach. Instead, they were fighting over which version of metaphysics is the better one. But then, they had a Pythagorean concept of metaphysics (rationality as scientificness) and a metaphysical concept of empiry.

As a result, the Pythagorean/Platonist psychology and the Pythagorean/Platonist pedagogy were kept. This is still a problem today in many respects. First of all, few people understand what is important in Mach's legacy. His ideas in physics led Einstein in a specific case, but they were just the result of his *erkenntnis*-psychology. This *erkenntnis*-psychology has enabled and will probably still inspire the thoughts to many Nobel prizes in diverse areas. Also, Mach's pedagogy lets many students understand. They would not understand with a Platonist pedagogy (and less than 10% would understand mathematics with a Pythagorean pedagogy). Changing to an empirical-genetic pedagogy will help millions of people.

The interesting question is, why few researchers are concerned with Mach as *erkenntnis*-psychologist or pedagogue, while many more are concerned with Mach as a physicist or Platonist philosopher. Here, Mach looks like a historical curiosity to study. As his philosophy deliberately avoids the Platonist concepts (and even

[48]He seems only lukewarm to the idea in the first place, but he sees no alternative.

[49]Carnap (1969, p. vii) still uses partly the Platonist frame for interpreting Mach's elements. He assumes with Parmenides that these elements are "data" in the sense that an element could be abstracted from its genesis, i.e. its time dimension. But one cannot abstract time from spacetime. Even for Carnap's revised elements, Kaila's criticism applies, Carnap still destroys the "inner structure" of Mach's elements as Gestalts. With his Frege/Platonist/Pythagorean view, he does not see that Mach's elements are Gestalts (process and product).

avoids calling itself philosophy), judging his philosophy from such concepts leads to arbitrary results. But it is not a historical curiosity, arbitrary philosophy or serendipity that led to the many developments of the empirical-genetic *erkenntnis*-theory.

The creativity of the Vienna circle came from Mach's *erkenntnis*-psychology. When the energy of this initial input was used up, the scientific creativity declined. Still today, the new ideas and developments from this direction come mainly with some "back to Mach" approach.

Implementing Mach's Transformative Legacy

Mach helped many people to make their fundamental concepts more flexible. This led to many creative scientific endeavors. One can observe that in later analyses of these processes, it often remains unrealized and unreflected that Mach had an effect or the reasons why Mach had an effect. Instead, there are *ex nihilo* interpretations of a "born genius", etc. Postulating some unknown force, gods or biological setup is a simpler substitute for a detailed analysis (see for instance Zilsel 1924/1990 for the Platonist use and abuse of the "religion of the genius").

But now the effects are described and they are reproducible. Einstein's question is empirically resolved. The intuition he had, namely that the effect Mach had on him, his colleagues and thereby revolutionizing all of physics is reproducible in principle for all areas of human knowledge. Furthermore, it is a method for all learners, not only for those that seek to become a Nobel laureate. Everybody can understand and has the right to understand, for instance mathematics, not just 10–20% of "high-achievers". The empirical-genetic approach also increased the number of "high achievers" in Finland by a factor of three, additional to its effect on eliminating the "low achievers" (until 2006, see Siemsen 2011a). Contrary to often stated general assumptions, Plato's pedagogy does not promote the supposed logico-mathematical elite, it reduces it substantially.

This was already empirically shown by the inventor of the intelligence test and scale, Alfred Binet after he had an intensive scientific exchange with Mach (see for example Siemsen et al. 2017). The empirical difference between an empirical-genetic approach versus a Platonist approach in education (and psychology) is striking (up to 500–1000%). The Platonist approach is deliberately designed to prevent learning and new ways of thinking.

Mach's approach is not perfect in promoting science education, but close to this. It needs especially the more consistent integration of Beneke's psychology as well as a systematic research on the basic scientific concepts involved. Plato's influence on education has to be rooted out. For this, the concepts have to be genetically reintroduced, i.e. before Plato deformed them. This means a systematic research on the use of these concepts by the Presocratics (see Siemsen 2017c). Such a research is also necessary for making the concepts flexible in the sense of the method of Mach, which Einstein described (historical-critical/historical-genetic).[50]

Mach did not apply his method to himself. Thus, he could not describe, how his method of teaching could be consistently replicated. This is now possible and empirically stable (i.e. predictable, see Siemsen et al. 2014). As Einstein had suggested a century ago, it has the potential to transform science in fundamental ways, not imaginable today.

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[50] Mach later tried to change the English subtitle of his *Mechanics* into historical-genetic instead of critical and historical (see letters from Mach to McCormack in the archive of The Open Court in Bloomingdale).

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Chapter 41
On the Influence of Ernst Mach on Contemporary Physics Curriculum at Schools: The Concept of Weight

Igal Galili

Abstract In his *Mechanics* of 1883, Ernst Mach opened a specific revision of the classical physics which launched a radical epistemological change in physics. Within this move, Mach introduced operational definition of physical concepts and thus changed the status of measurement in the foundation of physics. The paradigmatic change was introduced in the definition of inertial mass. This paper points to another physical concept, which went through a kind of similar change in definition – the concept of weight. In this perspective, we reviewed the history of conceptual transformation of the weight concept. We speculated for the reason that prevented this change to be performed within the classical physics as required another epistemological change introduced by Einstein in establishing of modern physics. It is within the new physics that Machian introduction of the operational concept definitions could fully develop towards operationalism and logical positivism. The anthropocentric nature of the weight concept left it however behind the frontier of theoretical physics. Yet, for the same nature, this concept remained central in physics education. The paper reviewed the status of the weight concept which divides the world of teaching physics into two big camps of educators those keeping with Newtonian (nominal) definition and those who argue for the modern definition drawing on the operation of weighing. The paper suggests a new educational approach to teaching weight – disciplinary cultural one. The latter implies exposure of the conceptual dialogue regarding weight definition and making explicit the epistemological reasons for the conceptual change regarding weight being illustrated with a set of representative physical situations. The evidence of the educational priority of the new approach is mentioned.

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Introduction

Concepts create the net of elements establishing the fundamental theories of physics. All historical changes of theories were mirrored in changes of concepts reflecting changing epistemology. It is therefore beneficial to consider concept development revealing important changes of physics knowledge and guiding its presentation in physics teaching. We consider here the concept of weight (gravity) for that purpose.

Measuring, counting and weighing were declared the way of science seeking the scientific truth about reality. Starting from Hellenic science, theory accounts for reality in terms of concepts defined theoretically. Measurement could point to the procedure of quantification of the concept subdued to its theoretical account on the first place. In his *Science of Mechanics* Ernst Mach[1] introduced a radical change towards the empiricist epistemology. *Inertial mass* of material bodies was redefined through the ratio of accelerations of two interacting bodies stated to be theory independent and directly *observed* and *measured.*[2] Despite the heavy critique,[3] this definition was attractive to physics textbooks[4] for being of operational type. Introduction of operational definitions reflected the effort of Mach to expel from physics "all metaphysical obscurity". Even if it were shown that the operational definitions could not fully account for physical concepts,[5] physics epistemology adopted the discovered value of the operational definitions and upgraded it to compound definitions – nominal (theoretical) and epistemic (operational).[6] Einstein Theory of Relativity drew on the operational definition of simultaneity and guided physicists towards the specific philosophical trend – operationalism.[7]

Mach considered the concept of mass but left aside the close to it – weight. In that, he remained with Newton who identified weight with gravitation. We will review the conceptual history of weight and analyze it in epistemological perspective. We will argue that the later introduced new approach – to draw on the account by a local observer – may explain why Mach, without such, did not revise weight concept. The revision was performed by Reichenbach[8] in 1927 while considering the implications of the Einstein principle of equivalence. He arrived

[1]Ernst Mach, *The Science of Mechanics/A critical and historical account of its development*. Chicago: The Open Court 1960.

[2]*Ibid.*, p. 218.

[3]Mario Bunge, "Mach's Critique of Newtonian Mechanics", in: *The American Journal of Physics,* 34, 1966, pp. 585–596. In his paper, Bunger stated that Mach in his definition of mass used Newton's laws as hidden assumptions, or presuppositions, at least.

[4]E.g. John Jewett/Raymon Serwey, *Physics for Scientists and Engineers*. Belmont, CA: Thomson 2008, p. 104.

[5]Mario Bunge, *Foundation of Physics*. New York: Springer 1967, p. 27.

[6]Henry Margenau, "The role of definitions in science", in: *The Nature of Physical Reality*. New York: McGraw-Hill 1950, pp. 220–244.

[7]Percy Bridgman, *The Logic of Modern Science.* New York: Macmillan 1927/1958.

[8]Hans Reichenbach, *The Philosophy of Space and Time*. New York: Dover 1927/1958.

at the necessity of divorce between the gravitational force and weight (gravity). Looking back to history, one could see that the same inference could be suggested by Huygens in 1659 who was close to the principle of equivalence when introduced the dynamical account by a rotating observer.

On our days, many educational practitioners resist splitting gravitation from gravity and ignore the new definition of weight while others do it. We will mention the specific studies considered the suggested change showing its pedagogical advantage. The transition goes with Mach approach to physical concepts and makes relevant addressing Mach ideas in physics class of today.

The History of Weight Definition

The concept of weight has a rich history and attracts attention from the dawn of natural science.[9] The first theoretical account of weight can be traced to Aristotle[10] who identified weight (gravity and its opposite – levity) with the effective cause of natural motion, the natural tendency of elements towards (or away from) the center of the universe[11] occupied with the Earth. This definition replaced the previous account by Plato[12] stating that weight presents the inclination of each element to move towards its kind. Drawing on the idea of inherent heaviness, Plato inferred proportionality of weight to the amount of matter.

The following Hellenistic science introduced an operational quantitative approach to concept definitions – changing the epistemology and focus of investigation.[13] The manifestation of weight as intrinsic heaviness came to the fore in its measurement by weighing. Euclid[14] introduced the operational definition:

> Weight is the measure of the heaviness and lightness of one thing, compared to another by means of a balance.

[9] Marshall Clagett, *The Science of Mechanics in the Middle Ages*. Madison: The University of Wisconsin Press 1959; Edward Grant, *A History of Natural Philosophy from the Ancient World to the Nineteenth Century*. Cambridge, UK: Cambridge University Press 2007.

[10] Aristotle, *On the Heavens*. Chicago: Encyclopedia Britannica 1952 De Caelo, II, 295$^{a\text{-}b}$, 296^{a}.

[11] Aristotle, *ibid*., I, 277$^{a\text{-}b}$.

[12] Plato. *The Dialogues. Timaeus*. Chicago: Encyclopedia Britannica 1952, 62, p. 463.

[13] John Losee, *A historical introduction to the philosophy of science*. New York: Oxford University Press 1993; Lucio Russo, *The Forgotten Revolution: How Science Was Born in 300 BC and Why It Had to Be Reborn*. Berlin: Springer 2004.

[14] Clagett, *op. cit.*, p. 24. Balance scale was the only method of weighing at that time. In fact, Plato, in his *Timaeus*, mentioned weighing by balance once as the obvious way of finding weight, not as its definition.

Archimedes as well as Heron[15] kept with this definition of weight as body *heaviness* and its property, not a force, which may compete with other forces (such as buoyancy). Gravity (*gravitas* in Latin) and *weight* remained very close synonyms.

During the middle ages, the science of weights (*scientia de ponderibus*)[16] became a major part of the medieval mechanics.[17] Buridan and Albert of Saxony related the concept of weight to the acceleration of falling objects. Keeping with Aristotelian proportionality of swiftness with weight, they refined it into two components: the "natural" weight/gravity of an object at rest, and an additional ("accidental") gravity acquired by a body in falling.[18] The additional component reflected the extra heaviness. Indeed, a greater force is required to stop falling objects than to support them at rest. The concept of accidental gravity merged with another concept – *impetus* introduced already by Hipparchus.[19] It was understood that while a body is falling, its heaviness continuously produces impetus.

Jordanus de Nemore (thirteenth century) further refined weight concept by *positional* weight or gravity (*gravitas secundum situm*) to account for descending of a body along the inclined plane.[20] The positional gravity of a body was taken being inversely proportional to the obliquity of the descent (the height to length ratio of the inclined plane).

Galileo kept with the dual concept of weight, referring to the heaviness at rest as "dead weight," and to the accidental, additional weight at motion as "impetus".[21] In his *De Motu*, Galileo applied somewhat similar split using *gravita* (weight) and *momento* (effective weight) in considering objects on the inclined plane.[22] Following Archimedes, Galileo dismissed the concept of *levity* (lightness – the counter pair of heaviness – by showing that compressed air weighs more and not less despite the increase of levity.[23]

[15] Archimedes, *On Floating Bodies*. Chicago: Encyclopedia Britannica 1978, II, 540, 543. Mark Schiefsky, "Theory and Practice in Heron's *Mechanics*", in: Walter Laird/Sophie Roux (Eds.), *Mechanics and Natural Philosophy before the Scientific Revolution*. Dordrecht, Netherlands: Springer 2008, pp. 15–50.

[16] Ponder – a synonym of gravitas in Latin – possesses the same meaning of burden, load.

[17] Walter Laird/Sophie Roux (Eds.), *Mechanics and Natural Philosophy before the Scientific Revolution.* Dordrecht, Netherlands: Springer 2008, p. 5.

[18] Clagett, *op. cit.*

[19] *Ibid.*

[20] Ernest Moody & Marshall Clagett, (Eds.), *The Medieval Science of Weights.* Madison: University of Wisconsin Press 1960, pp. 94–95.

[21] Abraham Wolf, *A history of science, technology, and philosophy in the 16th and 17th centuries*. Gloucester, Mass: Smith 1968.

[22] Egidio Festa/Sophie Roux, "The Enigma of the Inclined Plane", in: Laird/Roux (Eds.), *op. cit.*, p. 218.

[23] Russo, *op. cit.*, p. 303; Galileo Galilei, *Dialogue Concerning the Two Chief World Systems*. Chicago: University of Chicago Press 1953.

The Copernican conceptual revolution removed "seeking the center of the universe" making Plato's earlier "matter seeking its kindred" more apt to the new vision and approaching to the Newtonian conceptual revolution. The idea of attractive force among objects first introduced by Kepler in the celestial context was fully elaborated within the Newtonian Law of the Universal Gravitation. The gravitational force created a new quantitative account of how matter keeps together: the structure of solar system as well as its dynamics. By applying his rule I of reasoning[24] – "No more causes… than… sufficient…" – Newton (1687) demonstrated that celestial gravitational attraction was *the cause* of falling in the terrestrial realm, always related to *weight*. Newton separated between inertia (inertial mass) and gravitation (gravitational mass) which surprised him for their numerical sameness discovered by him experimentally in pendulum oscillations. However, he equated the gravitational force (the cause) with weight (the effect).[25] In that, Newton broke with the very long historical tradition: weight ceased to be a property of a single object but was conceived in pairs of attracting forces between any two objects, making weight of a particular object varying with respect to different partners of interaction ("weight towards…").

Defining weight as the force of gravitation exerted on a body opened an opportunity for a simple determination of weight using Newton's second law. Weight (W) of a massive body (m) falling with acceleration (g) due to gravitational attraction (F_g) is:

$$W = F_g = mg \tag{41.1}$$

The gravitational acceleration g in Eq. (41.1) should be calculated according to Newton's law of universal gravitation:

$$F_g = \gamma \frac{m_1 m_2}{r^2} \tag{41.2}$$

The actual measurement of g in falling, however, will not provide the same due to the spinning Earth.[26] Thus, weighing normally does not provide the weight defined as gravitational force Eq. (41.2). Weighing results depend on the geographical location. An object at the equator weighs 0.3% less than at the poles and formula (41.1) produces:

$$W = F_g = mg^* \tag{41.3}$$

[24] Isaak Newton, *Mathematical Principles of Natural Philosophy*. Berkeley, CA: University of California Press 1999, p. 794.

[25] This logical weakness could be related to Newton's epistemology apt to the unique global observer at rest in the absolute space.

[26] Atony French, "Is g really the acceleration due to gravity?" in: *The Physics Teacher*, 21, 1983, pp. 528–529.

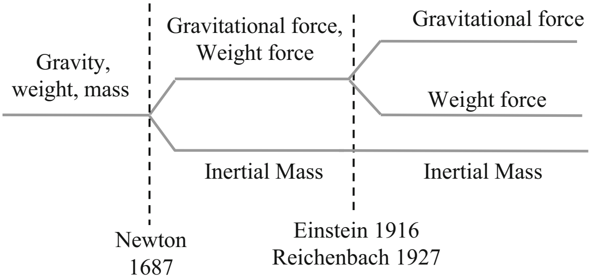

Fig. 41.1 Flowchart of conceptual changes in the cluster of weight-gravitation concepts. (Igal Galili, "Promotion of Content Cultural Knowledge through the use of the History and Philosophy of Science", in: *Science & Education* 21(9), 2012, pp. 1283–1316)

for the apparent not true weight. The effect was not a negligible and required calibration for trade and commerce.[27] The striking dissonance appears in the state of free fall where heaviness disappears regardless the gravitational weight.

The situation drastically changed and the problem of weight-weighing was resolved in the era of Einstein's Theory of Gravitation.[28] The new theory explained gravitation by postulating mutual influence of massive bodies and space-time. This approach *explained* the numerical equivalence of inertial and gravitational masses known to Newton only as an empirical fact. According to this equivalence, a local weighing cannot distinguish between gravitational and inertial forces; both may equally contribute to the result of weighing in an arbitrary frame of reference. Thus, an observer in a closed laboratory cannot know whether he/she measures gravitation or acceleration effect.

The new vision obliged to return to Euclid's idea of measuring heaviness. Consequently, a conceptual split with regard to weight was launched[29]: the gravitational force exerted on an object and attracting it to other objects divorced from its weight – the force the object exerts on its support. The two concepts were separated, and the new-old definition of weight as the result of weighing was readopted in physics. We may summarize this survey with a diagram showing two conceptual splits that took place in the course of history (Fig. 41.1).

The Epistemological Significance of Weight Definition

Philosophers related concept definitions to methodology of physics.[30] The status of a certain concept definition may vary in accordance with its role in a particular physics theory. Within the triadic structure of scientific theory (nucleus-body-

[27]Imagine disappearance of 20 kg of medical drug in the delivery of 1 ton sent from Berlin to Somali.

[28]Albert Einstein, "The Foundation of the General Theory of Relativity", in: *the Principle of Relativity*. New York: Dover 1923, pp. 111–164.

[29]Reichenbach, *op. cit.*, p. 223.

[30]Margenau, op. cit.; Philip Frank, *Philosophy of Science.* Englewood Cliffs, NJ: Prentice Hall, 1957; Carl Hempel, *Philosophy of Natural Science*. Englwood Cliffs, NJ: Prentice Hall 1966.

periphery),[31] definitions of basic concepts belong to the nucleus of the fundamental theories. Following conceptual changes, the older definitions may migrate to the *periphery* of a theory creating conceptual contrast with their counterparts in the nucleus and this way emphasizing the meaning of the new theory. The operational and gravitational definitions of weight illustrate this scenario.

The operational-gravitational pair of weight definitions corresponds to the dichotomy of empirical-theoretical nature and the opposition of empiricism and rationalism in physics knowledge. The modern science changed the meaning of empiricism from experiential to experimental. Yet, even if the role of experiment was upgraded to the back and force theory–experiment iteration in theory construction, once the "true" theory was invented (or perceived as discovered), the role of experiment (measurement) often looked to scientists as a mere "verification of the theoretically arrived results".[32]

Such was Newton's perspective. The *Principia* was presented as a deductive theory in the perspective of the unique super-observer, the one at rest in the absolute space. This account was expanded (already by others) to multiple observers but of a single type – inertial observers (inertial frames of reference). In his approach to concept definitions, Newton wrote[33]:

> An example is weight, which is greater in a larger body and less in a smaller body; and in one and the same body is greater near the earth and less out in the heavens. This quantity is the centripetency, or propensity toward a center, of the whole body, and (so to speak) its weight, and it may always be known from the force opposite and equal to it, which can prevent the body from falling.

Newton appealed to "measurement" but in no way it was a definition of a concept. Measurement illustrated theory.[34] Newton knew that weighing on the surface of the spinning Earth does not reliably inform about the gravitational force. To demonstrate the oblate shape of the spinning Earth, he drew on the changed "weights" of the shafts from the pole and equator to the center.[35] In that, he violated

[31] Michael Tseitlin/Galili Igal, "Teaching physics in looking for its self: from a physics-discipline to a physics-culture", in: *Science & Education*, 14, 3–5, 2005, pp. 235–261.

[32] Alexander Koyré, "An Experiment in Measurement", in: *Metaphysics and Measurement*. London: Charman/Hall 1966 pp. 90, 109.

[33] Newton, *op. cit.*, p. 407

[34] It is illustrative in this regard to quote Bunge who in his addressing operationalism actually repeated the perception of Newton. Bunge wrote (1967, p. 27): "Operationalism. The thesis that only terms referring to ("defined by", in the *incorrect* jargon) concrete operations are scientifically meaningful is the core of *operationalism* (Mach, 1883; Eddington, 1924; Heisenberg, 1927; Bridgman, 1927)." Bunge's correction of "defined" to "referring to" misrepresents operationalism, which *defines* concepts by specific measurement, not simply *refers* to it.

[35] Newton, *op. cit.*, pp. 826–827.

his own definition of weight but did not see it as a problem. Within his epistemology of the unique observer, there was no necessity for the operational definition[36]:

> Not only are good experiments based upon theory, but even the means to perform them are nothing else than theory incarnate,[37]

The conceptual change started with the critique by Mach of the concept definitions, which did not draw on the direct measurement. The first step was dismissing the Newtonian definition of inertial mass.[38] In parallel, Helmholtz[39] introduced his ideas regarding the *pragmatic truth* as determining the meaning of concepts in physics.[40] Frank[41] generalized this progress in physics methodology:

> Any great advance consists in creating some operational definitions that allow us to formulate the laws of physics more adequately and practically than did the older definitions.

Hempel[42] related the operational definition to the important standards of the scientific knowledge and its commitment to objectivity:

> One purpose of the operationist insistence on unequivocal operational criteria of application for all scientific terms is to insure objective testability for all scientific statements

Introduced within the classical physics, the new epistemology fully flourished in the scientific revolution of the twentieth century. Operational definitions entered to the nuclei of modern physics world – relativity and quantum theories. It is common to recognize the contribution of Bridgman to the new epistemological view regarding physical concepts[43]:

> In general, we mean by any concept nothing more than a set of operations; the concept is synonymous with the corresponding set of operations.

Yet, another important epistemological change took place in modern physics. Einstein introduced the modern commitment to draw on the *local* measurements in a *closed laboratory*. In considering weighing, Einstein and Infeld[44] addressed

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[36]Newton contrasted "absolute and relative, true and apparent, mathematical and common" concepts (*op. cit.*, p. 408) clearly providing unequal status in each pair, leaving to measurement the role of informing (possibly inexact and approximate) about the true reality.

[37]Koyré, *op. cit.*, p. 113

[38]Mach, *op. cit.*, pp. 265–266

[39]In considering the meaning of theoretical concerts in physics, Helmholtz wrote (Hermann Helmholtz, *Treatise on Physiological Optics*. New York: Dover 1867/1962, p. 19): "In my opinion . . . there can be no possible sense in speaking of any other truth of our ideas except of a practical truth. Our ideas of things cannot be anything than symbols, natural signs for things which we learn how to use on order to regulate our movements and actions."

[40]Jean Leroux, "Helmholtz and Modern Empiricism", in: Mathieu Marion/Robert Cohen (Eds.), *Logic, Mathematics, Physics and History of Science*. Dordrecht: Kluwer 1995, pp. 287–298.

[41]Frank, *op. cit.*, p. 217.

[42]Hempel, *op. cit.* p. 90.

[43]Bridgman, *op. cit.,* p. 5.

[44]Albert Einstein & Leopold Infeld, *The Evolution of Physics*. Cambridge, UK: University Press 1938, pp. 235–226.

the corrections to weighing explaining why it missed the gravitational weight. The principle of equivalence allowed more than one cause of weighing results and upgraded the weighing procedure to the constitutional rather than illustrative, never understood that way before. As Frank[45] generalized:

> Every change in our knowledge of natural laws must produce a change in the operational definition of which we are making use.

The gravitational definition of weight became obsolete and moved to the periphery of mechanics.

Yet, nothing should be oversimplified. Though the operational definitions became recognized in all further development of physics, the pure operational approach was criticized for oversimplification. Theoretical knowledge cannot be dispensed with.[46] Frank[47] wrote:

> We can easily see that, practically, operational definitions cannot be constructed in a domain of experience for which we don't know physical laws.

Physics epistemology, thus, arrived at the requirement of a compound definition for each physics concept – a symbiosis of theory and experiment. A pair of theoretical (nominal) and operational (epistemic) definitions complementing each other provides a comprehensive account of a physical concept[48] and answers the reservations against operationalism without losing its essential importance.

Implication of the Worldview

Mach changed the definitions of mass and force but refrained from discussing Newtonian weight. Yet, his reduction the status of force to a mere sign of the product m·a clearly showed his repelling from the idea of action at a distance. This position drastically changed his *Mechanics* making it different from other textbooks at his time and nowadays.[49] Mach mentioned the scholars who tried to account for gravity prior to Newton and described in length the approach of Descartes and Huygens though none of them succeeded beyond speculative account. Yet, in one important aspect, Mach fully adopted Newton's vision – the concept of centrifugal force, which contrasted the one introduced by Huygens. To appreciate this fact we juxtapose the two approaches.

[45] Frank, op. cit., p. 316.

[46] Frank, *ibid.*; Hempel, *op. cit.*; Bunge, 1967, *op. cit.*

[47] Frank, *ibid.*, p. 313.

[48] Margenau, *op. cit.*

[49] Indeed, it is weird for the reader not to see in classical mechanics the Universal Law of Gravitation and the formula $F_{grav} = G\frac{M_1 M_2}{R_{1,2}^2}$. In length, Mach presented Kepler's empirical kinematic laws, mentioned premature attempts to address gravity and Newton's hesitations expressed in private communication regarding the cause of gravitational interaction.

In 1659, in his seminal paper *De vi Centrifuga*, Huygens,[50] for the first time in theoretical physics, provided dynamical account of reality in view of an observer (O_1) in a rotating frame of reference (Fig. 41.2a). He wrote:

> Let us imagine some very large wheel, such that it easily carries along with it a man standing on it near the circumference but so attached that he cannot be thrown off; let him hold in his hand a string with a lead shot attached to the other end of the string. The string will therefore be stretched by the force of revolution in the same way and with the same strength, whether it is so held or the same string is extended to the center at A and attached there. But the reason why it is stretched may now be more clearly perceived.

Within this account, Huygens introduced force F_{cf} acting *on the rotating ball* m in the radial outward direction. Seemingly, in response to this account, Newton addresses a ball moving along the circular curb (Fig. 41.2b). In his account, he also introduced centrifugal force – the radial outward force[51]:

> And if a body, moved with a given velocity along the sides of the polygon, is reflected from the circle at the several angular points, the force, with which at every reflection it strikes the circle will be as its velocity: and therefore the sum of the forces, in a given time, will be as that velocity and the number of reflections jointly; … *This is the centrifugal force, with which the body urges the circle*; and the opposite force, with which the circle continually repels the body towards the center, is equal to this *centrifugal force*. (emphasis added – I.G.)

Newton "corrected" Huygens: the centrifugal force is applied by the rotating ball *on the curb* and *not on the ball.* In event, Newton called by the same name a different force, the interactive counterpart of the centripetal force. Here, Newton was consistent with his theoretical framework in which forces result interaction

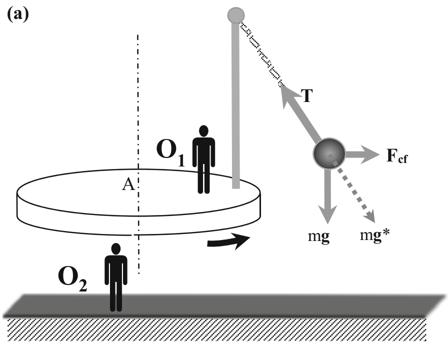

Fig. 41.2 (**a**) Huygens's account. A suspended ball on a rotating disc as conceived by observer O_1 on the disc. O_1 needs outward radial force F_{cf} exerted on the ball. (**b**) Newton's account. A ball is moving along the circular curb exerting on it centripetal force F_{cp}. The ball reacts on the curb with outward radial force F_{cf}. This account corresponds to the external observer O_2 at rest in (**a**)

[50]Christian Huygens, "On centrifugal force. De vi Centrifuga", in: *Oeuvres Complètes,* 1703, XVI, pp. 255–301.

[51]Newton, *op. cit.*, pp. 452–453.

and come in action-reaction pairs. This account is valid for inertial observers. Huygens considered a non-inertial rotational observer (the concept unknown to him). Therefore, his centrifugal force, though necessary, was not interactive; one cannot point to any counterpart of F_{cf}. Newtonian theory was stated for inertial observers, actually for the single observer: the one at rest in the absolute space that we all are immersed in. It appeared to be valid for all inertial observers but not for others.

Furthermore, by considering the increasing deviation of the rotating ball from the tangential potential movement (in case the suspending thread is cut off) Huygens succeeded to demonstrate that the action of the centrifugal force is identical to the force of gravitation, causing the same acceleration. He stated that both effects, that of gravitation and that of the centrifugal force, act on the ball in the same way causing the tension in the suspending thread, the heaviness of the rotating ball. In fact, Huygens arrived at the principle of equivalence, which we relate to Einstein and his theory of general relativity. Huygens did not realize the meaning of his finding and was far from considering inertial and non-inertial observers. The concept of frames of reference was not there. Only Einstein made the observer O_1 (Fig. 41.2a) legitimate and that immediately implied the possible contribution of both gravitational and inertial forces to the measured heaviness of the rotating ball causing mg* – the new weight of the ball (equal to force T in Fig. 41.2a).

Mach remained with Newton in sharing one global account for reality by the unique observer at rest. Even in describing the model suggested by Huygens to explain gravity by vortexes of hypothetical liquid media Mach wrote in complete coherence with Newton and not with Huygens[52]:

> The wooden balls receive a centripetal impulsion, comparable to buoyancy, which is equal and opposite to *the centrifugal force acting on the displaced liquid*. (emphasis added – I.G.)

It is clear, then, that this Mach's perspective helped him to miss the effect mentioned by Huygens – the equivalence of gravitational and centrifugal force. Within the perspective excluding centrifugal force as acting *on* the rotating body; it was easier to remain with Newtonian definition of weight, which equated weight/heaviness of the body solely with the gravitational force. It was considering the environment in a closed compartment of accelerating elevator – non-inertial frame of reference – together with the principle of equivalence of Einstein that allowed Reichenbach[53] arrive at recognizing the necessity of splitting between the weight as measured in weighing and gravitational force. It looks even stranger if one recollects the great closeness of the operationally defined weight with the sense perception of heaviness, which Mach could easily adopt given his sensitivity to the direct perception and measurement.

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[52] Mach, *op. cit.*, p. 199.

[53] Reichenbach, *op. cit.*, pp. 222–223.

Implication to Education

We may first mention the current split in physics education as portrayed in physics textbooks (in Europe it divides east from west). First, the gravitational definition of weight[54]:

> The attractive force exerted by the Earth on an object is called the gravitational force $\mathbf{F}_g$. This force is directed towards the center of the Earth and its magnitude is called weight of the object. (G1)

This trend culminates in following[55]:

> The weight of a body is the total gravitational force exerted on the body by all other bodies in the universe. (G2)

The latter definition – legitimate in rationalistic philosophy of science – becomes odious in the empiricist perspective since G2 weight is impossible to calculate and measure, in addition to its lacking of possible use in any physics problem (what a miss for Mach's *Mechanics*).

As to the operational definition, the following illustrates it[56]:

> The contact force w that an object exerts on whatever is supporting it is called weight (G3)

> [We] define weight of an object as the reading of a calibrated spring scale on which the object is stationary. That is, weight is a measurement, the result of weighing an object[57] (G4)

Though the authors slightly vary in wording, the conceptual dichotomy is apparent. The physical ideas behind the definitions are shown in Fig. 41.3.

Empirical Research

The great epistemological change regarding weight definition was not fully recognized in physics education. Teaching weight was investigated in several perspectives.[58] Dealing with personal epistemology demonstrated that providing concepts

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[54] John Jewett/Raymon Serwey, *op. cit.*, p. 106.

[55] Hugh Young/Roger Freedman, *University Physics*. New York: Pearson 2012, p. 406. Though we quote here from the 2012 edition, this definition of weight constantly appeared in the popular textbooks of college and university physics textbooks by Sears and Zemansky since the 50s and continues to appear in all later editions.

[56] Jerry Marion/William Hornyack, *Physics for Science & Engineering*. New York: Saunders 1982, p. 129.

[57] Randall Knight, *Physics for scientists and engineers*. Reading, MA: Pearson 2013, p. 146.

[58] Igal Galili, "Weight versus gravitational force: historical and educational perspectives", in: *International Journal of Science Education* 23, 10, 2001, pp. 1073–1093; Igal Galili/Yaron Lehavi, "The importance of weightlessness and tides in teaching gravitation", in: *American Journal of Physics*, 71, 11, 2003, pp. 1127–1135.

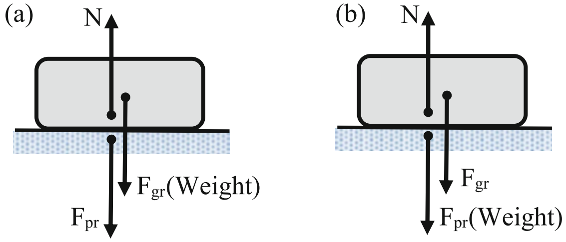

Fig. 41.3 Two dichotomy of weight definition. (**a**) Gravitational definition. The measured force (F_{pr}) is not necessary equal or determined by the gravitational force F_{gr}. (**b**) Operational definition. The measured force (F_{pr}) is the weight of the body regardless gravitational force F_{gr}

with definitions required high-level cognitive skills, analysis, synthesis and evaluation.[59]

We found that the advanced instruction of gravitational weight splits weight concept to "true weight" (the gravitational force) and the "apparent weight" (the results of weighing). However, this attempt to save the gravitational definition has low pedagogical effectiveness and students develop strong alternative accounts – misconceptions.[60] Connecting apparent weight to weighing transfers the open problem of operational definition to the "true weight". The strong psychological commitment of students to consider weight as heaviness directly perceived in regular experience apparently causes this conception to be commonplace of people's pre-instruction knowledge of weight.[61]

Karpus and Arons[62] emphasized the greater pedagogical/psychological appeal of the operational definitions in addition to its epistemological necessity. This agenda and specific critique of scholars[63] motivated us to investigate the transition of teaching to the operational definition of weight, splitting the gravitational force (as the cause of mutual attraction between bodies) from weight (as the heaviness

[59] Igal Galili/Yaron Lehavi, "Definitions of physical concepts: a study of physics teachers' knowledge and views", in: *International Journal of Science Education*, 28, 5, 2006, pp. 521–541.

[60] Igal Galili/Dov Kaplan, "Students' operation with the concept of weight", in: *Science Education* 80, 4, 1996, pp. 457–487; Albert Barlett, "Apparent weight: A concept that is confusing and unnecessary", in: *The Physics Teacher* 48, 8, 2010, p. 522.

[61] Igal Galili/Varda Bar, "Children's operational knowledge about weight", in: *International Journal of Science Education* 19, 3, 1997, pp. 317–340.

[62] Robert Karplus, *Introductory physics: A model approach*. New York: Benjamin 1969/2003; Aaron Arons, *A Guide to Introductory Physics Teaching*. New York: Willey 1990.

[63] Allen King, "Weight and Weightlessness", in: *American Journal of Physics*, 30, 5, 1962, p. 387; Keith Taylor, "Weight and centrifugal force" in: *Physics Education*, 9, 1974, pp. 357–360; Mario Iona, "Weight – An official definition", in: *The Physics Teacher* 37, 4, 1999, p. 238.

in supporting objects for an observer in a closed laboratory). In the empirical studies investigating the new pedagogy, it was shown its appealing and effective pedagogical advantage providing remedy to the misconceptions regarding gravity and significantly improving the pertinent conceptual knowledge of students[64] (Stein/Galili 2014; Stein et al. 2015; Galili et al. 2017).

We may summarize, therefore, in stating that the current curricular goal is not preserving the gravitational definition of weight (as never matching weighing results), but developing the new curriculum which would introduce contemporary students to the adequate scientific epistemology and familiarize them with the spirit introduced by Mach regarding physics concepts.

[64]Hana Stein/Igal Galili, "The Impact of Operational Definition of Weight Concept on Students Understanding of Physical Situations", in: *International Journal of Research in Science and Mathematical Education* 13, 6, 2014, pp. 1487–1515; Hana Stein/Igal Galili/Yaron Schur, "Teaching New Conceptual Framework of Weight and Gravitation in the Middle School", in: *Journal of Research in Science Teaching* 52, 9, 2015, pp. 1234–1268; Galili, I., Bar, V. & Brosh, Y. (2017). Teaching Weight-Gravity and Gravitation in Middle School−Testing a New Instructional Approach. *Science & Education*, 26(3), 977–1010.

Chapter 42
Mach's and Salcher's Photographs Inspire a Multimedia Project

Tobias Macke, Johannes Puschner, Wolfgang Schöner, and Clemens Ulrich

Abstract A series of Schlieren photographs of supersonic bullets, captured with their pressure waves, has achieved almost iconic status. Taken by Mach and Salcher in the 1880s, those original research documents were donated to the first Austrian school for photography. Now a vocational high school for graphic design, print, multimedia and photography, the "Graphische" still is an important institution and very popular with young creative minds. In order to honor Ernst Mach on occasion of the centenary celebrations, a project was set up with two multimedia students and two science teachers at this school, in order to re-enact the Schlieren photography with mordern means. In a first step, a Schlieren apparatus was successfully set up, allowing students to experiment with hot air from burning candles or hair dryers, and gases heavier than air – all made visible by that particular method of illumination. With the generous help of the Austrian Armed Forces, Schlieren images of supersonic bullets could eventually be captured. In order to fully appreciate the ingenuity of Mach and Salcher, the historical background, as well as the evolution of ideas and experimental methods, are considered.

Motivation

In the context of the Mach Centenary celebrations, the "Höhere Graphische Bundes-Lehr- und Versuchsanstalt" was reminded of its ownership of some of the most iconic scientific photographs: Pictures taken by Mach and Salcher in the 1880s depicting not only supersonic bullets, but their compression waves as well. The link between the vocational high school for photography, multimedia, graphics and print media on the one hand, and Mach on the other, was Josef Maria Eder, founding spirit of the school. As editor of the "Jahrbuch für Photographie und Reproduktionstechnik" (Eder 1888, 1891), Eder had kept the original photographs,

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F. Stadler (ed.), *Ernst Mach – Life, Work, Influence*, Vienna Circle Institute Yearbook 22, https://doi.org/10.1007/978-3-030-04378-0_42

reproductions of which appeared in the "Jahrbuch", as well as numerous articles by Ernst Mach who cared deeply about the education of the young in a free scientific spirit.

Thus arose the idea for a school project with the aim of setting up *Schlieren* experiments and creating multimedia content of them. Students of the multimedia department, coached by science teachers, were eager to see how far they could follow the footsteps of Mach and Salcher. Prior to re-enacting their historical experiments, it was deemed worthwhile to examine the scientific and technological interrelations.

Mach's Conceptual and Experimental Background

Different scientific and technological developments led to Ernst Mach's and Peter Salcher's celebrated experiments with supersonic bullets.

First there was Mach's research in the field of propagation of sound waves dating back to the time when he was a student of Christian Doppler.

Secondly, Mach participated in the rapid development of photography during the second half of the nineteenth century, regarding it as an important tool for the extension of human senses in order to arrive at new scientific findings (Mach 1888a, b). Thirdly, Mach took keen interest in developments in the field of weaponry, which led to faster bullets and new methods for measuring their speed.

Ernst Mach's Scientific Interest in Wave Propagation

In 1842 Christian Doppler postulated, that the observed frequency of a wave depends on the relative speed between the wave source and the observer (Doppler 1847). Later this principle was named the Doppler Effect. Nowadays, one can hear the changes in the pitch of the sound of passing cars at any crossroad. To confirm the Doppler Effect Christoph Buys-Ballot placed a trumpet player on a moving steam railroad train in 1845. As it passed a group of musicians, their trained ears could prove that there is a sudden jump in pitch of the sound of the trumpet.

Fifteen years later, at the age of only 22 years, Ernst Mach was able to confirm the Doppler Effect under reproducible conditions in the laboratory. Regarding his motivation for this experimental work he wrote, *"Not everyone can use a railroad for experiments". [„Eisenbahnen stehen als Experimentiermittel nicht jedem zu Gebote".]* (Mach 1874)

In light of the Doppler Effect the following question arose: What happens if the source of the soundwave travels faster than the speed of sound itself? As Mach himself pointed out in a talk in 1897 (Mach 1903), the bow wave of a ship and the head wave of a projectile – now known as Mach's cone – are both based on the same principle, enunciated by Christiaan Huygens already in the seventeenth century. Christian Doppler had published drawings of the wave pattern of a wave source travelling faster than the wave (Doppler 1847).

The Development of Photography

Ernst Mach took a keen interest in the fast development of photographic techniques, like dry photographic plates, which were easier to handle. Above all, more sensitive photographic emulsions were developed, allowing for shorter exposure times – a precondition for high-speed photography. An example for this advancement is Eadweard Muybridge’s pioneering work capturing motion using multiple cameras. In 1864 Muybridge famously proved, that during the motion of a galloping horse there is a phase where all four feet are off the ground.

In the same year, August Toepler introduced a special technique of illumination for the detection of inhomogeneities in optical glasses, which is comparable to the dark field illumination in microscopy. Toepler used this so-called *Schlieren* imaging also in order to visualize shock waves originating from spark discharges.

As Mach’s articles in the Jahrbuch für Photographie und Reproduktionstechnik (Eder 1888) show, he was fully aware of the importance of photography as a tool for scientific research.

Developments in the Field of Weaponry

During the wars in the second half of the nineteenth century (Crimean war in 1864, Prussian-Austrian war in1866, German-French war in 1870/71) new types of gunshot wounds, like exploded bones, burst organs, and small entry wounds with large exit lesions, were found. Both Germans and French accused one another of using explosive bullets. Soon, the relation of the new wound pattern and the higher velocities of the bullets became evident.

At a conference in Paris in 1881, Mach attended a talk given by Louis Melsens, a Belgian expert for ballistics, who assumed, that the additional explosive impact might be caused by the compressed air carried in front of the projectile. The ensuing scientific discussions aroused Mach’s interest in the development of new techniques to measure the velocities and shockwaves of bullets (Mach 1903).

Mach’s Experiments in Prague

In 1884 at the University of Prague, Mach and his student Josef Wentzel, developed a technique of combining high-speed (i.e. extremely short exposure) and *Schlieren* photography. Their aim was to obtain sharp images of both, the bullets in flight, as well as the air compressed by them. These early experiments were not successful due to the subsonic speed of the bullets from the pistol used. Nevertheless, Mach and Wentzel obtained sharp pictures of projectiles, as well as clear images of shock waves in the air, which were produced by spark discharges. They reported their results to the k&k-Academy of Sciences in Vienna in June 1884 (Mach and Wentzel 1884).

Mach's Cooperation with Peter Salcher

In order to apply his setup to supersonic bullets, Mach asked Peter Salcher, who worked at the Austrian Naval Academy in Fiume (today Rijeka, Croatia), for help. Salcher was a physicist and expert in both ballistics and photography. Since he also knew about *Schlieren* imaging from his days as a student of Toepler in Graz, he was the ideal collaborator for Mach. With the equipment of the Naval Academy at his disposal, Salcher successfully carried out the experiments according to Mach's suggestions. His photographs capturing the wave pattern surrounding supersonic projectiles have now achieved iconic status. In a letter to Mach Salcher wrote in 1886, *"The whole process seems to be very similar to waves caused by a moving ship". ["Der ganze Vorgang scheint viel Ähnlichkeit mit der Wellenbewegung zu haben, die ein fahrendes Schiff hervorruft".]* (Letter of Peter Salcher to Ernst Mach, Dez. 10th, 1886) (Fig. 42.1).

In a talk he gave November 10th, 1897, Mach argued that you might as well think that the photograph depicts not a bullet but a ship as seen from above, with the bow wave in front, and the swirls in the wake trailing behind:

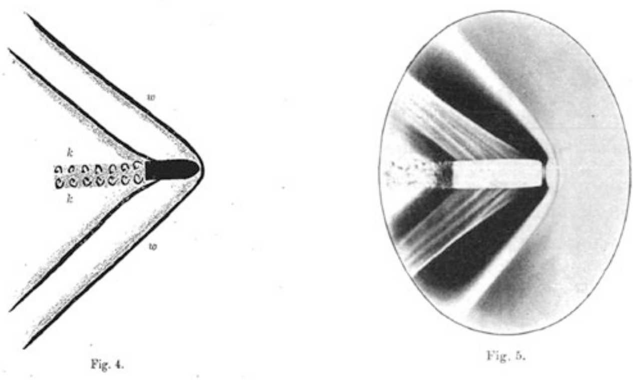

Fig. 42.1 Scheme and photograph of the wave pattern around a flying projectile with the original explanation by Mach

[Betrachten wir nun ein Projektilbild zunächst in der schematischen Fig. 4 und nachher in der fotografischen Aufnahme, Fig. 5, welche ich nach einem Originalnegativ auf den Schirm projiziere. Das letztere Bild entspricht einem Schusse mit dem österreichischen Mannlicher-Gewehr.

Wenn ich nicht sagen würde, was das Bild darstellt, so könnten Sie wohl glauben, dass es das Bild ist eines rasch auf dem Wasser dahinfahrenden Bootes, aus der Vogelperspektive aufgenommen.

Vorn sehen Sie die Bugwelle ww, hinter dem Körper eine Erscheinung kk, welche dem Kielwasser mit seinen Wirbeln sehr ähnlich sieht. In der Tat ist der helle, hyperbelähnliche Bogen am Scheitel des Projektils eine Luftverdichtungswelle, die ganz analog ist der Bugwelle eines Schiffes, nur dass erstere keine Oberflächenwelle ist.]. (Mach 1903). Results and pictures from Mach were also presented in (Eder 1891; Mach and Salcher 1887; Mach 1888c)

Experimental Setup for *Schlieren* Photography

Testing a *Schlieren* setup in the holography lab marked the first step in following Mach's footprints at the Graphische. All components could be conveniently mounted on a large, damped optical table, with a white high-power LED serving as a point light source. While Mach and Salcher used lenses to focus the light, a spherical mirror of 1000 mm focal length and 200 mm diameter was used to reflect the light, back onto the *Schlieren* edge.

The light of the point source, positioned at a distance of twice the focal length of the mirror, was focused onto a single point on the cutting edge of a razor blade. A photo camera was adjusted with the point on the edge exactly in focus. The *Schlieren* principle worked as follows: The light of the point source was completely blocked by the *Schlieren* edge as long as it was propagating in homogenous air. As soon as currents of hot air, e.g., from a hair dryer (see Fig. 42.2), or from a candle flame,

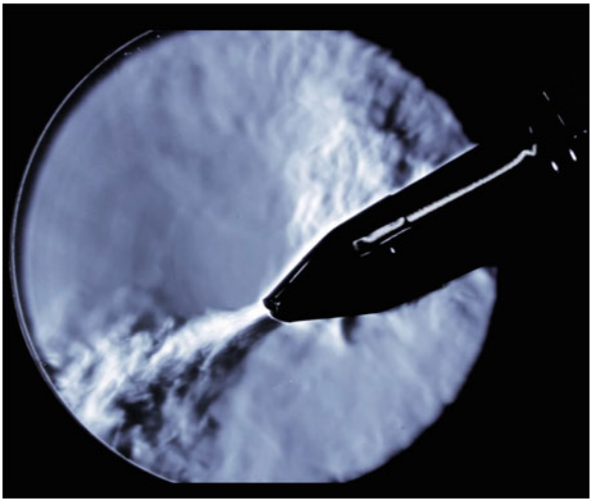

Fig. 42.2 Hot air streaming out of a hair dryer

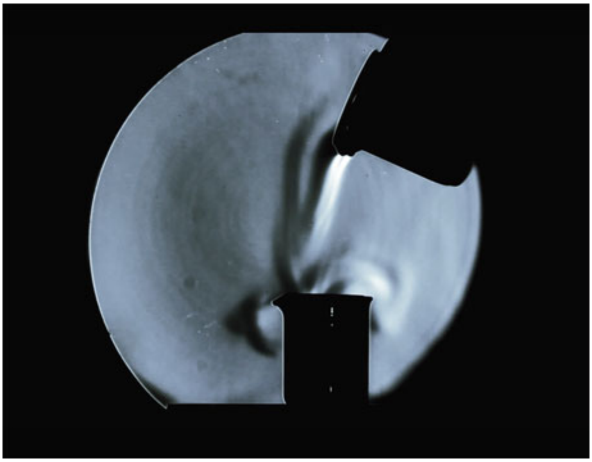

Fig. 42.3 Pouring of ether gas out of a glass

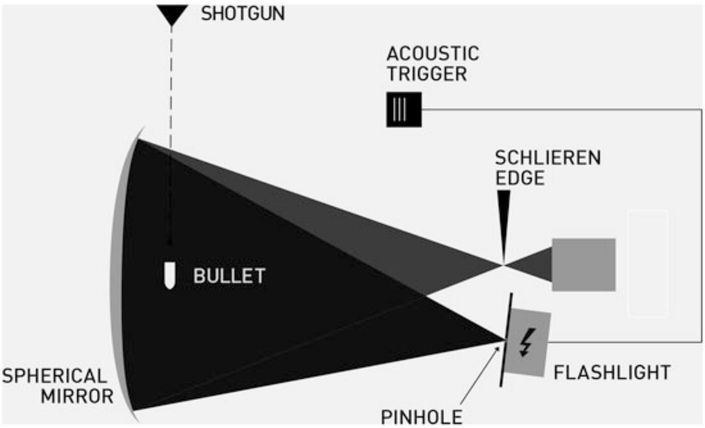

Fig. 42.4 Schema of the *Schlieren* setup. In the lab, instead of a photoflash, a white power LED was used

perturbed the air in front of the mirror, the light was diffracted and passed the edge of the razor blade. This led to contrasts in the shape of streaks or smears in the image ("Schlieren" in German). In a different experiment, the index of refraction was altered when ether, a transparent gas heavier than air, descended from a tilted beaker: the diffracted light between point source created *Schlieren* images evoking the pouring of a liquid (see Fig. 42.3). The *Schlieren setup is shown in* Fig. 42.4.

Experiments in Cooperation with the Austrian Armed Forces (Amt für Rüstung und Wehrtechnik)

After successful *Schlieren* experiments in the lab, the second phase of the Multimedia project started with the more ambitious aim of re-enacting Mach's and Salcher's experiments, albeit with the support of modern technology.

Since a camera with extremely high shutter speed would have been beyond the financial possibilities of the school, the exposure time was determined by the short duration of illumination. A photoflash, blocked off entirely with the exception of a pinhole, served as a switchable point light source. This is comparable to the historical setup, which used spark discharges. The main difference lies in triggering the illumination. In Mach's and Salcher's setup, the bullet itself closed the special electrical circuit ("*Verzögerungsschaltung*") and thereby the illuminating spark was released. In contrast, we used an acoustical trigger for the flashlight.

Tests using an air pistol to pop air balloons in the basement of the school demonstrated the feasibility of acoustical triggering of the photo camera, at least for low bullet speeds.

For mounting our *Schlieren* setup in the weapon-testing facility, an optical bench was improvised. The experts of the Austrian Armed forces weapons test facility were helpful and skilled, and supported the mounting and adjusting of the *Schlieren* arrangement. First, the mirror was adjusted with the help of a continuous LED light, which was then exchanged for the flashlight in the final alignment of the components. The most difficult task was to illuminate the bullet during the short period of time when it was passing directly in front of the mirror. To this end, the trigger microphone's position was changed until the first traces of bullets were captured by the camera. Fine-tuning was achieved by the shooter ever so slightly adjusting the gun, countless times, forward or back. The schema of the used setup is shown in Fig. 42.4 and the equipment is listed in Table 42.1.

Table 42.1 Equipment Used for *Schlieren* Photographs and Videos

Spherical mirror:	200 mm diameter
	Focal length: 1000 mm
	(Borrowed from our holography laboratory)
Light sources:	Nikon speedlight SB-28 for short time exposure of bullets
	White high power LED for continuous illumination
Pin-hole diaphragm:	1.5 mm diameter hole drilled in a spare sheet of aluminum
Schlieren edge (diaphragm):	Cutting edge of a razor blade
Photo camera:	Canon Eos 70D with 200 mm Canon Lens
Acoustical trigger:	Sabreswitch Triggersmart for photo cameras
	MCT-1 Motion Capture System, optical and acoustical trigger minimal trigger delay: 1 to 100 milliseconds (borrowed from one of our photo studios)

Render Visible the Invisible

Eventually, some good pictures with clear head-waves and swirls in the wake were obtained with bullets from a 9 mm Glock pistol, which are only slightly faster than sound (Fig. 42.5). Capturing the much faster projectiles of an STG-77 assault rifle proved even more difficult.

Nevertheless, a bullet and its shockwaves were eventually captured on a photograph after a long afternoon at the arms testing facility (Fig. 42.6). The image is blurred because the faster bullet travels a considerable distance during the time of illumination by the photo flash.

Mach's and Salcher's images of very fast bullets are sharp because of the extremely short duration of the discharge spark they were using. Also, there are no double images in the historical photos since lenses were used instead of mirrors.

Measuring the angles of the head waves on the pictures, the respective Mach numbers were calculated, i.e., the ratios of the projectile velocities to the velocity of sound. Using a value of 345 meters per second as the speed of sound (22 °C air temperature), the speed values of about 380 meters per second for the Glock pistol

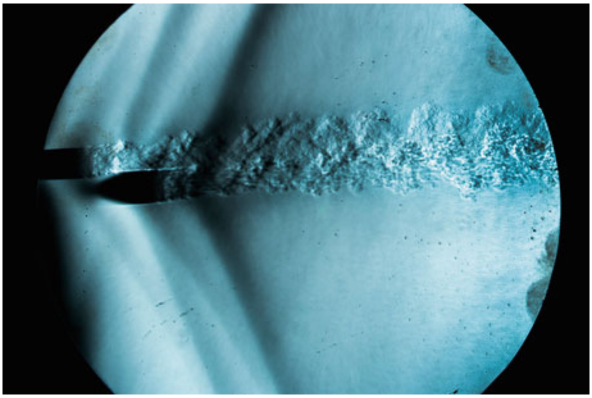

Fig. 42.5 Bullet from a 9 mm Glock pistol. The compression waves and the swirls in the trail are clearly visible

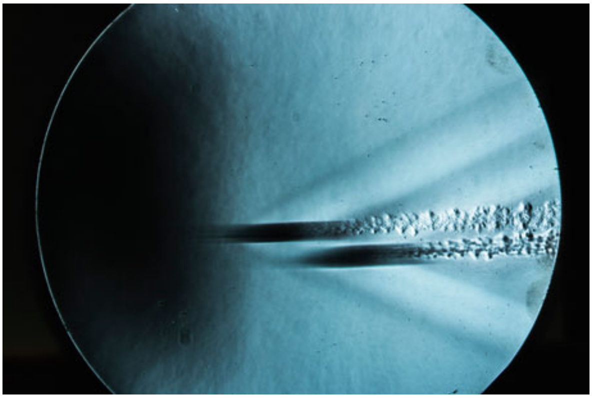

Fig. 42.6 Projectile from a STG-77 assault rifle. Due to the higher velocity, the image of the bullet is blurred

bullet, and about 870 meters per second for the assault rifle bullet, closely match the known values for those projectiles.

Mach anticipated the question of the practical relevance of observing projectiles in flight and stated: *"Certainly, you cannot make war with photographed bullets!"*

["Sie können nun sagen: Es ist ja recht schön und interessant, ein Projectil im Flug zu beobachten, was kann man aber praktisch damit anfangen? Darauf antworte ich: Kriegführen kann man mit photographierten Projectilen allerdings nicht!"] (Mach 1903). For this high school project, Mach's and Salcher's exemplary work in experimental science proved to be of great pedagogical merit, since it posed a fascinating challenge to follow them in their quest: to render visible the invisible.

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Chapter 43
Ernst Mach's Didactics in the Context of Austrian History of Education

Josef Pircher

Abstract On the didactical work of Mach focused already Adolf Hohenester and Michael Matthews. Recently, there are publications to find that go beyond this two established accounts. Hayo Siemsen puts Mach in a broader line of tradition, bringing together rather different names and times. Compared to Mach's entire work, the extent of his didactical contributions are small and the attribution to a didactical tradition seems doubtful. The paper addresses this assumed contradiction between oeuvre and impact as well as the influence on Mach as it is described by Siemsen. Avoiding presentism, it focuses on the texts and the respective historical context, i.e. how Mach wrote and for what purpose he wrote.

This historical account leads to the result, that Mach didn't create an own didactical system or that you can attribute to him a specific tradition, neither before nor after him. Out of his genuine scientific perspective, Mach's didactical work reflects and comments the educational changes of the time in Austria.

One peculiar thing about the reception of Mach's work today is, that people refer to him not only as a physician, but also as a philosopher, biologist, psychologist and educationalist.[1] There is good reason to do so, but it's irritating, that Mach throughout his entire life denies explicitly to be something else than a physician. Nevertheless his claims, his contributions to the other fields represent the nineteenth century state of the art, giving us nowadays the impression of an expert. The qualitative level of his contributions outside the field of physics, make him also highly influential in the twentieth century. In how far this can be stated for his didactical work is up to the following discussion.

[1] Rudolf Haller/Friedrich Stadler (Eds.), *Ernst Mach. Werk und Wirkung*, Wien: Hölder-Pichler-Tempsky 1988.

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This paper, following Otto Blüh,[2] deals with the didactical work of Mach, where the discrepancy between oeuvre and impact is more obvious respecting the small amount of publications in which he dealt with didactical questions. It's not to neglect his schoolbooks, the popular-scientific writings or the articles in the "Zeitschrift für den Physikalischen und Chemischen Unterricht" (ZfPCU) etc., but by numbers alone the dedication to the topic is confined. After recapturing the content of Mach's didactical work, this paper discusses the main historical research regarding the role of Mach as educationalist as pointed out by Thiele, Hohenester, Matthews and Siemsen. In a third step a new account is given, considering a specific historical context, the one of Austrian history of education.

Didactical Content

Compared to Mach's entire work, the extent of his didactical contributions is rather small. Stated this bibliographical fact again, the first question to deal with is the one about the content of this writings. Before going into detail, the distinction of the terms "education" and "didactics" is a necessary and crucial one.

Talking about "education" in the nineteenth century means in German speaking Europe talking about "Pädagogik" (pedagogy).[3] The term, used as a paradigmatic expression in a Kuhnian sense, refers to the evolving science of education on an academic level. It's a process throughout the nineteenth century, that was close to the developments of philosophy and, even more, psychology. The question, if education can be scientifically dealt with was at stake during the second half of the nineteenth century. What evolves out of this, from the beginning of the twentieth century on, is "Erziehungswissenschaft", confusingly also labelled in the English speaking world as "education". Brezinka puts this development for the German speaking part of the Habsburg monarchy to light in his 4 Volumes of "Pädagogik in Österreich".[4]

Although this process of the emerging discipline of education matches chronologically with the lifespan of Mach and considering that the field of philosophy and psychology was anything but alien to him, he is not involved in this general debates in the field of education at all. Though he could, given the following two facts: he was close friend to two main figures in education, Alois Höfler and Wilhelm Jerusalem. For the purposes in this paper the connection to Höfler is more relevant. With Höfler he founded the ZfCPU, arguably the first periodical devoted

[2] Otto Blüh, "Ernst Mach – His life as a teacher and thinker", in: Robert S. Cohen/Raymond J. Seeger (Eds.), *Ernst Mach. Physicist and philosopher*, Dordrecht: D. Reidel Publishing Company 1970.

[3] Heinz Elmar Tenorth, "Erziehungswissenschaft", in: Dietrich Benner/Jürgen Oelkers (Eds.), *Historisches Wörterbuch der Pädagogik*, Beltz: Weinheim 2004, p. 341–382.

[4] Wolfgang Brezinka, *Pädagogik in Österreich: die Geschichte des Faches an den Universitäten vom 18. bis zum 21. Jahrhundert*, Wien: Verlag der Österreichischen Akademie der Wissenschaften 2000, 2004, 2008, 2014.

to didactical questions. But beside this personal relationships, a second aspect gains importance. Mach was part of the faculty of philosophy, where the schism in Psychology and Pedagogy actually happened. He witnessed this development first hand. It's unplausibel Mach wasn't aware of the field of pedagogy, it makes rather clear he didn't want to enter that field. Blüh underlines this too, stating that "Mach was not an educator per se and he did not write at length on educational problems."[5]

Thiele attributed to Mach in the title of one of his article the label "Pädagoge".[6] As tried to explain above, a questionable terminology. Alois Höfler e.g. is indeed a "Pädagoge", holding the chair of pedagogy in Prag, later on in Vienna. Others would be Otto Willmann, Theodor Vogt or the already mentioned Wilhelm Jerusalem. Mach doesn't refer to them in his didactical articles, because he didn't deal with the same questions in his writings as they did.

Mach's work points on another aspect, it's a didactical contribution he makes. "Didactics" is understood until today in Europe, and so in this analysis, as a discipline of education, next to others. Crucial is thereby the focus on teachers, dealing with problems they are faced with. "The central questions of didactics are: 'What content is to be taught?', 'How is this content going to be taught?', and 'Why teach this content and why with these methods?'"[7] Exactly this questions are faced in all of the publications by Mach considered in relation to didactics, solely regarding the school-subject physics. In trying to give them an order, the difference between his texts arise from the differing public he speaks to: to pupils and students in his textbooks, to teachers in the articles in the ZfCPU and his part-authorship of a curriculum, and to adults in his Popular Scientific Lectures (PSL).

To the first and second didactical question, it's possible to subordinate most of Mach's writings. It's the tangible application of the mainworks. All the didactical articles mirror the main monografical publications by Mach. Obvious, when talking about his PSL. But also his "Mechanics", the "Theory of Heat" and his "Optics" we find in the 18 articles published in the ZfPCU. All of them are a adaptation of the mentioned main publications for teaching purposes. Making the example referring to his "Theory of Heat", teaching related articles are: "Über den Unterricht in der Wärmelehre",[8] "Modell des Mariotte-Gay-Lussac'schen Gesetzes"[9] and "Einfache Versuche über strahlende Wärme".[10]

[5]Otto Blüh, ibid. p. 12.

[6]Joachim Thiele, "Ernst Mach als Pädagoge", in: *Schweizerische Hochschulzeitung*, 36, 1963, pp. 221–230.

[7]Per-Olof Wickmann, "Learning Progressions: An International Perspective", in: Norman G. Lederman/Sandra K. Abell (Eds.), *Handbook of Research on Science Education*, New York: Routledge 2014, pp. 145–165, p. 146.

[8]Ernst Mach, "Über den Unterricht in der Wärmelehre", in: *Zeitschrift für den physikalischen und chemischen Unterricht*, 1, 1887/88, pp. 197–199.

[9]Ernst Mach, "Modell des Mariotte-Gay-Lussac'schen Gesetzes", in: *Zeitschrift für den physikalischen und chemischen Unterricht*, 5, 1891/92, p. 138.

[10]Ernst Mach: "Einfache Versuche über strahlende Wärme", in: *Zeitschrift für den physikalischen und chemischen Unterricht*, 7, 1893/94, pp. 113–116.

Looking at the "Theory of Heat", the reciprocal connection between Mach's teaching and his scientific reasoning is pointed out by him in the preface: "This book, just as the Mechanics, is on the one hand the result and on the other hand the basis of my lectures." (p. VII, Blüh S. 11).

The third question, why teach this content and why with these methods, answers Mach in an article of the ZfPCU clearly: "Man könnte als Ziel der Naturwissenschaft und des naturwissenschaftlichen Unterrichts in ziemlich erschöpfender Weise bezeichnen: Die Anpassung der Gedanken an die Thatsachen und die Anpassung der Gedanken aneinander."[11]

It's the same thought he brings up in "Knowledge and Error", when he deals with his philosophical views on physics. Another overlapping of argumentation can be identified in "Über Gedankenexperimente", also examined in "Knowledge and Error" at length. It shows, that acknowledging the quality of the main works of Mach leads to acknowledgment of the quality of his didactical views, because they are the same. According to this reciprocal view on physics and the teaching of it, the main ideas of Mach's didactics are the following[12]:

- Begin instructions with concrete materials and thoroughly familiarize students with the phenomena discussed.
- Aim for understanding and comprehension of the subject matter.
- Teach a little, teach it well.
- Follow the historical order of development of a subject.
- Tailor teaching to the intellectual level and capacity of students.
- Address the philosophical questions that science entails and which gave rise to science.
- Show that just as individual ideas can be improved, so also scientific ideas have constantly been, and will continue to be, overhauled and improved.
- Engage the mind of the learner.

Historical Role

Focusing on the didactical work of Mach, there is to state a major gap between his quite modest claims in his writings and the influence attributed to him by some researchers. Looking closer to the historical studies addressing an analysis of the broader historical role of Mach's didactics, i.e. influences on and trough him, there can be identified four different approaches to the topic, that differ at the end by relevant extent.

The first approach is made by Thiele,[13] who sees a direct influence on the work of Kerschensteiner and Martin Wagenschein. He points on the success of "exemplified learning", connected to Kerschensteiner and Wagenschein, in the twentieth century.

[11] Ernst Mach, "Über das psychologische und logische Moment im Unterrich", in: *Zeitschrift für den physikalischen und chemischen Unterricht*, 4, 1890/91, pp. 1–5, p. 5.

[12] Michael Matthews, *Science Teaching. The role of history and philosophy of science*, New York: Routledge 1994, p. 98.

[13] Joachim Thiele, ibid.

There is more to agree than to disagree, taken the fact that Mach's economy of thought leads to an exemplifying teaching procedure. But what is to doubt is, if similarity is the same as influence.

Adolf Hohenester[14] denies in part the connection made by Thiele by looking at Kerschensteiner's work. The counterargument says, that Kerschensteiner moves during his intellectual life away from a position similar to Mach to a position ascribed to the so called "Kulturpädagogik". What Hohenester suggests instead, is to stress out the analogies to Johann Friedrich Herbart. So do others too, like Michael Matthews. An unplausible claim, not only because it means putting him in the context of pedagogy, in which Herbart clearly is to put but not Mach. There is also no discursive proof of the influence by Herbart or his successors in Mach's writings. Central to spread out Herbart's thoughts in Vienna was Theodor Vogt. The first Viennese Professor for Pädagogik, was from 1883 on also board chairman of the "Verein für wissenschaftliche Pädagogik" at Leipzig, the centre of so called Herbartianism. But there is no bibliographical evidence in Mach's didactical work referring to Herbart, Vogt or the school of Herbartianism. Finally it seems doubtful that the "economy of thought" as it is applied for didactical purposes should be compatible in detail with the pedagogical ideas of Herbart. Those are based on a metaphysical psychology and ethics, being, philosophically speaking, on the opposite side of Mach's thinking.

Considering the central role of history and philosophy of science in Mach's publications, there is very good reason to identify similarities within the genetic method of learning developed in the twentieth century.[15] This third approach to Mach's work is made by Michael Matthews referring to the tradition of modern science education. Matthews lines out the crucial role of history and philosophy for teaching sciences, a didactical view rooted, next to others, also in Machian thoughts. To explain this coherence, the similarities between science education and the german-speaking didactics have to be highlighted again. "To science education research, the science content is as central to any inquiry into teaching as it is to didactics."[16]

In terms of publications, the newest account is given by Siemsen. He puts Mach's didactics in a broader line of educational tradition connecting Mach's didactical approach with many thinkers of the twentieth century, including rather different people as William James, Alfred Binet, Eino Kaila, Frank Oppenheimer or John Bradley.[17] Also when it comes to the question from where Mach derived his didactical views, a historical development is stated by Siemsen, arguing that he was

[14] Adolf Hohenester, "Ernst Mach als Didaktiker, Lehrbuch- und Lehrplanverfasser", in: Rudolf Haller/Friedrich Stadler (Eds.), *Ernst Mach. Werk und Wirkung*, Wien: Hölder-Pichler-Tempsky 1988

[15] Michael, Matthews, ibid.

[16] Per-Olof Wickmann, ibid. p. 147.

[17] Siemsen, Hajo: "Ernst Mach: A Genetic Introduction to His Educational Theory and Pedagogy", In: Michael Matthews (Ed.*), International Handbook of Research in History, Philosophy and Science Teaching*. Vol. III Frankfurt a.M: Springer 2014, pp. 2329–2358, S.2353.

influenced by Ratke, Comenius, van den Enden, Tschirnhaus, Jacobi and Beneke.[18] This view can be criticized in two steps, leading up to the result, that the account of Siemsen lacks of historical contextualization.

What Siemsen does in his papers, has been largely criticized by historians as "presentism". Lynn Hunt identifies two ways of presentism: "(1) the tendency to interpret the past in presentist terms; and (2) the shift of general historical interest toward the contemporary period and away from the more distant past."[19] Daniel Tröhler formulates this criticism in the field of history of education as follows: "What in the eye of an historian is so surprising is [. . .] that statements of former times seem to be used easily to build either a straight line to our present time — sometimes of decline or of advancement—or to compose a homogenous forum [. . .]".[20]

The reproach of presentism seems to be even more valid, when the central argument of bringing the mentioned names together brought forward by Siemsen is, that "much of this influence has been forgotten, because it is intuitive and therefore often not explicitly reflected."[21]

Looking at the main publications,[22] Mach follows always a similar way of argumentation, that can be roughly summarized in three aspects: He elaborates the topic from a historical point of view, combines it with his thoughts generated out of physics and compares them to contemporary literature. He doesn't hesitate to mention different approaches to his views. Watching closely to his references, he works precise and accurately. This seems to be the case according to the "Ernst Mach Studienausgabe" that gives only a few corrections regarding the footnotes. It shows also in the comments by the editors, how thoughtful Mach choose his remarks. Focusing on the text, accurately also in this sense that he would have mentioned influences on his didactical approach, as he does it with other topics. He mentions many names and sources of his thinking. But none of the mentioned persons by Siemsen Mach refers to in respect to didactics. Making the example of Beneke, he mentions him in other works, but never in his didactical writings.

As showed in this sequence, the four perspectives can be partly approved, partly criticized. To sum it up, they have two commons, one to agree and one to disagree. They have in common to watch at Mach as a historical singularity. Given the uniqueness of his main publications reflected in his didactics, this is not to deny. There are no other contemporaries of Mach to identify with the very same didactical thoughts.

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[18] ibid.

[19] Lynn Hunt: "Against presentism", In: *AHA* p*erspectives. Newsletter of the American Historical Association* 40, Nr. 5 Washington DC; Assoc. 2002, pp. 7–9, p. 7.

[20] Daniel Tröhler, "Philosophical Arguments, Historical Contexts, and Theory of Education", in: *Educational Philosophy and Theory*, 2007, pp. 10–21, p. 13.

[21] Hajo Siemsen, "The Genesis of Central Ideas of Ernst Mach", 2015, working paper.

[22] Friedrich Stadler (Ed.): *Ernst Mach Studienausgabe*, Berlin: Xenomoi 2009–2016.

The other common is, that they see Mach as part of a longitudinal development, but this view can answer one question not sufficiently: What are the didactical writings of Mach a reaction to? A proper answer to this, is only possible within the context of austrian history of education, it's not to reconstruct from his writings alone.

A Fifth View

During the lifespan of Mach, the Austrian educational system as a whole was reformed on a large scale, leading up to the structure of nowadays school system in Austria. This reforms started in 1848, but to realize them, the legal implementation was followed by a process that took until the beginning of the twentieth century. The change was due to different factors, involving the whole society, as these factors are highly contested in the daily press, in societies devoted to the topic and on an academic and political level at the time. The switch of supremacy in the educational system from the church to the state, the influence of the new social class of "Bürgertum" on school or the fight upon elementary schools for all citizens were debated in terms of religion, politics and sciences. So the change of the Austrian educational system was accompanied by a vast discourse, Mach was for sure aware of. "His inspirations were reactions rather than actions: reactions both to his reading in the history of physics and to classroom situations."[23]

In between all this discussions, here, the establishment of the sciences in the curriculum is crucial. Mach's most famous didactical article "Der relative Bildungswert . . . " has to be seen in this context. Most of Mach's didactical work is motivated due to this development. What Mach argues for is reached in 1907, the sciences were established as equal subjects on the secondary school level next to the philological dominated Gymnasium.[24]

To mention when speaking about this article, is first of all the first footnote, stating that he got the possibility to speak about the topic, not that he actively tried to give this talk and not that he was somehow eager to publish it. What follows next, are two references: first, the famous treatment of Friedrich Paulsen "Geschichte des gelehrten Unterrichts". Indeed was Paulsen the central figure of the establishment of sciences in the school curriculum in Prussia. The second reference "La question du latin" from Raoul Frary, matches with the thinking of Mach too. Taking Paulsen's and Frary's lead, Mach combines this with his own experiences and research. The result of that: "Es kommt mir hier durchaus nicht darauf an, viel Neues zu sagen, sondern vielmehr darauf, nach meinen Kräften zur Einleitung der unausbleiblichen

[23] Otto Blüh, ibid. p. 19.

[24] Helmut Engelbrecht, *Geschichte des österreichischen Bildungswesens*, Vol.4 Wien: Österreichischer Bundesverlag 1986, pp. 147–189.

Bewegung auf dem Gebiete des Schulwesens beizutragen."[25] So nothing new he has to add. What we can witness in this footnote is this to some extent paradox back stepping of Mach and at the same time delivering a highly sophisticated analysis of the topic. This paradox one can find in all didactical texts by Mach.

To make clear which phenomenon of the history of education Mach is part of, a closer look to a similar field as physics is to be considered, the one of engineering. The following is partly a result of a project realized 2016 within the Austrian Academy of Sciences, gathering biographical information on influential engineers in the Habsburg monarchy between 1849 and 1917.[26]

In Vienna existed a worldwide recognized society, that organized engineers from all over the Habsburg monarchy, called "Österreichischer Ingenieurverein" (ÖIV). From 1865 on also architects joined the society, so the name changed in "Österreichischer Ingenieur- und Architektenverein". The recognition in- and outside the country they gained through several successful projects: the regulation of the Danube, the water pipelines from Styria for the water supply in Vienna, the extension of the railway, especially in the alps, and the build-up of the new Viennese Ring. All the big names of Austrian architecture and engineering, such as Theophil Hansen or Carl von Ghega, went full members of the society. To enter the society, a pretty strict application procedure should guarantee the qualification. First, obviously, applicants and later members have to actually work in the field of engineering. Furthermore the society asked for two letters of recommendation by actual members. By the 1975 the society counted close to 2000 members.

Not only is it a technical area, what makes it useful for a comparison, but it's also the need for specialized training in schools and universities, they share with physics. By the mid 1900 there is no academic title for engineers established yet. The technical education they got from the "Polytechnikum" a secondary school. Some of them evolved around 1900 to technical universities. They share also the problems of the domination of the philological gymnasium. This is evident, looking at the publications of the society. They refer to the change in secondary schools (Mittelschulen) mentioned above directly. They formed a committee "betreffend der Frage der Reorganisation der Mittelschulen", existing from 1876 to 1879 and making it a steady institution from 1886 on within the society.[27] In general, a committee is a group of members, dealing with special topics interesting to the ÖIAV. They can deal with highly technical questions, like the committee devoted to train locomotives, but they deal also with social questions making an effort for more social appreciation of their doing. Both motivations we can find in the committee for middle schools.

[25] Ernst Mach, *Populärwissenschaftliche Vorlesungen*, Berlin: Xenomoi 2014, p. 255.

[26] Project Title: Nicht nur Ressel, Kaplan, Madersperger . . . Erfassung österreichischer Ingenieure anhand der "Zeitschrift des österreichischen Ingenieur- und Architekten-Vereines"zur Hebung der Technikerquote im *Österreichischen Biographischen Lexikon.*

[27] *Wochenschrift des ÖIAV*, 1886 p. 152.

Now, watching closer to the content of this discussions in the ÖIAV, we see similarly to Mach a sophisticated argumentation deriving from practical needs. They visited several Polytechnika, developed curricula and discussed schoolbooks. But by no means those engineers were educationalists. That should be stated with making the example of engineers: It was to show, that a didactical work was at Mach's time also produced and published by professionals, that are over their special interests not involved with scientific educational reasoning. Because of their expertise in the field, the outcome is considerable still today, but not of being influential on the didactical discipline itself. Because it was not published in the field of education or didactics, the reception of it was from the very beginning on limited.

The paper argues after this account, that Mach didn't create a didactical system or that you can attribute to him a specific educational tradition, but that his didactical works reflect and comment the educational changes of the 2nd half of the nineteenth century, from his genuine physical perspective.

Part VII
Mach, Duhem, and Comte

Chapter 44
Mach, Duhem and the Historical Method in Philosophy of Science

Anastasios Brenner

Abstract In 1903 Mach and Duhem, discovering one another's writings, acknowledged the proximity of the philosophical views that they had been elaborating independently. A correspondence followed, which lasted several years. And in their ensuing publications both of these philosopher-scientists were careful to discuss their interlocutor's claims. We have here ample matter for consideration. Mach and Duhem were to have an impact on the development of the Vienna Circle. Yet their conceptions are indeed different from those that followed. Characteristically, they drew on history and psychology. They were interested in the genesis of concepts, the evolution of theories and the patterns of discovery. If rational reconstruction and logical analysis were admitted, these techniques were counter-balanced by historical study. In view of recent evolutions in philosophy of science — the growing importance of cognitive science, history of science, interdisciplinarity — it is worthwhile to return again to the beginning of the twentieth century. The aim of this paper is then to reexamine the relation between Duhem and Mach, in particular with regard to the methods whereby they sought to provide a philosophical reflection on science.

Introduction

The encounter of Ernst Mach and Pierre Duhem is significant in several respects. Duhem, who had written a book on the history of mechanics, gave a lengthy and commendatory review of the latter's *The Science of Mechanics*, when it appeared

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F. Stadler (ed.), *Ernst Mach – Life, Work, Influence*, Vienna Circle Institute Yearbook 22, https://doi.org/10.1007/978-3-030-04378-0_44

in French translation.[1] He perceived a connection between Mach's principle of economy and his own definition of physical theory as an abstract representation of laws, and recognized his Austrian counterpart as a forerunner. In turn, Mach expressed their mutual understanding most forcefully in the Preface to the second edition of *Knowledge and Error:* "Duhem's *La Theorie physique, son objet et sa structure* [. . .] has given me great pleasure. I had not hoped to find so soon such far-reaching agreement in any physicist".[2] The claim that the aim of science is thought economy or abstract representation opened up a new perspective with regard to traditional views. Mach and Duhem came to share several other theses regarding experimental testing, measurement and mathematization. My aim is to explore this "far-reaching agreement".

Yet there are obvious differences between the two thinkers. First, Mach allotted a good amount of space in his historical studies to methods of observation, instruments, and experimental setups, whereas Duhem focused on concepts, theories and mathematical developments. *The Science of Mechanics* provided an abundant documentation on the history of experimental techniques, and Mach did not fail to mention some apparatuses he had devised for his teaching. On the other hand, Duhem was attentive in his works to the philosophical background, the conceptual changes, presenting the contrast between descriptive and explanatory theories in a broad discursive context. In summary, they approached the goal and nature of science from different angles, and one could point to other differences in scientific research, philosophical views and political opinions.

Despite such differences, both thinkers suggested a reading in which their endeavors complement one another. Duhem seized the opportunity of his agreement with Mach to dispel some objections raised by his views: although his presentation of physics is heavily mathematical and highly theoretical, his intention was not to overlook the empirical basis. Conversely, Mach could show how his analysis of experimental techniques threw light on the development of physics as a mathematized science. His aim was to understand the association of mathematics and the empirical world. Both Mach and Duhem contributed to our understanding of scientific activity. But how should we characterize their relationship?

Indeed, the interaction of Mach and Duhem attracted the attention of their contemporaries. One can point out two major directions in this respect. On the one hand, members of the Vienna Circle such as Philipp Frank, Hans Hahn and Otto Neurath combined the conception of Mach and Duhem in their effort to formulate a new positivism. On the other hand, Abel Rey discussed at length both thinkers

[1] Pierre Duhem, "Analyse de l'ouvrage d'Ernst Mach: *La Mécanique*", in: *Bulletin des sciences mathématiques* 27, Oct. 1903, pp. 261–283. Reproduced in Duhem, *L'Évolution de la mécanique* (1903). Paris: Vrin 1992. English translation Michael Cole, *The Evolution of Mechanics.* Alphen aan den Rijn: Sijthoff & Noordhoff 1980.

[2] Ernst Mach, *Erkenntnis und Irrtum: Skizzen zur Psychologie der Forschung* (1905), in: *Ernst Mach Studienausgabe*, Band 2. Berlin: Xenomoi 2011, pp. 5–6. English translation Thomas J. McCormack, *Knowledge and Error*. Dordreicht: Reidel 1976, p. XXXV. Elisabeth Nemeth and Friedriech Stadler's introduction to the *Studienausgabe* edition was useful in writing this article.

in his endeavor to develop what he termed already "historical epistemology". Here lies the point of departure of a major methodological divide — that between analytic philosophy of science and historical epistemology — which continues to this day to plague philosophers.

References to Mach and Duhem were to reappear in new settings. Their analyses were in turn called on in arguing against logical empiricism, revealing the possibility of different readings of their works. The dialogue between Mach and Duhem thus touches on issues that have come again to the fore: scientific representation as one of the options in the debate over realism, the psychology of science as renewed by cognitive science or the revival of historical epistemology.

The relation between Mach and Duhem has of course received attention. Klaus Hentschel published their correspondence with a commentary in 1988,[3] and the author of these lines devoted an article to Poincaré, Duhem and Mach in 1998.[4] In taking up the issue again, I shall follow a different approach, seeking to understand their conceptions on their own terms and to throw light thereby on current practices.

A Singular Meeting

Let us briefly mention the main facts concerning the encounter of Mach and Duhem. The first exchange was brought about by the almost synchronous publication of Duhem's *Evolution of Mechanics* and the French translation of Mach's *The Science of Mechanics*[5]: on 9 July 1903 Duhem sent a letter acknowledging receipt of the 3rd edition of the *Popular Scientific Lectures.*[6] He informed Mach that he had just completed a lengthy review of the French translation of *The Science of Mechanics* on the proofs. This was the beginning of a correspondence, which over the next 3 years would reflect a remarkable mutual recognition. Thereafter the letters became less frequent and the last letter known was sent by Duhem on 10 August 1909.

This is not however the end of the story. Later references go to prove that Mach and Duhem were not indifferent to each other's research in progress. Duhem resumed the discussion with Mach over the history of mechanics in 1910, in an

[3]Klaus Hentschel, "Die Korrespondenz Duhem-Mach: Zur 'Modellbeladenheit' von Wissenschaftsgeschichte", in: *Annals of Science* 45, 1988, pp. 73–91.

[4]Anastasios Brenner, "Les voies du positivisme en France et en Autriche: Poincaré, Duhem et Mach", *Philosophia Scientiae* 3, 2, 1998, pp. 31–42.

[5]Mach, *Die Mechanik in ihrer Entwicklung: Historisch-Kritisch dargestellt* (1883), in: Ernst Mach Studienausgabe, Band 3. Berlin: Xenomoi 2012. French translation Émile Bertrand, *La Mécanique: Exposé historique et critique de son développement* (1904). Paris: Gabay 1987. This edition contains a preface dated July 1903, not published elsewhere. The introduction by Gereon Wolters and Giora Hon to the *Studienausgabe* edition provides helpful information.

[6]Mach, *Populär Wissenschaftlichen Vorlesungen* (1896) in: *Ernst Mach Studienausgabe*, Band 4. Berlin: Xenomoi 2014. English translation Thomas J. McCormack, *Popular Scientific Lectures*. La Salle, Illinois: Open Court 1986.

article on the influence of Buridan on Italian Science of the sixteenth Century, later published in *Études sur Léonard de Vinci.*[7] The catalogue of Mach's library registers a dedicated copy of one of Duhem's articles dating from 1911 concerning the Gregorian reform of the calendar.[8] Here Duhem makes the claim that the theory of impetus appearing in Benedetti and Galileo can actually be traced back to Buridan, thus correcting Mach's account. It is likely that this prompted Mach to reply in the 7th edition of the *Science of Mechanics.* He refers to Duhem in the very Preface dated 5 February 1912:

> With regard to history, the criticism of Emil Wohlwill was valuable for me and especially illuminating concerning the early years of Galileo [. . .], as well as the critical observations of P. Duhem and G. Vialati [. . .]. With regard to the discussions on the critique of knowledge [erkenntniskritischen Diskussionen], P. Duhem, O. Hölder, G. Vialati and P. Volkmann participated intensely and, in my view, brought about advances.[9]

This acknowledgement is followed, in the body of the work, by two new sections, to which I shall return later. One could add yet another reference from Duhem's *German Science* in 1915[10]: although this piece clearly belongs to the war literature of the time, Mach is among the few German-language scientists not to be subjected to criticism. What we can gather from these facts is that the interaction between the two thinkers extends well beyond the correspondence as preserved. It takes us well up to the end of their lives.

There are nevertheless strong contrasts between Mach and Duhem. The two authors found themselves in different settings. Mach formulated an outlook imbued by freethinking, within the context of the Austro-Hungarian monarchy, where Catholicism was the official religion. Duhem, who elaborated his conception in the climate of secularization of the early French Third Republic, was bent on separating and also preserving religious convictions from the encroachments of science. Their positions appear diametrically opposed. Moreover, Mach was reacting against the emphasis placed on theory and mathematics within German-language physics of the second half of the nineteenth century; Duhem opposed rather the experimental trend of French physics of the time. Yet both thinkers chose to highlight their agreement over their divergences, encouraging such a reading among their disciples and followers.

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[7]Duhem, "La tradition de Buridan et la science italienne au XVI^{e} siècle", in: *Bulletin italien*, 10, 3, 1910, pp. 202–231. Reproduced in: Duhem, *Études sur Léonard de Vinci* (1906–1913). Paris: Archives contemporaines, 3 vols, 1984.

[8]Duhem, "Un document relatif à la réforme du calendrier", in: *Hommage à Louis Olivier.* Paris: Maretheux 1911, pp. 97–103.

[9]Mach, *Die Mechanik*, *op. cit.*, p. 5, translation mine.

[10]Duhem, *La Science allemande.* Paris: Hermann 1915, p. 122.

A Rational Reconstruction

Rather than follow merely the chronology of events, I prefer to seek to comprehend the significance of the relation of Mach and Duhem. It could be argued that for Mach the encounter with Duhem came too late in his career to have had a deep impact. His last major philosophical work, *Knowledge and Error*, had already been drafted. But this would be to neglect the numerous references to his French counterpart in the second edition as well as significant citations elsewhere. I believe that the dialogue with Duhem helped to shape the reception of Mach's work. As for Duhem, he was elaborating his major opus, *The Aim and Structure of Physical Theory*, when he was most engaged in the dialogue with Mach.

So, what was it that brought our two thinkers into contact? One may start by pointing to a fundamental thesis defended in common. As Mach formulated his basic idea in the preface to the French translation of his *Science of Mechanics*: "The concept of cause is replaced by that of function: a reciprocal dependence of phenomena, and their economical description becomes then the goal, while the physical concepts are but the simple means to this end".[11] Duhem expressed a similar view when he claimed that physical theory does not aim to explain things as they are but to represent experimental laws. We find here the expression of a positivist, anti-metaphysical attitude.

The Science of Mechanics, which went through seven editions during Mach's lifetime, encountered success, but it raised controversies concerning priority as well as the role ascribed to economy of thought. In the preface to the first edition, Mach, while claiming priority for his concept of economy of thought, was careful to point to thinkers holding similar ideas such as Gustav Kirchhoff and Hermann von Helmholtz.[12] He returned repeatedly to this issue. He made clear that Kirchhoff was not alone in holding a descriptivist or phenomenalist attitude. He could cite in this sense Hermann Grassmann, John Stuart Mill and William Whewell. Duhem went on to add to the list André-Marie Ampère, who had indeed empoyed the term representation to characterize the task of the scientist. In the 1904 edition of *The Science of Mechanics*, Mach specified that Kirchhoff's views corresponded only "in part" to his own and that his formulation was more "radical".[13] Two years later he devoted an article, "Beschreibung und Erklärung", precisely to the question at hand, in which he acknowledged that the economical nature of science "was recently brought out by P. Duhem in his book *La théorie physique, son objet et sa structure* [...] in a very expressive and convincing manner".[14] Reference to Duhem thus enabled Mach to emphasize the specificity of his view.

[11] Mach, *La Mécanique*, *op. cit*., "Préface", p. 2.

[12] Mach, *Die Mechanik*, *op. cit*., p. VI.

[13] Mach, *op. cit*., pp. 258–259. This section was added to the 5th edition.

[14] Mach, "Beschreibung und Eklärung" (1906), reproduced in the 1910 4th edition of *Populär Wissenschaftlichen Vorlesungen, op. cit.,* p. 425.

Before proceeding further, let us recall Kirchhoff's position. He wrote a series of volumes on mathematical physics. The first, which was published in 1876, was devoted to mechanics. It begins with the following statement:

> The point of departure of the presentation I have chosen differs from that generally adopted. It is usual to define mechanics as the science of forces, and forces as the causes that produce motion or tend to produce them [...]. But this presentation is vitiated by the obscurity inherent in the concepts of cause and tendency.[15]

Kirchhoff obviously had in mind the traditional definition given by Lagrange, according to which force or power is defined as the cause of motion. He then expounds his own presentation: "For this reason I assign to mechanics the task of describing motions that occur in nature and of describing them indeed completely [*vollständig*] and in the simplest manner possible [*einfachste*]".[16]

Let us pay heed to the precise wording of this passage: simplicity alone admits of degrees; completeness is taken absolutely. Physics should no longer search for the causes nor be given over to the explanation of things. The concept of force can be dispensed with. It only serves to simplify the mathematical expressions. The position just outlined can be qualified variously as descriptivism, nominalism or positivism.

Duhem, who had been acquainted with Kirchhoff's conception, prior to reading Mach,[17] was likewise intent on taking this idea further. First and foremost he supposed that completeness also admits of degrees.[18] And as regards the reasons for choosing a hypothesis, one should include exactness or accuracy. Duhem was thus led to spell out the various criteria involved in the choice of theories.

Mach came to deploy clearly the scope of his concept of economy in *Knowledge and Error*:

> The term 'description [*Beschreibung*]' which appears already in the discussion between J.S. Mill and Whewell has been generally adopted since Kirchhoff; in contrast, let me suggest the expression 'restriction on expectations' as pointing to the biological importance of the laws of nature. A law always consists in a restriction of possibilities, whether as a bar on action, as an invariable course of natural events, or as a road sign for our thoughts and ideas [*Vorstellen und Denken*] that anticipate events by running ahead of them in a complementary manner.[19]

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[15]Gustav Kirchhoff, *Vorlesungen über mathemathische Physik: Mechanik* (1876). Leipzig: Teubner 1877, p. V. Translation mine.

[16]*Ibid.*

[17]Duhem had translated Kirchhoff's "Zur Theorie der Lichtstrahlen" (1882) in: Annales scientifiques de l'École normale supérieures, 3, 1986, pp. 303–341. He alluded to Kirchhoff's conceptions in *L'Évolution de la mécanique*, *op. cit.*, p. 158.

[18]Duhem, *La théorie physique, son objet et sa structure* (1906). Paris: Vrin, 1981, p. 76; English translation Philip P. Wiener, *The Aim and Structure of Physical Theory*. Princeton: Princeton University Press 1954, p. 53.

[19]Mach, *Erkenntnis und Irrtum*, *op. cit.*, p. 450. English translation p. 352.

The biological twist Mach gives to the idea of description is noteworthy. He pursues his reasoning over the next few pages, invoking the mental operations of simplification, schematization and idealization. He then puts forth the following conclusion:

> Only a theory that represents facts more simply and precisely than can really be guaranteed by observation (because of the influence of always numerous and complicated subsidiary circumstances) corresponds to the ideal of unambiguous determinacy.[20]

It is difficult not to be struck by the similarity with Duhem's views, and indeed in the second edition of his book, Mach would add in this place a reference to Duhem. Both thinkers were seeking to move beyond Kirchhoff. Economy of thought is a general feature of science, continually enhanced; it involves a variety of criteria: simplicity, completeness, accuracy, etc. Furthermore, Mach takes into account the activity of classifying, which again echoes Duhem.

Intellectual Economy and Representation

It is time we turn to Duhem's well-known definition of theory given in *The Aim and Structure*, in which Mach saw a thesis similar to his concept of intellectual economy: "A physical theory is not an explanation. It is a system of mathematical propositions, deduced from a small number of principles, which aim to represent as simply, as completely, and as exactly as possible a set of experimental laws".[21] A scientific theory is then no longer conceived as the explanation of deep causes, but as an abstract representation of laws. Duhem proceeds to explain that theory consists in a symbolic construction characterized by four operations: the definition of concepts, the choice of hypotheses, the mathematical development, and the comparison with experiment. This series of operations is what Duhem designates by structure, and the second part of his book treats of each one in depth. One finds here the intuition of the standard view of theories, which the logical empiricists will further develop: a theory is an axiomatic system, a set of propositions deductively linked, separated into postulates and theorems, its empirical interpretation being provided by way of certain correspondence rules.[22]

When Duhem defines physical theory not as an explanation but as an abstract representation, he expresses a view similar to that of Mach. We are thus not surprised to see him call on the concept of economy of thought. But Duhem does not stay content with this definition of theory. He goes on to add that representation is also classification, and in the course of history, classifications are constantly improved.

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[20] Ibid., p. 457, English translation p. 357.

[21] Duhem, *op. cit.*, p. 24; English translation, p. 19.

[22] Concerning the proximity of Duhem's views to those of the Vienna Circle, see Brenner, *Les origines françaises de la philosophie des sciences*. Paris: Presses universitaires de France 2003.

They tend more and more toward a natural classification. In consequence, he comes to voice implicitly some disagreement with Mach:

> Logic does not [...] furnish any unanswerable argument to anyone who claims we must impose on physical theory an order free from all contradiction. Are there sufficient grounds for imposing such an order if we take as a principle the tendency of science toward the greatest intellectual economy? We do not think so [...]. We showed how diverse sorts of minds would judge differently the economy of thought resulting from an intellectual operation.[23]

Mach seized the occasion of the second edition of *Knowledge and Error* the very same year to respond in a long note.[24] He takes up Duhem's contrast between, on the one hand, deep and narrow minds and, on the other, ample and supple minds. He notes Duhem's concession that this characterization holds only in general, but he insists that one should speak only of degrees with respect to these types of minds. Mach is not ready to follow Duhem in his criticism of Maxwell's use of mechanical models. He then reasserts his principle: "The ideal of economic and organic adaptation of compatible judgments for a subject is reached when the minimum number of simple, independent judgments is found, from which the others are a logical sequel".[25]

Let us now direct our attention to the three terms that qualify representation in Duhem's definition of theory: simplicity, completeness and exactness. It is not difficult to understand why Duhem brought them up: he had rejected the Newtonian method of inductions as well as the procedure of crucial experiment, in summary the traditional schemas of justification. Hypotheses are now freely chosen, which does not mean that they are arbitrary; the theorist must motivate his choice. Hence the appeal to rational criteria. I do not have time to dwell on what Duhem has to say on each of these notions.[26] Suffice it to recall what belongs to exactness or accuracy in order to understand what he is after:

> The various consequences [...] drawn from the hypotheses may be translated into as many judgments bearing on the physical properties of the bodies [...]. These judgments are compared with the experimental laws which the theory is intended to represent. If they agree with these laws to the degree of approximation corresponding to the measuring procedures employed, the theory has attained its goal.[27]

Accuracy in physics is the agreement within the accepted degree of approximation. Duhem is led to distinguish between truth in ordinary contexts and truth in physics. He goes as far as to advocate dispensing with truth altogether. In other words the scientist must take into account the exact nature of the procedure of verification or confirmation. Accuracy, as indeed other criteria, must be related to

[23] Duhem, *ibid*, pp. 149–150. English translation, pp. 101–102.

[24] Mach, *Erkenntnis und Irrtum*, *op. cit.*, p. 178.

[25] *Ibid.,* p. 179.

[26] I have analyzed this issue in greater depth in Brenner, *Raison scientifique et valeurs humaines: Essai sur les critères du choix objectif.* Paris: Presses universitaires de France 2011.

[27] Duhem, *Ibid.*, pp. 25–26; English translation, p. 20.

the operations constituting scientific activity. It is interesting to note that Duhem explicitly acknowledged his debt on this point to earlier scientists, among others Kirchhoff and Mach, thus setting the representative view within a broad historical context.[28]

The Historical Analysis of Scientific Concepts

We have mentioned several references to Duhem in *Knowledge and Error*. One reference stands out, as it was set directly in the text of the second edition and, moreover, in the conclusion to the chapter "On the Psychology and Natural Development of Geometry":

> The history of science shows that a correct new insight correctly reduced to its foundations may become more or less confused in time, appear incompletely or in distorted form or even be altogether lost to some enquirers, only to reappear in full blaze later. A single discovery and utterance of an insight is not enough. Often it takes years and centuries to develop general thinking habits to the point where the insight in question can become common property and stay permanently alive. This is shown with especial elegance by Duhem in his detailed investigations on the history of statics.[29]

Mach is referring to Duhem's research as presented in *Les origines de la statique*.[30] The later had found in Jordanus Nemorarius, a thirteenth-century medieval savant, the concept of gravity *secundum situm*, which would play an important role in the later development of statics. This result would lead Duhem, in a series of historical studies, to formulate a new view of the birth of modern science. As analytic philosophy of science later came to discard the context of discovery, it is worthwhile to emphasize that Mach was intent on grounding his "psychology of research" on the history of science.

Let us turn to the two new passages, which were added in appendix to the 6th edition of Mach's *Science of Mechanics*, published in 1908, and were incorporated directly in the body of the text in later editions. Mach expanded notably chapter one, section five: "Retrospect of the Development of Statics", which begins with the following statement: "Knowledge of the development of a science consists of the study of the documents in their historical order and their mutual dependence".[31] He then summarizes Duhem's findings concerning Jordanus Nemorarius and Leonard da Vinci. He does not fail to recall Duhem's thesis according to which "the

[28]For a modern assessment of this problem, see Bas van Fraassen, *Scientific Representation*. Oxford: Oxford University Press 2008.

[29]Mach, *Erkenntnis und Irrtum*, *op. cit.*, p. 388. English translation p. 295–296.

[30]Duhem, *Les origins de la statique* (1905–1906). Paris: Gabay, 2 vols, 2006. Duhem refers to Mach's *Die Mechanik* in vol. 1, pp. 278–356.

[31]Mach, *Die Mechanik*, *op. cit.*, p. 75. English translation, p. 77.

continuity between ancient statics and modern statics was never interrupted".[32] Finally, Mach directs the reader, who wants to know more, to Duhem's book, which he qualifies as "brilliant [*prächtiges*]". He does however express some reservations over the positive role ascribed to Aristotle. If Duhem had started by holding an Aristotelian point of view, he later came to emphasize the break with Aristotle, which he would locate in the late fourteenth century.

The second passage, chapter two, section one: "Galileo's Achievements" commences thus: "Let us now ask ourselves what insights Galileo handed down to us".[33] Mach is basing his account on an article Duhem published in 1905 on the problem of free fall.[34] He readily adopts the interpretation given by Duhem of Descartes's contribution to mechanics. But he voices a difference of opinion concerning Duhem's description of Galileo's scientific practice. What Mach emphasizes is that Galileo was significantly not concealing something mysterious behind the concept of force.[35] It is true that Duhem had a tendency to diminish Galileo's achievements in favor of medieval authors. But he also held that the truly representative conception became prominent only recently.

In the opening pages of *The Aim and Structure,* Duhem claimes to provide "a simple logical analysis of the method by which physical science makes progress".[36] Yet his book contains a large amount of history. One finds numerous examples taken from the history of physics as well as a general interpretation of progress as a continuous process. History also enables us to go beyond the limits imposed on logical analysis. This association of history and logic is perhaps what is most astonishing for the modern reader. We are used to separating the historical study of science from the logical analysis of its language.

Let us take a closer look at the function of history in *The Aim and Structure*. Duhem's reasoning is frequently illustrated by examples taken from past science; each major claim is supported by historical arguments: representation, natural classification, analogy, etc. Furthermore, two crucial sections of the book are explicitly devoted to history: part one, chapter three: "Representative Theories and the History of Physics" and part two, chapter seven, paragraph six: "The Importance in Physics of the Historical Method". The following passage summarizes nicely Duhem's attitude:

> The legitimate, sure, and fruitful method of preparing a student to receive a physical hypothesis is the historical method. To retrace the transformations through which the empirical matter accrued while the theoretical form was first sketched; to describe the long collaboration by means of which common sense and deductive logic analyzed this matter

[32] Mach, *Ibid.*, p. 76.

[33] Mach, *Ibid.*, p. 145.

[34] Duhem, "De l'accélération produite par une force constante: Notes pour servir à l'histoire de la dynamique", in: Edouard Claparède (Ed.), *Rapports et comptes rendus du deuxième congrès international de philosophie*. Genève: Henry Kündig 1905, pp. 859–915.

[35] Mach, *Ibid.*, p. 149.

[36] Duhem*, La théorie physique, op. cit.,* p. XV. English translation, p. 3.

> and modeled that form until one was exactly adapted to the other; that is the best way, surely even the only way, to give to those studying physics a correct and clear view of the very complex and living organization of this science.[37]

On Relative Motion

One should not omit to consider a further reference in Duhem to Mach. In a series of articles on relative and absolute motion, which Duhem published between 1907 and 1909,[38] he brings up the debate over the principle of inertia and the system of coordinates with respect to which the motion of bodies is to be compared. Duhem was resuming discussion of an issue he had already raised in his review of Mach's *The Science of Mechanics*, and it is best to begin with this text in order to understand his position. Duhem devoted a section to examining in some detail Mach's discussion of "Newton's Views of Time, Space, and Motion". He recalls the critical analysis of absolute space and time given simultaneously by Mach and Carl Neumann.[39] He then brings out the different philosophical attitudes possible with regard to the problem of the choice of a clock and a system of coordinates: realist immaterialist, realist materialist and positivist. Duhem mentions Neumann's proposal to postulate a body alpha, adding that one need not ascribe a concrete material reality to this body alpha. And he ends by quoting Mach's conclusive remark in response to Emil Budde's suggestion to consider this body as a medium, somewhat like ether: the problem being that we have no physical means to detect the properties of this medium. Now, a difficulty arises in this debate: when Duhem took up the matter again, Mach was revising considerably his presentation; he dropped precisely this remark.

Returning to the issue in his article on absolute and relative motion, Duhem recalls Mach's principle as originally presented in *History and Root of the Principle of the Conservation of Energy* in 1872, according to which the influence of all celestial bodies must be taken into consideration:

> What share has every mass in the determination of direction and velocity in the law of inertia? No definite answer can be given to this by our experiences. We only know that the share of the nearest masses vanishes in comparison with that of the farthest. We would, then, be able completely to make out the facts known to us if, for example, we were to make the simple supposition that all bodies act in the way of determination proportionately to their masses and independently of the distance, or proportionately to the distance, and so on.[40]

[37] *Ibid.*, pp. 408–409. English translation, pp. 268–269.

[38] Duhem, "Le mouvement absolu et le mouvement relatif", in: *Revue de philosophie*, 11, 1907, p. 221–235 and 14, 1909, p. 489–508.

[39] Duhem, "Analyse de l'ouvrage d'Ernst Mach: *La Mécanique*", *op. cit*., p. 455.

[40] Mach, *Die Geschichte und die Wurzel des Satzes von der Erhaltung der Arbeit* (1872). Leipzig: Barth 1909. English translation Philip Jourdain, *History and Root of the Principle of the Conservation of Energy*. Chicago: Open Court 1911, pp. 79–80.

We know that this view, which Albert Einstein was to call Mach's principle, came to play an important role in his theory of general relativity. Retrospectively, one can only be disappointed on discovering that Duhem dismisses Mach's proposal in the following terms:

> This curious hypothesis formulated by Mr. Ernst Mach does not resolve the problem of place and absolute motion. It speaks of velocities and accelerations; it requires us then to inquire into the term, motionless by definition, with respect to which these motions are referred.[41]

Duhem then goes on to describe in some detail Neumann's body alpha. He gives his preference to this solution, as long as one does not conceive it as a real body. Mach had made it clear that his solution was different from that of Neumann, and accused the later of merely dressing in new garb the absolutist conception of space and time. His proposal was rather to reformulate the principle of inertia by taking into account all the masses of the universe.

Duhem obviously missed the importance of Mach's principle. His refusal is connected with his own definition of space and time, as he gave it in his scientific works. Thus in his *Traité d'énergétique*, in which he refers his reader to the historical survey mentioned, Duhem states — retaining what he says with respect to motion:

> The absolutely fixed system of coordinates [*triède de reference*] is a purely ideal one, having no existence outside of the mind of the theorist; for theory to accomplish its role, it is enough for us to know how to make [. . .] the absolutely fixed system of coordinates correspond *approximately* to a certain concrete system of coordinates.[42]

What is perhaps more interesting is the historical interpretation offered by Duhem. To outline it, Aristotle lies at the origin of discussions on the concept of space or place. He started from a definition of place as the boundary of a body with its surrounding environment. But as this environment could itself be in motion, Aristotle sought for an ultimate term of motion, which he believed could be identified with the earth, supposed to be at rest at the center of the universe. In other words, the term of motion is not a mathematical point but an actual concrete material body. Against this view arose two others. According to Philoponus, a sixth-century Christian thinker, inspired by neo-Platonism and stoicism, place is distinct from the bodies that fill it; it is assimilated with a pure three-dimensional space. In consequence, place lacks physical attributes; it is immaterial and has no influence on bodies. This is the absolute space that Newton came to develop for an infinite universe. A third conception, to follow the order given by Duhem, was set forth by Damascius, a neo-Platonic philosopher of the fifth century. According to him, place is the set of geometrical measurements making it possible to determine the position of the body. Position is inseparable from the body, which can change position even if no other bodies remain fixed. This does not mean that only relative motions exist,

[41] Duhem, *op. cit.*, 13, 1908, p. 649.

[42] Duhem, *Traité d'énergétique*. Paris: Gauthier-Villars, 2 vols, 1911, vol. 1, p. 13. Authors emphasis; translation mine.

for Damascius admits that the various motions of the universe have a place. But this place concerns neither a real body or abstract space. It corresponds to the best possible disposition of the universe, in other words an ideal state. Historical study reveals the interplay of these fundamental conceptions, as one proceeds from the finite world to the infinite universe. Duhem does not conceal his preference for Damascius's conception, which he reinterprets with respect to his own scientific views.[43]

Let us add that the historical survey of motion was conceived as part of a larger inquiry on pre-Copernican cosmology that Duhem carried out during the last years of his life, resulting in in his ten-volume *Système du monde*.[44] With this major work he established himself as one of the leading historians of science of his time. It is generally acknowledged that he gave the first thorough investigation of medieval science. He explored with a wealth of detail two essential contributions of the Middle Ages: the theory of impetus and the theory of the latitude of forms. The former relating to the motion of bodies, and the latter pertaining to intensive properties and their variations, represented a break with Aristotle and a step toward Galileo. In consequence, the birth of modern science appeared as a continuous, cumulative process. But he also analyzed the fundamental notions of our conceptual scheme — not only motion, but space, time, matter, etc. — as they have changed over centuries. Duhem thus provided a historical backdrop for current debates surrounding these notions. His scientific definitions were grounded on a thorough examination of past conceptions.

To be sure Mach and Duhem developed different accounts of the historical development of science. Mach was ready to take into account some of Duhem's findings concerning the Middle Ages, but not to revise entirely the Enlightenment conception of the scientific revolution, as an event carrying political and social values.

Conclusion

In the preceding pages we went over the evidence for the "far-reaching agreement" between Mach and Duhem. They can be considered as belonging to a broad movement of thought that questions classical mechanicism and causal explanations. They endeavored in common to integrate new branches of physics and to put forth economical description. Mach and Duhem were allied in their fight to promote such views in spite of strong resistance.

[43]For a historical survey after the advent of relativity theory, see Max Jammer, *Concepts of Space: The History of Theories of Space in Physics*. Cambridge, Mass.: Harvard University Press 1954. With an illuminating foreword by Einstein.

[44]Duhem, *Le système du monde*. Paris: Hermann, 10 vols, 1913–1959.

They also encouraged their readers to take note of the similarities of their conceptions. The members of the Vienna Circle were attentive to this proximity. Moreover, they combined the complementary analyses of both thinkers, in order to achieve a synthetic view, allowing both for axiomatic development and empirical grounding. As Philipp Frank has it, with regard to Duhem's holism: "One notes how far Duhem has proceeded on the way from Mach's conception of a physical theory to the conception which was later advocated by logical empiricism".[45]

We nevertheless encountered some differences between the two philosopher-scientists. Duhem condemned Maxwell's recourse to mechanical models, on the grounds that multiplying differing, discordant models would be an obstacle to the unity of physics. In addition, he refused Mach's principle concerning inertia, because one cannot speak meaningfully of the general order of the universe. But he also showed how economy of thought took on different forms within a precisely delineated analysis of theory structure. Whereas Duhem's highly formal unification of physics within the framework of a general thermodynamics provided a logically penetrating account, Mach's pluralistic methodology was more flexible and receptive to innovations.

Of course, the early reception of Mach and Duhem highlighted certain points to the detriment of others. In particular, the importance ascribed to history of science was in the main neglected. Owing to the evolution of philosophy of science during the past 20 years, we can now appreciate more readily this historical concern. Indeed, Mach and Duhem associated closely rational analysis and historical study. What they asserted thereby is that the way science actually developed is essential for the philosopher. Such a twofold approach has the advantage of connecting reflections on science with scientific practice.

Furthermore, they already anticipated — more precisely than is generally believed — the perspective of a historical epistemology. At the time Louis Couturat, clearly alluding to Mach, described his view as an "evolutionist epistemology",[46] and Rey, drawing on both Mach and Duhem coined the expression "historical epistemology"[47] to qualify the method he was promoting. Such a perspective, integrating historical study and conceptual analysis, has come again today to the fore.[48] It is not only of interest to recall its origins, but also to submit to a precise scrutiny early instances of this method, so as to determine, in knowledge of the fact, the role history is to play with regard to philosophy.

[45]Philipp Frank, *Modern Science and its Philosophy.* Cambridge: Harvard University Press 1949, p. 16.

[46]Louis Couturat, "La logique et la philosophie contemporaine", in: *Revue de métaphysique et de morale* 14, 3, 1906, pp. 318–341.

[47]Abel Rey, *La théorie de la physique chez les physiciens contemporains.* Paris: Alcan 1907, p. 13.

[48]For a recent example, see Matthias Schemmel, *Historical Epistemology of Space*: From Primate Cognition to Spacetime Physics. Vienna: Springer 2016.

Chapter 45
Duhem on Thought Experiments. Or: Did Duhem Really Reject Mach's Thought Experiments?

Marco Buzzoni

Abstract The conventional interpretation that Duhem condemned outright any type of thought experiment in Mach's sense should be, at least in large part, rejected. There are some interesting remarks made by Mach and Duhem that suggest a very different reading. In this paper I shall take up and develop these remarks, which lead to the conjecture that Duhem's criticism was not intended to be a complete rejection of thought experiments but a completion and supplement of Mach's theory. Duhem, while retaining the core idea of Mach's theory – according to which thought experiments cannot break free from the ultimate authority of real world experiments –, laid particular emphasis on the perils of thought experiment, which Mach had overlooked or, at least, underestimated.

Introduction

According to a traditional, stereotyped interpretation, which is ubiquitous in the literature, Duhem, in Section 4 of the chapter 7 of *La théorie physique*, rejected any type of scientific thought experiment (henceforth TE) in Mach's sense of the phrase.

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Brown and Fehige for example say that “Duhem [. . .] is almost alone in what has been understood as an outright condemnation of scientific thought experiments”.[1]

The evidence, however, does not, I think, support this interpretation. This reading, in the first place, clashes with the fact that Mach himself, albeit in one, very brief remark added to the second edition of *Erkenntnis und Irrtum* (1906), suggested a very different reading of Duhem’s position. He cited Duhem’s arguments against the use of “expériences fictives” in physics *approvingly, tacitly presupposing that Duhem’s term and notion of “expérience fictive” correspond essentially to his own, ‘Gedankenexperiment’.*

It is Mach’s reading that I am going to take up and develop in the present paper, by examining and establishing with exactitude the scope of Duhem’s criticism. After a brief reconstruction in Sect. 45.2 of Mach’s account of TE, the Sects. 45.3 and 45.4 deal with the difficulties of the stereotyped reading of Duhem’s criticism of TEs. As we shall see, Duhem’s criticism was not intended to be a complete rejection of TEs; it was intended to be a completion and supplement of Mach’s theory. It may be said that Duhem, while retaining the core idea of this theory – according to which real world experiments are the ultimate criterion of TEs–, laid particular emphasis on the perils of TE, which Mach had overlooked or, at least, underemphasized. For this reason, Duhem introduced a new title under which particular TEs may be mentioned or discussed: “expériences fictives”, or – as Adler translated into German – “fingierte Gedankenexperimente”. A comparison of this interpretation with what Mach and Duhem wrote on this point, as well as with a close reading of the relevant passages in Duhem will confirm this interpretation.

[1] James Robert Brown and Yiftach Fehige, “Thought Experiments”, The Stanford Encyclopedia of Philosophy (Spring 2016 Edition), Edward N. Zalta (ed.), URL = http://plato.stanford.edu/archives/spr2016/entries/thought-experiment/. Cf. also: Wolfgang Yourgrau, “On the Logical Status of So-called Thought Experiments”, in: *Proceedings of the 10th International Congress of the History of Science*, vol. I., Paris: Hermann 1964, pp. 359–362: 360; James Robert Brown, “Thought Experiments since the Scientific Revolution”, International Studies in the Philosophy of Science, 1, 1986, pp. 1–15: 2; Roy A. Sorensen *Thought Experiments*, Oxford: Oxford University Press 1992, pp. 48–49; Nancy J. Nersessian, “In the Theoretician’s Laboratory: Thought Experimenting as Mental Modeling”, in: *PSA: Proceedings of the Biennial Meeting of the Philosophy of Science Association,* Vol. 2, 1993, pp. 291–301: 291; Ulrich Kühne, *Die Methode des Gedankenexperiments*, Frankfurt a.M.: Suhrkamp 2005, pp. 203–205; Aspasia S. Moue, Kyriakos A. Masavetas, Haido Karayianni, “Tracing the Development of Thought Experiments in the Philosophy of Natural Sciences”, in: *Journal for General Philosophy of Science*, 37, 2006, pp. 61–75: 65; Mervi A. Asikainen and Pekka E. Hirvonen, “Thought Experiments in Science and in Science Education”. In: Michael R. Matthews (ed.). International Handbook of Research in History, Philosophy and Science Teaching, Dordrecht: Springer 2014, pp. 1235–1257: 1238.

Mach and the Intrinsic Link Between TEs and Real World Experiments

An important feature of Mach's account of real and TEs is that it highlights a fundamental similarity between the two types of experiments, namely the "method of variation" (*Methode der Variation*): while in real experiments what is varied are natural circumstances, in TEs it is representations that are made to vary in order to see the consequences of these variations.[2]

This similarity between real and TEs is connected with the fact that the latter presuppose that some real experiments have already been performed, at least at the level of common sense. As Mach says, the play of imagination can properly start only when physical experience is sufficiently rich.[3] From Mach's radical empiricist perspective, TEs must draw on a previous stock of experiences which accounts for their validity, as well as for their defects and errors, and explains how they can produce new knowledge apparently without resorting to experience.

In this way, Mach set down what was to become the typical empiricist solution to the fundamental problem of any theory of TE: TEs mobilise previously acquired information and skills, and thus enlarge our knowledge and significantly contribute to its progress.[4] As shown by Stäudner and Buzzoni,[5] there is a tension in Mach's conception of the primacy of real over TE into which I cannot enter now. Notwithstanding this, there is no doubt that the main tendency of Mach's view about the relationship between real world experiments and TE is to be found in the claim that real experiments are chronologically and logically prior to TEs. Chronologically because, to be able to formulate TEs, one must have had real experiences; logically because, when faced with some doubt about the conclusions of a TE, we have to resort to real experiments:

> The outcome of a thought experiment, and the surmise that we in our thoughts [*in Gedanken*] link with the varied conditions can be so definite and decisive that the author rightly or wrongly feels able to dispense with any further tests by physical experiment.

[2]Ernst Mach, *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung,* Leipzig: Barth, 2th edition 1906, p. 203. Engl. transl. (of the 5th ed. 1926) by T.J. McCormack, *Knowledge and Error*, Dordrecht: Reidel 1976, p. 149. French Transl. (of the 2nd ed.) by Marcel Dufour, *La connaissance et l'erreur*, Paris: Flammarion 1908, p. 213.

[3]*Ibid.*, pp. 187–188, Engl. transl., pp. 136–137.

[4]Cf. Ernst Mach, *Die Mechanik in ihrer Entwickelung. Historisch-kritisch dargestellt*, Leipzig: Brockhaus, pp. 27–28, English Transl by J.J. McCormack. *The Science of Mechanics. A Critical and Historical Account of its Development*, London: Open, 1919, pp. 27–28. Cf. in the same sense Mach, *Erkenntnis und Irrtum*, loc. cit., pp. 187–188, Engl. transl., pp. 136–137.

[5]Cf. Frank Stäudner, *Virtuelle Erfahrung,* Diss. Friedrich-Schiller-Universitat, Erlangen 1998, and Marco Buzzoni, *Thought Experiment in the Natural Sciences*, Würzburg: Königshausen+Neumann, 2008, chapter 2, § 1.

> [...] However, the less certain their outcome, the more strongly thought experiments urge the enquirer to physical experiment as a natural sequel that has to complete and to determine the result.[6]

According to the main tendency of Mach's account, TEs must not only proceed from experience, but also return to it, because experience is the ultimate criterion of all sorts of TE, and the warrant for any conclusion based upon a TE can be found only in experience.[7]

Mach's Interpretation of Duhem

I turn now, after this brief reconstruction of some of the fundamental aspects of Mach's theory of TE, to Duhem's criticism of "expériences fictives". As already mentioned, the conventional reading of this criticism is that Duhem condemned outright Mach's account of scientific TEs. However, a footnote added by Mach to the second edition of *Erkenntnis und Irrtum* (1906) is in conflict with this interpretation. For there we read:

> Duhem (Théorie physique, p. 331 [Engl. transl.: 201–202]) rightly warns against representing thought experiments [*Gedankenexperimente*] as though they were physical, that is pretending that *postulates* are *facts*.[8]

In this passage, instead of disputing Duhem's criticism against the "expériences fictives" contained in *La théorie physique*, Mach quotes it with approval. If he had interpreted Duhem's criticism of TEs as a blanket rejection, he would have certainly disputed it *rather than cite it approvingly, implicitly taking it as being little more than a restatement of his own view, and even tacitly assuming that Duhem's term essentially corresponds to his own, 'Gedankenexperiment'*. Mach's passage suggests very strongly that Duhem's criticism of TEs was, in its essentials, coherent with the fundamental requirement we have seen to be fundamental to Mach's account of TEs, namely that they are based on real world experiments, which are the ultimate criterion of their truth. In this way, Mach suggests an interpretation that is very different from the stereotype we have seen to be taken for granted in the literature about TEs.

The most obvious way out of this difficulty might lie in regarding Mach's remark as a gross misinterpretation of Duhem's criticism. However, we have no grounds for making a similar reproach to Mach. Also Kühne – one of the very few authors who have seriously looked for a way out of the traditional reading - concedes that there is no adequate explanation of Mach's misunderstanding, but, making a virtue of

[6]Mach, *Erkenntnis und Irrtum*, loc. cit., pp. 188–189, Engl. transl. (slightly modified), pp. 137–138.

[7]For more details on this point, see Buzzoni, *Thought Experiment in the Natural Sciences*, loc. cit., chapter 2, § 1.

[8]Ibid., p. 188, fn., Engl. transl. (original italicisation restored), p. 146, fn.

necessity, he interprets the passage in question in the sense that Mach "understood Duhem's criticism correctly *and* accepted it".[9] According to Kühne, Mach withdrew his account of TE, but he said nothing, whether in public or in private life, in order not to become embroiled in a dispute with Duhem, whom Mach thought to be a "comrade in arms for the same cause in the philosophy of science", that is, for the elimination of metaphysical elements from science.[10]

Is this a tenable view? It is easy to see that it is not, and for many reasons. Strictly speaking, this interpretation only shifts the problem from Mach's improbable misinterpretation to the even more improbable lack of some withdrawal on the part of him. Kühne's insistence that Mach found Duhem's criticisms so compelling as to abandon totally his conception of TE, appears to be totally *ad hoc* unless some independent reason can be given for it.

So the question: is there any evidence in Mach's writings that he later distanced himself from his own interpretation of TEs? The only clue that we get from Kühne in favour of this is a passage in which Mach replied to Adler's suggestion that, in translating Duhem's *La théorie physique* into German, they could simply leave out its second part (in which, it is to be remembered, Duhem's criticism of thought experimenting is contained). In this passage Mach rejected Adler's advice, and said that he was quite content with the degree of agreement with Duhem, notwithstanding the fact that Duhem was "an admirer of Thomas Aquinas".[11]

The main problem with this argument is that it shows the opposite of what Kühne thinks. First, Duhem's considerations about this point are placed in the context of a clear distinction between physics and metaphysics, and it seems much more probable that Mach emphasized his own *agreement* with Duhem from this point of view, as he did on several other occasions. Second, the fact that Mach thought Duhem to be a "comrade in arms" for the same cause in the philosophy of science not only does not explain Mach's silence on such an important issue, but clashes with it. If Mach had accepted Duhem's critique of his concept of TE, he should have openly rejected his own theory of TE – and not only in private, but still more in public – in order to render his case against metaphysics even more coherent and convincing. The only way to avoid this is to cast doubt upon Mach's intellectual honesty. However, we have no reason for doing so. On the contrary, so far as we know, Mach was immune from flattery towards his colleagues,[12] and we know many cases in which, when confronted with Duhem's objections, he did not hesitate either

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[9] Kühne, *Die Methode des Gedankenexperiments*, *loc. cit.*, p. 204.

[10] Ibid., pp. 203–204.

[11] Ernst Mach, "Brief Machs an Friedrich Adler vom 22. April 1908". In: T. Blackmore and K. Hentschel (eds.), *Ernst Mach als Aussenseiter. Machs Briefwechsel über Philosophie und Relativitätstheorie mit Persönlichkeiten seiner Zeit: Auszug aus dem letzten Notizbuch (Faksimile) von Ernst Mach*, Vienna: Braumüller 1985, p. 50; also in Rudolf Haller and Friedrich Stadler (eds.), *Ernst Mach-Werk und Wirkung*, Vienna: Hölder-Pichler-Tempsky 1988. Cf. also Kühne, *Die Methode des Gedankenexperiments*, *loc. cit.*, p. 205.

[12] Cf. Klaus Hentschel, "Die Korrespondenz Duhem—Mach: Zur 'Modellbeladenheit' von Wissenschaftsgeschichte", in: *Annals of Science* 45, 1988, pp. 73–91: 86.

to recognize his mistakes and change his mind or to reply and record all points of disagreement. Even though Mach sought agreement with Duhem, where it was not reached he provided a fair statement of disagreement.[13]

Moreover, up to this point I have assumed without question the most important premise of Kühne's interpretation, that is, that Mach made no further reference to Duhem's criticism against TE, except the one we have already discussed. But this is probably false. There is a passage of Mach's "Vorwort" to the German translation of *La théorie physique* that can be interpreted in this way. This passage suggests disagreement, though not a very serious one, or, more precisely – very much in accordance with the view I am advocating–, some divergences in spite of a substantial agreement. Mach writes:

> Duhem regards the model, like the picture, as a parasitic growth. That and where he seems here to go too far, I have explained elsewhere.[14]

There is some reason to think that Mach is here alluding Duhem's objections against TEs, given his reference to Duhem's attack on models. As is well known, it is in the context of his criticism of the inductive method that Duhem raised the issue of TEs. But Duhem's criticism of the inductive method is intimately connected with an illegitimate employment of imagination in science, which does not tend to construct a scientific "theory" in Duhem's sense (that is, as a "symbolic construction of the human mind"[15]), but only serves the purpose of inventing intuitive hypotheses or models that are not systematically connected with one another.[16] From this point of view, we may say that, according to Mach, Duhem's objections against TEs are in the main correct, even though he seems "to go too far" in rejecting perspicuity and intuitive representation. In fact, Mach ascribes to pictures and intuitive representations a key role in science and in thought experimenting,[17] so that we should not be too surprised to find here one of the most noteworthy divergences from Duhem.

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[13]Cf. for example Ernst Mach, *The Science of Mechanics. A Critical and Historical Account of Its Development*, Supplement to the Third English Edition Containing the Author's Additions to the Seventh German Edition, Translated and Annotated by Philip E. B. Jourdain, Chicago and London: Open Court 1915. See also Hentschel, "Die Korrespondenz Duhem", *loc. cit.*, especially pp. 86–88.

[14]Ernst Mach, "Vorwort zur deutschen Aufgabe". In: Pierre Duhem, *Ziel und Struktur der physikalischen Theorien* (Transl. by F. Adler of Pierre Duhem, *La Théorie physique. Son objet et sa structure*, Paris: Chevalier & Rivière, English translation by P. P. Wiener of the 2nd ed., 1914, *The Aim and Structure of Physical Theory*, Princeton: Princeton University Press, 1954; quotations are from this edition), Leipzig: Barth 1906 (repr. Meiner, Hamburg, 1998, with Introduction by Lothar Schäfer), pp. III–IV: IV.

[15]Cf. Pierre Duhem, *Les théories électriques de J. Clerk Maxwell. Étude historique et critique*, Paris: Hermann 1902, pp. 6–7, or, more generally, Duhem, *La Théorie physique*, chap. 2, § 1.

[16]Cf. *ibidem*, chap. 3, above all § 10, where he objects to the English scientists of confusing model with theory.

[17]Cf. for example Mach, *Erkenntnis und Irrtum*, p. 234, Engl. transl., pp. 172–173.

Duhem's Criticism of "*expériences fictives*"

In the preceding section we have seen that what Mach said about Duhem conflicts with the conventional reading of Duhem's criticism against TEs. But we come to the same conclusion if we take into account what Duhem said and did not say concerning his agreements and disagreements with Mach's theory of TEs.

In the first place, the traditional interpretation leaves totally unexplained the fact that we cannot find any explicit expression of disagreement concerning Mach's view about TE in the many passages in which Duhem made reference to Mach.

Second, a serious difficulty with the traditional interpretation is posed by the fact that, instead of using the most natural French translation of "Gedankenexperiment" – that is, "expérimentation mentale"–, Duhem used "expérience fictive". The question arises: Why did Duhem introduce in 1904 (and reconfirm in 1906) a brand-new phrase for what Mach had called "Gedankenexperiment", *even though he knew that this expression had already been translated into French by* "expérimentation mentale"?[18] For it must be remembered that Duhem knew the French translation of Mach's *Mechanik* since 1903 – that is, a year before its publication in 1904, when he reviewed it for the "Bulletin des Sciences Mathématiques".[19]

Both difficulties disappear in the light of the interpretation here defended, according to which Duhem's criticism was probably regarded not only by Mach, but also by Duhem *not as a complete rejection of TEs, but rather as a completion and supplement of Mach's theory*.

The first difficulty does not arise at all. As far as the second is concerned, a plausible answer is to be found in Duhem's review of the French translation of Mach's *Mechanik*, which, besides being entirely consistent with the reading here proposed, also provides an important clue as to why Duhem introduced a new expression. Here Duhem says of a long quotation from the *Mechanik,* in which Mach exhorts us to *imagine nothing* beyond "the observable facts", that "it seems to us that the thoughts here expressed are right and deep [les pensées qui y sont exprimées nous semblent justes e fortes]".[20] Here is a part of the quotation:

> Pour rester fidèles à la méthode qui a conduit les chercheurs les plus illustres, Galilée, Newton, S. Carnot [Duhem: Sadi-Carnot], Faraday, J.R. [Duhem: J.-R.] Mayer, à leurs grandes découvertes, nous devons limiter notre science physique à l'expression des *faits observables,* sans construire des hypothèses *derrière* ces faits, où plus rien n'existe qui puisse être conçu ou prouvé. Nous avons donc simplement à découvrir les dépendances réelles des mouvements des masses, des variations de la température, des variations de

[18]Cf. Mach, *Die Mechanik in ihrer Entwickelung*, French Transl., pp. 462 and 490–491.

[19]Cf. Pierre Duhem, „Mach (Ernst). La Mécanique. Étude historique et critique de son Développement (Compte Rendu) », in: *Bulletin des Sciences Mathématiques*, 2. Serie, 27, 1903, pp. 261–283.

[20]*Ibid.*, p. 278.

> valeur de la fonction potentielle, des variations chimiques, sans nous *imaginer* rien d'autre sous ces éléments, qui sont les caractéristiques physiques directement ou indirectement données par l'observation.[21]

It is sufficient to mention the important role played by imagination in Duhem's criticism of crucial experiments, in order to get a clue that it is this imaging – and not imagination as the capacity of the mind to counterfactually anticipate in thought what specific answer nature will give to our scientific questions put to nature–, which makes Duhem speak of "fictitious experiments" and mark off these latter from Mach's TEs. As Duhem writes:

> Between two contradictory theorems of geometry there is no room for a third judgment; if one is false, the other is necessarily true. Do two hypotheses in physics ever constitute such a strict dilemma? Shall we ever dare to assert that no other hypothesis is *imaginable* [French: *imaginable*]? Light may be a swarm of projectiles, or it may be a vibratory motion whose waves are propagated in a medium; is it forbidden to be anything else at all?[22]

In view of this, my conjecture is that Duhem wanted to mark off an illegitimate use of imagination from a legitimate one. For this purpose, he introduced a brand-new phrase for what Mach had called "Gedankenexperiment", even though he knew that this expression had already been translated into French by the most natural expression "expérimentation mentale". In other words, he set beside, not against Mach's expression, that of "expérience fictive", which expresses his rejection of any anticipation of nature in thoughts that loses connection with experimental practice. "Fictitious experiments" are the product of an illegitimate use of the imagination, namely, the same one that, according to Mach, leads to assume occult causes beyond phenomena.[23]

We find another point in favour of this conjecture in Mach's *Mechanik.* Here an implicit distinction is made between a responsible and a too free use of TEs, even though Mach does not make any terminological distinction. With reference to Carl Newmann, Mach writes:

> the celebrated mathematician appears to me to have made here too free a use of thought experiment [*Gedankenexperiment*], the fruitfulness and value of which cannot be denied. When experimenting in thought [*im Gedankenexperiment*], it is permissible to modify *unimportant* circumstances in order to bring out new features in a given case. But that the universe is without influence [*Dass aber die Welt einflusslos ist*] is not to be antecedently assumed.[24]

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[21]Mach, *Die Mechanik in ihrer Entwickelung*, *loc. cit.*, French Transl., pp. 466, last italics added; the points where Duhem's quotation deviates from the published version are enclosed in square brackets.

[22]Pierre Duhem, La Théorie physique, *loc. cit.*, p. 311, English transl., p. 189 (italics added).

[23]In this connection, it is interesting to note that the German expression "fingierte Gedankenexperimente" used by Adler to translate into German Duhem's "expériences fictives" (cf. Duhem, *Ziel und Struktur der physikalischen Theorien*, *loc. cit.*, p. 269) had already been employed by Mach himself, though in an essentially neutral context (Mach, *Die Mechanik in ihrer Entwickelung*, *loc. cit.*, p. 32).

[24]Mach, *Die Mechanik in ihrer Entwickelung*, *loc. cit.*, p. 291, Engl. transl. (slightly modified), p. 572.

Because we know that Duhem reviewed Mach's *Mechanik*, and in consistency with what has already been said, it seems to me not exceedingly hazardous to say that passages such as the above may have suggested to Duhem the advisability of marking off TEs that are dangerous, namely "fictitious" one.

To sum up. The conventional interpretation that Duhem condemned outright any type of TE in Mach's sense is implausible if we consider both Mach's and Duhem's claims on this point. If we appeal to their utterances and silences, all the evidence we have sweeps us towards the reading defended here, according to which Duhem's criticism was not intended to be a complete rejection of TEs; it was intended to be a completion and supplement of Mach's theory. Duhem, while retaining the core idea of this theory – according to which TEs cannot break free from the ultimate authority of real world experiments–, laid particular emphasis on the perils of TE, which Mach had overlooked or, at least, underestimated. So far as physics is concerned, he mistrusts any anticipation of nature in thoughts that posits unobservable causes inaccessible to experimental practice. This mistrust led him to reserve the word 'fictitious experiments' for forms of TEs that are seemingly means for investigating the world, but that are pieces of metaphysics in disguise.

The question we have now still to consider is whether such an interpretation stands up to a careful reading of the relevant passages that Duhem devoted to TEs. As we shall see, a close reading of Duhem's text confirms my interpretation.

Duhem recognises four kinds of "fictitious experiments": the unperformed experiment, the experiment which would not be performed with precision, the absolutely unperformable experiment, and the absurd experiment. The first two are invented only to convince students that some assumptions, which are still only hypothetical, rest on an experimental basis. Concerning the first of these two kinds of experiment, Duhem writes (using the word "imaginer" in the negative sense already spoken of):

> Obliged to invoke a principle which has not really been drawn from facts or obtained by induction, and averse, moreover, to offering this principle for what it is, namely, a postulate, the physicist imagines [*imagine*] an experiment which, were it carried out with success, would possibly lead to the principle whose justification is desired. To invoke such a fictitious experiment [*expérience fictive*] is to offer an experiment to be done for an experiment done.[25]

The second kind of fictitious experiment goes wrong by yielding results that are too inaccurate to be of any value:

> the very indecisive and rough results it would produce could undoubtedly be put into agreement with the proposition claimed to be warranted; but they would agree just as well with certain very different propositions; the demonstrative value of such an experiment would therefore be very weak and subject to caution. The experiment that Ampère imagined in order to prove that electrodynamic actions proceed according to the inverse square of the distance, but which he did not perform, gives us a striking example of such a fictitious experiment.[26]

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[25] Duhem, *La Théorie physique*, *loc. cit.*. p. 331, English Transl. (slightly modified), pp. 201–202.

[26] *Ibid.*, p. 331, English Transl. (slightly modified), p. 202.

In both cases, there is nothing which Mach would not have accepted. In both cases, Duhem does not wish to belittle the value of the formulation of the experimental question, but only to denounce the methodological mistake of those who try to pass off his wild speculations or too inaccurate and relatively indeterminate results in the guise of facts that have been experimentally ascertained.

The third kind of fictitious experiment "is not only not realized but incapable of being realized; it presupposes the existence of bodies not encountered in nature and of physical properties which have never been observed."[27]

Again, in this there is nothing which Mach should not have accepted. Duhem does not give an explicit definition of philosophical or metaphysical TEs, but what he says here seems to allude to them. He rightly rejects *scientific* TEs that do not have an at least implicit reference to a real experiment. By the way, I think he is right about this. A TE would be devoid of empirical meaning (that is, it would not be a TE proper to empirical science) if, in formulating and evaluating it, it did not possess, even while it is still in our minds, an intrinsic reference to experience. This is the ultimate reason why all empirical TEs must be thought of as translatable into real ones, and all real experiments as realizations of thought ones.[28]

Finally, Duhem discusses the "absurd experiment" ("expérience absurde") – "a form more illogical than all the others" – which "*claims to prove a proposition which is contradictory if regarded as the statement of an experimental fact*."[29] In this kind of TE assumptions are made that, though they are presented as facts of experience, it is "contradictory" to conceive in this way.

The interesting question then arises as to how "contradictory" should be understood. Duhem illustrates the absurd fictitious experiment by quoting a passage from Joseph Bertrand's *Leçons sur la Théorie mathématique de l'Électricité.* Here it is argued that, "if we accept it as an experimental fact that electricity is carried to the surface of bodies, and as a necessary principle that the action of free electricity on the points of conductors should be null," we can deduce that electrical attractions and repulsions are inversely proportional to the square of the distance. According to Duhem, however, the proposition "There is no electricity in the interior of a conducting body when electrical equilibrium is established in it," cannot be regarded as the statement of an experimental fact:

> how can we go about establishing whether there is or is not any electricity at this point? It would be necessary to place a testing body there, and to do that it would be necessary to take away beforehand the copper that *is* there, but then this point would no longer be within the mass of copper; it would be outside that mass. We cannot without falling into a logical contradiction take our proposition as a result of observation.[30]

[27] *Ibid.*, 332, English Transl., p. 202.

[28] Cf. Buzzoni, *Thought Experiment in the Natural Sciences*, *loc. cit.*

[29] Duhem, *La Théorie physique*, p. 333, English Transl., p. 201 (original italicisation restored).

[30] *Ibid.*, pp. 333–334, English Transl., p. 203.

Duhem's argument may be viewed as problematic for many reasons. However, the strength of Duhem's argument is much less important than its meaning. If we look at the spirit of Duhem's definition of absurd TEs, we may say that its point is similar, though distinct to that of the preceding kinds of fictitious experiments. To see this, it is important to remember that Duhem's objections against fictitious experiments are set forth in the section entitled "6. Consequences Relative to the Teaching of Physics". Their general purpose is to illustrate that the erroneous principle that each hypothesis of physics may be subjected in isolation to experimental tests leads to the unacceptable conclusion that physics "would be taught as geometry is: hypotheses would follow one another as theorems follow one another; the experimental test of each assumption would replace the demonstration of each proposition".[31]

In this context, Duhem's criticism of absurd experiments means essentially that we need to clearly distinguish between the propositions of geometry, which are neither to be confirmed nor refuted by experience, and the theories of physics, which are a system of mathematical propositions that aim to represent as simply, as completely, and as exactly as possible a set of experimental laws. Therefore, Duhem rejects a kind of TE that assumes as initial hypotheses propositions that are treated as facts, whereas they are freely chosen and experimentally testable only so far as they are connected with the experimental laws that the theory intends to represent as simply, as completely, and as exactly as possible. This is the sense in which we have to understand the "contradiction" of which Duhem speaks: it is a contradiction to consider some initial hypotheses as logico-mathematical propositions that can neither be proved nor disproved by experience, and at the same time as propositions that express a scientific theory, which must be confronted with experience.

Just as in the case of the preceding kinds of fictitious TEs Duhem, like Mach, only emphasises that the ultimate authority of TEs consists in experience, so also in the case of the "absurd experiments". In all cases, one must keep clearly in mind that TEs have their value only as they are based on real experiments or prepare them. Again, there is nothing in Duhem's remarks that explicitly rejects thought experiments in Mach's sense.

Thus we come along three diverse lines to the same result. The conventional interpretation seems to be in conflict (1) with Mach's utterances and silences, (2) with what Duhem said and did not say concerning his agreements and disagreements with Mach's account of TEs, and (3) with a close reading of the few pages Duhem devoted to the critique of fictitious TEs. Therefore, we are in a position to say that a fundamental error has been committed in interpreting this author as rejecting TEs clearly and completely.

[31] *Ibid.*, p. 329, Engl. Transl., p. 200.

Conclusion

As I have tried to show, the conventional interpretation that Duhem condemned outright any type of TE in Mach's sense should be, at least in large part, rejected. In this paper I took up and developed a different reading, first suggested by Mach, according to whom Duhem, strictly speaking, only denied that real world experiments are the ultimate criterion for evaluating scientific TEs. Analysing remarks made both by Mach and Duhem, and taking a second look at the relevant passages in Duhem's *La théorie physique* from a different angle, I maintained that Duhem only proscribed some kinds of TE, not TEs as such.

This does not mean that there is no difference between Mach's and Duhem's account of TEs. As mentioned before, there is, indeed, a difference in emphasis and focus between Mach's and Duhem's account of TEs. A more detailed exposition of this point will have to await another occasion because there is no space available to discuss further this point. But what I have been saying should at least make clear that this difference has to be seen against the background of a crucial point of convergence. Duhem adopts a very cautious attitude towards the use of TEs in physics, but what he rejects is not so much the use of TEs *per se* as their improper use, i.e. their use independently of real experiments, or still better, the risk of obliterating the fundamental distinction between real and TEs. He accepts in the main the very Machian point that real world experiments are the ultimate criterion of TEs, but a different emphasis is found in Duhem's considerations: worries about the perils involved in TEs predominate over the emphasis placed by Mach on their scientific fruitfulness. Duhem retained the core idea that TEs cannot break free from the ultimate authority of real world experiments, but laid stress upon the possible perils of TE, which Mach had overlooked, or better still, underestimated. For this reason, he introduced a new rubric, under which particular TEs may be mentioned or discussed: that of "expérience fictives," or – as Adler translated into German – of "fingierte Gedankenexperimente".

Chapter 46
Auguste Comte and the Monistic Positivism of Ernst Mach

Laurent Clauzade

Abstract A comparison between Ernst Mach and Auguste Comte is perfectly relevant: they both belong to the history of positivism. However relevant, such a comparison is complicated by three main difficulties. Firstly and secondly the scientific and the philosophical contexts are deeply different; thirdly, there is only a small number of direct (and often opaque) references to Comte in the works of Mach. From these issues it appears that the comparison between the two authors is necessarily a reconstruction, and not a commentary on explicit passages from Mach's works.

In this chapter we discuss two problems: on the one hand the question of the relationship between the history of science and the theory of knowledge and on the other hand the status of positivist explanation. The result of our enquiry, on both topics, is paradoxical. If we leave aside the system in which they are integrated, many claims endorsed by the two authors have the same 'positivist' sound and the area of agreement seem very large. However, if we link these claims with the systems they respectively belong to, it appears that such an agreement rests on a misunderstanding. The definition of the notion of "phenomenon" and the problem of the analysis of sensations will be the core of the disagreement. Such a disagreement explains in particular the non-reception of the *Analysis of Sensations* in the French twentieth century epistemology.

Introduction

It is always difficult to compare two authors, and the identification of similarities and differences is often subjective. Yet a comparison between Ernst Mach and Auguste Comte is perfectly relevant: they both belong to the history of positivism.

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Auguste Comte is the founder of the first positivism and at least popularizes the word "positivism" to refer to this new philosophical school that states that valid knowledge is based on the natural sciences. Although Ernst Mach always refused for himself the name of philosopher in its German acceptation perhaps he would have accepted, as Richard von Mises notes it,[1] the French meaning attached to the expression 'philosophie positive'. Mach is also a major figure of the history of positivism from a retroactive viewpoint: the retrospective reception of the Vienna circle presents him as a forerunner of logical positivism. Indeed it appears that, Mach, together with Pierre Duhem, belongs to a second phase of the history of positivism between the Comtean period and logical empiricism. In such a 'mid-positivism' John Stuart Mill and Auguste Comte, even if they remain important references, don't stand anymore on the foreground, as it was still the case for Brentano who wrote extensively on both authors. For example, Mach deals many times with the relations between different sciences, but, unlike Brentano before or Ostwald at the same period,[2] he never referred to Comte's classification of sciences. Nonetheless, Mach didn't hesitate to pay tribute, in a rather official context, to the epistemic and moral theses of Auguste Comte[3]: at least this address shows that he recognized that he was part of the same philosophical tradition.

However relevant, such a comparison between Mach and Comte is complicated by three main contextual issues. First the scientific contexts involved are quite different. In physics the early decades of the nineteenth century were dominated by the large syntheses of Laplace and Lagrange, and for Comte mechanics was thoroughly completed. On the contrary, at the end of this century electromagnetism and thermodynamics, which were hardly known to Comte, opened new fields of research and the foundations of mechanics were again an open issue.

[1]See Richard von Mises, "Ernst Mach and the empiricist conception of science", in: Robert S. Cohen/Raymond R. Seeger, *Ernst Mach Physicist and Philosopher*. Dordrecht: D. Reidel Publishing Company, 1970, p. 265.

[2]On this point see Denis Fisette, "Franz Brentano et le positivisme d'Auguste Comte" in Laurent Fedi (Ed.) *La réception germanique d'Auguste Comte*, *Cahiers philosophiques de Strasbourg* 35, 2014, pp. 85–128, and Jan-Peter Domschke, "L'influence d'Auguste Comte sur les conceptions philosophique de Wilhelm Ostwald", in L. Fedi, *op. cit.*, pp. 197–215.

[3]See "Inauguration du monument d'Auguste Comte sur la place de la Sorbonne à Paris. Hommage international à Auguste Comte", in: *Revue Occidentale*, 2nd série, t. XXVI, 2nd semester, 1902, p. 98: "Address of M. Ernst Mach, Professor in the Faculty of Philosophy of the University of Vienna (trans. by Mr. Imans, read by Mr. Laporte)./You have just erected a statue dedicated to the great French philosopher, Auguste Comte: to the man who has found in the exact sciences the clear source of a sound conception of the Universe; to the man who has fought with energy against metaphysical superstitions; to the moralist whose asceticism was worthy of Spinoza's, who had to suffer the same hostility from his contemporaries, and who wrote down on his flag the love of Humanity, who devoted his life to the Great-Being. Held away from you by imperative duties, I would like to associate myself to the international homage to the great thinker. This monument attests that the world has not forgotten Auguste Comte, and the Humanity keeps a thankful memory of him. But he erected for himself a much more imposing monument through his life and his works, the influence of which is growing every day among us." (Our translation; the German original text is missing in the Archives of the Maison d'Auguste Comte).

In biology we found two contrasting contexts as well. Mach endorses Darwin's evolutionism, both in his conception of biology and in his conception of the history of scientific thought: concepts such as evolution, adaptation, or 'struggle for self-preservation' are omnipresent in Mach's general views on science and used in an unequivocal Darwinian meaning. On the opposite side Comte is fixist, and advocates a preformationist conception of individual and social (or historical) development: the whole evolution of Humanity, including that of science, does not imply genetic modifications, but is analogous to the growth of an individual organism. In a word, Comte's historical evolutionism is predetermined by a fixed conception of human nature. Here again, as in physics, we have an opposition between a closed preformationism and an open Darwinian evolutionism.

Second the philosophical contexts are deeply different. Comte has never read Kant, and, as a rule, modern German philosophy was broadly ignored in France during the first half of the nineteenth century. It seems that the sole but, nonetheless, decisive reference common to both authors is David Hume.

Third, the last difficulty is the very small number of direct references to Comte in the works of Mach. And even though they are explicit, they are often deceptive. For instance, in the *Principles of the Theory of Heat*, Mach mentions Comte and Tylor about fetishism.[4] A careful reading shows that Mach combines the two authors. We find two well identified Comtean theses: that in fetishism our consciousness of willpower and of life is transferred to inanimate objects and that in physics there are traces of fetishism "so long as we consider heat, electricity, and magnetism as mysterious and impalpable entities[5]". However, it is necessary to add that Tylor himself endorses Comte's definition of fetishism, which becomes "a subordinate department" of Animism.[6] Indeed, Mach inserts the two Comtean theses in an argumentation which puts forward Tylor's general conception of Animism: phantom entities, images appearing in the dreams, worship of the dead and of demons, shades of deceased companions are typical of the development of the doctrine of the human soul exposed in *Primitive culture.*[7] To conclude, this case shows that even the rare direct references to Comte, which are sometimes opaque, must be considered cautiously.

From all the foregoing, and especially from the last issue, it appears that the comparison between the two authors will be necessarily a reconstruction, and not a commentary on explicit passages from Mach's works.

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[4]See Ernst Mach, *Principles of the Theory of Heat.* Dordrecht: D. Reidel Publishing Company, 1986, pp. 339–40.

[5]*Ibid.*, p. 340. In his "positive theory of hypotheses", Comte speaks of "mysterious entities", but these are metaphysical, and not fetishistic ones (cf. *Cours*, vol. II, Lesson 28, pp. 445–7, Martineau, p. 202 [for the references to the Cours, see note 9]). It is worth noting that Mach, in his *Mechanics*, directly attributes to Tylor the thesis that "modern science shows traces of fetishism", without mentioning Comte: see E. Mach, *The Science of Mechanics*, *a Critical and Historical Account of its Development*. Chicago: The Open Court Publishing Company, 1902, p. 463.

[6]Edward Burnett Tylor, *Primitive Culture*, 2 vols. London: John Murray: 1871, vol. II, p. 132.

[7]See *ibid.*, vol. I, pp. 387–8.

In what follows, we will discuss two problems: on the one hand the question of the relationship between the history of science and the theory of knowledge and on the other hand the status of positivist explanation. The result of our enquiry, on both topics, will be paradoxical. If we leave aside the system in which they are integrated, many claims endorsed by the two authors have the same "positivist" sound and the area of agreement seem very large. However, if we link these claims with the systems they respectively belong to it appears that such an agreement rests on a misunderstanding. The definition of the notion of "phenomenon" and the problem of the analysis of sensations will be the core of the disagreement.

The History of Science

Concerning the historical orientation of the philosophy of science, the agreement between Comte and Mach is large and they share, along with Duhem, many theses of what we term today "historical epistemology". Let us remember that Comte is seen as the founding father of this tradition[8] and that he claims in the second lesson of the *Cours* that "it is true that a science cannot be completely understood without a knowledge" of its history.[9] These words are echoed by the first lines of the *Mechanics*:

> The history of the development of mechanics is quite indispensable to a full comprehension of the science in its present condition. It also affords a simple and instructive example of the processes by which natural science generally is developed[10]

On this very point, the agreement between Comte and Mach is incontestable: historical study is the best method to understand a science. Such a statement is confirmed by their common reference to Lagrange. For both authors, "the beautiful stimulated introductions of Lagrange to the chapters of his *Analytic Mechanics*[11]" were a model for an historical approach of scientific questions. As Comte put it,

[8]According to Georges Canguilhem, Comte was the first "to conceive of the history of science as a critical history, that is, a history not only oriented toward the present but judged against the norms of the present": such a conception would be "the source of the French style in history of science" (Georges Canguilhem, "La philosophie biologique d'Auguste Comte et son influence en France au XIX^{e} siècle", *Etudes d'histoire et de philosophie des sciences.* Paris: Vrin, 1983, p. 63 (partially translated in: François Delaporte (Ed.), *A vital rationalist: selected writings from Georges Canguilhem*. New York: Zone Books, 2000, pp. 237–8).

[9]Auguste Comte, *Cours de philosophie positive*, 6 vols. Paris: Rouen puis Bachelier, 1830–1842, vol. I, Lesson 2, p. 28, quoted in: *The Positive Philosophy of Auguste Comte, Freely Translated and Condensed by Harriet Martineau*. New York: Calvin Blanchard, 1858, p. 43. In the following notes, for the *Cours*, we will give first the reference to the French original text (volume, lesson and page) and second the reference to the translation (name of the translator and page).

[10]E. Mach, *The Science of Mechanics*, *op. cit.*, p. 1.

[11]*Ibid.*, p. xi.

> (. . .) the sublime prefatory chapters of (. . .) the "Analytical Mechanics", prove the eminent superiority of Lagrange to all mathematicians since Descartes and Leibniz. By this exposition of the filiation of the chief conceptions of the human mind in regard to rational mechanics, from the origins of the science to our own time, Lagrange certainly anticipated the general spirit of the historical method[12]

In fact, Mach and Comte praise Lagrange not only for his historical chapters, but also for his conception of analytical mechanics: Lagrange brought it to its higher degree of perfection, and, by doing so, emancipated physics from theology and from metaphysical entities.[13]

Despite this major agreement, there are differences between the two thinkers. Let us focus on two major restrictions. The first one echoes the well known criticism of Duhem: in his history Mach neglected the links between science and metaphysics or theology.[14] Comte could have formulated a similar criticism, and even a stronger one for he claims that "we can know only the true history of each science – that is to say, the way in which the discoveries composing it were actually made – by making a direct study of the general history of humanity[15]". In other words, there is such an interlacement of science with every aspects of society that Mach's internalist point of view is at best abstract and arbitrary.

The second difference is far more important. History is undoubtedly for Mach a fundamental tool to investigate the nature of science. But we must immediately underline that for him the experimental basis of the philosophy of science is not exclusively an historical one. Psychology (along with evolutionary biology and ethnology) will also provide relevant models for the development of human knowledge in general.

This is not the case for Comte: the historical law of the three stages is the architectonic law which organizes the whole system.[16] Let us remind the twofold argument of Comte on this point. First, from the outset of his career, he sets up a new way of studying the human mind, which excludes the direct or interior observation of mind: Comte argues that the observation directed toward sciences and scientific

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[12] A. Comte, *Cours*, vol. IV, Lesson 49, pp. 531–2, Martineau, p. 496.

[13] For Mach, see *The Science of Mechanics*, *op. cit.*, p. 447: "Lagrange (. . .) declared his intention of utterly disregarding theological and metaphysical speculations, as in their nature precarious and foreign to science. (. . .) All subsequent scientists of eminence accepted Lagrange's view, and the present attitude of physics to theology was thus substantially determined".

[14] See Pierre Duhem, "Analyse de l'ouvrage de Ernst Mach: *La mécanique. Étude historique et critique de son développement*" in: Pierre Duhem, *L'évolution de la mécanique*. Paris: Vrin, 1992, pp. 451–2.

[15] A. Comte, *Cours*, vol. I, Lesson 2, p. 81, quoted in Auguste Comte, *Introduction to Positive Philosophy* revised translation by Frederick Ferré. Indianapolis: Hackett Publishing Company, 1988, p. 49.

[16] It is significant that the single direct reference to the law of the three stages in Mach's works is in a long ethnological passage, chiefly inspired by Tylor on the "exuberance of imagination": see E. Mach, *Knowledge and Error*. Dordrecht: D. Reidel Publishing Company, 1976, p. 72. The law of the three stages as such is no longer an architectonic law, but only an ethnological tool used to build an epistemological psychology.

methods, in other words, “la philosophie des diverses sciences”, is the only means to understand the laws of mind. In a second line of argument, which follows the fundamental tendency of his philosophy, Comte claims that sciences are sociological facts and that they therefore depend on the proper method of sociology, namely the historical comparison. For the French positivist, there is equivalence between “theory of knowledge”, “philosophy of science” and “history of science”, and this equivalence excludes psychology.

Positivist Epistemology

Concerning positivist epistemology as such, a superficial or non-contextual examination leads us to assert a broad agreement between the two authors. The well-known definition of positive state will supply the basis of our comparison:

> In the final, the positive state, the mind has given over the vain search after Absolute notions, the origin and destination of the universe, and the causes of phenomena, and applies itself to the study of their laws – that is, their invariable relations of succession and resemblance. Reasoning and observation, duly combined, are the means of this knowledge. What is now understood when we speak of an explanation of facts is simply the establishment of a connection between single phenomena and some general facts, the number of which continually diminishes with the progress of science[17]

We have here a set of classical claims which represents the positivist doxa. It is easy to show that Mach endorses such theses. Let us mention them, in the order of reading.

1. First the exclusion of absolute notions. Mach gets rid of all the metaphysical or theological concepts, as well as the causal and teleological explanations. Perhaps owing to a far more metaphysical context and to new findings in physics, he is certainly more eager than Comte to exclude such concepts as that of “substance” or of “body”. As he puts it, “One and the same view underlies my epistemological-physical writings (. . .) the view, namely, that all metaphysical elements are to be eliminated as superfluous and as destructive of the economy of science[18]”. In short, Mach and Comte, each in his own way, fully endorse the principle that, according to Comte, “Nothing is absolute in this world, everything is relative[19]”.
2. The second topic is the definition of the aim of positive study. Naturalism is an essential character of both systems: real knowledge has to establish invariable natural laws. It seems also that Mach would agree with the Humean definition of law as stating “invariable relations of succession and resemblance”. From such

[17] A. Comte, *Cours*, vol. I, Lesson 1, pp. 4–5, Martineau, p. 26.

[18] E. Mach, *The Analysis of Sensations*. Chicago: The Open Court Publishing Company, 1914, p. x.

[19] A. Comte, Letter to Valat, 15 May 1818, in: Auguste Comte, *Correspondance générale*, vol. I. Paris: EHESS, 1973, p. 37.

a definition which is the consequence of the rejection of causes, stems for Mach the idea that causal explanation is in fact a description: "where we assign a cause, we only express a relation of connection, an existing fact [*Thatbestand*]; that is to say, we *describe*[20]".

3. Lastly, the idea that explanation consists only in establishing a connection between a single fact and a law understood as a general fact also concurs with Mach's idea of science as an economical representation of reality. The following passage of Comte could have been written by Mach:

> Every science consists in the co-ordination of facts (...). We may even say, in general terms, that science is essentially destined to dispense, so far as the different phenomena permit it, with all direct observation, by enabling us to deduce from the smallest possible number of immediate data the greatest possible number of results. Is not this the real use, whether in speculation or in action, of the laws which we succeed in discovering among natural phenomena[21]?

This very conception of the economical nature of science leads us to a last agreement: they both share the idea of a sort of epistemological continuity between common or primitive knowledge and scientific research. In Comte's system, common sense (understood in a non-Scottish meaning), practical life and positivity are constantly linked together,[22] in a way which is similar to the relations that Mach establishes, in a Darwinian context, between self-preservation, 'primitive acts of knowledge' and 'scientific thought'.[23] On this very point it seems that Comte and Mach disagree with Duhem's discontinuism.

To sum up this rapid commentary, the foregoing considerations show that the main conceptions of Mach about explanation, description, and the economy of science are at least compatible with Comte's definition of positive science.

However, as we have seen regarding the history of science, this large agreement remains in a way superficial, and conceals some major differences. This disagreement bears upon the notion of phenomenon. More precisely Mach differs from Comte with regard to the relevant degree of analysis that ought to be applied to phenomena. Put in another way, Mach and Comte differ in the way they receive Hume's epistemological legacy. Comte limits his reading to the rejection of the notion of cause, and subsequently stresses the discovery of regularities as the aim of

[20]E. Mach, *Principles of the Theory of Heat*, *op. cit.*, p. 393 (translation slightly modified). Comte would agree with the whole of the Humean chapter devoted to "causality and explanation": see *ibid.*, pp. 390–397.

[21]A. Comte, *Cours*, vol. I, Lesson 3, p. 131, quoted in: *Auguste Comte, The Philosophy of Mathematics* translated by W. M. Gillepsie. New York: Harper & Brothers, 1851, p. 26.

[22]See A. Comte, *Cours*, vol. VI, Lesson 58, p. 706, Martineau. p. 800: "I have repeatedly declared in this work that the philosophical spirit is simply a methodical extension of popular good sense to all subjects accessible to human reason, – practical wisdom having been unquestionably the agency by which the old speculative methods have been converted into sound ones, by human contemplations having been recalled to their true objects, and subjected to due conditions".

[23]See E. Mach, *Popular Scientific Lectures*. Chicago: The Open Court Publishing Company, 1895, pp. 189–190.

science. Mach goes further and resumes the project to analyze phenomena in their elements or sensations. Two quotations from Mach show that he was fully aware of this difference.

The first citation highlights the fact that the analysis of sensations coexists within a Comtean epistemology:

> Thus the goal of science as a whole would be the most thought-sparing inclusion of reciprocal dependence of the sensory and conceptual experiences of mankind on one another.
>
> This goal would not be very different from that of Auguste Comte, except that for Comte the natural sciences are everything and psychology signifies almost nothing[24]

The second one underlines that the disagreement comes from the endorsement of Hume's psychology:

> That my starting point is not essentially different of Hume's is of course obvious. I differ from Comte in holding that the psychological facts are, as sources of knowledge, at least as important as physical facts[25]

The Analysis of Sensations and Comte's Dualism

The last part of our article will be devoted to the deep contrast induced by Mach's analysis of sensations.

Mach's claim that "there is only one kind of elements, out of which the supposed inside and outside are formed" leads immediately to a sort of monistic and critical epistemology: "if we resolve the whole material world into elements which at the same time are also elements of the psychical world (. . .) we may then reasonably expect to build a unified monistic structure[26]". From such a resolution of phenomena into one kind of elements stems the vanishing of the gap not only between the psychical and the physical, but also between physics and physiology. As Mach puts it, "the physiology of the senses" can result into a science "embracing both the organic and the inorganic[27]". All these claims are well-known.

Why Auguste Comte would not admit Mach's monism? One might consider that Comte would find this monistic position to be both metaphysical and psychological. But such an answer would be partly inadequate. First the psycho-physics of Mach is very different from spiritualistic introspection and it seems that it obeys the positivist canon of experimental research. Second, the moral consequences of neutral monism on the conception of the ego would not have been rejected by Comte. Quite the contrary, Mach is very close to Comte's theory of subjective life, when he claims that

[24]E. Mach, Draft foreword for the Russian translation of *Die Analyse der Empfindungen*, in: John Blackmore (Ed.), *Ernst Mach, a deeper look*. Dordrecht: Kluwer Academic, 1992, p. 115.

[25]E. Mach, *The Analysis of Sensations*, *op. cit.*, p. 46.

[26]*Ibid.*, p. 312.

[27]*Ibid.*, p. 101.

> contents of consciousness (. . .) that are of universal significance, break through the limits of the individual, and, attached of course to individuals again, can enjoy a continued existence of an impersonal, superpersonal kind, independently of the personality by means of which they were developed[28]

Such a statement allows us to suppose that the address of 1902 for the erection of the monument dedicated to Comte wasn't totally formal.

A far better answer is to remark that the monism of elements is deeply contrary to some of the most important tenets of Comte's philosophy, namely the classification of sciences on the one hand and the contrast between inorganic and organic world on the other.

Concerning the first point, Mach's monism obviously goes against the encyclopedic classification of sciences, the second great law of Comte's philosophy along with the law of the three stages. As we have seen above, according to Comte, a phenomenon is not a notion to be analyzed as such: "modern psychology" proceeds with an inaccurate level of analysis by pretending to resolve phenomena into sensations considered as elementary psychological facts.[29] Quite the contrary, a phenomenon is a notion which is defined by the different existing sciences. For Comte, there is no abstract or general phenomenon but always defined phenomena and the ontological neutrality of Mach's notion of sensation (a sensation of color, for example, can be viewed either as a physical object or as a physiological one) doesn't take place in the Comtean encyclopedia.

The law of classification rests upon such a pluralistic conception of phenomena: sciences are indeed ranked according to the nature of the phenomena they study: astronomical phenomena, physical phenomena and so on. The six or seven sciences of the encyclopedic scale are thus strictly separated and none of them can be reduced to another. The sole unification which is made possible is a sociological one, that is, a unification which depends on the principle we have already seen: every science is a sociological fact.

It could be objected to our last argument that sociology has in Comte's system the same function as that of the analysis of sensation in Mach's philosophy: an operator of unification. Such an objection is in many aspects relevant (especially as regard the criticism of the ego), but it could not help the acceptance of Mach's monism. Even the sociological unification would have to maintain the distinction between organic and inorganic world.

Such a contrast is indeed essential not only to the architectonics of Comte's system, but first and foremost to the conception of social phenomena considered as organic ones. The rift initially based upon the radical impossibility of explaining irritability and sensibility with physical conceptions, gradually infused all the aspects of positive philosophy. The encyclopedic scale is founded on this very

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[28] *Ibid.*, p. 24. In Comte's theory of subjective life, valuable thoughts but also great moral sentiments are preserved. For this theory, see A. Comte, *System of Positive Polity*, 4 vols. London: Longmans, Green and Co, 1875–1877, vol. IV (Richard Congreve tr.), pp. 89–95.

[29] See A. Comte, *Cours*, vol. VI, Lesson 58, pp. 707–8, Martineau, p. 800 (partial translation).

division, but it is as well involved in the definition of life as an interaction between organism and *milieu*. The idea that the fixity and the regularities of external laws regulate the moral faculties of mankind also depends on this distinction. And finally knowledge itself rests on this quasi ontological dualism:

> All positive speculation rests then ultimately on the continuous combination of Fatality with Spontaneity; the source respectively of our ideas of constancy and variation. Thus the fundamental doctrine of Positivism consists in a constant accordance of two kinds of laws, antagonistic yet at the same time inseparable; external or physical laws, and internal or logical laws. Or, to use terms at once more general and more definite, the Constancy of Natural Relations results from the permanent adjustment of biological to cosmological truth. (...) This great dualism, the basis of all human knowledge, has always been seen more or less indistinctly by true thinkers.[30]

Conclusion

We can claim without exaggeration that Mach shares with Comte most of the main orientations of epistemological positivism. Maybe it would be more relevant to trace such positivism back to Hume, or to make it a part of a broad history of positivism, similar to the genealogy Mill sketches in his book on Comte.[31] Nevertheless, it is not irrelevant to include Mach in this tradition of the nineteenth century positivism which begins with Auguste Comte, and with whom he shares at least two strong tenets: a systematic anti-metaphysical orientation, and a critical-historical approach of science.

But this statement must be immediately completed: in this history Mach opens a new chapter. Comte's Sociological unification of sciences was understood as a sort of political or moral regulation of science: such an attempt remained exterior to science. On the contrary, the project of the *Analysis of sensations* has been understood as an unification of science by science. In doing so, Mach changed the agenda of positivism: the question of the unity of sciences, and that of reductionism became central in the positivist problematics. And this move can also explain the non-reception of the *Analysis of Sensations* in the French twentieth century epistemology.[32] The tradition which was the most sympathetic toward the anti-metaphysical and historical theses of Mach, was also the most hostile to reductionism, and what is more, to a sort of psychological reductionism. Bachelard and Canguilhem with the assertion of epistemological regionalism, were indeed the heirs of Auguste Comte's classification.

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30 *Ibid.*, vol. I (John H. Bridges tr.), pp. 357–8.

31 See John Stuart Mill, *Auguste Comte and Positivism* (1865), in J. M. Robson (Ed.), *The Collected Works of John Stuart Mill*, Vol. X. Toronto: University of Toronto Press, 1979, pp. 266–267.

32 The *Analysis of Sensations* has not been translated before 1996 by F. Eggers and J.-M. Monnoyer: *L'analyse des sensations.* Nîmes: Éditions Jacqueline Chambon.

Part VIII
Mach Research – New Sources and Perspectives

Chapter 47
Proposal for a Complete Edition of Ernst Mach's Correspondence

Klaus Hentschel

Abstract To compile a comprehensive edition of the correspondence of the world-famous physicist, physiologist, philosopher, and pioneer historian of science, Ernst Mach (1838–1916) is an urgent desideratum. An estimated 5000 letters to and from Mach are kept in public and private archives worldwide. The largest part of this correspondence (most of the letters addressed *to* Mach preserved in his estate after his death in Vaterstetten near Munich in 1916) was formerly kept in the *Ernst Mach Institut für Kurzzeitdynamik der Fraunhofergesellschaft* in Freiburg/Breisgau and is now archived at the *Deutsches Museum* in Munich. A smaller partial estate, based on collections by Ernst Mach's son Ludwig has been transferred to the *Staats- und Universitätsbibliothek Göttingen*. Other major collections are kept in Konstanz, Vienna, Prague etc. Mach's own letters are spread throughout Europe and North America in hundreds of archives hosting private papers or estates of his contacts.

A comprehensive edition of the correspondence of the world-famous physicist, physiologist, philosopher, and pioneer historian of science, Ernst Mach (1838–1916), is an urgent desideratum. Altogether I estimate **a total of c. 5000 letters** to and from Mach kept in public and private archives worldwide. The largest part of this correspondence (most of the letters addressed *to* Mach preserved in his estate after his death in Vaterstetten near Munich in 1916), formerly kept in the *Ernst Mach Institut für Kurzzeitdynamik der Fraunhofergesellschaft* in Freiburg/Breisgau, is now archived at the ***Deutsche Museum* in Munich**: cf. the detailed published finding aid of these 2729 letters and other materials: Wilhelm Füßl & Margrit Prussat: *Der wissenschaftliche Nachlass von Ernst Mach (1838–1916)* (Veröffentlichungen aus dem Archiv des Deutschen Museums, vol. 4). Munich 2001, online summaries http://www.deutsches-museum.de/archiv/bestaende/nachlaesse/verzeichnis/m/mach-ernst/ and http://www.deutsches-museum.de/archiv/archiv-online/ernst-mach/ especially on his photographs.

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F. Stadler (ed.), *Ernst Mach – Life, Work, Influence*, Vienna Circle Institute Yearbook 22, https://doi.org/10.1007/978-3-030-04378-0_47

A smaller partial estate, based on collections by Ernst Mach's son Ludwig has been transferred to the *Staats- und Universitätsbibliothek Göttingen*, and others are kept in Konstanz, Vienna, Prague etc. Mach's own letters are spread throughout Europe and North America in hundreds of archives hosting estates of his contacts. A good, but not complete overview of holdings of Mach-letters in German archives is obtained in **Kalliope:** http://kalliope.staatsbibliothek-berlin.de/de/search.html?q=Mach%2C+ernst. An analogous search engine for European holdings of unpublished documents: "**MALVINE:** Manuscripts and Letters via Integrated Networks in Europe" was unfortunately discontinued in 2002.

A listing of all known letters to and from Mach is in preparation at the *Univ. of Stuttgart*. Currently, we are also preparing a survey list (a "Konvolutenliste", i.e., not yet a listing of individual letters, but only of groups of letters with their temporal range and current location), which already includes findings of Mach correspondence in the following towns worldwide: in Austria: Graz, Vienna; in Denmark: Copenhagen; in England: Cambridge, Corner Croft, Oxford, Wilmslow, Cheshire,;in France: Paris; in Germany: Aschaffenburg, Berlin, Bremen, Dortmund, Göttingen, Halle, Jena, Konstanz, Leipzig, Munich and Tübingen; in the USA: Berkeley and Claremont, California; Washington, D.C.; New York City; Carbondale, Illinois; Amherst and Cambridge, Mass; in the Czech Republic: Prague; in Croatia: Fiume and Zagreb, in Poland: Krakau/Cracowia; in Sweden: Uppsala; in Switzerland: Geneva and Zurich; in Israel: Jerusalem.

This listing is based on the decades-long research of John Blackmore (formerly Vienna and Tokyo, Japan, now Bethesda, Maryland, USA), Joachim Thiele (1931–1980) in Hamburg, Germany, until 1980, and of Klaus Hentschel (since 1981), furthermore on the publications of Mach scholars worldwide, esp. Dieter Hoffmann, Ryoichi Itagaki, W.G. Pohl, Friedrich Stadler, Setsuko Tanaka, Emilie Tesínská, Joachim Thiele, Gereon Wolters; etc. (in alphabetical order).

The Smithsonian Institution at Washington, D.C., has scanned its Mach-holdings and put them online http://library.si.edu/digital-library/book/ernstmachpapers00mach, faturing a pdf file with more than 700 pages, but without any finding aid; "digital volunteers" have in the meantime transcribed all of the handwritten materials in this collection, see https://transcription.si.edu/project/7824

The *Deutsches Museum in München* (DMM) in Munich, Germany, which will be a formal cooperation partner in the planned online-edition project described here, has also already scanned all of its 2729 Mach-letters in high-resolution tiff-format and will put them online together with other material preserved there (laboratory notebooks, photographic plates, ...) and in conjunction with an exhibition of new material mostly relating to Mach's sons Ludwig and Felix, recently obtained from the Univ. of Konstanz. Especially useful are the 942 scientific photographs, mostly scanned photographic glass plates of Ernst Mach's projectile photographs, to be found online at http://www.deutsches-museum.de/archiv/archiv-online/ernst-mach/ and the digitized portrait collection featuringdozens of photographs of Ernst Mach and his family, to be found here: http://www.digiporta.net/index.php?sf=2&al=&ti=&pe=Mach&oc=&rp=3&pl=&ds=&de=&rd=1.

These scans of projectile photographs and of scientific instruments will have to be linked to the pertinent letters of the Mach-correspondence with Peter Salcher and with Vincenz Dvorak. The Munich scans, and possibly material already online at other sites, will be used and either linked or mirrored in lower resolution to provide facsimiles of these letters. Copyright issues have to be clarified before this can be done – according to an estimate by Dr. Wilhelm Füssl, head of archives at the *Deutsches Museum München*, approximately 50 letters within Munich material are still restricted by copyright law. Seventy years after the author of a letter has died, German copyright protection ceizes; Ernst Mach died in 1916, so his writings and letters not any longer protected, and only few of his correspondents died after 1947, but a few of them, such as Albert Einstein's (1879–1955) four letters to Ernst Mach written between 1909 and 1913 (replies are not preserved), are of critical importance.

An online edition should strive at a **complete online coverage** of all of his existing correspondence (perhaps also incorporating a few supplementary pertinent letters *about* Ernst Mach or between his correspondents) in an online edition, similar in style to the already completed Sommerfeld correspondence project, prepared in Munich under the guidance of Dr. Michael Eckert (Deutsches Museum, Munich) and to the still ongoing Ernst Haeckel-Briefedition prepared in Jena under the guidance of Dr. Thomas Bach. **A select print-edition** should also be prepared. Both the complete online edition and the select paper edition should be **organized strictly chronologically**, which already marks the first difference from the various selective publications containing letters to or from Ernst Mach. Among those books, anthologies or articles already published with samples from Ernst Mach's correspondence, the following five are most important:

– Joachim Thiele: *Wissenschaftliche Kommunikation, Die Korrespondenz Ernst Machs*, Kastellaun: Henn, 1978 (based on various older articles in journals by Thiele on single correspondents, sorted by groups of correspondents covered in different chapters).
– J.T. Blackmore & K. Hentschel: *Ernst Mach als Außenseiter, Machs Briefwechsel über Philosophie und Relativitätstheorie mit Persönlichkeiten seiner Zeit, Auszug aus dem letzten Notizbuch (Faksimile) von Ernst Mach*, Vienna, Braumüller 1985 (sorted chronologically).
– Dieter Hoffmann & Hubert Laitko (eds.) *Ernst Mach. Studien und Dokumente zu Leben*
– *und Werk*. Berlin: Akademie-Verlag 1991 (G. Fechner, W.F. Behn, F. Zarncke, W. Ostwald, R.Lowie, E. Haeckel, H. Driesch, V.Schumann, O. Wiener, all little annotated).
– Rudolf Haller & Friedrich Stadler**:** *Ernst Mach - Werk und Wirkung*, Vienna: Hölder, Pichler & Tempsky, 1988 (w. letters to and from Heinrich & Theodor Gomperz, Friedrich Adler & Fritz Mauthner, little annotated)
– John T. Blackmore, Ryoichi Itagaki, Setsuko Tanaka (Hrsg.): *Ernst Mach's Vienna 1895–1930.* Dordrecht: Kluwer Academic Publishers, 2001 (unannotated

letters to and from, e.g., Friedrich Adler, Philipp Frank, Edmund Husserl, Wilhelm Jerusalem, Wilhelm Ostwald et al., only in English translation).

Most of Joachim Thiele's journal articles on Mach correspondents have been recollected in his: *Wissenschaftliche Kommunikation-Korrespondenz Ernst Machs* (1978) which altogether is probably the most important and most thoroughly annotated anthology of all of them.

- Ernst Mach's correspondence with Franz Brentano is edited in Roderich M. Chrisholm & Johann C. Marek (eds.) *Franz Brentano – Über Ernst Machs "Erkenntnis und Irrtum" aus dem Nachlaß herausgegeben und eingeleitet*, Amsterdam: Rodopi 1988, pp. 201–228.
- Ernst Mach's letters to Alexius Meinong are published in *Philosophenbriefe. Aus der wissenschaftlichen Korrespondenz von Alexius Meinong*, Graz: Akad. Druck- u. Verlagsanstalt 1965, ed. by Rudolf Kindinger, pp. 89–93.
- Albert Einstein's letters to Ernst Mach have been published by Helmut Hönl 1960 & Friedrich Herneck in 1967, commented upon by Klaus Hentschel 1982, Gereon Wolters in his habilitation thesis: *Mach I, Mach II, Einstein und die Relativitätstheorie*, Berlin: De Gruyter, *1987* and by many others; in Engl. transl. also in John Blackmore, *Ernst Mach- His Work, Life, and Influence,* Berkeley: Univ. of California Press, 1972, S. 107ff.
- Ernst Mach's correspondence with the other late nineteenth century pioneer of history of science Pierre Duhem is published in full with detailed annotation and commentary on their other intellectual exchange in Klaus Hentschel: Die Korrespondenz Duhem-Mach: Zur 'Modellbeladenheit'von Wissenschaftsgeschichte. In: *Annals of Science* 45 (1988), pp. 73–91.
- Recently, the complete correspondence of Ernst Mach with the ballistics expert Peter Salcher, who worked at the k.k. Marine Academy in Fiume, today Rijeka, was published by Günter Salcher and Gerhard Pohl in the *Mitteilungen der Österreichischen Gesellschaft für Wissenschaftsgeschichte* 21 (2001), pp. 25–51, with excerpts and a few facsimiles also in Plus Lucis 2(2002–1/2003, pp. 22–26; cf. futhermore Bernard Frankovic & Gerhard Pohl (Hrsg.) *Peter Salcher-Ernst Mach – A Successful Teamwork,* Zagreb: Hrvatska akademija znanosti i umjetnosti 2011.

All these pertinent publications and dozens of others focus on a few select correspondents. Some, such as the correspondence appendices to Blackmore, Itagaki & Tanaka (eds. 2001), or Blackmore & Hentschel (eds. 1985), are sparingly annotated without text criticism; others, such as Thiele (1978) or Hentschel (1988), are very thoroughly annotated with commentary but are restricted to individual correspondents. An online edition should offer full annotation in a format that can be phased in and out on-screen, so that the reader can either concentrate on the professionally presented primary source or select the option including annotation and commentary. Provided permission by the copyright holders is granted, one should also present the original documents in facsimile right next to the scrupulously checked transcription. The advantage of an interactive and collaborative online edition is that the scientific and historical annotation can be intensified and mutually corroborated as the project advances – online presentation also allows the incorporation of cross-links to other documents, and to external sources; furthermore it will be easy to search for particular terms, names, or places in the huge bulk of many thousands of documents. All mentions to persons and places should be identified and linked to viaf, GND and other standard identifiers. **Access to all on-line documents should be free of charge**, but active contribution to the edition should be limited to a group of experts who will meet on a regular basis (perhaps once a year) to coordinate their activities in the prospective centers involved, Munich, the location of the bulk of Mach papers, now also enriched by materials formerly kept in Konstanz; Göttingen with its smaller holdings; perhaps also Vienna, Graz and Prague, as the cities of Mach's academic activities, and perhaps others as well (depending on the feedback).

If you are interested to contribute to this project you are kindly asked to send an email with your full name and title, institute affiliation and brief comments on your possible contributions to this project to: hentschel-sekr@hi.uni-stuttgart.de.

Further progress of this project will be reported in publications and in the internet, first posted in June 2016 but moved to the new url: https://www.hi.uni-stuttgart.de/en/gnt/mach/. There, we have already started with the creation of a geotemporalized map of Mach's correspondence available on this site. The sample on our Stuttgart webpage is static, but the interactive map is online accessible at https://geobrowser.de.dariah.eu/?csv1=https://geobrowser.de.dariah.eu/storage/476966 and allows interactive regional zooming as well as an animated cursing through Mach's correspondence over time.

Weblinks (all internet links have last been consulted on Jan. 20, 2019):

For further details on Mach's vita, see the references in Klaus Hentschel's entry on Ernst Mach in the *Neue Deutsche Biographie* 15 (1987): 605–609, online at http://www.deutsche-biographie.de/sfz70598.html and the various links in https://portal.dnb.de/opac.htm?method=simpleSearch&query=118575767 and https://www.deutsche-digitale-bibliothek.de/entity/118575767 and further links conveniently collected in https://de.wikipedia.org/wiki/Ernst_Mach and https://de.wikisource.org/wiki/Ernst_Mach.

A reasonably complete Mach bibliography of papers and books 1860–1916 is available here: http://homepage.univie.ac.at/peter.mahr/2016.1.html.

Select books by Ernst Mach were recently re-edited with introductory comments in a *Studienausgabe*: http://www.xenomoi.de/philosophie/mach-ernst/216/ernst-mach-studienausgabe.

Links to many of Mach's books and some articles in pdf form are also available online: https://archive.org/search.php?query=creator%3A%28Ernst%20Mach%29.

Ernst Mach papers at the Archive of the Smithsonian Institution, Washington, D.C., are available without commentary or finding aid: http://library.si.edu/digital-library/book/ernstmachpapers00mach and transcripts of handwritten materials in this collection here: https://transcription.si.edu/project/7824.

Mach holdings (mostly letters to and from Mach) in German archives are listed in Kalliope: http://kalliope.staatsbibliothek-berlin.de/de/search.html?q=Mach%2C+ernst.

The Ernst Mach material at the *Deutsches Museum München w*ill be made available as facsimile.

Prof. Dr. Klaus Hentschel (Stuttgart) summarizes his project for a comprehensive edition of the c.5000 letters to and from Ernst Mach (1838–1916). The largest part of this correspondence (most letters addressed to Ernst Mach) is at the *Deutsches Museum* in Munich. A smaller partial estate, based on collections by Mach's son Ludwig, is in the *Staats- und Universitätsbibliothek Göttingen*; other letters, such as the surviving letters to his correspondents, are spread throughout Europe & North America.

A text-critical edition should strive at complete coverage of all of his correspondence in an online edition, similar to the Ernst Haeckel correspondence edition prepared in Jena, to be combined with a selected edition in several book volumes. Both the complete online and selected paper edition should be organized strictly chronologically. Annotation and commentary can be screened on and off in an online perusal of the documents, with links provided to other documents of the database as well as to external resources. All the mentioned persons and places should be identified and linked to VIAF, GND and other semantic identifiers according to modern XML-standards.

Chapter 48
Otto Blüh and Ernst Mach's Legacy: Inheritance and Task

Chantal Ferrer-Roca

Abstract Otto Blüh (1902–1981) was a professor of physics who maintained a lifelong interest in Mach and contributed actively to previous commemorations. Dozent and first assistant at the German University of Prague, he was forced into exile as a result of the German occupation and held research and academic positions in Birmingham (UK), and the universities of British Columbia (Canada) and Vanderbilt (USA). Blüh not only was a pioneer in recognizing the relevance that physics teaching had in Mach's ideas but developed many of them, highlighting critical thinking, the importance of history and philosophy in physics, bridging specialization and bringing humanism back to science. This paper provides an overview of Otto Blüh's life and ideas, with a *Bildung* and Machian character, and their relevance for today.

Introduction

Increasing attention is being paid to Mach's students and intellectual descendants, and the way they elaborated on Mach's inheritance. We should certainly include Otto Blüh (1902–1981), a professor of physics who not only maintained a lifelong interest in Mach and contributed actively to previous commemorations, but assumed Mach's interdisciplinary and enlightened ideas and put them critically into practice in his own work as a scientist, teacher and historian of science. My paper will provide an overview of Otto Blüh's life and ideas, and their relevance for today.

In December 1966, the American Association for the Advancement of Science held a symposium in Washington to commemorate the 50th anniversary of the death of Ernst Mach. Otto Blüh, a professor at Vanderbilt University (Nashville, Tennessee) gave an important contribution to this celebration, compiling materials on the life and publications of and about Mach. He also presented a pioneering

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F. Stadler (ed.), *Ernst Mach – Life, Work, Influence*, Vienna Circle Institute Yearbook 22, https://doi.org/10.1007/978-3-030-04378-0_48

paper[1,2] analysing Mach's teaching ideas, that until then had been taken for granted despite being essential for a correct understanding and critical approach to his scientific and philosophical legacy. Blüh portrays Mach both as a scientist and as a humane, liberal, enlightened and devoted teacher, whose scientific and philosophical outcomes arise from a deep and sincere effort to understand and convey physics to his students in a comprehensive way.

Blüh highlights Mach's pedagogical ideas with a stress on the processes of the learner's mind that he adopted in his lectures to medical students and in his books; his emphasis on the importance of moderate aims in education and his rejection of premature exposure to an abstract formalization that leads, in Mach's own words, to "a spider's web of thoughts too weak to furnish sure supports, but complicated enough to produce confusion". Breaking down the compartmentalization of physics and adopting a genetic exposition (deriving concepts from facts and introducing them when needed) are essential aspects of his economy of teaching, related to Mach's economy principle: not a doctrine about the general aims of science but a method for saving mental work and experience, a desideratum for organizing the richness of scientific material for students to understand it.

Mach's proverbial refusal of metaphysical speculations in science should be also revised: Mach was convinced that scientists "do not only attempt to make and accumulate observations, but want to create unifying, objective theories and concepts", bearing in mind that physics theories "orient ourselves in nature". Accordingly, they should proceed with extreme caution, avoiding the introduction of overgrown objectifications that hinder the progress of physics, or impositions on other sciences. Mach rejected any mysticism or dogmatism – specially coming from science- because he "wanted to protect science from the exuberance of human fantasy and emotionalism of any kind".

Mach's insight on the history of science and the evolution of physics ideas was also influential in his opposition to a "constant adherence" to permanent metaphysical concepts for which no proof could be found – even if scientists could and should introduce them as useful visualizations. In fact, in the same period[3] Blüh presents Mach as one of the first scientists who appreciated the educational potential of the history of science mainly "as an instrument for a critical evaluation of fundamental physical concepts", that Mach used himself. For Blüh "Mach did not expect [...this] to be achieved from special history of physics courses, but from a constant attention to the diversity of historical and critical considerations". The part devoted to Mach's *Principles of Physical Optics* is especially interesting.

[1] Otto Blüh, "Ernst Mach- His Life as a Teacher and Thinker", in: R. S. Cohen and R. Seeger (eds.) *Ernst Mach: Physicist and Philosopher* (Boston Studies in the Philosophy of Science, 6), Dordrecht Holland: D. Reidel PC 1970, pp. 1–22.

[2] Otto Blüh, "Ernst Mach as a Teacher and Thinker" in: *Physics Today*, 20, 6, 1967, pp. 32–42. This contains practically the same text as the previous one, but it was published nearer to the Mach celebrations.

[3] Otto Blüh, "Ernst Mach as a historian of physics" in: *Centaurus*, 13, 1, 1968, pp. 62–84.

Suspicious about Ludwig Mach's contribution to this treatise, Blüh reconstructs Mach's ideas about relativity to conclude that the only aspect that Mach could find unacceptable was the consideration of Minkowski's space-time mathematical construct as a reality.[4]

These pioneering contributions, among the last of Bluh's publications, have been cited several times in the long debate about the contemporary teaching of physics and education in general; see, for example.[5,6,7] But they were not certainly the first, as in 1938 Otto Blüh had joined Mach's celebrations in Brno[8,9] and written two newspaper articles celebrating both Ernst Mach and Josef Popper-Lynkeus, Mach's dearest friend of whom Blüh held a high opinion.[10,11]

Mach scholars have probably wondered who was Otto Blüh and why he was so interested in Ernst Mach. Practically no published information is available about him apart from his textbooks and papers in physics journals. Blüh himself wrote a short biographical note[2] summarizing his positions at the Universities of Prague, British Columbia and Vanderbilt, as well as his interest in physics teaching and the history of science.

We cannot address here the complex web of implications of historical, sociological and cultural nature suggested by the sequence Prague-Vancouver-Nashville. As Goronwy Rees wrote[12]: "Something has vanished from our intellectual life which cannot be replaced". If Reinhold Fürth "represents the genuine Prague tradition of physics which had been shaped by Ernst Mach",[13] Blüh, who was raised with the

[4] A similar comment is included in Otto Blüh, "The Galaxies and time" in: *The Journal of the Astronomical Society of Canada*, XLIII, 5, 1949, pp. 169–180. It is interesting to note that this paper deals with Milne's cosmological theory, an accepted alternative to Lemaître's *Big Bang* that explained observations just with special relativity, without a *space expansion.*

[5] Michael R. Matthews, "Ernst Mach and contemporary science education reforms" in: *International Journal of Science Education*, 12, 3, 1990, pp. 317–325.

[6] Michael R. Matthews, *Science Teaching: The role of history and philosophy of science*. New York/London: Routledge 1994.

[7] Hayo Siemsen, "Resettling the Thoughts of Ernst Mach and the Vienna Circle in Europe: The Cases of Finland and Germany" in: *Science & Education*, 18, 3, 2009, pp. 299–323.

[8] Martin Černohorský, "Trojí Instalace Pamětní Desky Ernsta Macha" (The Ernst Mach Memorial Tablet in Brno-Chrlice Mounted Three Times) In: DUB, Petr a Jana Musilová. *Ernst Mach – Fyzika – Filosofie – Vzdělávání*. 1. vyd. Brno: Masarykova univerzita, 2010, s. 29–57.

[9] Emilie Těšínská, private communication.

[10] Doz. Dr. Otto Blüh (Prag) "Ernst Mach. Zu Seinem 100. Geburtstag am 18. Feber 1838" *Brünner Tagesbote*. Brünn, Freitag 11 feb 1938.

[11] Doz. Dr. Otto Blüh (Prag) "Josef Popper-Lynkeus. Geb. am 21. Feber 1838" *Brünner Tagesbote*. Brünn, Mitwoch, 16 Feb 1938.

[12] Goronwy Rees "A Migration of Minds". Review of "The Intellectual Migration", by B. Bailyn and D. Fleming in: *Encounter*, March 1969, pp. 72–76.

[13] Michael Stöltzner, "Philipp Frank and the German Physical Society" in *The Foundational Debate: Complexity and Constructivity in Mathematics and Physics,* Werner Depauli-Schimanovich, Eckehart Köhler, Friedrich Stadler eds., Dordrecht, Springer Netherlands Imprint, Springer 1995. pp. 293–302.

same *Alma Mater*'s milk, joined Mach's celebrations to vindicate a scientific and cultural inheritance that inspired his work and ideas throughout his life, in particular during his exile.

I will first introduce a brief biography of Otto Blüh based mainly on primary archival sources,[14,15] and then focus on his work, that will shed some light on Blüh's ideas and his bonds with Ernst Mach and Prague.

Student and *Dozent* at the German University of Prague

Otto Blüh was born in September 2, 1902, in Ostrava (Moravia, then Austria-Hungary) the only child of Hermine (neé Robitschek) and Eduard, a businessman. After his studies in the Ostrava *Realschüle* and the fulfilment of his *Reifezeügnis* or *Matura*, he entered the newly founded Science School of the German University of Prague (GUP) in 1920, to attend physics and chemistry courses lectured by Meyer, Rothmund, Rausch-Traubenberg, Frank and Fürth, among others. He also spent some months in Vienna with Felix Ehrenhaft (1923) and in 1924, became Doctor (Rerum Naturalium) in Physics and Chemistry with the dissertation "About the existence of hybrid ions". Later that year he was appointed scientific assistant and also academic assistant to Rausch von Traubenberg (Fig. 48.1).

In 1925–1926 he collaborated with the Institute for Theoretical Physics and the *Biologisch-physicalische Arbeitsgemeinschaft* and travelled to Italy, Germany, Belgium and France. From 1927 to 1928 Blüh did postgraduate research mainly in Berlin, at the *Kaiser-Wilhelm Institute* of Physical Chemistry and at the Low Temperature Laboratory at the University of Berlin, directed by Franz Simon. In this period Blüh met and later married Margarete (Grete) Hornstein from Düsseldorf, who would later study physics and start some academic steps at the GUP as a demonstrator. In 1929, Blüh returned to Prague to be appointed first assistant and also to present the *habilitation* thesis "Investigation of colloidal particles in alternating fields of different frequencies". Already a *privatdozent*, he started lecturing at the GUP.

Until 1938–1939 Blüh held a physics course for first year students of pharmacy and natural history. He was also involved in various higher experimental courses for physics students: mechanics and thermodynamics, radiation physics, electricity or instructions for scientific work; and specific courses on optics, photography, different techniques (high vacuum, instrumentation etc.), determination of physical constants, radioactivity or special topics in atomic physics.[16] A critical approach

[14] Archives of: the Charles University of Prague, the Society for the Protection of Science and Learning (SPSL, Bodleian Library, Oxford, File 1938–46 MS. SPSL 324/6), Emergency Committee in Aid of Displaced Foreign Scholars, (ECADFS, New York Public Library).

[15] Otto Blüh's personal documents, kept by Pamela Bluh.

[16] Blüh is referred to as a *privatdozent* by Emilie Těšínská, "František Záviška (1879–1945) Physiker. Ein grosser Verlust für die tschechische Physik" in *Prager professoren 1938–1948, Zwischen Wissenschaft und Politik*, eds. Monika Gettler/Alena Miškovà, Klartext 2001, and

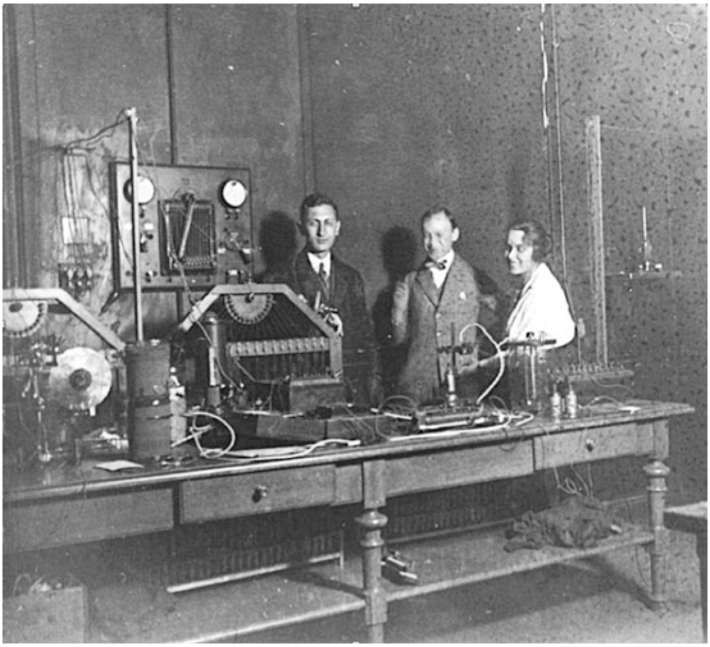

Fig. 48.1 Otto Blüh in a physics laboratory at the GUP, together with Reinhold Fürth and his wife, around 1923[15]. It has been recently donated to the Archives of the Czech Academy of Science

to Blüh as a teacher is beyond the scope of this paper,[17] but it is evident that he lectured on a wide range of topics and levels, both general and specialized, including courses on the history of physics and the teaching of physics in secondary schools. He also held seminars and colloquiums, on his own and together with Phillipp Frank, Reinhold Fürth and Walter Glaser.

During this period, he substituted for Fürth as head of the department in his absence, dealing with administrative matters and helping students in their laboratory experimental work and between 1926 and 1934 he also served as secretary of the German Physics Society (DPG) division in Prague.[13] Blüh's scientific research was directed to fundamental experimental topics mainly in physics, biophysics and physics-chemistry (studies of ampholytic solutions with short waves applying Debye's theory of dielectrics, colloid particles in oscillating electric fields, experiments regarding the electrical theory of gas absorption, low temperature

depicted as a pioneer in the introduction of radioactivity courses at the GUP by Emilie Těšínská *Dějiny Jaderných Oborů V Českých Zemích (Československu) Data A Dokumenty (1896–1945).* [*A History of The Nuclear Fields in The Czech Lands (Czechoslovakia). Historical Data and Documents (1896–1945)*).] Praha: Ústav pro soudobé dějiny AV ČR, v. v. i., 2010.

[17] I am preparing a publication on Blüh's complete biography and work.

measurements or thermal diffusion). In 1939 he had more than 30 publications excluding those of the 20 students he had supervised.

Fürth remarked on Blüh's early and outstanding independent thinking, experimental aptitude and excellent work in this period that lead to a considerable number of publications, and Francis Simon would remember Blüh's exceptional qualities as a teacher and colleague in Prague.[18] Such qualities were probably recognized when the Science Faculty Collegium proposed Blüh for a position of extraordinary (a. o.) professor in 1937, envisaging a regular academic career. The Munich events of September 1938 not only prevented the formalization of Blüh's appointment, but he was dismissed that autumn, as were many other *non-Aryan* scholars. Some studies about the GUP around the Nazi takeover have been appearing in the last years,[19,20] but very little can be found about the dismissed scholars in exile -with the exception of some well-known individual cases- from which a richer picture might emerge. Emigration implied a restart and adjustment of one's life and career in distressing circumstances in which personal connections or the tone of an endorsement letter determined one's chances.[21] These important questions cannot be addressed in the following outline of Blüh's life in his forced exile.

Exile and Post-war Period

Finding a position abroad was far more difficult in 1938–1939, as many available jobs had been filled by previous waves of earlier émigrés who had fled from Nazi Germany and Austria. After a frantic period from January to March 1939, typing and sending letters and CVs abroad,[22] Blüh obtained a temporary grant from the Society for the Protection of Science and Learning (SPSL) and 2 weeks after the German invasion of Czechoslovakia, Otto and Grete Blüh left Prague for Birmingham (UK), the location of a centre directed by Markus Oliphant devoted to radar research. Blüh had already visited there in 1938 as he had common research interests with Thomas Ibbs.

Given Blüh's expertise in thermal diffusion techniques, he was assigned to experimental work on the separation of Uranium isotopes. Otto Frisch collaborated

[18] Testimonials by Reinhold Fürth and Franz Simon (1938), from note 15.

[19] Alena Míšková, "Die "Arisierung" an der Deutschen Universität Prag" in *Wissenschaft in den boehmischen Laendern 1939–1945* (Studies in the history of sciences and humanities, vol. 9). Antonin Kostlan ed. KLP, Prague 2004. Pages 97–106.

[20] Alena Míšková, "*Die Deutsche (Karls-) Universität vom Münchener Abkommen bis zum Ende des Zweiten Weltkriegess*" Karls-Universität Prague Verlag Karolinum 2007. Pages 97–106.

[21] Arthur Beer, a friend of Otto Blüh's with whom he kept in contact also after the war is an example of someone who found a good position thanks to Einstein's help.

[22] Izaak Kolthoff, a famous analitycal chemist and professor at the University of Minnesota, who had known Blüh in a visit to the GUP helped him to find a position abroad. (ECADFS).

Fig. 48.2 Otto Blüh at Victoria, British Columbia (Canada), summer 1955. (Photo by Dr. Peter Mar[15])

also on this task after his arrival in the summer of 1939.[23] The impossibility to be involved in war-related projects hindered the refugees' research,[24] so upon the ending of his grant Blüh accepted a position as a school physics master in Worcester while trying to maintain contact with the University (1942–1945). In this period he reflected intensively about physics teaching, education, science and democracy. His ideas about State planning,[25] a very much discussed topic in those years also in relation to science, are in agreement with those of the *Society for Freedom in Science* – led by Michael Polanyi[26] – of which Blüh was a member. He also became a fellow of the Institute of Physics.

In 1946, after realizing that a return to the University of Prague would be impossible, Blüh accepted a position as assistant professor at the University of British Columbia (BC) in Vancouver (Canada), where he started lecturing and also resumed his research, becoming Associate Professor in 1952. He was in charge of the organization of physics courses for pre-medical and biology students and also developed specialized biophysics and history of science courses. He became a member of the Canadian Society for the Study of the History of Science and served as president of the BC section (Fig. 48.2).

[23] J. L. Heilbron and Robert W. Seidel, *Lawrence and His Laboratory, A History of the Lawrence Berkeley Laboratory* Volume I, University of California Press, Berkeley, 1990 (p. 450).

[24] Otto R. Frisch mentioned Otto Blüh and their difficulties in his letters to Bohr. (Correspondence and personal papers. Trinity College Library, Cambridge).

[25] Otto Blüh "Science and Government", *Nature*, 147, 298 (1941).

[26] Otto Blüh might have met Polanyi at the Kaiser Wilhelm Institute in Berlin around 1928, taking in account they were both interested in gas adsorption.

Due to his teaching and research experience and after two semesters as a visiting professor (1959–1960), in 1961 he was offered a full professorship at Vanderbilt University in Nashville (USA), where he organized and taught premedical and radiological physics courses and was engaged in biophysics research at the school of medicine, until his retirement in 1968.[27] Even afterwards, his expertise was valued at the universities of North Carolina (Chapel Hill) and Western Kentucky (Bowling Green, KY) where he lectured as a visiting professor until 1972. He died in Nashville in 1981.[28]

Machian Ideas in a Singular Textbook

As a physics dozent who lectured about physics to biology and pharmacy freshman students, Blüh wrote the textbook *Einführung in die Physik* in 1937. Its distribution in Germany was banned when the *Jewish physics* campaign by the German Physical Society (DPG) hit its peak in 1937,[29] so it was republished in Prague the following year.[30] It received extraordinary reviews in different science journals. Max von Laue, for example, wrote[31]:

> The author, obviously a well-educated man not only with regard to physics, places physics in context with often overlooked other sciences, from philosophy and other humanities to technology and medicine. Here, first of all, physics manifests itself as a small, but essential aspect of the greater cultural development of mankind. For this reason, we recommend this book most warmly.

While in England (1939) Blüh attempted its publication by the Cambridge University Press aided by Charles P. Snow and John D. Bernal, as both shared an enthusiastic opinion, but the war prevented it.[15] Finally, in 1955, in collaboration with Joseph D. Elder, a translated and expanded version was published by Oliver & Boyd.[32] There were also two Japanese editions (Heibonsa eds.) in 1957 and 1973. Twenty years after the German edition a reviewer still reported on its thought-provoking approach and its emphasis on the border-fields of physics and the interrelations of physics with the humanities. But the Sputnik era (1957), with its

[27] Robert T. Lagemann, *To Quarks and Quasars, a History of Physics and Astronomy at Vanderbilt University*, Nashville: Wendell Holladay ed. 2000 and the archives of Vanderbilt University.

[28] Information provided by Pamela Bluh. Also, United States Social Security Death Index database (Alexandria, Virginia: National Technical Information Service).

[29] Dieter Hoffmann and Mark Walker (ed.), *The German Physical Society in the Third Reich. Physicists between Autonomy and Accommodation*, Cambridge University Press 2011.

[30] Otto Blüh, *Einführung in die Physik*, Berlin: Gebrüder Bornträger, 1937. Prague: Academia Verlagsbuchhandlung 1938.

[31] Max von Laue review. *Chemiker Zeitung*, 1937.

[32] Otto Blüh and Joseph D. Elder *Principles and Applications of Physic*, Edinburgh/New York: Oliver & Boyd/Interscience Publishers 1955.

aims directed to the massive enrollment of physics students and drastic changes in scientific education, was just starting.

As Blüh himself declares in the preface, this textbook is intended to provide students with a coherent picture of physics: with advances of modern physics there is an ever growing and dispersed quantity of knowledge that must be organized and relations established between the different domains. Mach's essential ideas are present at different levels, adapted to newer physics, and a new historical time, with the same anti-dogmatism that characterized Mach himself. This is evident from the very introduction, where Blüh explains how the book reflects the two existing trends in science: physical phenomenology (mathematical formulation of physical observations) and construction of *concepts* or *pictures* for microscopic processes, as both have advanced science. The book followed an unconventional approach and an innovative arrangement: in the first part the macroscopically observed phenomena (mechanics, thermodynamics, electromagnetism and relativity); in the second, microphysics: corpuscles, the Quantum Theory, atoms and their structure. Blüh explains that the traditional chapter divisions according to sense perception has lost its meaning now that theoretical physics has shown many inner connections between the phenomena. On the other hand, many atomic experiments do not involve proper "observations" and need the use of auxiliary concepts (see point 48.6). There is also a most singular third part about physics in relation to other sciences, philosophy, history of science and society, sensibly enlarged in the English version, that seems inspired by chapters IV and V of the *Mechanics,* where Mach "discloses his *Weltanschauung*".[3]

In the recent years textbooks have become objects of research in their own right and valuable sources for historians of science. Blüh's physics textbook deserves a complete study[33] in context with the German and European physics textbooks in the 1930s as well with American physics education projects in the 1950s and 1960s such as PSSC or (Harvard) Project Physics Course.[34]

Education, Physics Teaching and HPS

Throughout his life and especially after his expulsion, Otto Blüh kept a deep interest in physics education (and education *tout court*), as well as in the history and philosophy of science and what he thought should be an essential relationship between them. Let us analyse briefly some examples highlighting their Machian ancestry and influence.

[33] I am preparing a publication on Blüh's physics textbook and physics teaching ideas.

[34] Josep Simon, "Physics textbooks and textbook physics in the XIX and XXth centuries, in: J. Buchwald & R. Fox (eds) *The Oxford Handbook of the History of Physics,* Oxford Univ. Press, 2013, pp. 651–678.

Blüh seems familiar with the state of the art in the history of science in a period in which it was still striving to become an independent discipline, and he authored a number of papers, often citing George Sarton. The topics and questions addressed by Blüh have been at the centre of debate for a long time. For example, the possible influence of Spinoza on Newton,[35,36] the priority of the discovery of the principle of conservation of energy[37] and the correspondence between R.J. Mayer and Popper-Lynkeus[38] or the importance of experiments in Greek science, in a paper that continues and expands Mach's interest and recognition for this period.[39] Many studies that have been published in the last decades on the advanced Hellenistic and Alexandrian scientific and technological achievements and their relationship with our modern science seem to follow this line.

Blüh published various papers about physics teaching (both for students of physics and the sciences, and for those in the liberal arts) and also about education in general,[40,41,42,43] facing contemporary concerns from a Machian economy of teaching: he advocates, from high school to college and specialized courses, for a compact, non-encyclopaedic and well-structured curricula, that allows a clear understanding without renouncing a real cultural orientation, exhorting for a unified conception of science and culture. This integration can be better accomplished by introducing historical, philosophical and cultural aspects in the physics curriculum that aid in understanding its contents and their evolution, as well as the variability of views in each historical period.

Above all, Blüh considers that such an approach is a safeguard against a growing specialization: the idea that science is a bearer of automatic progress together with ignorance of the scientific method, results in magic and irrationalism. Scientists think of themselves as objective by default and, as a consequence, believe they deserve a privileged position to lead society – a danger for democracy as Blüh

[35] Otto Blüh "Newton and Spinoza" in: *Nature* 135, 1935, pp. 658–659

[36] Otto Blüh "Newton and Spinoza", Congress of the History of Science; GUERLAC, Henry pres.: ITHACA *Actes du dixième Congrès International d'Histoire des Sciences; Proceedings of the Tenth International Congress of the History of Science*. 1964.

[37] Ernst Mach himself defended Meyer's contribution to the principle of energy conservation in his *Mechanics*

[38] O. Blüh "The Value of Inspiration. A Study on Julius Robert Mayer and Josef Popper-Lynkeus" in *Isis: A Journal of the History of Science* 43, 1952, pp. 211–220.

[39] O. Blüh "Did the Greeks perform experiments?" in: *Am. J. Phys*. 17, 6, 1949, pp. 384–388.

[40] I will just cite some of the published papers titles: "Physics examinations and the new curriculum", "L. W. Taylor's challenge to the teacher", "Physics textbooks-annuals or perennials", "Physics in Premedical Education", "Physics for the Biologist", "The history of Physics and the old humanism", "Physics and Culture" "On the History and Philosophy of Science. A Reply". All of them can be easily retrieved in the search engine of the Web of Knowledge on-line as well as that of the *American Journal of Physics*.

[41] "Men of Science and higher education in a democracy" in: *Science education*, 21, 1, 1941.

[42] O. Blüh, "German Education" in: *Journal of Education* (British), 1946. A proposal for a democratic school in post-war Germany.

[43] O. Blüh, "The maladjusted curriculum", in: *The Journal of Education BC*, 4, 53, 1960, pp. 53–62.

witnessed in Germany and Austria in the thirties. Enlightenment and humanism, not science, are for Blüh, the real shield against superstition.

More famous exponents of this line of thought, include, for example, Yehuda Elkana,[44] who emphasized the acquisition by scientists of a "second order thinking" or Jean Marc Levy-Leblond,[45] who advocated for the inclusion of a proper cultural dimension in the scientists' training and education.

As a result of his exile, Blüh not only lost a highly acculturated milieu that conceived and shaped physics beyond its utilitarian aspects, but had to thrive in a new one that was even hostile to any concern about history and philosophy, not to say towards an integrated conception with science. Comments by physicists like Oliphant[46] and Bragg[47] about Blüh's excessive interest in philosophy are indicative of the intellectual isolation in which he developed his work, attenuated by contact with some congenial epistolary friends such as prof. Lloyd W. Taylor (Oberlin College).[48] He probably tried to give continuity to his intellectual life and was unsuited for *adjustment*, as happened to many other exiles.

Otto Blüh and Mach's *Conversion* to Atomism

Around 1966, Otto Blüh wrote a parodic skit in the form of a dialogue between Mach and his best friend Popper-Lynkeus[49] probably for his own amusement.[50] It dramatizes the controversial story of how Mach ends up *believing* in the reality of atoms after he sees the scintillations produced by alpha particles on the screen of a spinthariscope brought to him by Stephan Meyer, who is also the source of this story. Blüh considered it just a fabrication: "Was he supposed to give up a founded

[44] J. M. Levy-Leblond *Science in want of culture*, Paris: Futuribles 2004. is one of the many references by Levy-Leblond.

[45] Yehuda Elkana, "Rethinking-not Unthinking- the Enlightenment" In W. Krull (ed.), *Debates on issues of our common future*, pp. 283–313. Weilerswist:Velbrück Wissenschaft. 2000.

[46] "Blüh is very Germanic in his outlook in the sense that he is much more interested in the philosophical trappings of physics than in the science itself, and his great ideal is writing books on the subject". Letter from M. Oliphant to Bragg (see footnote 14).

[47] "Oliphant might ... [guide] ... Blüh away from too much philosophy and into more practical needs". Letter by Bragg to Miss Simpson, secretary of the SPSL (see footnote 14).

[48] "I believe that Dr. Blüh has a real contribution to make to the teaching of physics at the college and university level on this side of the Atlantic and I hope, for our own sake, even more than for his, that he will have an opportunity of making it." (Letter from Lloyd W. Taylor to W. Kaemmpfert, Oberlin College archives).

[49] Chapter 49 in this volume is devoted to this skit. On proposal by Chantal Ferrer-Roca, the dialogue *Ernst Mach's 'Bekehrung' Zum Atomismus* (*Ernst Mach's "Conversion" To Atomism*) by Otto Blüh was performed by RRemi Brandner and Wolfgang Nitsch on Saturday, June 18 at the International Conference "Ernst Mach- Life, Work, Influence", Vienna 2016.

[50] The idea of using theatre performances related to the history of science was not popular at that time as it is nowadays. In fact, I will publish an analysis of this skit in such context.

scientific attitude in one moment of *inspiration*?".[51] In fact, according to S. J. Brush "Mach said that he would agree that the atomic theory was the best and most useful hypothesis for physics, without necessarily accepting the *real existence* of atoms".[52]

As Otto Blüh points out in his physics textbook,[32] when dealing with atomic physics "we are concerned with processes that are no longer *observations* in the true sense. From an observation with an instrument or apparatus it is a long step to the actual process, which remains hidden from direct sense perception". In order to conclude that the spinthariscope light speckles, similar to *snow* on an old TV set, correspond to what we know as alpha particles, we need to articulate a complex argumentation based on the atomic theory and many other experiments.

It may be appropriate to discuss here one of the few references to Otto Blüh in the literature[53]:

> Heinrich Löwy in Vienna and Otto Blüh (1902–1976?) in Prague and later in America also supported continuity physics while continuing to reject the reality of atoms . . . [Professor Blüh also defended continuity theory vis à vis atomism in conversation with J. Blackmore.])

Now, as a practising physicist who worked on amphoteric ions, colloids or thermal diffusion of gases and as a teacher and author of a textbook that included atomic phenomena, quantum physics and the most recent theories on nuclear physics, Blüh dealt on a daily basis with physics laws and principles related to matter as made of molecules and atoms. Blackmore's comment is inadequate and reflects a misunderstanding of any physicist's work, whatever her or his ontological *beliefs*: Blüh worked within the accepted and established physics framework, using the theories and models that best suited the specific problem at stake: Even the most convinced *realist* or *atomist* will use a continuum theory of matter when required, to solve, for example, hydro-dynamics problems. As Philipp Frank pointed out,[54] "Atoms are auxiliary conceptions just like others that can be employed advantageously in a limited domain. [. . .] Once we have adopted this point of view, we are all the freer in employing the concept of atoms wherever it is admissible".

Conclusion

Otto Blüh's contribution to previous Mach's commemorations both in 1938 and even more 1966, were probably motivated by a sincere desire to pay tribute to an eminent personality who had shaped Prague's physics tradition. But celebrating

[51] Endnote number 25 in reference 1, page 22.

[52] Stephen J. Brush, "Mach and Atomism" in: *Synthese*, 18, 1968, pp. 192–215.

[53] John Blackmore (2005) "Philosophie in Österreich 1920–1951, The Vienna and the Brünn Circle, 806–817, in *Verdrängter Humanismus- Verzögerte. Aufklärung* - Band V, Benedickt et al. eds. WUV, 2006.

[54] Philipp Frank, 'The Importance of Ernst Mach's Philosophy of Science for Our Times' (orig. 1917), in: R. S. Cohen and R. Seeger (eds.) *Ernst Mach: Physicist and Philosopher* (Boston Studies in the Philosophy of Science, 6), Dordrecht Holland: D. Reidel PC 1970, pp. 219–234.

Mach was not just a one-day event to remember someone of historical relevance. Beyond his physics specialization and often in non-propitious exile destinations, Blüh involved himself in a rediscovery of Mach's enlightened, humanistic and interdisciplinary ideas about physics and education, displaying a distinct *Bildung*. He encouraged educational and cultural values within physics and worked for an integration of history and philosophy of science with science and education. High schools and universities would be the natural places where a cultural approach to science should be undertaken, both for a proper understanding of science and as a safeguard for democracy.

The kind of questions we pose about Mach not only shed new light on his work and personality, but define us and the place that Mach finds in our present time. Blüh was Mach's true heir as he *practiced* Mach critically and without dogmatism, in a historical time that was different in many respects both in science and society. In his ideas and work Otto Blüh had truly assumed, to quote Derrida, that "inheritance is never a given, but always a task".

Chapter 49
Ernst Mach's „Bekehrung" zum Atomismus / Ernst Mach's "Conversion" to Atomism – A Dialogue Between Mach and Popper-Lynkeus

Otto Blüh

Abstract Otto Blüh was a great admirer of Ernst Mach's and contributed a number of papers to Machian scholarship. It is believed that he wrote this skit around 1966, perhaps to coincide with the celebration of the 50th anniversary of Mach's death and most likely for Blüh's own amusement, as it was never published. It consists of an imaginary conversation in pseudo-Viennese dialect, between Mach and his friend, Josef Popper-Lynkeus based on the questionable tale of Mach's conversion to atomism. This paper includes a brief introduction to the skit as well as its transcription and translation into English, published for the first time. It was also dramatized for the first time in occasion of the Ernst Mach Centenary Conference (Vienna 2016).

Introduction to the Skit by Chantal Ferrer-Roca

Otto Blüh (1902–1981), dozent in the German University of Prague and, after WWII, professor of physics at the Universities of British Columbia (Canada) and Vanderbilt (USA), maintained a lifelong interest in Ernst Mach and gave pioneering contributions recognizing the relevance of Mach's teaching ideas for a critical approach to his scientific and philosophical legacy. A more detailed account of Blüh's life and the importance of Mach in his work can be found in.[1]

Around 1966, maybe in connection with the commemorations of the 50th anniversary of the death of Ernst Mach, Otto Blüh wrote – probably for his own

[1] "Otto Blüh and Ernst Mach: Inheritance and Task" by Chantal Ferrer-Roca, in this volume.

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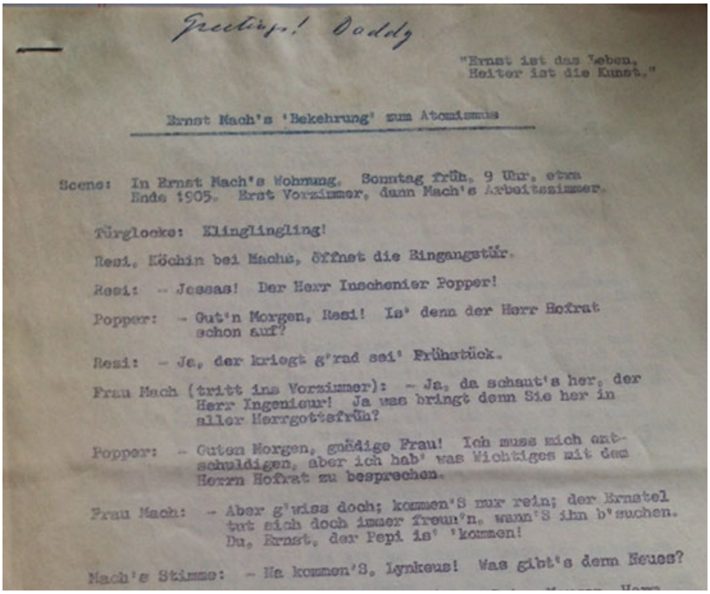
F. Stadler (ed.), *Ernst Mach – Life, Work, Influence*, Vienna Circle Institute Yearbook 22, https://doi.org/10.1007/978-3-030-04378-0_49



Greetings! Daddy

"Ernst ist das Leben,
Heiter ist die Kunst."

Ernst Mach's 'Bekehrung' zum Atomismus

Scene: In Ernst Mach's Wohnung. Sonntag früh, 9 Uhr, etwa Ende 1905. Erst Vorzimmer, dann Mach's Arbeitszimmer.

Türglocke: Klinglingling!

Resi, Köchin bei Machs, öffnet die Eingangstür.

Resi: – Jessas! Der Herr Inschenier Popper!

Popper: – Gut'n Morgen, Resi! Is' denn der Herr Hofrat schon auf?

Resi: – Ja, der kriegt g'rad sei' Frühstück.

Frau Mach (tritt ins Vorzimmer): – Ja, da schaut's her, der Herr Ingenieur! Ja was bringt denn Sie her in aller Herrgottsfrüh?

Popper: – Guten Morgen, gnädige Frau! Ich muss mich entschuldigen, aber ich hab' was Wichtiges mit dem Herrn Hofrat zu besprechen.

Frau Mach: – Aber g'wiss doch; kommen'S nur rein; der Ernstel tut sich doch immer freun'n, wann'S ihn b'suchen. Du, Ernst, der Pepi is' 'kommen!

Mach's Stimme: – Na kommen'S, Lynkeus! Was gibt's denn Neues?

Fig. 49.1 First page (partial) of the original skit written by Otto Blüh

amusement[2] – a short skit in German (Fig. 49.1), an imaginary dialogue between Ernst Mach and Josef Popper-Lynkeus[3] that had remained unpublished. It was recently transcribed, translated into English and presented and dramatized[4] for the Ernst Mach Centenary Conference (Fig. 49.2).

Blüh's skit is based on the apocryphal story about Mach converting to atomism (i.e. believing in the real existence of atoms) that, according to the literature, is to be attributed to Stefan Meyer.[5] Let us cite Stephen J. Brush[6]:

[2]Blüh liked writing parodic versions of famous poems that he used to send to his daughter. See, for example, Schiller's modified quotation at the beginning of the skit (note the double meaning for the word "Ernst"). Information provided by Pamela Bluh.

[3]Otto Blüh was a fervent admirer both of Ernst Mach and Popper-Lynkeus.

[4]"Ernst Mach's 'Bekehrung' Zum Atomismus" (Ernst Mach's "Conversion" to Atomism) by Otto Blüh has been transcribed and translated into English by Pamela Bluh and reviewed by Chantal Ferrer-Roca, who proposed its dramatization for the International Conference "Ernst Mach- Life, Work, Influence", Vienna 2016. After a presentation by Ferrer-Roca, it was performed by actors RRemi Brandner and Wolfgang Nitsch on June 18 (Fig. 49.2).

[5]Stephan Meyer started his career as assistant to Boltzmann (until Boltzmann's death in 1906), and then to Exner. He became professor of Physics in Vienna in 1908 and was later appointed director of the Institute for Radium Research in Vienna where he worked on this radioactive element (Now *Stefan-Meyer-Institute for subatomic physics*).

[6]Stephen J. Brush, "Mach and Atomism" in: *Synthese*, 18, 1968, pp. 192–21.

Fig. 49.2 Actors Wolfgang Nitsch (Popper, Resi and Mach's wife – despite the *physique du role*, he did not play Mach's character) and RRemi Brandner (Ernst Mach) dramatizing Otto Blüh's skit "Ernst Mach's 'Bekehrung' zum Atomismus" in German during the Ernst Mach Centenary Conference (Vienna 2016)

> Stefan Meyer has reported the following incident, which occurred around 1903. The apparatus invented by Elster and Geitel, and by Crookes, had made it possible to display the flashes made by individual alpha particles on a screen, [. . .] Be that as it may, there was naturally great curiosity in Vienna to see what impression the new device would make on Ernst Mach. Whenever any of the atomists would speak of atoms to him, he would always say: 'Have you seen one?'. Up to then, the atomists had to admit that they had not. But now the tables were turned. Though already sick and partially lame, Mach came to the laboratory to look at the spinthariscope. When he saw the flashes, he made no hair-splitting qualifications, but said simply: 'Now I believe in the existence of the atom' An entire world picture had changed for him in a few minutes (according to Stefan Meyer).

Meyer's story provides the background for Blüh's invented dialogue that can be summarized as follows: Popper arrives at Mach's home early on a Sunday morning and asks Mach why Meyer is going around Vienna saying that he now believes in the real existence of atoms. Mach explains that Meyer visited him to make him look through the spinthariscope and "see" atoms. Fed up with Meyer's insistence, Mach pretends to have seen them, just to get rid of Meyer. But now Mach regrets it, aware that it may have been a joke played by Boltzmann and his assistants, and afraid that historians of science may take his false conversion seriously.

A realist contextualization is introduced through the use of a simulated Viennese dialect[7] and other Viennese elements in that period, such as the coffee house – the

[7]Including the old Viennese expression "Der soll das der Frau Blaschke erzählen". It is not known who Frau Blaschke is, but it means the person you are speaking with does not believe what you are saying. The colloquial Viennese term means "Yeah, right - tell it to Miss Blaschke!", indicating doubt about a claim, a statement or a story (it's incredible!). http://www.wienerzeitung.at/nachrichten/english_news/236376_Frau-Blaschke.html (retrieved 13 Jan 2018).

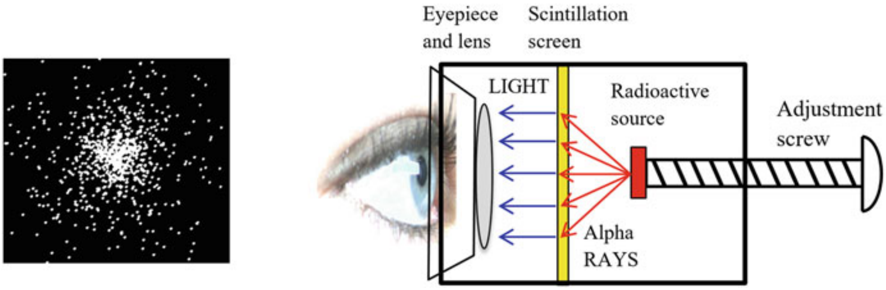


Fig. 49.3 The spinthariscope contains a small ore of some radioactive source (radium, uranium, etc.), whose decay (alpha rays in this case) causes flashes of light on a scintillating screen. By holding the tube up to your eye (once you get used to the dark) you can see flashing speckles, that should be evidence of the alpha particles impinging on the screen

modern “agora” where news and ideas were discussed and spread – or the famous journal “Die Fackel”, edited by Karl Kraus.

Blüh sets the scene in 1905, Einstein’s “annus mirabilis” in which, among other works,[8] he published his famous paper on Special Relativity – mentioned by the Mach character. Boltzmann and his assistants, as well as Ostwald, Avenarius and Lampa (on the other side of the Mach-Boltzmann controversy) are named by Mach, also Planck, who had a low esteem of Mach in that period. Various members of Mach’s family also appear throughout the conversation, in particular his son Ludwig.

It may be interesting to remember that a spinthariscope is a simple device containing a radioactive sample that emits alpha particles that produce light speckles or flashes upon impinging on a scintillating screen (see Figs. 49.3 and 49.4). They can be seen when the eye (accustomed to the darkness) looks through the eyepiece.[9]

According to this controversial story, Mach is supposed to have watched through the spinthariscope when the idea of the atom as the smallest and indivisible particle was just being challenged, and radioactivity as the emission of atomic fragments was still being explored. It was Rutherford who, in 1908, definitively identified alpha radioactivity as Helium ions and later (in 1911), after different experiments by Geiger and Marsden, he presented his model of atomic structure with the atomic mass concentrated in a tiny nucleus. It is thus unclear if the atoms Mach was supposed to “believe in” were alpha particles or the atoms that emitted them, or even something else. As the Mach character claims: Meyer is [. . .] telling me [. . .] that these flashes of light are the alpha particles [. . .] that are being flung out of the uranium atoms, and so on. First he had to confirm that Uranium has atoms!”

[8]In 1905 Albert Einstein also published his papers on Brownian motion on account of atomic motion, the theoretical explanation of the Photoelectric Effect -considered one of the first steps towards quantum physics.

[9]Light speckles in the spinthariscope can be compared to the *snow* on the screen of an old analog TV set, that could be seen when the antenna signal was missing. These points were produced by a controlled electron beam impinging on a scintillator screen as well.

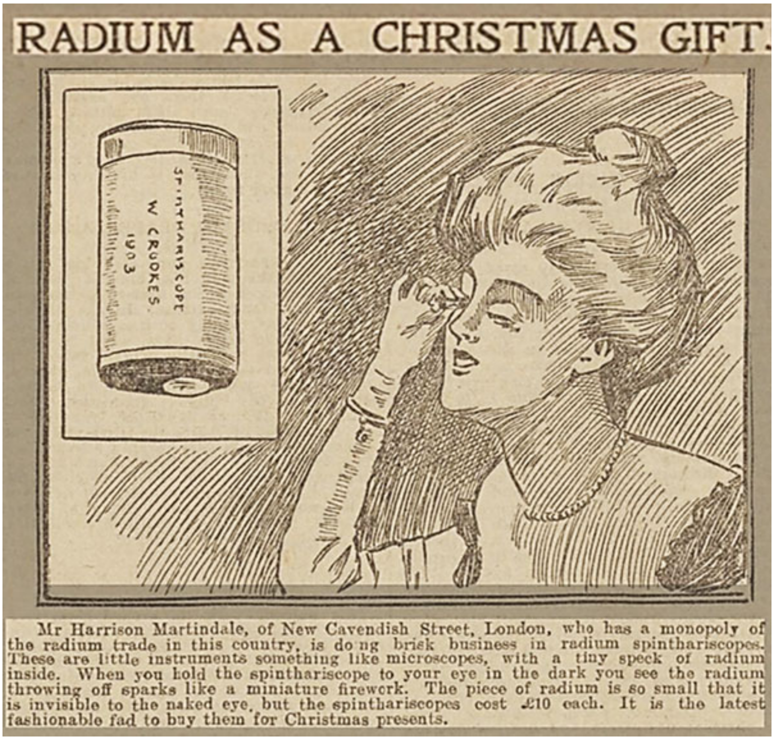


Fig. 49.4 Spinthariscopes were popular toys and curiosities in the first decade of the twentieth century, as this old advertisement shows (1903). Similar versions are still available today. Image retrieved from unknown source in https://londonist.com/2014/12/the-weirdest-christmas-gifts-in-londons-history [15 January 2018]

or “Thomson in England, with his cathode rays has clearly demonstrated that these so-called atoms are clearly NOT the smallest parts of matter!!”.

Brush[6] disbelieved Meyer's story and thought that Mach had not accepted atomism by the end of his life, as he had never written anything about this question. But maybe there are stronger reasons to reject the idea of a conversion, as Blüh himself recognized.[10] “Conversion” or “belief” are inadequate terms, since for Mach atoms (as with other abstract entities in physics) are ideas or models devised to explain reality giving account of all facts. Again, according to Brush[6]:

> At about the same time, Einstein talked to Mach about atomism, and asked him whether he would not accept the atomic theory if (as now seemed likely) it turned out to be the only one that could account for the experimental facts. There are at least three extant accounts of this meeting, all of which agree in essentials: Mach said that he would agree that the atomic

[10] A discussion on Otto Blüh's ideas about this controversy, both on the status of the atom (reality or model?) and Mach's attitude about it, is included in [1], in section 48.6 and references therein.

theory was the best and most useful hypothesis for physics, without necessarily accepting the ‘real existence’ of atoms.

Be that as it may, Blüh’s imaginary dialogue is a little gem: it illustrates Mach’s ideas and the atomic controversy very well, with a detailed historical contextualization and a charming sense of humour. Enjoyable as a short reading as well as a performance, it can be a very interesting and valuable piece for science teaching and popularization of science.[11]

Transcription from original by Pamela Bluh

“Ernst ist das Leben,
Heiter ist die Kunst.”

Ernst Mach’s ‘Bekehrung’ zum Atomismus von Otto Blüh (1966 ca.)

Scene:	In Ernst Mach’s Wohnung, Sonntag früh, 9 Uhr, etwa Ende 1905. Erst Vorzimmer, dann Mach’s Arbeitszimmer.
Türglocke:	Klinglinkling!
Resi:	Köchin bei Machs, öffnet die Eingangstür.
Resi:	Jessas! Der Herr Inschenier Popper!
Popper:	Gut’n Morgen, Resi! Is’ den der Herr Hofrat schon auf?
Resi:	Ja, der kriegt g’rad sei’ Frühstück.
Frau Mach (tritt ins Vorzimmer):	Ja, da schaut’s her, der Herr Ingenieur! Ja was bringt den Sie her in aller Herrgottsfrüh?
Popper:	Guten Morgen, gnädige Frau! Ich muss mich entschuldigen, aber ich hab’ was Wichtiges mit dem Herrn Hofrat zu besprechen.
Frau Mach:	Aber g’wiss doch; kommen’S nur rein; der Ernstel tut sich doch immer freun’n, wann’S ihn b’suchen. Du, Ernst, der Pepi is’ ‘kommen!
Mach’s Stimme:	Na kommen’S, Lynkeus! Was gibt’s denn Neues?
Popper (ins Arbeitszimmer eintretend):	Guten Morgen, Herr Hofrat! Wie geht’s denn? Ham’S gut g’schlafen?
Mach:	Ja, wie soll ich denn gut g’schlafen haben? Alles geht mir im Kopf ‘rum; kaner kommt mich b’suchen, und wenn aner kommt, wie der Stefan Meyer, der will mich nur frozzeln.

[11] The idea of using drama performances related to science or the history of science for teaching or popularization is a recognized pedagogical tool nowadays. An analysis of this skit will be published by the author in this context.

Popper: Ja, der Stefan Meyer, wegen dem komm' ich ja so früh. Der rennt ja überall herum in Wien und erzählt Herr Hofrat haben sich zum Atomismus bekehrt. Ja was ist denn gescheh'n? Wieso nimmt der Klachel sich denn das heraus? Hat er sich das aus den Fingern gezuzzelt?

Mach: Na schaun'S her, das war so. Vor a paar Tagen kommt der Dozent Meyer, er will mir was zeigen. No, ich war grad' dabei, dem Ostwalt zu gratulieren zu dem schönen Artikel, in dem er die Atomtheorie gründlich demoliert, und da kommt dieser Lausbub, und will mir beweisen, dass die Atome existieren! Wo doch der Thomson in England mit seinen Kathodenstrahlen klar bewiesen hat, dass die sogenannten Atome nicht die kleinsten Teilchen der Materie sind!

Popper: Das ist doch klar wie Schuhwichs!

Mach: Und glauben'S mir, Herr Popper, s'wird nicht lang dauern – wir werden's noch erleben – und jemand wird zeigen, dass es kleinere elektrische Ladungen gibt als die sogenannten Kathodenstrahlen!!

Popper: Ja, aber ich komm' grad' wegen dem Meyer und sein' Lugen. Woher hat er denn diese Geschichte von Ihrer Bekehrung zum Atomismus?

Mach: Ja, der Meyer kommt also vor a paar Tagen rauf, und was bringt er mit: a Spinthariskop! Na, sag ich zum ihm, 'was hat er denn da?' Und er sagt, 'a Schpinthariskop, das mir das K. und K. Ministerium für Kultus und Unterricht extra bewilligt hat. Mit dem können der Herr Hofrat einzelne Atome sehen.' 'No, wenn'S das können,' sage ich zu dem Meyer, 'dann werd' ich mich am End' noch zum Atomismus bekehren müssen.' Hab' ich g'sagt, und g'lacht.

Popper: So ein Spinthariskop muss doch grausslich teuer sein: das kann halt doch leicht 25 Gulden kosten! Aber haben'S denn die Atome g'sehen, Herr Hofrat?

Mach: Schaun'S her, das mit dem Spinthariskop is' ja net so anfach; da müssen's erst a Plait übern' Koft ziehen, und under der Decke müssen'S a halbe Stund'n sitzen, um das Auge zu adaptieren, und dann, wann'S das Spinthariskop ans Aug' halten, ja da sieht man halt so wie a paar Blitze, alle Sekunden oder so, wie Sterne, und der Meyer red't alleweil in mich hinein, dass das die Alphateilchen sind, die auf den Szintillationsschirm auffallen und ihn zum Leuchten bringen. Das ich nicht lach'! Und der Meyer hört nicht auf zu reden, dass das die Teilchen sind, die aus den Uranatomen herausfliegen, und so weiter. Da müsst' er mir erst beweisen, dass das Uran Atome hat!

Popper: Ja was haben Sie ihm denn gesagt?

Mach: Na, endlich hat er mir den Plaid zum Koft g'rissen und er hat immerfort weitergeredet, von der Radioaktivität, und das doch diese Strahlen von wo herkommen müssen, und dass die Alphateilchen wahrscheinlich selbst Atome sind. Der reinste Konfusionsat. Erst hat das Uran Atome, also unteilbare Partikel, und dann kommen andere Atome aus den Atomen. A Stuss, sag' ich Eahna! Aber der Meyer gibt ka' Ruh', und mir hat schon der Kopf weh' 'tan, und da hab' ich halt g'sogt: "Na ja, jetzt glaub' ich halt an die Existenz der Atome,' und hab' 'glaubt, jetzt bin ich ihn los; aber na! Der Meyer fahrt fort, und ich will ihn loswerden, und sag' nach amal, "Ja wenn das Atome sind, was da so blitzt, dann glaub ich auch an die Atome.' Das hat ihn dann befriedgt, und er ist abgezogen mit san Schpinthariskop. Wenn ich g'wusst hätt', dass der mir soviel Scherein Machen wird! Der Ludwig hat g'sagt, wenn er z'Haus g'wesen wär', hätt' er ihm ans geklebt: da würd' er Sterne g'sehen hab'n ohne a Schpinthariskop!

Popper: Aber, Herr Hofrat, der Meyer hat die Ironie nicht verstanden, und jetzt rennt er überall herum, nebbich, mit der G'schicht! Was könnt man denn tun, um es zu dementieren?

Mach: S'tut mir scho' leid, dass ich das g'sagt hab', aber ich wollt' ihn doch loswerden, und dann hab' ich mir 'dacht: A Jud, wenn er auch 'tauft ist, wird doch net so naiv sein und an Spass verstehen. Nix für ungut, Herr Popper.

Popper: Da haben'S recht, Herr Hofrat, der muss halb teppert sein. Ein Chammer! Ich möcht' aber doch raten, dass Sie die G'schicht ehestens widerlegen, denn ich kann mir vorstellen, dass in funfzig[12] Jahren a paar Historiker der Naturwissenschaften die G'schicht ausgraben werden und damit a grosses G'schrei machen, wie der Herr Hofrat Mach sich mit dem Atomismus einverstanden erklärt haben.

Mach: Ja, das wär' für die a g'sundes Fressen, und b'sonders in Amerika, wo's auf solche G'schichten reinfallen. No, ich hab' schon dem Lampa g'schrieben, dass an der G'schichten ka Wort wahr is', – der is' loyal – und wann ich Gelegenheit hab', werd' ich die Angelegenheit sicher auf's Tapet bringen. Ich wett', die wern mir eines Tages noch einreden wollen, ich hab' bei der Relativitätstheorie G'vatter g'standen! Ich werd' dass alles in der Vorrede zur Optik behandeln und der Ludwig wird auch das Seinige beitragen. Ich lass' mir das nicht gefallen! Aber, sein'S so gut, Herr Popper, und wann'S im Kaffeehaus

[12] Note by Pamela Bluh: In the original typescript, the word is spelled without the umlaut – funfzig, but the correct spelling should be „fünfzig".

Leut' sprechen, die davon g'hört ham, so können'S die Sach' in meinem Namen entschieden dementieren. Den Fackel Kraus möcht' man brauchen, um dem Meyer die Antwort zu geben, die ihm g'bührt!

Popper: Aber regen'S Ihnen nur net auf, Herr Hofrat. S'glaubt ja eh kaner was von dem, was der Meyer herumtratscht. Der soll das der Frau Blaschke erzählen.

Mach: Na sagen'S dös net, Herr Popper. Wissen'S, es is' ja gar net der Meyer, es is' der Boltzmann, der mir das eingebrockt hat.

Popper: Ja, wieso der Boltzmann?

Mach: Ja der bildet sich doch ein, er hat die Atome erfunden, und überall verteidigt er die Atomtheorie und schmipft wie a Rohrspatz, auf den Ostwald, den Avenarius und mich. Na, ich stell' mir das halt so vor: Da sitzen's in der Berggassen, der Boltzmann, und der Smoluchowski, und der Přibram, und der Exner, der Hasenöhrl und der Frank, und da kommt der Meyer mit san Schpintariskop und red't an Stuss von den radioaktiven Atomen, und da sagt der Boltzmann: "Sie, Meyer, gehn'S doch 'rauf zum Mach und schauen'S amal, was er sogt, wenn er die Atome sieht. Er sogt doch immer, wann ich mit ihm streit': "Ham'S ans g'sehen?" Na, jetzt kann er doch nicht leugnen, dass er ans – nöt ans, – aber a Hundert seh'n kann." (Pause) Sie, Gift möcht' ich nehmen, dass mir das der Boltzmann eingefädelt hat, und die andern ham sich a Hetz versprochen, weil ich a "Böhm'" bin, und ham dem Meyer zugered't, er soll dach zu mir geh'n und mich aufziehn mit san Schpinthariskop. Und der Meyer will sich doch beim Boltzmann einweimperln, und so is' er mir ins Haus g'stiegen.

Popper: Aber das haben sich der Herr Hofrat doch nur ausgedacht!

Mach: No, sagen'S dös net, Herr Popper. Das is' scho' wahr wir ich da leb'. Der Boltzmann is' amal so, und auch die anderen; auch der Höfler und der Lecher in Prag. Und in Berlin der Herr Planck, mit sein' Energieatomen, wenn der mir was antun könnt, der spitzt nur schon so drauf.

Frau Mach (entretend): Ernsterl, jetzt sollst doch Dein Vormittagsschläfchen halten, bevor wir Mittagessen.

Popper: Ich werd' jetzt gehn, Herr Hofrat, und überall die Sach' richtigstellen. Ich empfehl' mich, gnädige Frau! Grüssen Sie das Lenerl und die Buben. Und was macht denn das Enkerl, der Toni? Das muss doch schon a grosser Bub' sein?

Mach: Und g'scheit is' er auch! Der interessiert sich schon für die Elektrizität: ich wett' mit Ihnen, der kommt noch amol nach Amerika zum Edison.

Popper: Küss' die Hand, gnädige Frau! Adieu, die Herrschaften!

Mach und Auf Wiederschaun, Herr Ingenieur! Kommen'S bald wieder.!

Frau Mach:	
Resi (öffnent die Eingangstür):	Grüss Gott, Herr Inschenier!

English Translation by Pamela Bluh, scientific revision by Chantal Ferrer-Roca

Life is earnest,
art is cheerful (Schiller)

Ernst Mach's "Conversion" to Atomism by Otto Blüh (1966 ca.)

Scene:	In Ernst Mach's home. Early Sunday morning, 9 am, circa end of 1905. First the foyer, then Mach's office.
Doorbell:	Ringing!
Resi:	Mach's cook, opens the door.
Resi:	Oh my goodness! Dr. Popper!
Popper:	Good morning, Resi! Is he (*Herr Hofrat*[13]) already up?
Resi!:	Yes, he's just having his breakfast.
Mrs. Mach (comes into the foyer):	Yes, look who it is, the engineer! What brings you here so early in the morning?
Popper:	Good Morning, Madam. Please do excuse me, but I have something very important to discuss with your husband.
Mrs. Mach:	Certainly. Come in; Ernst is always very pleased, when you visit him. [turning to speak to Mach] Look, Ernst, Pepi is here!
Mach's voice:	Well, come in Lynkeus! What's new?
Popper (stepping into Mach's office):	Good Morning, Sir. How are you? Did you sleep well?
Mach:	Yes, well, how can I sleep well? Everything is running around in my head: no one comes to visit me, and when someone does come, such as Stefan Meyer, he only wants to confuse me.
Popper:	Exactly, it is on account of Stefan Meyer than I'm coming to see you so early in the morning. He is running all over Vienna saying that Mach has converted to atomism. So, exactly what happened? How is it that this fellow says this? Did he make this up?
Mach:	Now, see here, this is what happened. A few days ago, Meyer came here, he wanted to show me something. I was just getting ready to congratulate Ostwald for his nice article, in which he

[13]Note by Chantal Ferrer-Roca: "Hofrat" of the "Geheimrat" was a counselor of the Austrian Empire. The term dates back to the Holy Roman Empire. In Austria the professional title of Hofrat (Court Councilor) has remained in use as an official title for deserved civil servants.

thoroughly discounted the atomic theory, when this ruffian arrives to convince me that atoms exist! Whereas Thomson in England, with his cathode rays has clearly demonstrated, that these so-called atoms are clearly NOT the smallest parts of matter!

Popper: That is as clear as shoe polish!

Mach: And believe me, Popper, it won't take long – we will live to see it – and someone will demonstrate, that there are smaller electric charges than these so-called cathode rays.

Popper: Yes, but I'm here because of Meyer and his lies. Where did he get his story about your conversion to atomism?

Mach: Well, a few days ago, Meyer came here, and what does he bring with him, but a spinthariscope! So, I say to him "what do you bring?" and he says "a spinthariscope that the Ministry of Culture and Instruction gave me special permission to use. With this machine you will be able to see individual atoms". So, I say to Meyer, if that is really possible, then I will finally become a convert to atomism, and I laughed.

Popper: A spinthariscope must be very expensive, it must be at least 25 Guilders! But, did you actually see the atoms?

Mach: Look here, this business with a spinthariscope is not so simple: first you have to put a blanket over your head and sit under this blanket for a half an hour, until your eyes adapt to the darkness, and then, when you hold the spinthariscope to your eye, one sees something like a few flashes of light every second or so, flashes like stars, and Meyer is talking and telling me the entire time, that these flashes of light are the Alpha particles, that are projected on the scintillation screen and light up. Didn't I laugh! And Meyer continues to chatter, that these are the little particles that are being flung out of the uranium atoms, and so on. First he must prove that Uranium has atoms!

Popper: So, what did you say to him?

Mach: Well, finally he took the blanket from my head, all the while still talking about radio activity, and that these rays had to come from somewhere, and that the Alpha particles are most likely themselves atoms. The most confusing words. First Uranium has atoms, that are indivisible particles, and then there are other atoms from those atoms. Finally I say, stop! But Meyer won't stop, and already I have a headache and I told him to stop: "Alright, now I believe in the existence of atoms," and I thought, finally he will leave, but no! Meyer just keeps going, and I want to be rid of him, and once again I say "Yes, if those are atoms, that are sparkling there, then I too believe in atoms." That finally satisfied him and he took off with his spinthariscope. Had I only known, that he would make so much trouble for me! Ludwig did say, had he been at home, he would have given him such a hit, he would have seen stars without the spinthariscope!

Popper: But, my dear sir, Meyer did not understand the irony, and now he's running around with this story! What can one do to deny the story?

Mach: Now I'm sorry that I said it, but I just wanted to be rid of him, and then I thought, "a Jew, even though he's been baptized, won't be so naiive and will understand that this is a joke." No offense, Popper.

Popper: You are right, sir, he must be half demented. What a shame! I would advise however, that you deny the story as soon as possible, because I can very well imagine, that in 50 years, a couple of historians of science will dig up the story and make a great fuss about it, that the great Mach accepted the existence of atoms.

Mach: Yes, that would be quite a feast, and especially in America, where they latch on to such stories. I've already written to Lampa, that the story is completely false, he is loyal and when I have an opportunity I will certainly broach the subject. I bet, one day they will convince me, I am the godfather of the theory of relativity! I will address all this in the foreword to the book on optics and Ludwig will also do it in his book as well. I won't let this happen. But, be so kind Popper, when you speak with people in the coffee house who have heard about this matter, you can tell them, for me, that I deny the story. I could use the Kraus' Fackel to give Meyer the answer he deserves.

Popper: Don't you worry, sir. No one really believes what Meyer is spreading around. He should tell it to Mrs. Blaschke!

Mach: Don't say that, Popper. Do you know, it isn't really Meyer, it is Boltzmann, who introduced this to me.

Popper: Really, how so was it Boltzmann?

Mach: Yes you know, he imagines he discovered atoms, and everywhere he goes he defends the atomic theory and complains like a fishwife about Ostwald, Avenarius, and me. Well, this is how I imagine it: Boltzmann, Smoluchowski, Pribram, Exner, Hasenohrl, and Frank are sitting in a café on the Bergstrasse, and Meyer shows up with this spinthariscope and talks about these radioactive atoms and Boltzmann says "Look here, Meyer, go on to Mach's and see what he says when he sees the atoms. He also says to me, when I argue with him: have you seen them?" Now, he can't lie, that he's seen one, not one, but a hundred." (Pause). Look here, I'd take poison, that Boltzmann set this up and the others thought this would be a good joke, because I'm from Bohemia, and they put Meyer up to it, that he should visit me and tease me with the spinthariscope. And Meyer wants to be in Boltzmann's good graces, so he came along to my house.

Popper: But you just thought of this!

Mach: Don't say that Popper. What I've just told you is true. Boltzmann is like that, and the others as well, also Hoefler and Lecher in Prague. And in Berlin, Planck, with his energy atoms, if he could insult me, he's just dying to do that.

Mrs. Mach Ernst, now you should have your little morning nap, before lunch.

(coming into the room):	
Popper:	I'll go now, sir, and set the matter right. My regards to you, madam. Greetings to Lenerl and the boys. And what about your grandson, Toni? He must be quite a big boy by now?
Mach:	And very clever too! He's already interested in electricity; I'll bet you, one day he'll go to America and work with Edison.
Popper:	Kisses, madam! Goodbye my friends!
Mach and Mrs. Mach:	Goodbye. Come again soon!
Resi (opening the door):	Farewell!

General Part: Reviews

Review Essay

Felix Kaufmann – "A Reasonable Positivist"?

Alexander Linsbichler (University of Vienna)

Robert S. Cohen & Ingeborg K. Helling, *Felix Kaufmann's Theory and Method in the Social Sciences,* Cham: Springer (Boston Studies in the Philosophy and History of Science, Volume 303) 2014, x+357 pages.

A Versatile Mediator

Almost 80 years after the publication of Felix Kaufmann's *Methodenlehre der Sozialwissenschaften* in 1936, Cohen and Helling accomplished the meritorious task of making a translation into English available. Admittedly, Kaufmann's own efforts to write an English version resulted in *Methodology of the Social Sciences* (1958 [1944]). However, the extensive changes, notably adaptations to the American pragmatist context, rather make this a new, separate book. Only now, scholars not proficient in German can track Kaufmann's intellectual development and read his views as they originated in the specific setting of interwar Vienna.

The Viennese public sphere of the 1920s and 1930s was anything but poor in intellectuals with exceptional courses of life and a broad variety of interwoven interests. Yet, the versatility of Kaufmann's endeavors stands out even among his scholarly contemporaries. Having obtained doctorates in *Staatswissenschaften* (law,

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economics, and political science) and philosophy, he lectured as a *Privatdozent* (private lecturer) at the University of Vienna from 1922 on. Although Kaufmann had to earn a living in a full-time job as a business-manager for the Anglo-Iranian Oil Company, he managed to foster his diverse intellectual interests. His publications astonishingly reach from logic, mathematics, general philosophy of science, and legal theory to epistemology, political theory, economics, and other social sciences. With his name already on proscription lists due to his Jewish origins, Kaufmann emigrated to New York in 1938. There he was appointed a professorship at the New School for Social Research.[1]

Kaufmann is most prominent for his role as a mediator between phenomenology, logical empiricism, the theory of pure law, and aprioristic theories of (economic) action. Contemporaries describe the extensive knowledge he acquired, his precise analytical skills, and that he soberly avoided confrontational manners without however easily backtracking from his theses. These qualities allowed Kaufmann to regularly attend meetings of discussion groups as diverse as the Vienna Circle, Mises' private seminar, the Geistkreis, and the Kelsen Circle.

The complex network of intellectual connections around and with Kaufmann is portrayed in a sublime, 102-pages introductory essay by Helling. Her expertise, particularly on Kaufmann's attempts to approximate Dewey's pragmatism, clearly turns up in the informative first section, which mainly outlines Kaufmann's methodological positions in comparison to his contemporaries. Without a doubt the most entertaining section of the entire book, but also enormously rich in information is the subsequent selection of interviews with friends and colleagues of Kaufmann. These reminiscences not only bring flesh and blood to the man Felix Kaufmann, but over and above that highlight subtle gradations and fascinating contraries in the different perceptions of his positions.

Theory and Method in the Social Sciences

The very first sentence of Kaufmann's introduction is indicative of the form and content of the *Methodenlehre:* "The main difficulties in the methodological analyses of the social sciences arise from the excessive multiplicity of intersecting and interpenetrating problems." (Cohen and Helling 2014, p. 105) Kaufmann is certainly proficient in all of these difficile problems and their interdependencies as well as balanced in the evaluation of opposing positions – to some readers' taste perhaps balanced to the point of barrenness.

However, the complexity of the interwoven topics and Kaufmann's diligent approach to them obviously do not result in an easy read. As a textbook to methodology of the social sciences the *Methodenlehre* can be recommended with

[1]This first paid academic position in his life relieved his family's situation. For the sacrifices Kaufmann's first wife made, see (Zilian 1997, p. 10). For George Kaufmann's assessment that his father prioritized his academic work over his family see (Cohen and Helling 2014, p. 36).

severe reservations only. Otherwise, readers with a portion of previous knowledge about some philosophical and scientific debates of the interbellum can benefit tremendously from Kaufmann. His subtle refinement and integration of various influences including Husserl, Kelsen, Mises, Weber, and Schütz is as illuminating as the application of the resulting approach to specific problems and theses.

Unfortunately, the new paper edition lacks a subject index and a table of contents, both of which are included in the German original. This constitutes an unnecessary obstacle to a convenient read of a book with so many internal cross connections. By contrast, the quality of the translation ranks among the praiseworthy aspects. For prototypical terms and phrases the original is displayed in brackets and the general style closely resembles Kaufmann's dry and somewhat ponderously purple German.[2]

Aside from the introduction, the main body of the *Methodenlehre* consists of two parts, one on general philosophy of science and one zooming in on the philosophy of the social sciences. The next paragraphs provide a nowhere near exhaustive sketch of the topics discussed by Kaufmann. Then the review at hand supplements Helling's rich panorama of his intellectual environments with a few deliberations on his relations to logical empiricism, the Austrian School of economics, Popper, and pragmatism.

Actually reaching back to Plato and Euclid, Part One of the *Methodenlehre* starts with reviewing basic philosophical considerations concerning the nature of knowledge. Kaufmann goes on focusing on special cases by criticizing psychological and empirical conceptions of logic and mathematics. Their "materially based conventions" have to be distinguished from statements of facts and from empirical laws, which Kaufmann interprets as procedural rules enabling predictions of facts. Finally, several problems with regard to concepts of value are carefully separated from each other and dealt with from a substantiated anti-psychologistic basis, thereby preparing the treatise of value-free science and the *Methodenstreit* (dispute over method) in Part Two. Among other themes, Part One also analyzes aspects of the psycho-physical problem and of the structure and function of experience. Finally, it proposes a "Universal Methodological Schema" in order to classify and analyze problem situations, knowledge claims, and types of objections.

Drawing on definitions and results from Part One, the second part applies Kaufmann's meta-method of clarification to problems in the methodology of the social sciences, including their delimitation against the natural sciences, psychology, axiology, history, and metaphysics. Most of these debates can be interpreted as different manifestations of a *Methodenstreit* that tend to reappear in the history of science and its philosophy. For instance, the so called (third) positivism dispute between the Frankfurt School and critical rationalism or more recently the science wars include and rearrange most of the open questions, implicit presuppositions, and

[2]Kaufmann himself thought that in his later English works he improved clarity. In any case, he reduced intricate sentence constructions. However, his plans to write an introduction to philosophy for laymen never materialized.

polemic accusations that Kaufmann rationally reconstructs and evaluates in earlier contexts. Finally, making use of the "Universal Methodological Schema" and the insights of Part Two, the last two chapters directly address controversies in marginal utility theory and legal theory. The latter section constituted the core of early draft versions of the *Methodenlehre,* which were even named "Reine Rechtslehre" (pure theory of law) then. (Zilian 1997, p. 9) It also represents a waypoint in the continual dissociation of Kaufmann's position from his mentor Kelsen's, while their mutual personal appreciation never ceased.[3]

Kaufmann and Logical Empiricism

Although Kaufmann regularly attended the discussions he did not regard himself as a proper member of the Vienna Circle. In her introductory essay, Helling recapitulates a list of agreements and disagreements. (Cohen and Helling 2014, p. 5–16) More explicit attention could be called to three points of consensus: Firstly, Kaufmann adheres to the distinction between analytic and synthetic propositions and he harshly criticizes the idea of a synthetic a priori. This point should be kept in mind when he is sometimes labelled as a Kantian or Neo-Kantian. Remarkably, he even prefers the Humean notions "relations of ideas" and "matters of fact" in his English writings. Secondly, his "Universal Methodological Schema" is expressive of an affirmation of (moderate) unity of science. According to Kaufmann, rules of scientific procedure, scientific problem situations, the role of intersubjectivity, and relations between pieces of knowledge share similar features in all scientific disciplines, including the social sciences, mathematics, and the theory of law.

The most striking overlap between Kaufmann and other logical empiricists, however, is their common conception of the scope and aims of methodology and philosophy (of science). Particularly, the antagonism between Carnap and Kaufmann tends to be overstated, and hence their ongoing friendship appears unexpected. (*id.,* p. 41) Notably, both advocate a division of labor in the study of science and do not themselves deal with "generalized description[s] of the scientist . . . however interesting they may be from the point of view of the history of theories, the psychology and sociology of knowledge" (*id.,* p. 104). Instead, conceptions of philosophy and methodology are restricted to the context of justification.[4] In his rational reconstructions, Kaufmann eliminates equivocations, for instance of the phrase "sphere of economic events" and clarifies ambiguous concepts as

[3] See (Winkler 1999).

[4] As a caveat, Kaufmann's phenomenalistically inspired conception of the context of justification might be more likely to also involve the "context of formation" (Formierungszusammenhang), i.e. for instance rationally reconstructing the preconditions of a successful scientific world conception. See Rinofner-Kreidl (2007). However, Zilsel and Stegmüller are closely affiliated with logical empiricism and undertook kindred tasks without phenomenalistic motives. It should also be noted that the scope of the context of justification in Reichenbach's (1938) classical presentation includes fields that are often subsumed under the context of discovery.

early as 1923,[5] long before Carnap's strive for explication gained momentum. Kaufmann's sophisticated project of clarification is not restricted to the analysis of the meaning of terms and sentences, but also encompasses rationally reconstructing the methods and rules of verification and falsification and the epistemological status of statements in general. Prominent examples which Kaufmann deals with include ambiguities between analytical and empirical laws of marginal utility, as well as the specific content and openness to revision of various claims regarding the rationality of human action. At least the latter is a matter of interest and controversy until today. Ultimately, it is the rational reconstruction of the procedural rules of scientific justification and criticism that dominates Kaufmann's deliberations, in later years increasingly so. Trenchantly, he outlines the scope and the primary concern of (his) methodology of science:

> [From this point of view] the procedure of an empirical science consists in the acceptance or elimination of propositions in accordance with given rules. Whatever else the scientist may do, whether he looks through microscopes or telescopes, vaccinates guinea pigs, deciphers hieroglyphics, or studies market reports, his activities will result in changing the corpus of his science either by incorporating propositions that did not previously belong to it or by eliminating propositions that previously did. Such a change in the corpus of science may be called a scientific decision. The scientist must not make a decision arbitrarily. To do so would be a violation of the rules to which he has implicitly pledged himself by engaging in scientific inquiry. He must give grounds for each decision, i.e. he must show that it is permissible (correct) in terms of the presupposed rules of scientific procedure. (Kaufmann 1958 [1944], p. 48)

Accordingly, Kaufmann may have extended a warm welcome to Carnap's late work in inductive logic and to recent progress in decision theory.

Given the common ground of so-called typical logical empiricists and Kaufmann, what then are the faultlines? Kaufmann maintains that the main contenders in the protocol-sentence debate hold a naive sensationalist stance. He insists on taking the lessons of Husserl's phenomenology more seriously by analyzing the structure of experience and its preconditions. Such investigations apparently reveal that each experience is necessarily connected to presuppositions. Admittedly, the most fastidious distinction between the presuppositions of an empirical (or analytical or normative apropos) judgement, its meaning, its manner of verification, and its consequences is provided by Kaufmann. Helling though slightly attenuates this portrayal of a most salient distinction between logical empiricist philosophy of science and Kaufmann's stance. Moreover, she criticizes him for not consistently abiding by the separation of meaning and manner of verification himself. Indeed, mature logical empiricist views as held by Waismann, Neurath, Neider, Hahn, Carnap, and others essentially incorporate most of Kaufmann's demurs. In fact, Carnap's and Hahn's position that there is no meaningful talk of a "given" prior to the specification of a (linguistic) framework is probably an even more radical form of relativism than Kaufmann would advocate. What he did, however, was employing

[5] See (Kaufmann 1923).

the dependence of every experience on presuppositions for lines of thought more typical of him:

Firstly, as Helling points out as well, Kaufmann argues for a continuity between experience in science and in daily life. Although he focuses on methodology of science, his analysis of experience can be read as a complementing basis for Schütz's general sociology of communication. One might easily be misled by the unconcern with everyday life in Kaufmann's writings; but an interpretation of Kaufmann which stresses the necessity of preconditions of experience for scientific conduct only[6] does not seem to comply with his phenomenological leanings very well.

Secondly, alleged differences between outer and inner experience shrink since both depend on preconditions. In further consequence, judgements both in the natural and the social sciences can be evaluated only relative to a reference system. The most elaborated example of this is the meaning-interpretation of actions. Kaufmann dissects how, based on the assumptions that other men exist and possess analogous consciousness, the method of specific understanding ("Verstehen") can be applied to interpret human behavior as purposive action. In comparison to Weber, Kaufmann refines "Verstehen" by relativizing it to schemata of interpretation that have to be specified.

Kaufmann rejects intuition as an anti-naturalistic criterion of truth, but his meaning-interpretations indeed seem to rely heavier on inner experience than many logical empiricists would allow for. Once a schema of interpretation is specified precisely enough, however, it possibly resembles physicalist meaning postulates and theoretical laws for theoretical terms such as preferences, aims, and predispositions. Actually, nearly all the alleged traits of the Vienna Circle in Helling's lucid list of disagreements with Kaufmann were contested or abandoned by mature logical empiricism. Even so, Neurath's attempts to convince Kaufmann of the non-reductionist character of physicalism nevertheless remained mostly in vain.[7] What Kaufmann therefore delivered to posterity, the Geistkreis, and Mises' private seminar as the doctrine of the Vienna Circle was by and large one of verificationism and reductionism.

Kaufmann and the Liberal Wing of Viennese Late Enlightenment

Kaufmann's selective or sometimes even slightly distorting presentation of logical empiricism, or rather positivism in this case, contributed to a self-perception of Mises, Hayek, and other influential representatives of the Austrian School of economics as entirely opposed to the ideas of the Vienna Circle. At first glance, the political liberalism, philosophical apriorism, and methodological anti-inductivism of the Austrian School all seem antithetical to logical empiricism indeed. Albeit,

[6] For such an interpretation see (Rinofner-Kreidl 2007).

[7] For the correspondence with Neurath in 1935 see (Uebel 2007, p. 379–380).

closer investigations of the relationship between these two internationally most influential intellectual movements with Viennese origins are desirable: "Although these two renowned traditions have of course been studied both historically and systematically, esp. over the last decade, we still lack research on both together, n their similarities and differences, mutual influences and interaction in the course of the development of science." (Stadler 2007, p. 603)

Such investigations are likely to reveal neglected parallels and alleviate some of the purportedly unbridgeable antagonisms between logical positivism and the Austrian School. If not, they ought to explain why the proponents of these intellectual movements respond so differently to the philosophical, scientific, and political problems of their time – notwithstanding they started out from a common motivation inspired by "Viennese Late Enlightenment" (Stadler 1981, 2007). The more prominent empiricist, left and the overshadowed apriorist, liberal wing of Viennese Late Enlightenment share numerous philosophical, scientific, and (life-threatening) political opponents as well: intuitive universalism, other forms of essentialism, methodological collectivism, objective theories of value, psychologism, and clericalism, conservatism, communism, fascism, National Socialism respectively.

Kaufmann could ideally serve as a starting point for the desired comparison between the Vienna Circle and the third generation of the Austrian School.[8] His role has been described as a mediator, reporting about physicalism in Mises' private seminar, in which problems of economics and its methodology were discussed. Topics in the Geistkreis used to be more diverse, with Kaufmann's lectures ranging from logic, mathematics, and the theory of relativity to science of art and intellectual righteousness. (Hagemann and Krohn 1999, p. 314) Certainly, a closer look at these intellectual circles reveals that they were politically and philosophically much more diverse than some Neo-Austrian interpreters of Mises suggest.

Kaufmann and Popper

One momentous line of knowledge transfer is almost missing in Helling's excellent contextualization of the thick intellectual network around Kaufmann: his relation to Popper. This probably most powerful impact on intellectual history, however, has altogether not been sufficiently acknowledged yet. In Part Two of the *Methodenlehre,* Kaufmann meticulously discusses the theses of naturalism and anti-naturalism. While the first argues that the social sciences ought to adopt the methods of the natural sciences exclusively, the second insists that the methods of the natural sciences including formal mathematics and logic are inapplicable in the social sciences and humanities. Most versions of anti-naturalism maintain that the purportedly categorically distinct social reality necessitates altogether

[8]Another possible starting point is the many-faceted intellectual encounter between Mises and Neurath. See (Linsbichler 2015).

different methods.[9] Kaufmann's *Methodenlehre,* including a highly critical analysis of naturalistic behaviorism and anti-naturalistic introspectionism, was carefully studied by Popper in 1937. (Hacohen 2000, p. 363–365) But while content-wise this becomes clearly noticeable in Popper's famous *The Poverty of Historicism* (1957 [1944])*,* which in effect entirely consists of a damnation of naturalistic and anti-naturalistic doctrines, Popper misses to mention Kaufmann by name. It is the same Kaufmann, who helped to get *The Open Society and its Enemies* published and assisted Popper on his job search both in England and New Zealand, for which he was pledged: "I shall never forget what you have done for me, and the way you did it." It is also the same Kaufmann, whom Popper described as a mere distant relationship a few years later without mentioning these efforts. (Hacohen 2000, p. 322–323) Effectively, Kaufmann's role in this much-debated chapter in intellectual history has been buried. A single footnote in close friend Hayek's *The Counter-Revolution of Science* (1955, p. 214) did not suffice. Moreover, Hayek in contrast to Kaufmann and Popper advocates a version of anti-naturalism. Still, in the interview he speaks in high terms of his old colleague from the Geistkreis and the Mises' private seminar and added: "Well, he was a positivist one could talk with, a reasonable positivist." (Cohen and Helling 2014, p. 57).

Kaufmann in the United States

Commenting on Kaufmann's later interaction with pragmatism, Nagel even more pointedly describes him as "more positivistic than the positivists" (*id.,* p. 25). This refers to the increased attention Kaufmann turned on rules of scientific procedure and scientific decisions, when he published *Methodology of the Social Sciences* (Kaufmann 1958 [1944]). Admittedly, by referring to it as "a very different book" (*id.,* p. vii) compared to *Methodenlehre* Kaufmann stresses the novelties, which he incorporated impressed by Dewey and trying to combine their respective forms of pragmatism and logical empiricism. However, firstly Helling queries this self-assessment by rightly identifying alleged novelties as mere shifts of emphasis. Secondly, most commenters including Dewey himself opined that Kaufmann overestimated the similarities between their positions.

In an arduous self-application of clarification, Kaufmann and pragmatists like Dewey and Bentley tried to carve out misleading equivocations and underlying differences of opinion in their correspondence. Ultimately, Kaufmann's mature conception of methodology is a logic of research procedure and a theory of scientific criticism that functions solely in the context of justification, whereas rational reconstructions and separation of contexts of discovery and justification are alien to pragmatist philosophy of science. Moreover – and this is an upshot of what

[9]Notably, Mises' provisos against the use of mathematical methods in economics are much more cautious and qualified than those of Rothbard and other prominent Neo-Austrians claiming to work in his tradition. See (Linsbichler 2017, p. 99–104).

Kaufmann himself identifies as the crucial point of disagreement with Dewey that motivated *Methodology of the Social Sciences* – being a kind of logical empiricist, phenomenologist, and Neo-Kantian he maintained that rules of logic do not emerge in interaction, but at least some of them have to be (revisably) presupposed.

Rediscovering Kaufmann's Methodology

In any case, the translation of *Methodenlehre* at hand facilitates future more detailed analyses of the nuanced changes in Kaufmann's position towards pragmatism from 1936 to 1944. Such a case study would not be of historical interest only, but over and above that could inform current methodological challenges faced in HPS: How can and should historical, sociological, and philosophical approaches to science be integrated? Or can a division of labor yield more fruitful results in many cases, as the bipartite metatheory suggests? Expected benefits for answering those question brought about by a second look at the interactions between logical empiricism and pragmatism have been suggested. While the relevant investigations have been partly conducted, Kaufmann is virtually missing in these discussions by now.[10] When evaluating the eventually modest success of his attempts to combine logical empiricism and pragmatism, one should in any case also consider external factors. These include the unfavorable political context, the then dominating empirical, hands-on approach to social sciences in the United States, and last not least personal motives of certain gate keepers.[11]

Further external reasons why Kaufmann's oeuvre with a few exceptions fell into oblivion include the adverse points in time when his major works got published. His intuitionistic book on the foundations of mathematics (Kaufmann 1930) was soon overshadowed by Carnap's *Logical Syntax* and Gödel's incompleteness theorems. In 1936, when the *Methodenlehre* was published, most former attendees of the Mises' private seminar as well as many members of the Vienna Circle had already left Vienna. Consequently, a cautious reflection on methodology written by a Jew without a paid position at a university, who was forced to exile in 1938 unsurprisingly did not gather too much attention in the German speaking academia of the time. Without a doubt, Kaufmann's scientific working conditions improved in the United States, as he held a position of assistant professor and in 1944 became full professor. But unfortunately, during emigration he gradually lost his hearing and became more and more secluded subsequently.[12]

[10] See for instance (Mormann 2010; Uebel 2010, 2015). Noteworthy, (Misak 2013) does not mention Kaufmann at all and (Philström et al. 2017) but once.

[11] See (Cohen and Helling 2014, p. 33–34). Moreover, see (Cunha 2012) for ad hominem slurs against Carnap and Morris on the part of Bentley. His personal reservations against Kaufmann are mild in comparison.

[12] One can perhaps estimate how devastating his impairment must have been for Kaufmann, taking into consideration that he took both authorship and intonation of the ingenious *Songs of the Mises-Kreis* rather serious. See (Kaufmann 1992), and also (Kaufmann 2010), although some of the wit

These obstacles, an uncareerist attitude, and his diligently deliberating approach void of catchy slogans for methodological debates hindered a broader dissemination and discussion of Kaufmann's results and proposals. So far, neither a book-length English appraisal of his philosophical positions nor a biography are available.[13] Cohen's and Helling's work offer a welcome impetus to intensify research concerning Kaufmann and his multi-faceted, yet underrated scientific achievements.

Apart from specific claims, it is primarily Kaufmann's rigorous vindication of clarification as a means to solve methodological problems, which can still serve as a helpful model today. True, he could not foresee the contemporary scholarly and public debates about rationality or about pluralism in economics and other fields. But we might nonetheless be wise to apply his central proposition that there is never only one single expedient approach or method and that "[w]hat ought to be overcome, and can be overcome, is the exaggeration of methodological conflict due to pseudo-scientific argumentation." (Cohen and Helling 2014, p. 307)

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and impartiality is lost in the unauthorized translation. Furthermore, Hagemann and Krohn (1999, p. 314) give an account of the picturesque anecdote how in Kaufmann's rental agreement in London it was insisted that he was allowed to sing out the Radetzky March loudly every morning.

[13] Readers mastering German can at least resort to the recommendable (Zilian 1990).

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Reviews

Hermann von Helmholtz, *Philosophische und populärwissenschaftliche Schriften*, Michael Heidelberger, Helmut Pulte, Gregor Schiemann (eds.), 3 vols. Hamburg: Meiner, 2017., ISBN 978-3-7873-2896-3.

Hermann von Helmholtz is a key figure of modern science and modern philosophy. Not only did he promote a classical view of the liberal arts as intimately related to the scientific endeavor, but in doing so he adopted an approach that was considerably ahead of his time.

He offered a paramount example of philosophical investigation motivated by concrete scientific research, which he practiced in his extensive work as a physiologist and a physicist.

Helmholtz's body of work in philosophy and the popularization of science enjoyed remarkable success among his contemporaries. His first collection of popular lectures on scientific subjects, ranging from experimental physiology and mechanics to musicology, appeared in two volumes in 1865 and 1871, respectively, under the title "*Populäre wissenschaftliche Vorträge*". The full collection, including Helmholtz's popular lecture on the foundations of geometry of 1870, appeared in three volumes in 1876. Helmholtz himself included relevant additions and later substantial contributions to this collection in two subsequent editions as "*Vorträge und Reden*" in 1884 and 1896 (appeared posthumously). In sum, Helmholtz's collected popular lectures enjoyed three editions during his life time and five editions, all of which were followed by English translations, until 1903.

Helmholtz's philosophical work, in particular his work on physical geometry and the foundations of measurement, enjoyed a new wave of interest after Einstein's general theory of relativity. This culminated with the collection of his epistemological writings as "*Schriften zur Erkenntnistheorie*", edited and commented by Paul Hertz and Moritz Schlick on the occasion of the centenary of Helmholtz's birth, in 1921. This collection, along with Schlick's comments, contributed to set the philosophical agenda for logical empiricism and is still one of the main references for the philosophical scholarship. More generally, Helmholtz's epistemological views were seminal for the late nineteenth-century project of a scientific philosophy and remain an important contribution in contemporary philosophy of science.

More recent scholarship initiated in the 1990s has emphasized that the originality of Helmholtz's approach, even beyond his impact on later philosophy, lies in its constant connection with scientific research. The transformation of physiology in the nineteenth century plays a particularly important role here. Not only did Helmholtz engage in the debates surrounding the establishment of experimental methods in the life sciences, but he started from these debates to develop insights in other fields of knowledge. To put it in the words of a well-known collection of studies on these topics (Krüger 1994), Helmholtz deserves a very particular place in intellectual history as a "universal genius". This title is indeed no exaggeration when one thinks about Helmholtz ability to answer general philosophical questions while at the same time deliver groundbreaking work in diverse special sciences.

The broadening of perspective brought by these historical studies gave new impulse to further collections of Helmholtz's works that aimed to better reflect the wide spectrum of his scientific and cultural interests (see esp. Cahan 1995).

The new edition of Helmholtz's philosophical and popular writings on scientific subjects offers the most comprehensive existing collection in the wake of this tradition, along with an informative introduction on Helmholtz's life and work. The first two volumes include all of the papers originally published in the different editions of "*Populäre wissenschaftliche Vorträge*", supplemented by Helmholtz's subsequent additions, relevant papers published by him in English and relevant texts or extracts from his scientific works, including *Ueber die Erhaltung der Kraft*, *Handbuch der physiologischen Optik*, *Wissenschaftliche Abhandlungen*, *Vorlesungen über theoretische Physik.* For each text, the editors provide a full editorial history, including all reeditions and translations into English and French. The third volume includes all philosophically relevant texts from Helmholtz's Nachlass at the Archives of the Berlin-Brandenburg Academy of Sciences and Humanities and from Königsberger's (1902–1903) transcription, followed by a complete bibliography of Helmholtz's published work in German, English and French.

On the whole, this collection provides new and extremely valuable materials for historical and philosophical studies. The authors offer a chronology of Helmholtz's work amended in the light of new historical research. This sheds further light on how Helmholtz's philosophical ideas emerged from the thematic affinities between different areas or knowledge, as well as from a wider circulation of ideas within the international scientific community. Helmholtz's extensive exchanges with English and French-speaking scientists and philosophers is well documented by his publications in these languages listed in the third volume of the collection.

The editors also provide a selected bibliography of the secondary literature, with a particular focus on the German-speaking literature. For a more comprehensive account of the secondary literature in English, see especially Patton (2014).

Given the extent and variety of the material collected in the volume, the editors had to renounce to provide the original texts with a critical apparatus. A critical edition of Helmholtz's philosophical writings remains a desideratum for both a more accessible reading and scholarly work. As Hertz and Schlick emphasized, Helmholtz's texts raise several interpretative issues, the discussion of which is still controversial in the literature. Besides the abovementioned edition of Helmholtz's epistemological works, a useful introduction to some of the texts, along with new English translations, has been provided by David Hyder in Luft (2015).

These interpretative issues notwithstanding, the collection is a very valuable philosophical contribution. This is in virtue of the covered topics and the critical organization of the collected materials. A few examples will help to show the relevance of this collection to a variety of issues, which range from intellectual history to history, philosophy and sociology of science.

The opening text of the collection, the introduction to "Ueber die Erhaltung der Kraft", offers a synthesis of Helmholtz's research program across experimental physiology, chemistry and mechanics. Helmholtz was a student of Johannes Müller, who founded the physiological school in Berlin. This school was characterized by the reliance on experimental methods and by a mechanistic view of nature. This implied a reduction of organic processes to mechanical laws. Helmholtz addressed this issue from a more general viewpoint by investigating the conditions for a reduction of all motions to motions dependent on spatial relations alone. In Helmholtz's terminology, all "forces" ought to be reduced to central forces of the kind of Newton's gravitational law. Helmholtz's law is known today as the conservation of "energy", after the formulation given by William Thomson (Lord Kelvin), namely, as the constancy of the sum of potential and kinetic energy.

While Helmholtz presented "Ueber die Erhaltung der Kraft" as a treatise in physics, the broader scope of this work is well documented by Helmholtz's introduction as well as by his popular writings. This includes "Ueber die Wechselwirkung der Naturkräfte und die darauf bezüglichen neuesten Ermittelungen der Physik", "On the Application of the Law of the Conservation of Force to Organic Nature", "Ueber das Ziel und die Fortschritte der Naturwissenschaft", all of which are found in the first volume of the collection. Helmholtz also held a lecturing course with the title "Ueber die Erhaltung der Kraft" in Karlsruhe in 1862–1863. The introduction to this course was first published in *Populäre wissenschaftliche Vorträge* in 1871. The collection includes a reproduction of the original edition with illustrations and the "Lectures on the Conservation of Energy" held by Helmholtz at the Royal Institution of Great Britain in 1864. Among the various applications of the conservation of force, Helmholtz here drew special attention to how his law offers a better account of some processes in animals and plants than the assumption of a vital principle or force.

The collection also offers a thorough account of how Helmholtz modified the formulation of his law at different stages of his intellectual career, by comparing the original texts with later additions. It emerges clearly from this comparison that Helmholtz had to restrict his law to empirically given points and relative coordinate systems following Rudolf Clausius's critiques. Consequently, Helmholtz distanced himself from the mechanism of the physiological school and admitted dynamical shifts in drawing the borderline between the principles and the experimental part of physics.

In the measure that Helmholtz defined his empiricist attitude towards the principles of science, he also took different stances towards the assumption of a priori elements of knowledge. Helmholtz maintained in "Ueber das Sehen des Menschen" that at least the principle of causality and the subjective forms of intuition can be considered a priori in a modified Kantian sense, as conditions for the comprehensibility of nature. Unlike Kant's a priori knowledge, a priori assumptions in Helmholtz sense allow for an empirical investigation. So, for example, in the abovementioned lecture, Helmholtz maintained that the Kantian theory of perception found a new confirmation in Johannes Müller's theory of the specific nerve energies. However, Helmholtz later distanced himself from his former teacher's theory as a form of nativism. In order to account for spatial perception, Helmholtz proposed a "sign" theory, according to which the perceiving subject learns to form associations via unconscious inferences from the sense data to their unknown causes. In this view, different kinds of sensations are signs that allow for different combinations and the representation of space is the common denominator of all possible forms of localization.

Subsequently, Helmholtz addressed these issues from a different angle in his investigation of the foundations of geometry. Helmholtz's arguments for the empirical origin of geometrical axioms and the imaginability of non-Euclidean spaces became a standard reference in the post-Kantian debate on the possibility of a priori knowledge in the face of scientific change. Helmholtz's popular lectures on these topics, including "Ueber den Ursprung und die Bedeutung der geometrischen Axiome", "The Axioms of Geometry", "Die Thatsachen in der Wahrnehmung", set up the conceptual framework for different strategies to deal with physical geometry, from geometrical conventionalism to the relativization of a priori knowledge.

Besides the abovementioned popular lectures and writings, the collection include the most relevant texts for a reconstruction of Helmholtz's thought from the nativism/empiricism debate in the physiology of vision to his first geometrical papers. This includes the public lecture "Ueber das Sehen des Menschen" and the lecturing course "Die neueren Fortschritte in der Theorie des Sehens", as well as the opening chapter of the psychological part of Helmholtz's *Handbuch der physiologischen Optik*, "Von den Wahrnehmungen im Allgemeinen". As Helmholtz suggested (17, p. 554), his investigation of spatial perception provided a starting point for his attempt to deduce a Riemannian metric of constant curvature from the free mobility of rigid bodies in "Ueber die thatsächlichen Grundlagen der Geometrie" and "Ueber die Thatsachen, die der Geometrie zum Grunde liegen".

Another recurrent theme in Helmholtz's scientific and philosophical work is his engagement with measurement problems. As mentioned above, in order to counter Clausius's objections against Helmholtz's proof of the positional dependence of forces, he had to take into account the problem of establishing the empirical conditions for the determination of distance and of direction. Helmholtz attained new standards of precision in his physiological work by offering one of the first measurements of the propagation velocity of nerve impulses. Another of his seminal contributions was the invention of the ophthalmometer, which has become a standard medical device. Helmholtz used the ophthalmometer to show that the retina adjusts to the perceived objects according to their distance. He relied on this result in his geometrical papers to describe the hypothetical adjustments of spatial perception to non-Euclidean displacements.

Helmholtz proposed a new standpoint for establishing the conditions of measurement in general in "Zählen und Messen, erkenntnistheoretisch betrachtet". Not only did he address the problem of measurability in the life sciences (in particular the psychophysics), but he was one the first to propose an axiomatic approach to the characterization of quantities. In doing so, he foreshadowed a new branch of mathematics, which became known in the twentieth century as measurement theory.

The collection includes a reedition of "Zählen und Messen", along with the relevant texts for the scientific background of Helmholtz's theory of measurement. This includes the abovementioned popular lectures on physics, geometry, and perception, as well as Helmholtz's introduction to his *Vorlesungen über theoretische Physik*. This lecturing course provides evidence of Helmholtz's engagement with the discussions on measurement by British physicists such as Michael Faraday and James Clerk Maxwell.

The collection offers extensive evidence of Helmholtz's engagement with scientific policy and education. Although these topics have not been in the focus of the secondary literature, they deserve a closer consideration for the philosophical relevance of lectures delivered for scientific organizations, including "Ueber Goethe's naturwissenschaftliche Arbeiten" (*Deutsche Gesellschaft*, Königsberg 1853), "Lectures on the Conservation of Energy" (*Royal Institution*, London 1864), "Ueber die akademische Freiheit der deutschen Universitäten" (*Rektoratsrede*, Berlin 1877), "Bemerkungen über die Vorbildung zum akademischen Studium" (*Kommission des preußischen Unterrichtsministeriums*, Berlin 1890), to mention only a few. Moreover, Helmholtz was one of the first physicists in Germany to appreciate the inductive approach of Anglo-Saxon physicists and generally to defend the methodological pluralism of the international community, for example in “Zöllner contra Tyndall” and in “Heinrich Hertz”, the preface to his former student’s *Prinzipien der Mechanik im neuen Zusammenhange dargestellt*.

These are only some of the examples of themes from Helmholtz’s work as a scientist, which reflect back on how he created an original synthesis of ideas in his popular and philosophical writings. To sum up, this new edition delivers an essential tool for a better understanding of the different but interrelated paths of Helmholtz’s investigations. It is my conviction that less explored paths will deserve closer attention from the philosophical and scientific community, after a careful consideration of the material collected for the first time in this edition.

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Cheryl Misak, *Cambridge Pragmatism. From Peirce and James to Ramsey and Wittgenstein*, 2016, Oxford University Press, 321pp., ISBN 978-0-19-871207-7.

The aim of the book is to show how pragmatism made its way into the philosophical discussions starting in Cambridge Massachusetts and appearing at nearly the same time in Cambridge England. The author argues against two standard stories, which she admits she used to tell herself, namely that: (1) Russell, Moore, and, to a lesser extent, Wittgenstein “savaged pragmatism, leaving it never to fully recover” [Misak, 2016, 1]; and (2) Ramsey and especially Wittgenstein put forward their novel positions without drawing much influence from outside of Cambridge England.

Now, instead, the main thread running through the whole manuscript is the connection between both Cambridges, and specifically the influence American pragmatism had on Cambridge England. Furthermore, the readers follow the development of Russell’s thought from his anti-pragmatist attacks on James and Schiller, to the final pull pragmatism had on him, to the extent that Ramsey holds in “Facts and Propositions” that his pragmatism is derived from Mr. Russell. We also discover how Peirce’s writings shaped Ramsey’s own ideas, leading him to develop his interpretation of probability theory and a nearly finished, theory of belief and truth, both exhibiting strong pragmatic attitudes.

At the same time, the author updates the history of naturalism, of which pragmatism is a variety, by examining in detail how the four great naturalists – Peirce, James, Ramsey and the post-1929 Wittgenstein dealt with the question of how to understand normative notions, e.g. truth, necessity, consistency, rationality, or progress, given that we live in a natural world and cannot step outside our beliefs in order to determine whether they make sense with objective facts.

The author also make the important connection between pragmatism and logical empiricism and Tractarian Wittgenstein. She illustrates how they all shared the aim of identifying a simple language directly connected to the world, how they all emphasised the central role on the truth-preserving formal logic, and how they considered the goal of philosophy to be making sense of the world by clarifying the concepts and verifying them.

The pragmatist turn is presented chronologically, enabling the reader to follow its development starting with Peirce and James in America, followed by Schiller, Welby and Ogden building bridges across the Atlantic and finally arriving in England and finding its greatest recipients: Russell, Ramsey and Wittgenstein. The author makes multiple references throughout the manuscript pointing to direct influence American pragmatists had on their European colleagues. This is most valuable in order to understand the origins and the evolution of the pragmatic thought.

In the first part – *Cambridge Massachusetts* we read that American pragmatism began there in 1867, in a discussion group including philosophers, mathematicians, scientists and lawyers. Peirce and James were the two most influential American philosophers spreading their views onto the prominent European Cambridge thinkers, in particular on Russel, Ramsey and Wittgenstein.\par.

Even though Peirce wrote a lot, not many of his writings have been published. Six of his articles which were reprinted in *Chance, Love and Logic* deal with topics that stay with Peirce for the rest of his life: belief, doubt, meaning, truth, logic, and probability. His 1878 article "How to Make Our Ideas Clear" is the first expression of his pragmatic maxim which tells the reader what is needed in order to arrive at clear concepts. The author follows the development of Peirce's thought providing the necessary references and making the essential connections to Ramsey's ideas, e.g. the type-token distinction introduced into the literature by Peirce, that Ramsey picked up and for which he became known. Furthermore, Peirce's theory of signs, where he develops an account of what it is to understand the signs humans use, is sketched. It is essential that Peirce does not reduce meaning to action, and hence does not put forward an early functionalist or behaviourist account of meaning, however, Misak calls Peirce's theory a *pragmatist* account of meaning, i.e. that effects or behaviour must be *part* of the analysis of meaning. The reader also learns about Peirce's contributions to the study of belief, where Peirce calls his view "critical commonsensism" and emphasises that real doubt does not arise from one wrong belief, and he denies that there are any beliefs which are immune to real doubt. We cannot doubt everything, nor can we assume that some beliefs are indubitable. The author shows how Peirce's account of truth can be understood as that presented by the modern deflationary theories. At the same time, she points to the limits of deflationism and explains why Peirce, in going beyond the equivalence scheme, delivers a more complete account of truth.

The second major contribution of Peirce's pragmatism to the study of belief is actually the idea taken from Alexander Bain, that a belief is a disposition to act. Peirce expands on Bain's idea and argues that a belief is a habit of action, which, however, is but one property of belief. Here, the author makes an immediate connection to Ramsey's theory. She navigates through the complex analysis of belief discussing Bain's influence on Peirce and how it was reflected in Ramsey's writings, for example how desires shape our actions, or that beliefs are answerable to the facts.

For Peirce a belief is true if it would not be improved upon, a belief to we would come to at the end of our inquiry. As soon as we form a belief about what is real we form an interpretation. Both Peirce and Ramsey maintain a kind of realism in which truth doesn't depend entirely on what we think, but where the world exerts independent normative force on belief. At the same time Peirce rejects transcendental truth theories such as correspondence and replaces it with pragmatism. Peirce thought of himself first and foremost as a logician and was in fact seen as one. He developed a quantified first-order logic with a sound and complete diagrammatic proof system, independently and at the same time as Frege, discovered the Sheffer stroke decades before Sheffer and made advances in the logic of statistical reasoning. He conceived of logic as a 'normative science' along with ethics and aestetics which, naturally, struck Ramsey as right.

James's 1890 *The Principles of Psychology* is a classic, most important book in the history of psychology, demarcating psychology from philosophy and making points about the mind and brain that are still important today.

James was committed to the view that experience is the source of all knowledge, as he held that we can only think or talk about the things with which we have acquaintance already. The author argues that James improves upon British empiricism presenting his account of the nature of consciousness: ideas are not discrete and divisible entities as Hume believes, or 'complex mental states' are not 'resultant of the self-compounding simples ones' as Mill and Wundt believe. Consciousness is rather a stream of thought which cannot be broken up into individual parts, and experience is changing us every moment. The author points to parallels between Peirce and James's accounts, and how Wittgenstein was persuaded by James's view and provides further references. In 1904–1905 James set out a position called 'natural monism', never using this term himself, stating that there is one fundamental 'stuff' that is neither material nor mental. James tried to understand the world and the way we experience and represent it, leaving room for freedom and creativity.

F. C. S. Schiller, Victoria Welby, and C. K. Ogden are the three 'bridges across the Atlantic' responsible for bringing American pragmatism to Cambridge. James didn't need Schiller as a bridge for he traveled to England frequently, however, the author argues, it is Peirce's philosophy that had most influence on Russell and Ramsey, but was not well known. Victoria Welby, a self-educated and well traveled woman, was herself interested in signs and in how meaning changes with experience. She corresponded with leading philosophers, logicians, scientist and novelists of her time: Bergson, Bradley, Carus, Cook Wilson, Huxley, both William and Henry James, Poincaré, Ogden, Russell, Schiller and Peirce. She circulated letters of Perice to Ogden and Russell and got replies from them. She wrote to Peirce in 1911 that she found him a disciple at Cambridge – Ogden, who in turn played a vital role in the dissemination of Peirce's work, by getting it to print in England, but most importantly by giving Welby-Peirce correspondence to Ramsey.

The second part – Cambridge England begins with a presentation of the revolt the three giants of philosophy – Russell, Moore and Wittgenstein, set against idealism and pragmatism.

Russell took the new formal logic to be vitally important to philosophy, and he focused on the relationship between logic, language, experience and thought. Wittgenstein took up this project enthusiastically when he began to study with Russell in 1911, and so did the Vienna Circle. Russell, Moore and Tractarian Wittgenstein shared a methodological claim that philosophy must be proceeded – by logical analysis. The author also argues that because logical empiricism and pragmatism had much in common, some logical empiricist were led to turn to pragmatism, after their programme had failed to solve the problem of truth,

Russell knew James's and Schiller's work as well as Dewey's, however Peirce's work always remained in the shadows for Russell, even though he knew Peirce tied meaning to action, it was only in Ramsey's work that it found reflexion. Russell understood pragmatism only as the theory of truth held by James and Schiller. Russell's critique of James's work has extended onto all of the American pragmatists for he accuses them of conflating the criterion of truth with the meaning of truth. Misinterpretations as well as the correct accounts of both sides are thoroughly, chronologically displayed. The notions of action, belief, correspondence and truth all play a vital role in the discussions the philosophers of both Cambridges had in print. As the author points out, they were not always talking about the same thing, in spite of using the same terms, which definitely added to confusion on both sides.

Wittgenstein arrived in Cambridge in 1911 to study with Russell and they had very intense philosophical conversations from the very moment they met. Wittgenstein soon shared Russell's problems: the foundation of mathematics, the nature of propositions, and the relationship between language and the world. The author talks about the early period of Wittgenstein's though, culminating in *Tractatus*. Wittgenstein's unique way of going about philosophical issues contributed to the impression that his mind was like no other. Misak, however, argues that Wittgenstein was neither as isolated nor as unique a thinker as he may have seemed. Further, she discusses Wittgenstein's intellectual development and its influence on other philosophers, e.g. Russell or Ramsey. We also read about Wittgenstein's intersections with the Vienna Circle and their reception of *Tractatus*. The scientific world conception aspired by the Vienna Circle was received with much recognition at Cambridge. The author also describes the points of disagreement Wittgenstein had with Russell and the Circle and how they eventually led to them parting ways. From shared ideas that ethics and metaphysics cannot be expressed in the elementary language, they drew very different conclusions. For the Vienna Circle if something was unsayable it was nonsense, not so for Wittgenstein. Ethics and religion are only a couple of points of disagreement.

As Ramsey came onto the philosophical scene, Wittgenstein was looming large at Cambridge. Russell, Wittgenstein and Ramsey used much of the same language and many of the same concepts but they were not in agreement at all. The author argues that Ramsey had been moving in the direction of pragmatism even earlier than in his unfinished manuscript. He became more and more a Peircean pragmatist. Peirce linked degrees of belief to objective probabilities which inspired Ramsey, as well as his accounts of belief as a disposition to act, probability, reasoning and truth.

Ramsey and Wittgenstein are a whole new book. Ramsey helped, or rather in fact translated the *Tractatus* inspiring many of Wittgenstein's ideas. After its publication Ramsey wrote a critical notice in *Mind* praising the book for its originality, but also rising a number of pressing issues. The author argues convincingly, that a young Ramsey had a very strong impact on Russell's views, attacking his multiple accounts of propositions, and showing that general propositions pose a problem for logical analysis, as well as on Wittgenstein.

Ramsey's points of connection with Peirce on probability go well beyond the core insight that belief and action are inseparable. Ramsey adopts Peirce's conception of logic – the aim of logic is to tell us how to think.

We read about the many interpretations of the notion of 'verificationism' used by Peirce, James, Russell, Wittgenstein, Ramsey and the Vienna Circle. In the late 1920s, Ramsey, Wittgenstein and the Vienna Circle were all considering the statuses of mathematical and logical statements. They mostly agreed on these, but also saw that other kinds of statements are not that easily dealt with. The author discusses Ramsey's understanding of truth, as well as his ethics. She shows how Ramsey moved from a redundancy theory to a pragmatist theory of truth.

In the final chapter the author argues that the post-*Tractatus* Wittgenstein turns more towards pragmatism and that it went unnoticed. She argues, against some interpretations, that there was an important pragmatist turning point in Wittgenstein's philosophy, and that it was due to Ramsey, calling it 'the post-Ramseyan Wittgenstein'. Here, she makes another central claim of the book, namely that late Wittgenstein was a pragmatist and that due to Ramsey. She discusses the very intense relationship between Wittgenstein and Ramsey, for in spite of the occasional hard feelings between them, they were very close friends, intellectually and personally. In the last few months before Ramsey's death, the two dominated Cambridge. She argues that between 1929 and 1932 Wittgenstein turned away from the position he expressed in *Tractatus* mostly due to Ramsey's pragmatism. Her arguments are based on what she "painstakingly excavated from Wittgenstein's notebooks and from the general context of what was going on in Cambridge and Viennese philosophy at the time" [Misak, 2016, 233]. Wittgenstein too read Peirce's papers, however, his interpretation differs from Ramsey's. He was mostly inspired by James's thoughts about religion and forms and meaning of life. A detailed, supported by dated notes, account of Wittgenstein's transformation is given. We see that the post-Ramseyan Wittgenstein rejects fully the picture theory of language, a view he held until his death. We also read about his views on truth, rule-following and behaviour before we see how his rejection of the logical analyst picture between 1929 and 1931 accounts for his views on religion, ethics and the meaning of life. Misak argues against Rescher and Majer that Ramsey's ideas expressed in *On Truth* had a major impact on Wittgenstein, and hence on the direction of a significant movement in the history of philosophy.

Misak concludes that even though there are many different variations of pragmatism they all share a firm link between belief and action. Even though the four main characters: Peirce, Russell, Ramsey and Wittgenstein adopted different forms of it at different times, they all rejected phenomenologist or introspectionist accounts of meaning and belief, requiring them to be linked to behaviour.

For the wealth of historical evidence and the soundness of the arguments, not only is this book most valuable for the history of analytic philosophy, especially for logical empiricism but also it is central to current discussions on pragmatism.

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William M. Johnston, *Zur Kulturgeschichte Österreichs und Ungarns 1890–1938.*

Auf der Suche nach verborgenen Gemeinsamkeiten Vienna: Böhlau 2015, 328 pages, ISBN 978–3–305-79541-4.

With *Zur Kulturgeschichte Österreichs und Ungarns 1890–1938* (On the Cultural History of Austria and Hungary between 1890 and 1938), William M. Johnston presents a compendium of the present knowledge on his subject. The work can only impress the reader with its density, breadth, thoroughness, intensity and, given that Johnston revises his own work of the 1970s, its intellectual integrity. He is inspired by three publications (Wolfgang Grassl and Barry Smith *A Theory of Austria* 1986, Virgil Nemoianu *Learning over Class* 1993 and Charles S. Majer *City, Empire, and Imperial Aftermath* 1999) to reconsider his own insights regarding "Vienna 1900" and to widen his horizons; the main focus is not on the capital of the Austro-Hungarian Monarchy but more on intellectual developments in Hungary. To this end he draws on "less well-known" and therefore less feted colleagues. Individual chapters deal with the history of architecture, the ethics of education, psychoanalysis, the creative mind or critiques of the culture of Austro-Hungary. Works by Ákos Moravánszky, Moritz Csáky, György M. Vajda, Peter Weibel or Joseph Peter Maria Stern form the centrepieces of the work's thirteen chapters.

Johnston is enthusiastic about his topic, and the reader senses his motivation. He believes in the "Austrian Man", the subject of his last book of 2010. This humanistic public official, serving the supranational state of the Habsburgs with loyalty and devotion, unites in himself the positive characteristics of the epoch, and is, conversely, a creation of the specific circumstances of the Empire. His world was destroyed by the collapse of 1918. Johnston believes in the "double monarchy as an arena of innovative ideas" with "Vienna 1900" as its most famous manifestation. He works tirelessly to find further periods and fields in which this innovative spirit was manifested.

The volume presents a wealth of information, provides numerous categories such as the “Arena of Innovative Ideas”, the “Central European Ethics of Education” and “Soul of a Nation”, the capacity for “Cultural Exchange”, “Cultural Plurality”, the “Realm of Beautiful Appearances”, the “Benign Parallel Universe”, or the “Emergence of a Third Culture” between the arts and the sciences. Johnston discusses persons “overfulfilling their tasks”, “politely satirizing the overabundance of seriousness”, and “stripping their affiliation to a nation.” At the same time the work raises questions regarding its basic structure concerning these categories and the subject areas discussed.

The Cultural History of Austria and Hungary between 1890 and 1938 poses numerous questions. For example, what was it that began in 1890, and what ceased to exist in 1938? Whilst in 1890 there was the Austro-Hungarian Monarchy, a political construct without social, cultural or even political unity, except for the figure of the monarch and what was known as “common affairs”, in 1938 there was no Austria but the Eastern March as part of the German Empire and Hungary with extended borders as a result of the First Viennese Decision. Is it thus possible to discuss the developments between 1890 and 1918 in the same terms as those relating to the period between 1918 and 1938?

In 1972 William Johnston presented the volume *The Austrian Mind. An Intellectual and Social History 1848–1938* and started the discussion on “Vienna 1900”. Allan Janik and Stephen Toulmin’s *Wittgenstein’s Vienna* appeared in 1973 and Carl Schorske followed with *Fin-de-Siecle Vienna. Politics and Culture* in 1981, the latter a collection of papers presented since 1961. With these volumes the trend was set for Jacques Le Rider, Steven Beller and also for the exhibition *Traum und Wirklichkeit* (Dream and Reality) in Vienna in 1986, featuring international acclaimed figures such as the artists Gustav Klimt and Egon Schiele and the architects Otto Wagner and Adolf Loos. Johnston’s approach has to be distinguished from those of Schorske, Le Rider and Beller in so far as he not only focused on “Vienna 1900”, but delivered an overview of Austria-Hungary between 1848 and 1938. For him too, the zenith was nevertheless “Vienna 1900”, and his book was read that way. In 2015 Johnston sees all this in a much more nuanced fashion. First of all, he recognises that what he started concentrated on Austria instead of on Austria-Hungary, and thus how one-sided the discussion was. And, thirdly, he appreciates how myopic this perspective was, since “Vienna 1900” is only one interpretative scheme among others. Nevertheless, in 2015 he accomplishes something similar to what he managed to do in 1972: again, he includes as much as possible. In 1972 he analyzed hundreds of creative minds. In 2015 he discusses hundreds of theoreticans. And both times he makes the same error. He does not see the wood for the trees.

What is the wood here? What are the big, comprehensive aspects that must be made visible to the reader? These are the centripetal forces suggested above, resulting in the collapse of the world which “Vienna 1900” is supposed to symbolise, a catastrophe with millions of deaths, to be precise. These forces were at work in 1867 when the Austro-Hungarian Monarchy was established, in 1890, when Johnston starts his narrative, and also in 1938, when Austria disappeared from the map as an autonomous country and Hungary began to be redrawn on it. A second issue is the dynamics determining the specific developments in the Dual Monarchy as well as in Austria and Hungary. Works of art, texts, buildings, scientific and technical achievements, project plans and historical events represent isolated data. Why the one or the other came into being, what it means, how it was perceived, and what it effected cannot be explained in isolation or situated in one of many causal chains. What is important here is the great dynamics into which every single phenomenon was integrated, in which it took effect negatively or positively, as an achievement or as a problem. A cultural-historical overview like Johnston's is an opportunity in exactly this sense. Since an incomprehensible amount of data has to be presented in a comprehensible volume, the author is forced to concentrate on the big regulative forces and trajectories. Which Johnston allows to slip away, again overwhelmed by the weight of the material, this time by the overwhelming number of interpretations he considers.

For example: in outlining the school systems of the period from Empress Maria Theresia to Emperor Franz Joseph that is, from 1740 to 1916, Johnston takes the ideology of these institutions for granted. He is unable to understand that what is at stake here is not the opportunity to rise through the ranks in Habsburg society (and that we should not talk about a "way up" in those society but rather a "way in", namely into the state bureaucracy); the issue, to at least the same degree, is the mechanisms of exclusion, the establishment of selection lines and the indoctrination of precisely those ideologies that Johnston accepts without hesitation. It is a mistake to argue that it was the "Theresian Ethics of Education" that resulted in "Vienna 1900" (as on page 67). On the contrary, the dynamics of repression in the educational structures of the Austro-Hungarian Monarchy – discussed for example in Robert Musil's *Törless* in 1906, which Johnston does not mention, because for him Musil has to represent something different – and the progress of the parallel developments of modernity resulted in something which was included neither in conservativism nor in modernism, but in a form of aestheticism. The problem with Johnston's work is that he ignores the very contradictions and scientific problems – relocating a few in the book's final chapter, isolating them and thus making them static – which he should instrumentalise in order to highlight the internal tensions manifested in them.

One of the problems is thus the arbitrary time period, which does not correspond with the developments of the geographical region under discussion. A second problem is that Johnston uncritically accepts parts of the ideology of the late Habsburg Empire, such as that of the "Ethics of Education". Thirdly, his choice of subjects and methods cannot explain the nature and development of those events and phenomena that constitute the wealth of data listed in the book.

What could be the subjects on the basis of which one might grasp the specificities of the cultural space which Johnston refers to as Austria and Hungary between 1890 and 1938? Four recommendations:

The avant-garde can be interpreted as a specific form of modernity. The development process which we call modernity is complex not only in terms of the inextricability that see it effect all parts of life, but also in its historical process and in its specific dynamics. Part of these dynamics is crises, ruptures and turns, caused inter alia by asynchronicities or by unexpected leaps forward. Avant-gardes are cultural peaks connected to social and political breakthroughs. In the years between 1890 and 1938 they are referred to as the classical avant-garde, manifested in movements categorised stylistically as futurism, constructivism or surrealism. To speak in the categories of the established avant-garde research, Austria and Hungary are extremely interesting fully autonomous territories. Scholarship has discussed the relevant parallels, differences, contradictions and conflicts – which are also reflected, curiously enough, in the Austrian and Hungarian avant-garde research itself. These difficulties could be summed up by the question: why was there a Hungarian but no Austrian avant-garde? Or: why did the most productive phase of the Hungarian avant-garde in the first half of the 1920s take place in Austria?

The Austrian philosophy of science, climaxing in the activities of the Vienna Circle between 1924 and 1936, is considered – at least by Rudolf Haller and Friedrich Stadler – a centrepiece of the Austrian philosophical tradition. It had parallels in Hungary in the discussions of small groups like the educational association of the Galilei Circle, in the translations of papers by, for instance, Ernst Mach, or in attempts at interpretations such as those by Anton Fischer. None of this amounted to an independent, original philosophical contribution however. At no point did any of these attempts define what Hungarian philosophy is. The problem is that the Austrian philosophy of science cannot be adequately discussed within Johnston's framework, because this philosophy has to be related to German and British developments and because it contradicts the "spirit of Austria-Hungary" as well as that of the Austria of the First Republic. The Vienna Circle was not integrated into the inner dynamics of Austria, but was rather an alien element, to be eradicated using all means. Including murder.

Moritz Csáky works on a plurality of subjects. He has long been responsible for institutions, projects and project groups, he has published articles, monographs and edited volumes. His subject is plurality – and it is therefore more than puzzling why Johnston tries to reduce the activities of Csáky to one single publication. Csáky has written on urbanization, modernity as well as the Baroque and post-modernity, memory and rememberance, persons such as Hermann Bahr or Johannes Brahms, individual issues of the theory of culture and methodology such as identity, multiple identity and complex identity, hybridity, post-colonialism, transnationalitiy, migration, and on the big questions of the cultural sciences such as what culture is. He has addressed phenomena of everyday culture such as food or music – but it is only latter on which Johnston focuses: the publication *Ideologie der Operette* (Ideology of the Operetta) from 1996. With all of these studies, Csáky achieved by and large what Johnston does not: he considers the central subjects and categories suitable for grasping the complexity of a period and a region without limiting himself with fixed dates and borders. Csáky illustrates with his oeuvre that it is rather the crossing of the borders, the permeability of the space, the prehistories and the after-effects that count, for the very simple reason that these aspects are the decisive ones.

The history of Hungary is specific at least to the same extent as Hungarian historiography. It is crucial to differentiate between narratives of this history in the nineteenth, twentieth and twenty-first centuries by historians, politicians, writers and the "common nation" on the one hand and other possible interpretations on the other. In Hungary it is the autonomy of this history that is emphasized, especially in the periods when Hungary was ruled by foreign absolutist powers, as was the case up to 1867 during the reign of Emperor Franz Joseph for instance. Another possible interpretation could be for example that modern Hungary, including during the First World War, was not autonomous but rather belonged to the Habsburgs, since the Crown of St. Stephan adorned the heads of this dynasty. According to this interpretation, it was not until the autumn of 1918 that an autonomous Hungary came into being, together with a series of other countries in Central Europe. The history discussed in Hungary thus has a specific dynamic, is effective in all aspects discussed by Johnston regarding the developments of "Austria and Hungary between 1890 and 1938". It therefore makes no sense to discuss the cultural history of the period and the region without considering this perspective, which remains politically charged to this day.

The listing of these four topics – the avant-garde, philosophy of science, Csáky's oeuvre and the history of Hungary – does not mean that Johnston excludes these subject areas entirely. He mentions Stadler's *Der Wiener Kreis* (Vienna Circle) of 1991 in the bibliography and dedicates an entire chapter to the avant-garde research of Peter Weibel. Does he do justice to Weibel's work? No, because Weibel is naturally complex too and cannot be reduced to one project like the exhibition and catalogue *Jenseits von Kunst* (Beyond Art) 1997, and because the project Beyond Art is itself problematic. It postulates something – namely a specific spirit unfolding in Austria and in Hungary which could be called "a biotope of geniuses" – which can only appear so because Weibel and his co-authors allow themselves to be dazzled by single points of light, overlooking anything that could call for a nuanced approach. Beyond Art lists more than two hundred persons active in science and in the arts, including the authors of the catalogue, since numerous original documents are printed and since many of the authors, such as Weibel, see themselves as creative scholars. These persons constitute a panorama of the Third Culture, from the architect Margarete Schütte-Lihotzky to the mathematican Wolfgang Maass. Peter Weibel is an artist, curator and scholar. He connects all these fields. Naturally, dealing with academic problems creatively can be inspiring, but it still requires the control to adhere to scientific standards. Which is missing in Weibel's oeuvre. His ideas considering, for instance, the Austrian avant-gardes are not sufficiently elaborated, since Weibel is trying to construct an Austrian avant-garde instead of asking the question as to why it did not exist. To discuss this problem seems to be too much for Johnston, because it would have led to self-criticism that would ultimately impede work on this very book. Instead, Johnston found in Weibel what he was looking for: richness, wealth, the glamorous in particular and at large.

Both Johnston and Weibel want too much, simply everything, and that is the reason why they are unable to reach their goal: the system, the overview. They provide no reasonable interpretation, no dynamic structures, no appropriate categories, because these should correspond to the contradictions that led to the collapse of Austria-Hungary and because with the growing number of personalities, works, theses, topics to be considered a complexity arises that is unmanageable even for academics of the stature of William Johnston.

Johnston's *Cultural History* bristles with an overabundance of striking observations, comparisons, bull's eyes. Nevertheless, at no point in the book does Johnston see the wood for the many trees, the shadows between the trees, the undergrowth, the scrub and the weeds.

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F. Stadler (ed.), *Ernst Mach – Life, Work, Influence*, Vienna Circle Institute Yearbook 22, https://doi.org/10.1007/978-3-030-04378-0