soul as like, or partly composed of, *pneuma*. In Stoic philosophy it played a broader role. The Stoics hypothesized that *pneuma*—for them, a kind of hot air—is distributed throughout all other matter in the cosmos. Supposing that all action happens by bodies in contact, yet needing to account for apparent cases of action at a distance, the Stoics held that the pervasiveness of this single material accounted for the "sympathy" between distant bodies, as well as the cohesiveness of the cosmos as a whole and the qualities of individual things. Associated with the divine intelligence pervading the cosmos, the part of the cosmic *pneuma* pervading living things is the soul.

The Greek term *pneuma* was later used in religious contexts and associated with spirit and the divine. The physiological use of *pneuma* to account for functions of living things is echoed in the early modern notion of "animal spirits."

See also Aristotle; Epicurus; Stoicism; Strato and Stratonism.

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POINCARÉ, JULES HENRI

(1854–1912)

Jules Henri Poincaré, the French mathematician and philosopher, was born into a distinguished family at Nancy. His cousin Raymond was both prime minister and president of the Third French Republic. At an early age Poincaré showed an interest in natural history and the classics, and at the age of fifteen he developed an interest in mathematics. However, he trained first as a mining engineer, studying mathematics on his own during this training. In 1879 he was appointed to teach courses in mathematical analysis in the Faculty of Science at Caen. In 1881 he moved to the University of Paris, where he was soon given charge of the courses in mathematics and experimental physics. He lectured on mechanics, mathematical physics, and astronomy. Poincaré wrote an enormous number of papers on mathematics and physics and several important books on the philosophy of science and mathematics, as well as popular essays on science. His most important mathematical contributions were in differential equations, number theory, and algebra. In 1887 he was elected a member of the Académie des Sciences, and in 1899 he was made a knight of the Légion d'Honneur for his work on the three-body problem. In 1906 he became president of the Académie des Sciences, and in 1908 he was elected to the Académie Française.

Poincaré's work in the philosophy of science was in the tradition of Ernst Mach and Heinrich Hertz, and he admitted a debt to Immanuel Kant. His work was clearly influenced by his mathematical approach, and his interest was largely in the formal and systematic character of theories in the physical sciences. He showed less concern with epistemological problems connected with their support and establishment although he did write on the psychology of discovery. Albert Einstein had a profound respect for his work in both mathematics and the philosophy of science. He is often claimed as an ancestor of logical positivism, although the justification is not always easy to see.

AIMS AND GENERAL CHARACTER OF SCIENCE

Underlying scientific procedures, Poincaré held, is a belief in a general order in the universe that is independent of us and our knowledge. This is what mainly distinguishes the sciences from mathematics, which presupposes, if anything, merely the ability of the human mind to perform certain operations. The aim of the scientist is to discover as much as possible of the order of the universe, a point which must be borne in mind when Poincaré's view is called "conventionalism."

The method of discovery is basically inductive, proceeding by generalizing from observed facts; its lack of finality is due to its basis in a belief in a general order, since we can never be sure that the discovered order is absolutely general. Modifications in scientific conclusions spring from the constant pursuit of this generality. The discovery of facts depends upon observation and experiment, but these, in turn, depend upon selection because scientists cannot observe and absorb everything at once. There must be some principle of selection, but this principle must not be one of morality or practical utility. The search for an acceptable principle of selection led Poincaré to the idea of simplicity and a somewhat unusual defense of this idea. The best scientists are motivated by disinterested curiosity about how the world is, and their interest in general truths leads them to select those facts that "have the greatest chance of recurring." These are simple facts—that is, facts with few constituents. On grounds of probability there is more chance of the recurrence of a few constituents together than of the recurrence of many constituents together. However, familiar facts are more likely to appear simple to us than are unfamiliar facts. This seems to involve an unresolved conflict between two conceptions of simplicity.

What did Poincaré mean by "facts"? This is a question to which he gave less attention than it deserves. He held that science is to some extent objective. He toyed with sensationalism, but as a means of obtaining the necessary objectivity, he asserted that many sensations have external causes. Thus, he cannot strictly be regarded as a sensationalist. Objects are groups of sensation but not merely this; the sensations are "cemented by a constant bond," and science investigates this bond, or relation. Our sensations reflect whatever it is in the external world between which relations hold; science teaches us not the true nature of things but only the true relations between things. Scientific conclusions may thus be true of the world since they can give us a picture of its structure, though not of its content. We should expect theories of light, for example, to tell us not what light is but only what relations hold between the various occurrences of whatever light is.

The two main aims of scientific investigations are to relate what previously appeared unrelated and to enable us, by using these relations, to predict new phenomena.

CONVENTIONS

Poincaré constantly compared the physical sciences with pure mathematics and said that their methods of discovery are similar even though their methods of supporting conclusions are different. His view of science emerges most clearly from his comparison of it with geometry, in *Science and Hypothesis.* The space of geometry is not the space of sense experience; we can arrange conditions so that two things that look equal to a third thing do not look equal to each other. The mathematical continuum is invented to remove this disagreement with the law of contradiction; then, in mathematics things equal to the same thing are equal to one another *whatever* our senses tell us. This is one of those axioms of analysis, not geometry, which Poincaré called "analytical a priori intuitions."

Some geometrical axioms look superficially like this—for example, the Euclidean axiom that through one point only one line parallel to a given line can be drawn. The development of non-Euclidean geometries has shown that such axioms do not, as was formerly supposed, state fundamental properties of observable space. Coherent systems of geometry can be constructed based on the denial of Euclid's axioms, and these new geometries, when suitably interpreted, are translatable into Euclidean geometry. Moreover, they have physical applications. The applicability of the various systems is a function of context, or scale. The representation is purely structural.

Poincaré concluded that geometrical axioms are not synthetic a priori truths, for they are not of necessity true, and not experimental truths, for geometry is exact. They are conventions, or disguised definitions. It does not follow, as some critics have supposed, that they are arbitrary, for our choice is controlled by observation, experiment, and the need to avoid contradictions; nevertheless, such axioms cannot be either true or false. They are adopted because in certain contexts they are useful for saying how the world is. For most purposes Euclidean geometry is the most convenient. The application of geometry to the world involves an idealization. "Thus we do not *represent* to ourselves external bodies in geometrical space, but we *reason* about these bodies as if they were situated in geometrical space." No experimental support for Euclidean or any other geometry is possible, since experiments tell us only about the relations between bodies and nothing about the relations of bodies to space or of one part of space to another.

The physical sciences contain a conventional element as well as experimental, mathematical, and hypothetical elements, a fact which has been missed by most scientists. For example, the principle of inertia, according to which a body under the action of no force can move only at a constant speed in a straight line, is neither a priori nor experimental. It was originally conceived as experimental but has become a definition and so cannot now be falsified by experiment. Scientific conclusions are always conventional to some extent since alternatives to any hypothesis are always possible and, other things being equal, we choose those that are most economical. Because we have no means of knowing that the qualitative features of our hypothesis correspond to the reality, it does not make sense to regard the chosen hypothesis as the one true hypothesis.

In the physical sciences there are two kinds of statement—laws, which are summaries of experimental results and are approximately verified for relatively isolated systems, and principles, which are conventional postulates, completely general, rigorously true, and beyond the reach of experimental testing because for reasons of convenience we have made them so. Science is not entirely conventional because it does not consist wholly of principles. We begin with a primitive law, or experimental conclusion, but this is broken up into an absolute principle (definition) and a revisable law. Poincaré's example is the empirical statement "The stars obey Newton's law," which is broken up into the definition "Gravitation obeys Newton's law" and the provisional law "Gravitation is the only force acting upon the stars." Gravitation is an invented, ideal concept, but the provisional law is empirical and nonconventional because it predicts verifiable facts. The law of the conservation of energy is an outstanding example of a convention; it defines the concept of energy.

Prediction involves generalization, and generalization involves idealization. We connect a number of points on a graph by a smooth curve which does not pass through every one of them, and so we presuppose that the law we seek is best represented by a smooth curve even if this does not exactly fit the experimental results.

Points chosen midway between the existing points have a much better chance of showing which curve we should draw by eliminating one of them. A hypothesis is most strongly supported when it passes the tests that it was most likely to fail.

UNITY AND SIMPLICITY

We can obtain new knowledge only through experiment, and the role of mathematics in the physical sciences is to direct our generalizations from experiment. But experiment and generalization depend on presuppositions, most of which we make unconsciously. Among our presuppositions the most important are beliefs in the unity and simplicity of nature. Unity involves the possibility that various parts of the universe act upon one another as do the various parts of the human body, in the limited sense that to understand and describe one phenomenon, we may have to investigate other, superficially unrelated phenomena. The presupposition of simplicity is weaker: We can generalize any fact in an infinite number of ways, and we actually generalize in the simplest way until we have evidence against this way.

Two opposing trends can be discerned in the history of science. There is a movement toward simplicity and unity when we discover new relations between apparently unconnected objects and a movement toward complexity and diversity when, with the help of improved techniques, we discover new phenomena. The progress of science depends upon the first tendency, for "the true and only aim is unity." The second tendency is important, but it must ultimately give way to the first. Poincaré argued, referring to the growing unification of the studies of light, magnetism, and electricity, that there are signs of a continued victory for the tendency toward unity. But there are also signs that this does not always go along with simplicity since unity can sometimes be achieved only by revealing the increased complexity in things when shown to be related. However, unity is essential and simplicity merely desirable.

Poincaré's account, like many others, suffers from a lack of clarity concerning precisely what is meant by "simplicity."

HYPOTHESES

Poincaré distinguished three kinds of hypotheses. The first kind he called "natural and necessary," and they are the very general hypotheses that we use in making judgments of relevance—for instance, when in physics we judge that the effect of very distant bodies is negligible. These form the common basis of theories in mathematical physics and should be the last to be abandoned.

The second kind he called "indifferent," and these are useful artifices for calculation or pictorial aids to understanding. Hypotheses are of this kind when they are alternatives that cannot be distinguished by experiment. Thus, he said, the two hypotheses that matter is continuous and that matter has an atomic structure are indifferent because experiment cannot establish the real existence of atoms. Such hypotheses may be useful, but they may also be seriously misleading if they are not seen for what they are.

The third kind of hypotheses he called "real generalizations." They are direct generalizations from observations and are indefinitely open to further testing. Whether or not they are finally accepted, they are always valuable, if only for their suggestiveness.

THEORIES AND THE ROLE OF MATHEMATICS

The aim of experiments in physical science is to break up complex phenomena into simple ones with respect to time and space, to connect each moment in the development of phenomena with immediately contiguous moments and each point in space with immediately contiguous points. We also aim to break up complex bodies and events into elementary bodies and events. Because observable phenomena may be analyzed in this way and be regarded as the result of large numbers of elementary phenomena similar to one another, they are conveniently described by differential equations. This accounts for the ease with which scientific generalization takes a mathematical form. Mathematical physics depends upon the approximate homogeneity of the matter studied, since this enables us to extrapolate.

A physical theory may be superseded by another that uses qualitatively different concepts but the same differential equations; the equations are merely given different interpretations in the two theories. The superseded theory will be just as valuable for prediction because it contains the same relations as the new one, and as long as these stand up to testing, we can say that these are the real relations between things in the world. Both theories are true in the only way in which it makes sense to talk of the truth of a theory. Any advantage that the new theory has over the old will be merely psychological and will lie in its suggestions rather than in its implications. It is relatively unimportant that one theory of light refers to the movement of an ether and another refers to electric currents; what is important is the extent to which their equations agree, and it is on this that their truth must be judged.

Theories do not set out to explain, although they may provide possible explanations. They are devices enabling us to connect and predict phenomena but not to describe reality in all its details. The assertion that, for example, atomic theories explain the behavior of matter implies that we are able to establish the actual existence of atoms as delineated by the theories. But this is a metaphysical and not a scientific assertion because such existence can never be established by scientific means.

MATHEMATICS AND LOGIC

In mathematics Poincaré was, on the whole, an intuitionist, holding that the integers are indefinable and that underlying all mathematics is the principle of mathematical induction whose validity is intuitively recognized—that is, synthetic a priori.

In his last years Poincaré made a lively attack on the logic of Giuseppe Peano, Bertrand Russell, and others, especially on the logistic attempt to reduce mathematics to logic (*Mathematics and Science: Last Essays,* Chs. 4–5). He thought it important to study not only the consequences of adopting given conventions but also the reasons for adopting these conventions rather than others. He argued that it is impossible to derive all mathematical truths from the accepted logical principles without further appeals to intuition. He pointed, for example, to the difficulty of defining numbers without begging the question, and he saw even in the foundations of Russell's logic a reliance, inescapable on any satisfactory account, on synthetic a priori principles. He objected to the idea of an actual infinity, which he claimed was essential to Russell's system, and held that the logical paradoxes could be avoided by excluding nonpredicative definitions—that is, definitions of particular members of a class which refer to all the members of that class (*Science and Method,* Book II, Chs. 4–5). He expressed a general dissatisfaction with the extensional interpretation of logical constants.

See also Mathematics, Foundations of.

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POLITICAL PHILOSOPHY, HISTORY OF

The history of political philosophy is the succession of notions about the actual and proper organization of people into collectivities and the discussion of those notions. It is philosophical in character, because it is concerned with obedience and justice as well as with description; the persistent preoccupation of political philosophers has been the definition of justice and of the attitude and arrangements that should create and perpetuate justice.

A distinctive characteristic of political philosophizing is that it has usually been undertaken in response to some particular political event, or possibility, or threat, or challenge. This has led to a raggedness, even an incoherence, in works devoted to it and to an emphasis on intuitive argument which compares unfavorably with the content of other philosophical literature. Political philosophy has sometimes been supposed to confine itself to a particular entity called "the state," but in fact political philosophers have always concerned themselves with the collectivity as a whole, even when they have drawn a distinction between "state" and "society."

Problems of definition and description might appear to be prior to problems of analysis and prescription in political philosophy. In fact, however, ethical doctrine has always had a powerful effect on the view that a political thinker takes of the collectivity; he has tended to see it in terms of what he thinks it ought to be. Nevertheless, it has become usual to separate the empirical element from the normative. Empirical study has been further divided into sociology and political science. These definitions and divisions are no more satisfactory than others devised for similar purposes, and although we talk with some confidence of "sociologists," "political scientists" have only very recently emerged as an independent class of thinkers.

It is often useful to look upon political philosophy as in some sense systematic, proceeding from a view of reality and knowledge (ontology and epistemology) to a view of the individual (psychology) and a view of the social bond (sociology), and so to a general ethic, a political ethic, and finally to a set of recommendations about the form of the state and about political conduct. The expression "political philosophy" will be used in this sense here, and it will be considered solely in terms of the Mediterranean-European tradition.

CRITIQUE OF THE SUBJECT

There are several ways in which the history of political philosophy has been found important. Every thinker who engages in speculating about state and society and in formulating principles concerning them is anxious to know of the performance of his predecessors, to learn from them and to share their minds. Every thinking citizen is in this position too, to some extent, at least in the democracies: The questions raised in political life are frequently philosophical questions. Both thinkers and citizens, moreover, have good reason to believe that the intellectual and cultural life which they share with their contemporaries, together with the institutions which make political and social life possible for them, in some sense embody notions inherited from past political philosophy and philosophies. Certainly neither political attitudes nor political behavior nor political machinery can be understood without knowledge of this kind.

These various requirements have led to differing standards for the study. Insofar as it is the record of thought about state and society, its level of accuracy has to be as high as possible. For academic historical purposes, every word of the text of Aristotle, or Marsilius of Padua, or Jefferson must be correctly registered, his intentions known, the circumstances of the writing and publication of his work discovered and recorded. But neither the conscientious citizen nor the inquiring political theorist need be much affected by the particular version of a given work which he reads, even if it is an indifferent version, clumsily translated and abbreviated perhaps, or a brief and tendentious summary in a general history. The complete book need not be known, nor the attitude of its author. It may even help if little fables are allowed to grow up around such works. The misunderstanding of one political philosopher by another, or the misreading of