*WHY DID MAXWELL’S PROGRAMME SUPERSEDE AMPERE-WEBER ONE?*

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*Abstract.* Maxwell’s programme did supersede the Ampere-Weber one because it did assimilate some ideas of the Ampere-Weber programme, as well as the presuppositions of the programmes of Young-Fresnel and Faraday. But the opposite proposition is not true. Ampere-Weber programme did not assimilate the propositions of the Maxwellian programme. Maxwell’s victory over his rivals became possible because the core of Maxwell’s unification strategy was formed by Kantian epistemology looked through the prism of William Whewell and such representatives of Scottish Enlightenment as Thomas Reid and William Hamilton.

*Key words***:** Maxwell, Kant, Whewell, scientific revolution, electrodynamics.

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*Introduction.*

The aim of the present paper is to answer the question “*Why did Maxwell’s programme supersede Ampere-Weber one?*” - To answer it one has to make a further step in revealing the *inter-theoretical context of Maxwellian electrodynamics genesis and development*. The reconstruction should provide a “theoretically progressive problemshift” relative to other “internal” reconstructions and argue that Maxwellian revolution is a more complex phenomenon than appears from the standpoints of some well-known scientific revolution conceptions [Kuhn 1977; Lakatos 1978]. I’ll try to demonstrate that *the Maxwellian programme had superseded that of Ampere-Weber because it had constantly communicated with it.* The Maxwellian programme did assimilate some of the propositions of the Ampere-Weber “hard core”, as well as some propositions of the Faraday and Young-Fresnel programmes. But the opposite proposition is not true. Ampere-Weber programme did not assimilate the propositions of the Maxwellian programme. Maxwell’s research programme did supersede that of Ampere-Weber because it was a “*synthetic*” one (in the sense that was in more detail disclosed in Nugayev, 1999b). It appeared, according to one of Maxwell’s (Kantian) philosophical teachers, one of “successive steps by which we gradually ascend in our speculative views to a higher and higher point of generality” [Whewell 1847, vol. 2, p.74]. Contrary to Maxwell’s, the Ampere-Weber programme was a *reductionist* one (see Nugayev 1999b for details) for it tried to reduce all the theoretical ontologies to one and the same ontology of “action at a distance”. According to Ludwig Boltzmann ( 1904), “It is certainly useful to set up Weber’s theory as a warning example for all times that we should always preserve the necessary *mental flexibility*”. Boltzmann constantly emphasized the need for a “*plurality of approaches*”, including both mathematical formalism and picture-based physical theories. In particular, Maxwell’s programme was not only successful to assimilate the propositions of the Ampere-Weber hard core, combining them with Faraday’s “field” notions, as well as with those of Fresnel-Young optics; it was open for the synthesis with other research traditions as well. This “abundance of the relations” (Heinrich Hertz) was due to that Maxwell did put forward as a synthetic principle the idea, that differed from that of Ampere-Weber by its flexible and contra-ontological, strictly epistemological, Kantian character. For Maxwell, ether was not the ultimate building block of physical reality, from which all the fields and charges should be constructed. “Action at a distance”, “incompressible fluid”, “molecular vortices” were “*contrived analogies*” [Hon and Goldstein, 2012] for Maxwell, capable only to direct the researcher at the “right” mathematical relations. From the “representational” point of view all this hydrodynamic models were doomed to failure efforts to describe what cannot be described in principle – “things in themselves”, the “nature” of electrical and magnetic phenomena. On the contrary, Maxwell aimed his programme to find empirically meaningful mathematical relations between the electrodynamics basic objects, i.e. the creation of concordant electromagnetic field equations system. Hence even Ludwig Boltzmann agreed with Hertz that Maxwell’s concepts of charge and current were “irremediably obscure”. In his lectures he adopted Hertz’s view that electricity was a “thing of thought , serving to picture the integrals of certain equations”. It seems to me that one of the drawbacks of current Maxwellian revolution studies [see, for instance, Siegel, 1991; Morrison, 2000; Darrigol,2001] is an *underestimation of Maxwell’s own methodology* created by himself for his ambitious project of mechanics, electrodynamics and optics unification. In every field of creativity (including epistemology) Maxwell always took his own way; and he tried to teach his students in the same way too. It seems to me that one should take Ludwig Boltzmann’s comments on Maxwell’s works more seriously. In his lectures on Maxwell’s theory as well as in his comments on Maxwell’s electromagnetic papers (that he had translated into German), the founder of statistical mechanics had pointed out that many Maxwell’s works but especially his early electrical papers “were *not properly understood*”. Perhaps it can be explained by the fact that these works “written according to the *long-term plan*” demonstrate that their author “ was as mastermind in theory of knowledge as he was in the field of theoretical physics” (Boltzmann 1895). Maxwell’s methodology that sprung out from an intention to find a fruitful compromise between the extremes of Kantian relativism and Scottish “common sense realism” was a necessary part of his ambitious unification of optics and electromagnetism design. Previous nineteenth century physics studies have oscillated between *two extremes*. On the one hand, in the more traditional vein, differences between research traditions were considered to be insignificant and communication unproblematic. On the other hand, in the more recent, post-Kuhnian, studies, differences between traditions are often taken to be so radical that communication is impossible among them.

This study originates from an *intermediate picture*. According to it, profound differences between the field and action at a distance research traditions existed at various levels, ranging from ontological commitments and up to epistemological beliefs. Yet these antagonistic traditions were able to communicate in the creative acts of such men of science as Maxwell, Helmholtz and Hertz. They communicated in the ways that permitted comparisons, adaptations and *cross-fertilizations* of different traditions as well. The intermediate picture of our study comes from the critique of Kuhnian and Lakatosian conceptions’ drawbacks : they lack the mechanisms of the paradigms’ (or scientific research programmes’) *interactions* [Nugayev 1985a,b].To meet the critical comments, a “mature theory-change model” was proposed based on the “communicative rationality” concept [Nugayev 1999,a]. According to the epistemic model, the origins of scientific revolutions lie not in a clash of fundamental theories with facts, but of “old” fundamental theories with each other, leading to contradictions that can only be eliminated in a more general theory. The key role in theory change is played by the proponents of the old paradigms’ *dialogue* that leads to intercorrections and interpenetrations of the participants’ initial views . The very realization of reductionist and synthetic research programmes is brought about by the clash of mature theories which they are designed to eliminate. Having compared the heuristic potentials of the reductionist and the synthetic programmes, I favor the latter one since it has the following objective advantages [Nugayev, 1999b]. Firstly, synthetic programmes should provide a greater empirically-progressive shift of problems solved than the reductionist ones. Secondly, only these programmes can rationally explain the use of the so-called *crossbred* theoretical objects which spring from the coincident theories. For instance, if one considers the structures of two mature modern theories - quantum theory and general relativity - he finds that their global theoretical schemes arose from the unification of the crossbred theoretical ones. Every case of different programmes’ meeting leads to a situation when a domain of *hybrid* models occurs formed by simple conjunctions from the models of different research programmes. However, the mongrel models appear to be self-contradictory; and when this is realized, the crossbreeds from the basic objects of all the cross-theories are constructed. A new mature theory is formed due to crossbred domain growth.

*&1.Maxwell’s methodology of synthetic mature theory construction.*

Maxwell was not the first to unify optics and electromagnetism. Yet he did not like the way his predecessors had done it: the theories of action at a distance were too formal and abstract to grasp the connections between the electromagnetic phenomena [Maxwell, [1856/1890], 1952, p.155]. His predecessors were Hans Christian Oersted (1777 – 1851), Andre-Marie Ampere (1775-1836), Wilhelm Weber (1804-1890), Michael Faraday (1791-1867) and William Thomson (1824-1907). Yet Maxwell’s Weltanschaugung was characterized by *an extraordinary high level of philosophical culture***.** A brilliant student at Edinburgh and Cambridge and a post-graduate at Cambridge was enchanted by a profound skepticism of David Hume, George Berkley and Immanuel Kant at the lectures of Sir William Hamilton on mental philosophy at Edinburgh University. Hamilton’s lectures, which were a prominent element in the Scottish university curriculum, “*interested him greatly*”. From the Class of Metaphysics his mind “gained many lasting impressions” [Lewis & Campbell 1882]; the lectures of Sir Hamilton made a strong impression on him, in “stimulating the love of speculation to which his mind was prone” . Sir William Hamilton (1788-1856) was one of the outstanding representatives of Scottish “common sense philosophy”, an heir of Thomas Reid and James Stewart. Yet he stressed *Kant’s proposition that all knowledge is relative*; so we know nothing about things themselves except by their *relationship* to other things. He had stimulated a spirit of criticism in his pupils by insisting on the great importance of *psychology* as opposed to the older metaphysical method. Hamilton’s “philosophy of the conditioned” surely had a strong Kantian flavor. Like Kant, he held that we can have knowledge only of “the relative manifestations of an existence, which in itself it is our highest wisdom to recognize as beyond the reach of philosophy”. But unlike Kant , however, *he had argued for the position of a “natural realism***”** in the Reidian tradition. The relativism or phenomenalism which Hamilton adopted from Kant and sought to engraft upon Scottish philosophy is absent from the original Scottish doctrine. Thus, denying Hume’s skepticism, Hamilton did his best to *find a compromise* between Kant’s relativism and Reid’s realism; and it was namely that that Maxwell have pointed out as a basic thesis of his metaphysical programme on moving from Edinburgh to Cambridge:

 “in the meantime I have my usual superfluity of plans…4. Metaphysics – *Kant’s Kritik of Pure reason in German, read with a determination to make it agree with Sir W. Hamilton…*” [Campbell & Garnett 1882, p.77].

 The “Copernican revolution” in epistemology that had been initiated by Kant consisted in that the world of usual every-day experience (or Husserl’s “lebenswelt”) had lost its dominating position in interpreting things that can be perceived by our senses. Kant had exchanged the world of common experience by the world of Galilean experimental and mathematical physics based on the idealizations of the “lebenswelt” phenomena. Hence truth became something not spontaneously revealing and disclosing itself but something that can be comprehended only by a special (“scientific”) method. On the other hand, if truth is comprehended only in experience and we can grasp not “the things by themselves” but just the “phenomena”, it is necessary to reject the opportunity of reaching the absolute truth. Our sensory representation is by no means a representation of things “in themselves” , but only of the way in which they appear to us. Hence the “*analogies of experience*” are especially important in Kant’s epistemology. Kant states that the cognition *according to analogy* does not signify, as the word is usually taken, an imperfect similarity between two things, but rather a perfect similarity between two *relations* in wholly dissimilar things. For instance, such is an analogy between the legal relation of human actions and the mechanical relation of moving forces. One can never do anything to another without giving him a right to do the same to me under the same condition ; just as a body cannot act on another body with its motive force without thereby causing the other body to react just as much on it. Right and motive force are here completely dissimilar things, but in their relation there nonetheless complete similarity. By means of such an analogy one can therefore provide a concept of a relation to things that are absolutely unknown to him [Kant [1783], 2002,pp.146-147]. A more detailed exposition of Maxwell’s research programme that he had followed through all his life is given in his truly philosophical works – in a speech “*Are There Real Analogies in Nature?*” read at the “Apostles” Cambridge club in 1856 ( just after the publication of his most profound paper “*On Faraday’s Lines of Force*” , 1855-1856) – and in his trailblazing paper “*Helmholtz*” (1877). The Cambridge speech is not a crude exposition of Kant’s epistemology but a tense discussion of Maxwell with “Kant in himself”. It is not accidental that the very heading of the speech contains a question and not an assertion: ”*Are There Real Analogies in Nature*?” - Maxwell gives no definite and unambiguous answer - in full accordance with Kant’s antinomies that occur to Human Reason as attempts to overstep the Limits of Experience. He multiplies arguments pro and contra the proposition that certainly there are real analogies in Nature. Certainly Maxwell’s thinking in terms of Kantian antinomies is not accidental. Following Hamilton’s traditions, Maxwell tries to find *his own way* between the Scylla of Kantian transcendentalism and the Charybdis of Scottish common sense realism. In modern literature the Scottish view of knowledge is characterized by the following principles [Mertz 1964; Olson 1975]. 1. All knowledge is relational. 2. Analogies are among the chief such relational ways of knowing. 3. Analogies are necessary for psychological reasons. For most people, understanding requires the use of analogies for simplifying and organizing knowledge. 4. Strong psychological tendencies in the Scottish Common Sense tradition admit reconciliation with logical and analytical trends of Kant’s philosophy. Hence for Maxwell the philosophical resolution of the antinomies comes from adopting *partial points of view*, as all human knowledge is partial. No absolute truth is attainable. What remains is establishing correspondences or analogies. Whenever one sees a relation between two things he knows well, and thinks that there must be a similar relation between things less known, he reasons from the one to another. It supposes that although pairs of things may differ widely from each other, the relation in the one pair may be the same as that in the other. Since in a scientific point of view the *relation* is the most important thing to know, a knowledge of the one thing leads us a long way toward a knowledge of the other. If all that one knows is relation, and if all the relations of one pair of things correspond to those of another pair, it will be difficult to distinguish the one pair from the other, although not presenting a single point of resemblance , unless one has some difference of relation to something else whereby to distinguish them. Such mistakes can hardly occur except in mathematical and physical analogies. Thus, the first lesson taught by Kantian epistemology – (I) “*the principle of relational character of scientific truth*” stating that the *relation* is the most important thing to know. It should be pointed out that even the examples of the analogies are taken by Maxwell from Kant’s “Prolegomena”. Hence it is not surprising that the second principle – (II) “*theory laidenness of observation*” – is also extracted from Kant:

“The dimmed outlines of phenomenal things all merge into one another unless we put on the focusing glass of theory, and screw it up sometimes to one pitch of definition and sometimes to another, so as to see down into different depths through the great millstone of the world [Maxwell; quoted from Campbell & Garnett 1882, p.125].

The importance of the principle (II) for Maxwell’s methodology cannot be overestimated. In nature all the phenomena are interconnected and merge into one another; all the differences in theoretical approaches are due to the fact that their authors focus on the different facets and different levels of the phenomena investigated. Hence a theoretician’s task is to provide the “appropriate ideas” (Whewell’s term) to cover the various domains of experience. But where should he find them? – In experience, from immediate generalizations of the experimental data? – Another piece of Maxwell’s creativity – a part of his 1854 letter – makes it possible to take a glance at his thought laboratory:

“It is hard work *grinding out* ‘appropriate ideas’, as Whewell calls them. I think they are coming out at last, and by dint of *knocking them against* all the facts and half-digested theories afloat, I hope to bring them to shape, after which I hope to understand something more about inductive philosophy that I do at present” [Maxwell; quoted from Campbell & Garnett, 1882,p.112].

Now it is clear where the “appropriate ideas” come from: they are not the slavish copies of things, but are the a priori forms by which a chaos of sensations is “brought to order”. At first the “appropriate ideas” are vague and dim; however in the long run they are “grinded out” by knocking them with the “facts” and the other theories. However the theoretician’s task is not only to introduce and polish subtle notions “reflecting” the different facets of the phenomena under consideration, but also to unify the notions in synthesis. The outlines and the stages of such a synthesis are described in Maxwell’s paper “*Hermann Ludwig Ferdinand Helmholtz*” . Maxwell points out that the ordinary growth of human knowledge is by accumulation round a number of *distinct* centers. Yet the time must sooner or later arrive when two or more departments of knowledge can no longer remain independent of each other, but *must* be fused into a consistent whole. But though scientists may be profoundly convinced of the necessity of such a fusion, the operation itself usually is a most arduous one. For though *the phenomena of nature are all consistent with each other*, we have to deal not only with these, but with the hypotheses which have been invented to systematize them. It by no means follows that because one set of observers have labored with all sincerity to reduce to order one group of phenomena, the hypotheses which they have formed will be ***consistent*** with those by which a second set of observers have explained a different set of phenomena. Each science may appear tolerably consistent within itself, but before they can be combined into one, each must be stripped of the “daubing of untempered mortar” by which its parts have been prematurely made to cohere [Maxwell [1877/1890], 1952, p.592]. This paper is not accidental for Maxwell. In other works Maxwell himself emphasized the value of the next principle (III) - “*cross-fertilization* of the sciences” [Maxwell 1890, vol.2, p.744] evoking the image of bees pollinating flowers [see Harman 2003 for further details]. The typical example of “ the daubing of untempered mortar elimination” principle (IV) for Maxwell was the progress of mechanics in Newton’s time which consisted in getting rid of the celestial machinery with which generations of astronomers had encumbered the heavens, and thus “sweeping cobwebs off the sky ” [Maxwell [1873b/1890], 1952].

 *&2. Stages of Maxwellian Programme Realization.*

“*A Treatise on Electricity and Magnetism*” [Maxwell 1873] was mainly an encyclopedia and a textbook; the basic electromagnetic results were obtained in a sequence of three papers: “*On Faraday’s Lines of Force*” [Maxwell 1856], “*On Physical Lines of Force*” [Maxwell 1861-1862] and “*A Dynamical Theory of Electromagnetic Field*” [Maxwell 1864]. The first paper [Maxwell 1856] is dedicated to elaboration of the “ *analogies*” method founded on Kantian epistemology. The method rejects the “ontological” approaches looking for the “essences” of electrical and magnetic phenomena and proclaiming that “in reality” electricity and magnetism are “fields” and not “action at a distance” phenomena, or vice versa. Maxwell’s proposal is to consider Faraday’s lines of force as a kind of tubes filled with ideal incompressible fluid. And in the other parts of the paper Maxwell renders the ways by which the idea of incompressible fluid motion can be applied to the sciences of statical electricity, permanent magnetism, magnetism of induction, and uniform galvanic currents. The core element of his innovations consisted in the construction of “*neutral language*” for description and comparison of the consequences from the rival theories. Maxwell’s “neutral language” was not Carnap’s and Reichenbach’s “observation language” springing out from the “protokolsatze” generalizations. Maxwell is aware of the theory - laidenness of the observation data (“experimental laws already established, which have generally been expressed in the *language of other hypotheses*” – Maxwell [1861-1862/1890], 1952, 162). He clearly understands that every observation always carries the footprints of the theoretical language that helps to describe it. (“The daubing of untempered mortar”, as he will call them later in his “Helmholtz” paper). In order to compare and to unite in a theoretical scheme lacking contradictions all the results of the different experiments carrying the footprints of different theoretical languages, it is necessary to construct an *artificial* theoretical language equally distant from the languages of theories under comparison. This language appeared to be the language of solid state mechanics (with hydrodynamics as its part). Maxwell’s ultimate aim was to rewrite all the known empirical and theoretical laws of electricity and magnetism using the neutral language and then to compare them in order to create a system without contradictions. The final result of the 1856 paper was a system of equations lacking the “displacement current”. It was not accidental that one of the main drawbacks of the incompressible fluid theory consisted in that the latter, apart from some simple cases, was unable to explain interrelations and interactions of electrical and magnetic fields and electric currents, as well as Faraday’s (1845) interconnection between optical and electromagnetic phenomena. Maxwellian programme’s ultimate goal was to reveal the connection “between electricity at rest and current electricity” absent in the Ampere-Weber electrodynamics. Was it reached in 1856? – Certainly not. The connection between the current density **j** and the charge densityρ was lacking in Maxwell’s initial 1856 scheme. It was to appear later, after the “displacement current” introduction and finding out its consequence – the continuity equation div **j** + $∂ρ/∂t$ = 0.So, in 1861 the publication of Maxwell’s second paper [Maxwell 1861-1862] consisting of four parts begins. Its aim was to rederive the results of Weber and Neumann theories on the basis of a new mechanical hypothesis containing the *vortices of incompressible fluid*. The theory started from W. Thomson’s investigations; he showed that the connection between magnetism and electricity has the same mathematical form as that between certain parts of phenomena, of which one has a *linear* and the other a *rotatory* character. It is important that W. Thomson introduced the vortices theory in incompressible fluid while reflecting on Faraday’s experiments on the rotation of the plane of polarized light when transmitted along the lines of magnetic force. So, they were the efforts to theoretical reconstruct the Faraday effect that provided the meeting of optics and theory of magnetism. In the second Maxwellian theory the magnetic field was represented by a set of vortices in incompressible fluid with the axes of rotation coinciding with the direction of magnetic field at a point. But one of the most intricate problems of the vortices theory that puzzled even Daniel Bernoulli who invented it in XVIII-th century[Whittaker 1910] was: how can the rotation be transferred from one vortex to another so that “ vortices in a medium exist side by side, revolving in the same direction about parallel axis”? – The only conception that aided Maxwell in conceiving this kind of motion was that of the vortices being separated by a layer of particles called the “*idle wheels*” . Is it possible to connect these particles with electricity? And in the second part of his 1861 paper “*The Theory of Molecular Vortices applied to Electric Currents*” Maxwell comes up to the *hardest problem* of his research programme : what is “the physical connexion of these vortices with electric currents, while we are still in doubt as to the *nature of electricity*”. It is this point where Maxwell has to admit the principal *limits* of pure mechanical theories and to *borrow the elements of action at a distance theory!* Or, using the methodological language of Nugayev, 1999 , one can conclude that Maxwell had to construct the “*crossbred theoretical objects*” from the languages of both cross-theories that combine the properties of quite different theoretical schemes. According to Maxwell’s theory, an electric current is represented by the transference of the moveable particles interposed between the neighboring vortices. As a result, these particles, in his theory, *play the part of electricity.* Their motion of translation constitute an electric current and their rotation serves to transmit the motion of the vortices from one part of the field to another. On introducing such abstract objects as “electrical particles” and “electric current representing the motion of such particles” Maxwell had deviated significantly from Faraday’s notions. According to Michael Faraday, the electrical charges should be considered as created by the ends of lines of force; they lack an independent substantial existence. Correspondingly, in his *genuine* research programme the electric current has to be considered not as the motion of real particles but as an “energy axis”. This is the nub of the British field programme: the fields are primary, and the particles are only secondary. Later on Maxwell’s eclecticism was followed by H.A. Lorentz’s dualism. Lorentz initiated it in a 1875 paper: “I shall start with instantaneous action at a distance: thus we will be able to found the theory on the most direct interpretation of observed facts” [quoted from Darrigol 2001,p.323]. So it was not a temporary retreat. Even after 1861 Maxwell many times introduced the notions of the Ampere-Weber atomism into his theories [Darrigol 2001]. Yet the results obtained were of course insufficient; the theoretical derivation of Coulomb’s law was lacking. Namely that was done in the third part of 1861-1862 paper “*The Theory of Molecular Vortices applied to Statical Electricity*”. It is important that the vortices theory contained too many ad hoc assumptions. To eliminate at least some of them “*Maxwell’s miracle*” was invented. It appeared that if one transposes in the course of Fresnel optics and electromagnetism theory meeting the ether properties from optics to electromagnetism, he can eliminate at least one ad hoc supposition. Indeed, it is necessary to suppose, in order to account for the transmission of rotation from the exterior to the interior parts of each cell, that the substance in the cells possesses *elasticity of figure*, similar in kind, though different in degree, to that of observed in solid bodies. The undulatory theory of light requires one to admit this kind of elasticity in the luminiferous medium, in order to account for transverse vibrations. Hence he need not then be surprised if the magneto-electric medium possesses the same properties. This peculiarity has a vital significance for Maxwell’s neutral language . If we can now explain the condition of a body with respect to the surrounding medium when it is said to be ‘charged’ with electricity, and account for the forces acting between electrified bodies, we shall have established a connexion between *all* the principal phenomena of electrical science. Thus, the extrapolation of the molecular vortices theory on the electrostatic domain became possible due to the elasticity of the vortices that enabled the medium to maintain the elasticity waves. As a result,

“the velocity of transverse undulations in our hypothetical medium, calculated from the electromagnetic experiments of M.M. Kohlrausch and W. Weber, agrees so exactly with the velocity of light calculated from the optical experiments of M. Fizeau, that we can scarcely avoid the inference that light consists of the same medium which is the cause of electric and magnetic phenomena” [Maxwell [1861-1862/1890], 1952, p.22].

The displacement current introduction was due to Maxwell’s efforts to link the equations relating to electrical current with that of electrostatics, which demanded the Ampere law modification for the sake of a new term introduction; the term had to describe the elasticity of the vortices medium. The displacement current introduction driving force came from Maxwell’s efforts to unify all the main empirical laws belonging not only to electricity and magnetism but to optics as well. As a result Maxwell obtained his famous system of equations along with the continuity equation describing that electrical particles that transform the rotations from one vortex to another does not appear from nothing and cannot disappear to nowhere. But one could not state any final unification of optics and electromagnetism in 1861. It was possible to tell only on the *beginning* of their reconciliation, on the beginning of rather different theoretical ontologies “grinding”. And at last in 1864 Maxwell proposed a modified version of his 1861-1862 paper that tried to avoid any special suppositions on the nature of molecular vortices. In his 1864 paper Maxwell derives his equations from abstract dynamics of Lagrange. The Lagrangian function L is found as the difference between the kinetic and potential energies of a system. From those he was able to derive the basic wave equation of electromagnetism without any special assumptions about molecular vortices or forces between electrical particles. Although displacement retained a prominent position in “*A Dynamical Theory of Electromagnetic Field*”, its role was rather different from the role it played in 1861-1862 paper. It was no longer associated with changes in positions of rolling particles; rather, Maxwell defined it simply as the motion of electricity , that is, in terms of a quantity of charge crossing a designated area. However, despite Maxwell’s claim to provide deductions from (three) experimental facts, his account still required the *postulation* of a displacement current, something that could neither be verified by nor deduced from experiment [Morrison 2000; Darrigol 2001]. And at last Maxwell’s creativity ends with “*A Treatise on Electricity and Magnetism*” conceived as an encyclopedia of the electrical and magnetic effects. In his “*Treatise*” Maxwell goes further in purifying his deductions from the model remnants and in strengthening the Lagrangian approach. |Yet it is important that in his “*Treatise*” Maxwell faced with the same problem as in 1864 paper: the problem of Lagrangian mathematical formalism application to the case of electromagnetic field. Maxwell himself used a fitting comparison with a belfry. He aimed to develop a Lagrangian formulation of electromagnetism in which the ether mechanism would be the analogue of the mechanism in the belfry, whilst the positions and velocities of the ropes would have their analogues in measurable charge and current distributions serving to determine the electromagnetic energy. However on twenty pages of his “*Treatise*’ chapter Maxwell gave a detailed Lagrangian treatment for interacting closed conduction currents only. And when, two chapters later, he came to build on his Lagrangian formulation to formulate the *general* equations of his electromagnetic theory, he *simply added* the displacement to the conduction current ”by hands” to give the total current. But this move by Maxwell in fact undermined the major attraction of his Lagrangian method [see Chalmers, 2001, for details]. The first direct experimental evidence for the existence of displacement currents emerged only with Hertz’s experiments culminating in production of radio waves in 1888. As always, the Lagrangian formulations were retroactive attempts to accommodate results obtained by other means. Nicolas Copernicus had pioneered in considering the Earth as an ordinary planet orbiting the Sun; hence he had created a crossbred theoretical object capable of extrapolating the mathematical principles from divine phenomena on the mundane ones. On the other hand, through the same crossbred object the physical principles were extrapolated from mundane objects on the skies [ Nugayev, 2013]. Similarly, James Maxwell had constructed a crossbred object – the displacement current - and was able to extrapolate the electromagnetic principles on the optical phenomena, and vice versa.

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