MAXWELLIAN SCIENTIFIC REVOLUTION: A CASE STUDY IN KANTIAN EPISTEMOLOGY

Rinat M. NUGAYEV

ABSTRACT: It is exhibited that maxwellian electrodynamics was created as a result of the old pre-maxwellian programmes reconciliation: the electrodynamics of Ampere-Weber, the wave theory of Young-Fresnel and Faraday's programme. The programmes' meeting led to construction of the whole hierarchy of theoretical objects starting from the genuine crossbreeds (the displacement current) and up to usual mongrels. After the displacement current construction the interpenetration of the pre-maxwellian programmes began that marked the beginning of theoretical schemes of optics and electromagnetism real unification. Maxwell's programme did supersede its rivals because it did assimilate some ideas of the Ampere-Weber programme, as well as the presuppositions of the programmes of Young-Fresnel and Faraday. Maxwellian programme's victory over its 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.It was Kantian epistemology that enabled Hermann von Helmholtz and his pupil Heinrich Hertz to arrive at such a version of Maxwell's theory that could serve a heuristical basis for the radio waves discovery.

KEYWORDS: James Clerk Maxwell, Hermann von Helmholtz, Heinrich Hertz, scientific revolution, Immanuel Kant, epistemology

Introduction

The aim of the present paper is to answer the question "Why did Maxwell's programme supersede its rivals?" It appears that to answer it one has to take a further step in revealing the inter-theoretical context of Maxwellian electrodynamics genesis and growth. 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.[1] I'll try to demonstrate that *the Maxwellian programme*

[1] Thomas Kuhn, "Objectivity, Value Judgement and Theory Choice," in his *The Essential Tension* (Chicago: University of Chicago Press, 1977), 320-339; Imre Lakatos, "The Methodology

had superseded its rivals because it had constantly communicated with them. For instance, 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 statement 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*"[2] one. It appeared, according to one of Maxwell's (Kantian) philosophical gurus, one of "successive steps by which we gradually ascend in our speculative views to a higher and higher point of generality."[3] Contrary to Maxwell's, the Ampere-Weber programme was a *reductionist*[4] one for it tried to reduce all the theoretical ontologies to one and the same ontology of "action at a distance."

According to Ludwig Boltzmann, "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*."[5] 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. For instance, as Heinrich Hertz had put it,

> From the outset Maxwell's theory excelled all others in elegance and in *the abundance of the relations* between the various phenomena which it included.[6]

This "abundance of the relations" 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.

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of Scientific Research Programmes," in his *Philosophical Papers*, *Volume 1* (Cambridge: Cambridge University Press, 1978).

[2] Rinat Nugayev, *Reconstruction of Mature Theory Change: A Theory–Change Model* (Frankfurt am Main: Peter Lang, 1999).

[3] William Whewell, *The Philosophy of Inductive Sciences: Founded Upon Their History,* Second edition, vol. 2 (London: John W. Parker and Son, 1847), 74.

[4] Nugayev, *Reconstruction of Mature Theory Change.*

[5] Quoted from Jed Buchwald, *The Creation of Scientific Effects: Heinrich Hertz and Electric Waves* (Chicago: The University of Chicago Press, 1994), 261.

[6] Heinrich Hertz, *Electric Waves* (London: Macmillan, 1893), 19.

> By referring everything to the purely geometrical idea of the motion of an imaginary fluid, I hope to attain *generality* and precision, and to avoid the dangers arising from a premature theory professing to explain *the cause* of the phenomena.[7]

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"[8] for Maxwell, capable only to direct the researcher at the "right" mathematical relations. Maxwellian analogy is contrived and is not intended to illustrate anything in nature. Maxwell gave a new meaning to analogy that comes close to modeling in current usage. For instance, according to John von Neumann, modern sciences do not try to explain, they hardly even try to interpret, they mainly make models. And model is a mathematical construct which, with the addition of certain verbal interpretations, describes observed phenomena. The justification of such a construct is that it is expected to work.

Usually the defining feature of all analogies is supposed to be a *bidirectional* relation between the two domains for which an analogy is established. Neither domain is privileged over the other. Relation holds both ways: one can move from one domain to its analogue and vice versa. But this feature does not hold in Maxwell's novel methodology of mathematical analogy – it is *unidirectional* , from a fictional system to a physical system, where the purpose of introducing the fictional system is to gain insight into the physical system and ultimately to recast it into the mathematical formalism.

The principle of usual ("physical") analogy between theories in two different domains that are identical in nature came from William Thomson. But for Maxwell the methodology of analogy was only a tool. Contrary to Thomson, both mathematically identical systems need not exist in nature. In a pair of such systems one of them could be imaginary ("imaginary fluid"), and the other real ("physical").

From the "presentational" 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 at finding empirically meaningful

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[7] James Maxwell, "On Faraday's Lines of Force," *Transactions of the Cambridge Philosophical Society*, X, part 1 (1856). Reprinted in *The Scientific Papers of James Clerk Maxwell*, *vol. 1* (New York: Dover, 1952), 155-229.

[8] Giora Hon and Bernard R. Goldstein, "Maxwell's Contrived Analogy: An Early Version of the Methodology of Modeling," *Studies in History and Philosophy of Modern Physics* 43 (2012): 236–257.

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."[9]

It seems to me that one of the insufficiencies of current Maxwellian revolution studies[10] 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.

As the author of *Treatise on Electricity and Magnetism* himself put it in one of his letters, "I find I get fonder of metaphysics and less of calculations continually."[11] One can remember Gustav Kirchhoff: "He is a genius, but one has to check his calculations."

It seems to me that one should take Ludwig Boltzmann's comments on Maxwell's works more literally. 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.*"[12] Maxwell was a great scientist as well as a great innovator of methodology.[13] Maxwell's methodology that sprung out from an intention to find a fruitful

[9] Quoted from Buchwald, *The Creation of Scientific Effects*, 258.

[10] See, for instance, Daniel Siegel, *Innovation in Maxwell's Electromagnetic Theory: Molecular Vortices, Displacement Current, and Light* (Cambridge: Cambridge University Press, 1991); Margaret Morrison, *Unifying Scientific Theories: Physical Concepts and Mathematical Structures* (Cambridge: Cambridge University Press, 2000); Olivier Darrigol, *Electrodynamics from Ampere to Einstein* (Oxford: Oxford University Press, 2001).

[11] Lewis Campbell and William Garnett, *The Life of James Clerk Maxwell* (London: Macmillan, 1882), 298.

[12] Ludwig Boltzmann, *Ueber Faraday's Kraftlinien, von James Clerk Maxwell. Herausgegeben von. L. Boltzmann.* (Leipzig: W. Engelmann, 1895).

[13] Mary Hesse, "Logic of Discovery in Maxwell's Electromagnetic Theory," in *Foundations of Scientific Method: The Nineteenth Century*, eds. Ronald N Giere, Richard Samuel Westfall (Bloomington: Indiana University Press, 1973), 86-114; Peter Achinstein, "What to Do if You Want to Defend a Theory You Cannot Prove: A Method of 'Physical Speculation,'" *The Journal of Philosophy* 107 (2010): 35-55.

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.

For instance, James Clerk Maxwell himself many times, beginning from his first paper and up to the last one, had pointed out that the key ideas of the Ampere- Weber electrodynamics were as useful for electrodynamics development as those of the field theories. Even at the beginning of his electrodynamics studies, on May 1855, a post-graduate student at Cambridge writes a letter to his father, stressing the importance of studying the theories of "heavy German writers." Further, completing his theory creation on the basis of Lagrangian formalism, in his introduction to *A Dynamical Theory of Electromagnetic Field* (read December 8, 1864) Maxwell characterizes action at a distance theory as "exceedingly ingenious and wonderfully comprehensive." Yet he had to make the following reservation:

> The mechanical difficulties, however, which are involved in the assumption of particles acting at a distance with forces which depend on their velocities are such as to prevent me from considering this theory as an *ultimate* one, though it may have been, and *may yet be useful in leading to the coordination of phenomena.*[14]

And, at last, in his *Treatise on Electricity and Magnetism* (1873), Maxwell renders the creation of his system of equations in the following way:

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[14] James Maxwell, "A Dynamical Theory of Electromagnetic Field," *Philosophical Transactions of the Royal Society of London* 155 (1865): 459-512. Reprinted in *The Scientific Papers of James Clerk Maxwell, vol.1* (New York: Dover, 1952), 526-97.

> I was aware that there was supposed to be a difference between Faraday's way of conceiving phenomena and that of the mathematicians, so that *neither he nor they* were satisfied with each other's language. I had also the conviction that this discrepancy did not arise *from either party being wrong*.[15]

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.*[16] To meet the critical comments, a "mature theory-change model" was proposed based on the "communicative rationality" concept.[17] 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.[18] 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.

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[15] James Maxwell, *A Treatise on Electricity and Magnetism*. 2 vols, third ed. (New York: Dover, 1954), 499.

[16] Rinat Nugayev, "A Study of Theory Unification," *The British Journal for the Philosophy of Science* 36 (1985): 159–73; Rinat Nugayev, "The History of Quantum Theory as a Decisive Argument Favoring Einstein over Lorentz," *Philosophy of Science* 52 (1985): 44–63.

[17] Rinat Nugayev, "Einstein's Revolution: a Case Study in Communicative Rationality," *Foundations of Science* 4 (1999): 155-204.

[18] Nugayev, *Reconstruction of Mature Theory Change*.

The aforesaid is not to diminish the role of experiments in science. On the contrary, the epistemic model proposed seems to elaborate further the point of view stated in the current literature that both theorists and experimentalists have breaks in their respective traditions, but they are not typically simultaneous.[19] Theory development must have, to some extent, a life of its own. The development of two main cultures within science does not mean that the two do not speak to each other.

The epistemic model was illustrated with reference to physics in the early twentieth century, the three "old" theories in this case being Maxwellian electrodynamics, statistical mechanics and thermodynamics.[20] The world of "old," pre-Einsteinian physics was conceptually and socially fragmented. It was split on at least 3 research traditions belonging to electrodynamics, thermodynamics and mechanics. Traditions organized around different groups of phenomena generated little support for one another. The practitioners of each theoretical tradition acknowledged the existence of the other but went their own separate ways. With the advent of relativity and quantum theory, the conceptual unification of worldviews was accompanied by a social unification of practice.

1. Maxwellian Methodology of Synthetic Mature Theory Construction

Maxwell was not the first to unify optics and electromagnetism. Yet he was dissatisfied with the way his predecessors had done it. Why? The following passage helps to find the answer: the theories of action at a distance were too formal and abstract to grasp the intricate connections between the electromagnetic phenomena.

> No electrical theory can now be put forth, unless it shows the ***connexion*** not only between electricity at rest and current electricity, but between the attractions and inductive effects of electricity in both states… The results of this simplification may take the form of a purely mathematical formula or of a physical hypothesis. In the first case we entirely lose sight of the phenomena to be explained; and though we may trace out the consequences of given laws, we can never obtain more extended views of the *connexions* of the subject.[21]

His predecessors were Hans Christian Oersted (1777-1851), Andre-Marie Ampere (1775-1836), Wilhelm Weber (1804-1890), Michael Faraday (1791-1867)

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[19] Andrew Pickering, *Constructing Quarks. A Sociological History of Particle Physics* (Chicago: The University of Chicago Press, 1985); Peter Galison, *How Experiments End* (Chicago: The University of Chicago Press, 1987).

[20] Nugayev, "The History of Quantum Theory."

[21] Maxwell, "On Faraday's Lines of Force," 155.

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;"[22] 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 Reverend Thomas Reid (1710-1796) directed his *An Inquiry into the Human Mind on the Principles of Common Sense* (1764) against Hume and Berkeley. It is here – he argued – that the "danger of the idealism" lies – in its reduction of reality to "particular perceptions," **essentially *unconnected*** with each other. The unit of knowledge is not an isolated impression but a judgement; and in such a judgement is contained the reference both to a permanent subject and to a permanent world of thought, and, implied in these, such judgements, for example, as those of existence, substance, cause and effect. Such principles are not derived from sensations, but are "suggested" on occasion of sensation, in such a way as to constitute the necessary conditions of having perceptive experience at all.

The doctrine of relativity of knowledge has seemed to many – including James Stewart Mill – contradictory to his realism. But for Hamilton, the two are held together by a kind of intuitionism that emphasizes certain facts of

[22] Campbell and Garnett, *The Life of James Clerk Maxwell*.

consciousness that are both primitive and incomprehensible. They are though constitutive of knowledge, “less forms of cognitions than of beliefs.”[23]

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**….”[24]

The “Copernican revolution” in epistemology that had been initiated by Kant consisted in that the world of usual every-day experience (or Edmund 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

[23] Quoted from Robert Audi, ed., *The Cambridge Dictionary of Philosophy* (Cambridge: Cambridge University Press, 1999), 360.
[24] Campbell and Garnett, *The Life of James Clerk Maxwell*, 77.

therefore provide a concept of a relation to things that are absolutely unknown to him.[25]

In more detail, in *The Critique of Pure Reason* [1787], Kant considers a more interesting example:

> we are able, with the guidance of these analogies, to reason in the series of possible perceptions from a thing which we do really perceive to the thing we do not perceive. Thus, *we cognize the existence of a magnetic matter penetrating all bodies from the perception of the attraction of the steel-fillings by the magnet,* although the constitution of our organs renders an immediate perception of this matter impossible for us.[26]

It is rather important that *even the example of the analogy of experience was taken by Kant from the domain of electromagnetism* thus paving the way to Maxwell. The latter had pointed out many times that things we can measure directly, like mechanical force, are merely the outward manifestations of deeper processes, involving entities like electric field strength, which are *beyond* our power of visualization.[27]

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 lecture 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.

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[25] Immanuel Kant, "Prolegomena to any future metaphysics that will be able to come forward as science," in *Immanuel Kant. Theoretical Philosophy after 1781*, trans. Gary Hatfield (Cambridge: Cambridge University Press, 2002), 146-47.

[26] Immanuel Kant, *The Critique of Pure Reason* (University Park: The Pennsylvania State University Press, 2010), 170.

[27] Basil Mahon, *The Man Who Changed Everything. The Life of James Clerk Maxwell* (London: John Wiley, 2003).

In modern literature the Scottish view of knowledge is characterized by the following principles:[28]

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 by Maxwell 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

[28] John Mertz, *A History of European Thought in the Nineteenth Century*, 4 vols. (Edinburgh: William Blackwood and Sons,1964); Richard Olson, *Scottish Philosophy and British Physics, 1750-1880: A Study in the Foundations of the Victorian Scientific Style* (Princeton: Princeton University Press, 1975).

> definition and sometimes to another, so as to see down into different depths through the great millstone of the world.[29]

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.[30]

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.

[29] Maxwell; Quoted from Campbell and Garnett, *The Life of James Clerk Maxwell*, 125.
[30] Maxwell; Quoted from Campbell and Garnett, *The Life of James Clerk Maxwell*, 112.

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.[31]

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" evoking the image of bees pollinating flowers.[32]

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."[33]

2. Stages of Maxwellian Programme

A Treatise on Electricity and Magnetism (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" (1855-56), "On Physical Lines of Force" (1861-1862) and "A Dynamical Theory of Electromagnetic Field" (1864).

The first paper (1855-56) is dedicated to elaboration of the "analogies" method founded on Kantian epistemology (see the last part for details). 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.

> I propose then, […] ; and lastly to show how by an extension of these methods, and the introduction of another idea due to Faraday, the laws of the attractions and inductive actions of magnets and currents may be clearly conceived, without making assumptions as to the **physical nature** of electricity, or adding anything to that which has been already proved by experiment.[34]

It is crucial for a Kantian that the incompressible fluid has nothing to do with experimental reality. The constraints on the theory proposed consist in the

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[31] James Maxwell, "Hermann Ludwig Ferdinand Helmholtz," *Nature*, XV (1877). Reprinted in *The Scientific Papers of James Clerk Maxwell*, vol. 2 (New York: Dover, 1952), 592.

[32] Peter Harman, *The Natural Philosophy of J.C. Maxwell* (Cambridge: Cambridge University Press, 2001).

[33] James Maxwell, "On Action at a Distance" (1873). Reprinted in *The Scientific Papers of James Clerk Maxwell*, vol. 1 (New York: Dover, 1952), 315-20.

[34] James Maxwell, " On Faraday's Lines of Force," 159.

demand that the mathematical constructs should not contradict each other. In all the other matters the physical analogies method admits an unlimited freedom of imagination. Even the conservation laws can be broken down!

Maxwell stresses the generality of the lines of force paradigm, for it can account for any kind of force. For instance, it does not exclude the force of action at a distance which varies inversely as the square of the distance, as force of gravity or as observed electric and magnetic phenomena.

> This is a significant remark which is probably intended to undermine possible objections that, in principle, the method excludes the dominant theory based on action at a distance.[35]

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 game"*[36] 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-ladenness of the observation data ("experimental laws already established, which have generally been expressed in the *language of other hypotheses*."[37] 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

[35] Hon and Goldstein, "Maxwell's Contrived Analogy," 243.

[36] Ludwig Wittgenstein, *Philosophical Investigations*, trans. G.E.M. Anscombe (London: Basil Blackwell, 1953).

[37] James Maxwell, "On Physical Lines of Force," *Philosophical Magazine,* Series 4, 21 (1861-1862), 161-175,281-291. *Philosophical Magazine*, Series 4, 23 (1861-1862), 12-24, 89-95. Reprinted in *The Scientific Papers of James Clerk Maxwell*, vol. 1 (New York: Dover, 1952), 162.

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 density ρ 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 $\mathrm{div}\,\mathbf{j} + \partial\rho/\partial t = 0$.

So, in 1861 the publication of Maxwell's second paper 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 now a role of neutral language is played not by tube hydrodynamics but by a theory of stresses in the medium where the necessary relations among the forces are described by mathematicians with the help of mathematical entities that now are called *tensors*; the most general type of a tensor describing the most general type of stress consists of a combination of three principal pressures or tensions, in direction at right angles to each other. The tensor apparatus of solid state mechanics provided the creation of new neutral language "dialect;" it enabled to calculate the force upon an element of the medium: $\mathbf{F} = \mathbf{F}_1 + \mathbf{F}_2 + \mathbf{F}_3 + \mathbf{F}_4 + \mathbf{F}_5$. The first term $\mathbf{F}_1$ refers to the force acting on magnetic poles; the second term F_2 refers to the action on bodies capable of magnetism by induction; the third F_3 and fourth F_4 terms refer to the force acting on electric currents; the fifth term F_5 refers to the effect of simple pressure that lacks an electromagnetic analogy.

But one of the most intricate problems of the vortices theory that puzzled even Daniel Bernoulli who invented it in XVIII-th century[38] 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 Nugayev's methodological language, 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. The tangential pressures thus called into play constitute electromotive force. Nevertheless,

> the conception of a particle having its motion connected with that of a vortex by perfect rolling contact may appear somewhat *awkward*. I do not bring it forward as a mode of connexion existing in nature.[39]

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

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[38] Edmund Whittaker, *A History of the Theories of Aether and Electricity: From the Age of Descartes to the Close of the Nineteenth Century* (London, New York: Longmans, Green and Co, 1910).

[39] Maxwell, "On Physical Lines of Force," 345.

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.[40]

So it was not a temporary retreat. Even after 1861 Maxwell many times introduced the notions of the Ampere-Weber atomism into his theories.[41]

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

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[40] Quoted from Darrigol, *Electrodynamics from Ampere to Einstein*, 323.

[41] Olivier Darrigol, *Electrodynamics from Ampere to Einstein*.

> 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.[42]

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.[43]

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

[42] Maxwell, "On Physical Lines of Force," 22.

[43] Morrison, *Unifying Scientific Theories*; Darrigol, *Electrodynamics from Ampere to Einstein.*

remnants and in strengthening the Lagrangian approach. In the final chapter XX, dedicated to the electromagnetic theory of light, the basic argument in defense of electromagnetic waves is posited out:

> To fill all space with a new medium whenever any new phenomena is to be examined is by no means philosophical, but if the study of two *different* branches of science has independently suggested the idea of a medium, and if the properties which must be attributed to the medium in order to account for electromagnetic phenomena are of the same kind as those we attribute to the luminiferous medium in order to account for the phenomena of light, the evidence for the physical existence of the medium will be considerably strengthened.[44]

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.[45] 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.

But let me return to Maxwell's synthetic programme. Eventually Maxwell found that his elastic vortex medium *would* propagate waves whose velocity, calculated from electromagnetic constants, was that of light. Yet he said nothing about *how* electromagnetic waves might be generated, nor did he attempt to derive the laws governing reflection and refraction. Hence the task of extracting a cogent theory from the *Treatise* and of casting it into a form in which it could

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[44] Maxwell, *A Treatise on Electricity and Magnetism*, 781.

[45] Alan Chalmers, "Maxwell, Mechanism and the Nature of Electricity," *Physics in Perspective* 3, 4 (2001): 425-38.

command general assent fell to others. Later they were called "the Maxwellians:" George Francis Fitzgerald (1851-1901), Sir Oliver Lodge (1851-1940), and Oliver Heaviside (1850-1925).

Of their advances one should mention the Bath meeting where the Maxwellians made clear that Maxwell's displacement current was not just a dispensable appendage to the theory, but its keystone: remove it, and the whole theoretical structure would collapse. Without displacement currents, electromagnetic waves could not exist.

But the most important step in consequent optics and electromagnetism unification, i.e. in electrodynamics principles extrapolation on optical phenomena was made in 1879 by Francis Fitzgerald. He first broached the possibility of combining Maxwell's theory with Mac Cullagh's. In 1839 James Mac Cullagh had devised a Hamiltonian formulation of wave optics which yielded equations describing the main optical phenomena, including reflection, refraction and double refraction. Fitzgerald, by drawing correspondences between the terms in Mac Cullagh's theory and electromagnetic terms, was able, in 1879, to translate Mac Cullagh's theory into an electromagnetic theory of light. It should be noted, however, that Mac Cullagh's theory suffered from serious mechanical difficulties, pointed out in 1862 by Gabriel Stokes. Stokes showed that Mac Cullagh's theory implied attributing elastic properties to the ether which were quite unlike those of any known substances.

The merger not only resuscitated Mac Cullagh's theory but extended Maxwell's own theory in important new directions, yielding as one of its first fruits a prize that had eluded Maxwell himself: an electromagnetic theory of the reflection and refraction of light.

In his last scientific work – in a review of George Fitzgerald's paper (1879) – Maxwell described his own treatment of the Faraday effect in 1862 paper as a "**hybrid**" one in which he had combined his electromagnetic theory of light with elements of an elastic solid theory. He had treated light waves as actual motions of the ether and had traced how these would disturb the spinning of the magnetic vortices in such a way as to cause the plane of polarization of the light to rotate. Maxwell had found this detour into a "hybrid theory," in which electrical and mechanical actions were combined, the least satisfactory part of his own explanation of the Faraday effect.[46]

And Fitzgerald's 1879 paper brought out, more clearly than before, the fundamental incompatibility between Maxwell's theory and an elastic ether. Fitzgerald had shown that Maxwell's theory was mathematically equivalent to

[46] Bruce Hunt, *The Maxwellians* (Ithaca: Cornell University Press, 2005), 18.

Mac Cullagh's, while Stokes had shown in 1862 that Mac Cullagh's theory, considered as an elastic solid theory, was untenable. The following conclusion was inescapable: if Maxwell's theory were to survive, it had to be cut loose from reliance on an elastic solid ether and given a new basis. Attempts to produce a 'hybrid' theory, such as Maxwell had pursued in his own account of the Faraday effect, had to be abandoned.[47]

Thus, in his encyclopedia on the phenomena of electricity and magnetism Maxwell sums his results up. His Copernican deeds consisted in combining arguments for electromagnetic and luminiferous ethers' identification and constructing the crossbred theory with displacement current that was capable of electromagnetism and optics unification.

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.[48]

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. Introducing a kind of "*complementarity principle*" in the XXIII chapter called "Theories of Action at a Distance," Maxwell comes to the following conclusion. We are ignorant of what is really moving between magnets and conductors, but if we decide to describe it we have no other "appropriate" images except "waves" and "particles."[49]

3. Maxwellian Electrodynamics in Germany: Helmholtz and Hertz

Due to Kantian background, Maxwell's programme development should be especially fruitful in Germany. And it was. Maxwell's efforts to find a reasonable compromise between the three research programmes (that of Young-Fresnel, Faraday and Ampere-Weber) were picked up by Maxwell's friend Hermann Helmholtz. He had sought from the middle of 1860-s to reach consensus between the major directions in electromagnetic research of the second half of the nineteenth century, namely, Newton's instantaneous action-at-a-distance concept as used by Weber, and Faraday's contact action concept. In Helmholtz's paradigm charges and currents were considered as the sources of electrical and magnetic

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[47] Hunt, *The Maxwellians.*

[48] Rinat Nugayev, "The Ptolemy-Copernicus Transition: Intertheoretic Context," *Almagest* 4, 1 (2013): 96-119.

[49] Maxwell, *A Treatise on Electricity and Magnetism*, 488.

fields. It led directly to H.A. Lorentz's dualistic picture of the field equations and the equations of motion in his 1892-1900 papers.

By the time of Helmholtz's first attempt of reconciliation (1870), the research programmes of Weber and Faraday had successfully incorporated all well-established empirical facts. Hence when trying to arrive at results similar to Maxwell's without losing the elements of action at a distance, Helmholtz assumed that the electrostatic forces are constantly present as a field in space and that the change in the polarization or the displacement of the charges signaled the change in the electrostatic field.[50] Under these assumptions, Helmholtz in his 1870 paper successfully derived generalized equations very similar to those of Maxwell and found that in a limited case they yield equations identical to Maxwell's. Yet in addition to the ordinary transverse electromagnetic waves, Helmholtz discovered the existence of longitudinal electric waves which turned to be instantaneous at the Maxwell's limit $k = 0$.

To check the consequences from his theory in 1879 Helmholtz proposed a prize competition "to establish experimentally a relation between electromagnetic action and the polarization of dielectrics" and persuaded one of his pupils who's name was Heinrich Hertz to take part.

And in 1886-1888, at Karlsruhe, Hertz attempted to establish the compatibility of the theories of Helmholtz and Maxwell in a new series of experiments. He designed his measurement procedures, taking into account Helmholtz's ingenious separation of the total electric force into the electrostatic and electrodynamic parts to which different velocities of propagation were ascribed. In his own words. According to Coulomb's law, the electrostatic component was thought to be proportional to the inverse square of the distance, whereas the electrodynamic part was only proportional to the inverse of the distance. In the usual theory of the Lienard–Wiechert potential it would correspond to decreasing rates of the bound-field, or longitudinal, component and the radiation field, or transverse component, respectively.

Hertz's experiments were carried out within Helmholtz's research programme. According to Hertz,

> Notwithstanding the greatest admiration for Maxwell's mathematical conceptions, I have not always felt quite certain of having grasped the physical significance of his statements. Hence it was not possible for me to be guided in my experiments directly by Maxwell's book. I have rather been guided by

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[50] Hermann Helmholtz, *Wissenschaftlische Abhandlungen*, vol.1 (Leipzig: J.A. Barth, 1882), 611-628.

> Helmholtz's work, *as indeed may plainly be seen from the manner in which the experiments are set forth*.[51]

Hertz had planned a series of experiments and his efforts appeared to be fruitful. Yet it should be noted that the title of his 1888 paper "On the Finite Velocity of Propagation of Electromagnetic Action" is perhaps misleading nowadays, because usual Maxwellian electrodynamics does not employ the Helmholtzian "action" terminology, nor does it split the total electric force into electrodynamic and electrostatic parts. But for Hertz's contemporaries who supported the Helmholtz theory, the underlying meaning of the presented results was clear enough: Hertz's experiments could qualitatively conclude about the finite propagation of the electromagnetic part, but could say nothing definite about the electrostatic component

According to one of modern action at a distance devotees,[52] some of Hertz's measurements tended towards the instantaneous nature of the electrostatic modes. Yet he was still not convinced of this instantaneity and preferred to be cautious.

Furthermore it was Hermann Helmholtz who convinced Berlin Academy of Science to set up a special prize for experimental confirmation of Maxwell's theory. And it was Helmholtz's pupil Heinrich Hertz who got the prize in 1888. From two possible explanations of his experiments,[53] Hertz (1889) had chosen the simplest one:

> Helmholtz distinguishes between two forms of electric force – the electromagnetic and the electrostatic – to which, until the contrary is proved by experience, two different velocities are attributed. An interpretation of the experiments from this point of view could certainly not be incorrect, but it might perhaps be *unnecessary complicated*.[54]

It seems to me that it was namely the attempt to justify the rationality of choosing the simplest explanation that appeared one of the reasons to force Heinrich Hertz after 1888 to give up his electromagnetic experiments fruitful both from heuristic and technological vistas and to devote the last three years of his life to his extremely ambitious project of classical mechanics rebuilding.

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[51] Hertz, *Electric Waves*, 20.

[52] Roman Smirnov-Rueda, "Were Hertz's 'Crucial Experiments' on Propagation of Electromagnetic Interaction Conclusive?" in *Instantaneous Action at a Distance in Modern Physics: Pro and Contra*, eds. Andrew E. Chubykalo, Viv Pope, and Roman Smirnov-Rueda (New York: Nova Science Publishers, 2001), 57-69.

[53] Smirnov-Rueda"Were Hertz's 'Crucial Experiments.'"

[54] Hertz, *Electric Waves*, 123.

In his *Principles of Mechanics* he put it clear that it is premature to attempt to base the equations of motion of the ether upon the laws of mechanics until we have obtained a perfect agreement as to what is understood by this name.[55]

It is important that the methodological principles for classical mechanics rebuilding were to be found by Hertz in Kantian epistemology; even before he met Helmholtz, Hertz had attended in Dresden a course on Kantian philosophy.

> We form for ourselves images or *symbols* of external objects […] When from our accumulated previous experience we have once succeeded in deducing images of the desired nature, we can then in a short time develop by means of them, as by means of *models*, the consequences which in the external world only arise in a comparatively long time, or as the result of our own interposition […] *The images* which we have speak of are *our* conceptions of things. With the *things themselves* they are in conformity in one important respect, namely, in satisfying the above-mentioned requirement. For our purpose it is not necessary that they should be in conformity with the things in any other respect whatever […]. The images which we may form of things are not determined without ambiguity by the requirement that the consequents of the images must be the images of the consequents. Various images of the same objects are possible, and these images may differ in various respects. We should at once denote as inadmissible all images which implicitly contradict the laws of our thought.[56]

As a result, scrupulous analysis of the simplicity criterion ends by the following conclusion:

> A doubt which makes an impression on our mind cannot be removed by calling it metaphysical; every thoughtful mind as such has needs which scientific men are accustomed to denote as metaphysical […] It is true we cannot a priori demand from nature simplicity, nor can we judge what in her opinion is simple. But with regard to images of our own creation we can lay down requirements. We are justified in deciding that if our images are well adapted to the things, the actual relations of the things must be represented by simple relations between the images.[57]

Hertz's Kantian background manifested itself not only in the epistemological scheme described. According to Jed Z. Buchwald,[58] already in 1884 Hertz had proposed a version of Maxwell's equations that was free of the ether notion completely.

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[55] Heinrich Hertz, *The Principles of Mechanics Presented in a New Form*, trans. D.E. Jones (London: Macmillan, 1899), XXI.

[56] Hertz, *The Principles of Mechanics*, 1.

[57] Hertz, *The Principles of Mechanics*, 23.

[58] Buchwald, *The Creation of Scientific Effects*, 278.

And, what is more important, quite unlikely Maxwellian field theory, in Hertz's theoretical scheme the source continued to exist as an entity in and of itself. In Hertz's diagram the material object remains unknown, whereas the inferred field is known. This diagrammatic inversion encapsulates the originality of Hertz's physics. It was because Hertz ignored the physical character of the object that produced his radiation – because he boxed it in with a mental quarantine against asking questions against it – he was able to make progress.[59]

Being a pupil of Helmholtz, Hertz learned to watch for novel interactions between laboratory objects without worrying overmuch about the hidden processes that account for the object's effect-producing power.

Thus the nature of electromagnetic waves appeared to Hertz as a kind of "thing in itself" that admits a variety of interpretations. Researcher chooses the version that is the simplest one to work with. The most important thing is the equations depicting the relations between the objects under investigation.

[59] Buchwald, *The Creation of Scientific Effects*, 272.