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University of Sussex
Brighton

J. GIEDYMIN

A Note on the Forgotten Logic of Hertz's 1888 Experiments and the Problem of the Comparability of Theories

Uwagi o zapomnianej logice doświadczeń Hertza z 1888 roku a problem porównywalności teorii

Замечание о забытой логике экспериментов Герца от 1888 года и проблема сравнимости теории

The empiricist tradition in philosophy, historiography and the teaching of physics has always favoured the interpretation of the famous 1888 Hertz experiments as an <u>experimentum crucis</u> which ultimately decided for the acceptance of Maxwell's theory of the electromagnetic field and against the earlier, Continental theory based on the assumption of <u>actio distans</u> either combined with the hypothesis of the atomic structure of electricity (Weber) or in a purely phenomenalistic form (Neumann). According to this traditional empiricist interpretation, Hertz's experiments verified one of the predictions derived by Maxwell from his theory, viz. that electromagnetic actions were propagated in wave-form with finite velocity (equal to that of light). No such prediction was derivable from the Continental theory based on <u>actio distans</u>. The historical importance of Hertz's experiments was enhanced by the fact that the result they verified constituted an important step in the direction of Special Relativity which rules out any distant actions and implies that the velocity of light is the limiting velocity.

Although this account is basically correct, nevertheless - as recent historical research has shown - the logic of Hertz's experiments was much more complicated and this seems to have an important bearing on some of the problems debated in the philosophy of science in the last twenty years, in particular on the problems of conceptual (in)commensurability and rational choice between scientific theories.

In the first place, as we know from Hertz's own report [1], he did not rely directly on Maxwell's theory of the electromagnetic field which - together with other Continental physicists - he regarded as conceptually obscure and incomprehensible (for this reason he was later to produce his own formulation of Maxwell's equations - equivalent to Heaviside's - used in today's textbooks). Instead he relied on Helmholtz's 1870 "dielectric polarisation" theory [2] which was a generalisation of Neumann's potential theory and which was designed to reduce - in a sense - all existing electromagnetic theories, including those of Weber, Neumann and Maxwell, as special cases: in Helmholtz's formula for the electromagnetic potential there occurs a parameter k such that for k = -1 one should obtain Weber's law, for k = 1 Neumann's law and for k = 0 Maxwell's theory. But in accordance with the Continental tradition and in oppposition to the views of the Cambridge School of Faraday and Maxwell, Helmholtz's theory was based on the assumption of actio distans. Features peculiar to the Faraday-Maxwell theory, such as the propagation of electromagnetic actions in wave form with finite velocity, are obtained within Helmholtz's theory (for the case when k = 0) on the basis of the idea of polarisation derived from the earlier Poisson theory of magnetic induction and generalised to dielectrics (including the ether). Strictly speaking, therefore, the 1888 Hertz's experiments - as an experimentum crucis - decided in favour of the Maxwellian case within Helmholtz's theory, Helmholtz's-theory (k = 0) for short, and against some other cases within Helmholtz's theory. But what - if any - is the logical relation between Helmholtz-s theory (k = 0) and the Faraday-Maxwell theory of the electromagnetic field? After all, it was not Helmholtz's-theory (k = 0) but the Faraday-Maxwell theory which was accepted on the basis of Hertz's experiments.

Maxwell, who in his Treatise [3] refers to Helmholtz's (1870) "powerful memoir" in connection with the criticisms of the theories of Weber and Neumann, did not raise any objections - whether of logico-mathematical of physical nature - to the Helmholtzian reduction of his theory, i.e.with respect to Helmholtz's-theory (k = 0). His main objection to the Continental theories by which, however, Helmholtz's-theory (k = 0) was unaffected, was that they did not explain where the potential energy - or whatever is propagated in the case of electromagnetic actions - was located when it left one body and before it reached another. To explain this, Maxwell wrote, one needed the ether assumption and, if so, this assumption "ought to occupy a prominent place in our investigations" [4].

However, others after Maxwell have criticised Helmholtz's reduction. So, for example, L.Rosenfeld [5] argued that although Maxwell's formulae are derivable from $H(k = 0)$, nevertheless the latter completely "spoils the subtle harmony of Maxwell's conceptions":in other words, Helmholtz's-theory $(k = 0)$ and the Faraday-Maxwell theory, though perhaps mathematically equivalent, were conceptually disparate. Others, for example, J.Z. Buchwald [6] , went further and argued that not even the mathematics of the Faraday-Maxwell theory is rigorously derivable from Helmholtz's-theory $(k = 0)$. A similar claim had already been made by J.J.Thomson [7]. If these criticisms are correct and if neither the equivalence relation nor one-sided derivability holds between Helmholtz's-theory $(k = 0)$ and the Faraday-Maxwell theory, then what is the logic of Hertz's 1888 experiments and by what logic could their result have affected the acceptance of the Faraday-Maxwell theory?

In response to these questions the following account of the logic and pragmatics of Hertz's experiments is offered here:

(a) Helmholtz's-theory $(k = 0)$ and the Faraday-Maxwell theory are not equivalent nor is one derivable from the other; a weaker relationship holds between these theories, viz. they are similar with respect to their mathematical structure in at least the sense that the wave equation for transverse vibrations is derivable from either and that each of these theories is compatible with certain more general assumptions, such as the principle of energy conservation. The latter, discovered between 1842 and 1847 independently by Mayer, Joule, Colding and Helmholtz, played an important role in the theoretical disputes between proponents of rival electromagnetic theories. For example, one of the reasons why Maxwell opted for Faraday's electromagnetic views in preference to the Continental theory was the proof, given by Helmholtz in 1847 and subsequently shown to have been at fault, that Weber's theory violated the energy conservation principle [8]. Similarly, when Weber argued that his theory had the advantage of implying the induction law, Maxwell replied that any theory - strong enough to yield the Ampère law - would yield, if conjoined with the energy conservation law, the law of induction [9].

(b) All theories reduced by Helmholtz's 1870 theory had a common experimental basis at least in the pragmatic sense that - according to general consensus - each of them was able to save the electromagnetic phenomena known at the time, in particular such results as Oersted's 1820 experiment and the empirical laws such as the laws of Coulomb, Ampère and the Faraday induction law (formulated by Neumann in terms of potentials). In fact, before 1870 all the rival theories reduced by Helmholtz's theory were regarded as observationally equivalent [10]. One of the main aims of Helmholtz was to find a difference between them which would be susceptible to experimental discrimination. Helmholtz's theory in the Maxwellian case was based on three hypotheses, viz. that a changing dielectric polarisation creates the same electromagnetic forces that would be created by an equivalent conduction current; that electromagnetic forces can produce dielectric polarisation and that the vacuum is a dielectric; these three hypotheses implied finite propagation of electric action and the existence of electromagnetic waves in air [11]. The same predictions had been derived by Maxwell from the Faraday-Maxwell theory. There was, therefore, agreement at least concerning the following points on which Hertz's experiments concentrated:whatever electromagnetic actions are, they are propagated with finite velocity through space and they exhibit wave properties such as diffraction, interference, etc.

(c) At the time of Hertz's experiments in 1888 it was thought that waves required a material medium. Hence, the conclusion seemed inevitable that Hertz's experiments proved the existence of the electromagnetic ether postulated in Maxwell's theory [12]. Maxwell himself had been for a time ambivalent with respect to the realist or instrumentalist interpretation of the ether assumption but seems to have ultimately opted for the realist one. In his Treatise (1873) he writes of the "prejudice" or "a priori objection against the hypothesis of a medium"[13].among Continental physicists and mathematicians such as Gauss, Riemann, Neumann, etc. It is this "a priori objection" which seems to have been removed by Hertz's experiments. Had etherless electromagnetic theories such as that of Ludwig Lorenz (1867) been better and more widely known at the time, it is possible that the use of retarded potentials rather than the ether hypothesis understood in a realist fashion would have been seen as preferable [14]. Another step towards Special Relativity would have been made.

(d) The fact that in his experiments Hertz relied on Helmholtz's-theory ($k = 0$) rather than directly on the Faraday-Maxwell theory came to be seen - after 1888 - as part of his private "situational logic", which changed soon when Hertz also accepted the Faraday-Maxwell interpretation. The consequences of Helmholtz's-theory ($k = 0$) relevant to the experiment were common to many theories, either widely known at the time or not (e.g. Lorenz's). One of the advantages of Maxwell's approach was the electromagnetic theory of light and, hence, the reduction of optics to electromagnetism.

(e) The development of electromagnetism in the 19th Century within the general framework of Newtonian physics, the role played in it by the two rival schools - the British and the Continental - and, finally, the role of Hertz's 1888 experiments in the acceptance of Maxwell's theory through the mediation of Helmholtz's 1870 theory, constitute a fascinating object for historical and philosophical reflection. Although different interpretations are always possible, nevertheless it seems plausible to argue that there is no evidence here in support of the claim (Kuhn 1962) that important theoretical changes in physics consist in the replacement of old theories by new ones in a process that is more akin to religious conversion than to decision-making based on rational argument and experiments. On the contrary, there is plenty of evidence to show that in spite of serious conceptual and doctrinal disparity between the two rival schools, their representatives managed to exchange experimental findings and used rational arguments - based on shared assumptions such as energy conservation - in criticising and evaluating each other's theoretical position. The decisive step towards the resolution of the disagreement between the two schools, i.e. towards the acceptance of Maxwell's theory, was made by a leading representative of the Continental school, Hermann v.Helmholtz who not only provided his colleagues with a unifying theoretical framework to facilitate intertheoretic comparison from their point of view, but also persuaded his gifted student, Heinrich Hertz, to design and carry out relevant experiments. The fact that Helmholtz's mediating theory was needed at all and that the Maxwellian case (for $k = 0$ and the ether assumption) within it was regarded by later maxwellians as a conceptual distortion of Maxwell's original theory, indicate conceptual disparity or incommensurability. However, the latter did not result in misunderstanding and breakdown of communication. Similarity between the mathematics of Maxwell's original theory and the Maxwellian case within Helmholtz's theory (the derivability of the wave equation from either theory) allowed the latter to be used vicariously in place of the former as the basis of Hertz's experiments while consensus on relevant experimental results was sufficient for rational comparison of rival theories and the verdict in favour of Maxwell.

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STRESZCZENIE

W artykule pokazujemy, że w przeciwieństwie do tradycyjnych interpelacji książkowych, eksperyment Hertza z 1888 roku nie był testem teorii Maxwella. Opierał się on bowiem na teorii polaryzacji dielektrycznej Helmholtza z 1870 roku, która obejmowała jako przypadki szczególne wszystkie, rywalizujące między sobą w tym czasie teorie elektromagnetyczne. Głęboka sprzeczność między teorią Helmholtza a teorią Maxwella wypływała z faktu, że teoria kontynentalna zakładała oddziaływanie na odległość, podczas gdy teoria Faradaya-Maxwella przyjmowała oddziaływanie lokalne. Z logicznego punktu widzenia w eksperymencie podlegała więc konfirmacji teoria Helmholtza.

W tekście podkreśla się, że obie konkurencyjne teorie były nie tylko pojęciowo niewspółmierne, ale także kwestionowano możliwość wyprowadzenia formuł Maxwella z teorii Helmholtza. Na powstające pytanie, jak zatem można zaakceptować eksperyment Hertza jako test teorii Maxwella można zaproponować następującą odpowiedź. Obie teorie opisywały tę samą dziedzinę zjawisk, a więc były obserwacyjnie równoważne. Były też formalnie podobne, przynajmniej w sensie, że z obu wynikły równania falowe i obie nie łamały prawa zachowania energii. W efekcie można obie teorie uznać za porównywalne. Pytanie czy są one lepiej zrekonstruowane jako pojęciowo współmierne nie podlega empirycznej ocenie ani nie może być rozstrzygnięte w oparciu o argumenty historyczne.

Р Е З Ю М Е

В работе доказывается, что вопреки распространенной в учебниках интерпретации, эксперимент Герца от 1888 года не являлся тестом теории Максвелла. Эксперимент этот базировался на теории диэлектрической поляризации Гельмгольца от 1870 года, которая включала, как частные случаи, все тогда конкурирующие между собой электромагнитные теории. Глубокое противоречие между теориями Гельмгольца и Максвелла вытекало из того, что континентальная теория принимала дальнедействующие взаимодействия, в то время как теории Фарадая-Максвелла базировалась на локальном взаимодействии. С точки зрения логики в эксперименте проверке подвергалась теория Гельмгольца.

В статье подчеркивается, что обе конкурирующие теории были не только несовместными с точки зрения использовавшихся понятий, но даже опровергалась возможность вывода формул Максвелла из теории Гельмгольца. На вопрос, как тогда эксперимент Герца считать тестом теории Максвелла, можно предложить следующий ответ. Обе теории описывали ту самую область явлений, и тогда были равноценными с экспериментальной точки зрения. Они были тоже формально похожими - по крайней мере в том смысле, что из обоих вытекали волновые уравнения и обе не нарушали закона сохранения энергии. В результате обе эти теории можно считать совместными. Вопрос: лучше ли реконструированы они как логически равноценные,не подлежит эмпирической проверке и не может быть решен на базе исторических аргументов.