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To what Extent did Lorentz Predict the Existence of the Electron

1. Introduction

In his monumental article "The Historical Structure of Scientific Discovery", T.S. Kuhn (1962) pointed out as follows:[1]

> Many scientific discoveries, particularly the most interesting and important, are not the sort of event about which the questions "Where?" and, more particularly, "When?" can appropriately be asked. Even if all the conceivable data were at hand, those questions would not regularly possess answers.

The troublesome class consists of those discoveries – including oxygen, the electric current, X rays, and the electron – which could not be predicted from accepted theory in advance and which therefore caught the assembled profession by surprise.

The present paper concerns the last part of the above quotation, I mean, the problem whether the discovery of the electron "could not be predicted by accepted theory in advance". This problem seems the more interesting because Kuhn pointed out also that there is the second class of discoveries. As for the latter case, Kuhn said,[2]

> Into this second class of discoveries fall the neutrino, radio wave, and the elements which filled empty places in the periodic table. The existence of all these objects had been predicted from theory before they were discovered, and the men who made the discoveries therefore knew from the start what to look for.

The analysis of the discovery of the electron regarded, in accordance with Kuhn, as one among the first class of discoveries has recently been made by T. Arabatzis (1996) in his article "Rethinking the 'Discovery' of the Electron". He put forth, as a criterion of the discovery, the "historicist approach" which regards, as the essential aspect of scientific discovery, "consensus formation" in the scientific community.

[1] KUHN (1962).
[2] *Ibid.*, pp. 166-7.

Upon this view, he criticized the usual attribution of the merits of the discovery to J.J. Thomson, and stated instead as follows:[3]

> The electron was not the product of a sudden discovery. Rather, it emerged out of several problem situations in the study of chemical phenomena (electrolysis), in the context of electromagnetic theory, and in the study of the discharge of electricity in gases. By 1900 those diverse situations had found a single solution in the form of the electron qua sub-atomic, charged particle. Several historical actors provided the theoretical reasons and the experimental evidence. However, none of these people discovered the electron.

I almost agree with him, except for the last sentence; “none of these people discovered the electron”. In my view, the discovery of electron was not an isolated single event, but consisted of a series of discoveries by individual scientists. In other words, it takes a long while after the discoveries by individual scientists, before the scientific community at large comes to reach consensus with regard to the existence of the object. The point of departure from Arabatzis is the problem that I posed at the start. I mean, the problem whether the discovery of the electron had not been predicted from theory in advance, particularly the question concerning the role played by H.A. Lorentz and other electron theorists.

It should be noted here that, as is well known, the person who made the first determination of *e/m* value was not J. J. Thomson but P. Zeeman. Zeeman determined it, by way of Lorentz’s theory, prior by a half year to Thomson. As for this matter, Arabatzis claimed that Lorentz’s ‘ions’ were assumed to be identical with the ions of electrolysis and that they were transformed into ‘electrons’ only as a result of Zeeman’s discovery.[4] On the other hand, N. Robotti and F. Pastorino (1998) stated that the mass and charge of the ions, in Lorentz’s theory, were free parameters and that the theory neither gave them a value, nor indicated a method for determining them.[5] I will discuss this point more closely in the next section.

My viewpoint with regard to this matter derives from a portion of P. Ehrenfest’s address of 1923 entitled “Professor H.A. Lorentz as Researcher”. In it, Ehrenfest stated as follows:[6]

> A twofold line of communication runs between Lorentz’s work and the tracking down of the Zeeman effect.
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> […]
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> First: as early as 1883, somewhat in connection with his dissertation, Lorentz had established a connection between two effects of the magnetic field, an electrical effect (the Hall effect) and an optical effect (the Kerr effect). And when Kammerling Onnes organized his laboratory he concentrated the work of his students into two groups, the one devoted to the molecular theories of Van der Waals, and the other broadly speaking to circle of ideas

[3] ARABATZIS (1996).
[4] *Ibid.*, p. 422.
[5] ROBOTTI and PASTORINO (1998).
[6] EHRENFEST (1923).

> in Lorentz's work. Young Zeeman's researches belong to this magneto-optical group and crown them with the discovery of the Zeeman effect.
> […]
> Second: only an electric force acts on an electron at rest, but a moving electron is also acted on by the magnetic field. This second force naturally played a major part in Lorentz's theory of electrical phenomena (1892, 1895); (students of physics and electrical engineering call this the "Lorentz force" everywhere in the world outside of Leiden). It is this same force which in 1896 acted on the "vibrating" electron in the sodium flame as soon as Zeeman turned on the magnetic field.

Thus, we can see that Zeeman's discovery, which resulted in the first determination of the charge to mass ratio of the electron, was intimately connected with the works by Lorentz.

2. Lorentz's View on His Charged Particles

In his dissertation of 1875, Lorentz developed further the electromagnetic theories of light by J.C. Maxwell and by H. von Helmholtz, and explained the reflection and refraction of light from that viewpoint. It was in his 1878 paper sequel to his dissertation, that Lorentz first introduced his charged particles. There, he tried to explain also the dispersion of light from that viewpoint. After the description of several unsuccessful attempts, he stated as follows:[7]

> If we accept the electromagnetic theory of light, there is nothing left, in my opinion, but to look for the cause of dispersion in the molecules of the medium themselves. And we can indeed obtain formulae from which a dispersion follows if we adopt the supposition that, in such a molecule, as soon as an electric moment is excited, a certain mass is at the same time brought into motion.

Let us imagine, for this purpose, certain particles in the molecule provided with free electricity and mutually transferable by an external electromagnetic force.

We can see from the above that he introduced his charged particles as necessary ingredients of a molecule indispensable to explaining the dispersion of light.
The natural question here arises as to whether his charged particles were atoms (or "ions" in up-to-date meaning) themselves or their components. An answer to this question is found in the final part of that paper. Lorentz (1878) stated there:[8]

> If it should appear in this way that the refractive index of these compounds can be calculated in the same manner as it can be in a mixture, we should be able to explain this by assuming an electric moment can be excited in every atom of a chemical compound.

Therefore, as he later asserted,[9] his charged particle is placed, together with whatever it is bound to, within a single atom; hence, it is smaller than the atom.

[7] LORENTZ (1878).
[8] *Ibid.,* p. 118.

During 1880's, Lorentz made two further steps forward. In 1886, he compared and examined theoretically the views of Fresnel's stationary ether and Stoke's dragged ether, and stood firmly on the former view.[10] Moreover, owing to the discovery of electric waves by Hertz in 1888, he changed his view on the electromagnetic interaction from action-at-a-distance to a contiguous one.[11] Thus, he formulated his theory, later called "Lorentz's electron theory", in his 1892 article, where "the Lorentz force" mentioned by Ehrenfest was derived for the first time.[12]

In this 1892 article, his charged particles came to play the decisive role. In his stationary ether view, matter was perfectly transparent to the ether, therefore the ponderable matter and the ether were entirely independent of each other mechanically. Yet, in electromagnetic phenomena there were apparently interactions between them. It was "in order to surmount this difficulty", that he reintroduced his charged particles.[13] Lorentz (1892) said:[14]

> It will be sufficient, in these applications, to admit that all ponderable bodies contain a multitude of small particles bearing positive or negative charges, and that the electric phenomena are produced by the displacement of these particles.

Utilizing these charged particles, he treated also the propagation of electromagnetic waves in a material medium. Taking into consideration the secondary electromagnetic waves emitted by induced oscillations of electric dipoles, he could deduce the light velocity in the material medium. Moreover, he extended this method further to the case of moving material media, and obtained the so-called Fresnel's drag coefficient without the picture of the dragged ether.

As we have seen, if we put the electromagnetic field in place of the ether in his theory, his charged particles play just the same role as that played by the electrons in our present-day theory of optics. Thus, his charged particles in many respects share the physical properties of the electrons. The fact that Lorentz regarded their introduction as indispensable to his theory testifies that he was in some way or other predicting the existence of something like electrons, i.e. subatomic charged particles. Although in the next monograph of 1895 he named his charged particles as "ions",[15] it was only because he wanted to justify their introduction by adducing the example of electrolysis. As Robotti and Pastorino (1998) stated, Lorentz never mentioned explicitly that his charged particle had the same value of charge or mass as the ion of electrolysis. This fact is also acknowledged by Arabatzis (1992) himself.[16]

[9] LORENTZ (1902).
[10] LORENTZ (1886).
[11] LORENTZ (1891).
[12] LORENTZ (1892).
[13] HIROSIGE (1969).
[14] LORENTZ (1892), p. 228. The English translation is adopted from HIROSIGE (1969), p. 198.
[15] LORENTZ (1895).
[16] ARABATZIS (1992).

3. Discovery of the Electron

Then, is it justified if we say that Lorentz predicted the existence of the electron? I would say "yes" under the condition that the question concerns the "existence" of the particles playing the same role as that played by the electrons in our present-day theory of optics. But, the interesting problem here is, rather, whether the discovery of the electron belonged to the second class of discoveries in Kuhn's categorization. That is, whether the men who discovered them *knew* from the start what to look for, and whether the electrons were predicted by the *accepted* theory in advance. Let us inspect the cases of Zeeman and Thomson for that matter.

As pointed out by Ehrenfest, Zeeman belonged, in the University of Leiden, to the research group of magneto-optical phenomena devoted to Lorentz's theory. In that group, Zeeman was engaged in the Kerr magneto-optical studies, that is, he was inspecting the change in a light caused by its reflection from a pole-surface of a magnet. In fact, Zeeman (1897) started his paper reporting his famous discovery:[17]

> Several years ago, in the course of my measurements concerning the Kerr phenomenon, it occurred to me whether the light of a flame if submitted to the action of magnetism would perhaps undergo any change.

Continuity from his study of the Kerr effect to that of the Zeeman effect is obvious: the only difference between the two effects lies in whether it is in the process of reflection or of emission that a change in a light is exerted by the magnetic influence. As for Lorentz's theory, Zeeman (1897) wrote:[18]

> A real explanation of the magnetic change of the period [of revolution of the charged particle] seemed to me to follow from Prof. Lorentz's theory. In this theory […].

After some explanations of Lorentz's theory, Zeeman continued as follows:[19]

> Prof. Lorentz, to whom I communicated these considerations, at once kindly informed me of the manner in which, according to his theory, the motion of an ion in a magnetic field is to be calculated. The amount of widening [of the spectrum of the emitted light] then be used to determine the ratio between charge to mass, to be attributed in this theory to a particle giving out the vibration of light.

The method of calculation Lorentz taught to Zeeman was nothing but that utilizing the "Lorentz force" as emphasized by Ehrenfest.

The above quotations from Zeeman indicate that what Zeeman was seeking is not the electron but merely the consequence of magnetic effect exerted on a light source.

His only purpose in utilizing Lorentz's theory was to explain and justify his experimental results. Therefore, the very man who knew from the start what to look for is not Zeeman but Lorentz himself. And, this point should have been to do with the

[17] ZEEMAN (1897).
[18] *Ibid.,* p. 231.
[19] *Ibid.,* p. 232.

final purpose of the research group of magneto-optics devoted to Lorentz's theory. Therefore, if the existence of the electron was first confirmed and discovered by Zeeman's experiment, the merits of the discovery should be attributed more heavily to Lorentz than to Zeeman.

For its corroboration, one more thing should be pointed out here. That is, the person who first determined the values of electron mass and charge separately was not Thomson but Lorentz himself.[20] He accomplished this in his 1898 article entitled "Optical Phenomena Connected with the Charge and Mass of the Ions". By the application of his theory of dispersion to observed refractive indices of hydrogen, he obtained the value of e^2/m and combined this with that of e/m from Zeeman's experiment. Thus, Lorentz (1898) wrote:[21]

> This result shows clearly that the light ion is only a small part of the hydrogen molecule. If M'is the mass of a hydrogen atom, we should have m/M' = 1/350.
> […]
> It is interesting to compare this value [of e/M'] with a result which one can derive from the electrochemical equivalent of Hydrogen.
> […]
> So that the charge of a light ion and that of a hydrogen ion in an electrolyte appear to be of the same order of magnitude.

As for the case of Thomson, I gave a talk, at the International Congress of History of Science held at Liège in July 1997, concerning the relationship between Thomson's discovery and the electron theories of Lorentz and Larmor. As I pointed out there, it was not until his delivery of the "Presidential Address" to BAAS in September 1896 that Thomson set out for the experiments on the cathode-rays vigorously assisted by his research students.

In that address, Thomson (1896) took up recently discovered X-rays. He explained the absence of refraction in the case of X-rays stating:[22]

> The theory of dispersion of light shows that there will be no bending [of light] when the frequency of vibration is very great.

The reference to "the theory of dispersion of light" suggests his great concern with contemporary electron-theories. Thus, identifying X-ray as a kind of light with extremely short wavelength, he made a remarkable statement as follows:[23]

> On the electromagnetic theory of light we might expect two different types of vibration if we suppose that atoms in the molecule of the vibrating substance carried electrical charges. One set of vibrations would be due to the oscillations of the bodies carrying the charges, the other set to the oscillations of the charges on these bodies. The wave-length of the second

[20] See e.g. *op. cit*., 9, p. 24, or *op. cit*. 5, pp. 181-2.
[21] LORENTZ (1898).
[22] THOMSON (1896).
[23] *Ibid.*, p. 704.

> set of vibrations would be commensurate with molecular dimensions; can these vibrations be the Röntgen rays?

It is clear from the above that he looked upon the charges carried by an atom as its constituent elements. Thus, we can infer that he had already conceived the ideaof subatomic charged particles at the time of this "Presidential Address" in order to explain the generation of X-rays.

In the above statement, "the electromagnetic theory of light" should be regarded as the electron theories of Larmor and Lorentz or as their predecessor Helmholtz's theory. As I have already stated, Lorentz's electromagnetic theory of light has its roots in Helmholtz's theory. What is more, there is evidence that show Lorentz's influence on Larmor,[24] and Thomson's familiarity with the latter's theory.[25] Thus, we can find here the evidence of intimate relationship between the electron theories and Thomson's conception of "corpuscles".

It was only seven months after this address that he made his famous discourse at the Royal Institution entitled "Cathode Rays". As an introduction to it, showing the continuity of his concern from the last address, Thomson (1897) expressed his motivation for the research as follows:[26]

> Recently a great renewal of interest in these [cathode] rays has taken place, owing to the remarkable properties possessed by an offspring of theirs, for the cathode rays are parents of the Röntgen rays.

The reported results of the behavior of cathode rays in a magnetic field just coincided with those predicted for the negatively charged particles by the "Lorentz force." Then, he introduced "corpuscles" as negatively charged very small particles constituting the atoms of elements. Thus, we see that his "corpuscles" were introduced as a natural extension of "the charges on atoms" stated in the "Presidential Address". The discourse ended with reference to Zeeman's experiment.

The reason Thomson did not utilized the name 'electron' is stated in his 1899 paper that he interpreted the term "electrons" as "charges without matter", and that, in order for his "corpuscles" to constitute atoms, they should have their own masses constituting those of atoms.[27]

4. Discussion

Then, what is the answer to the question posed before: whether the men who discovered them *knew* from the start what to look for and whether the electrons were

[24] The letter from Larmor to Lodge, 29 May 1895, quoted in Warwick, A., "On the Role of Fitzgerald-Lorentz Contraction Hypothesis in the Development of Joseph Larmor's Electronic Theory of Matter", AHES, 43 (1991), pp. 29-91, on 56.

[25] Thomson was the referee for Larmor's papers on his electron theory, see e.g. J.Z. BUCHWALD: From Maxwell to Microphysics, Chicago: University Chicago Press, 1985, p. 162.

[26] THOMSON (1897).

[27] THOMSON (1899).

predicted by the *accepted* theory in advance? As for the former question, the answer is clearly "yes". As I have already stated, Lorentz knew from the start what to look for, that is, subatomic charged particles albeit without the knowledge of the values of their charge or mass. As for the case of Thomson, after his "Presidential Address", he did know what to look for. He was searching, in the cathode rays, subatomic negatively charged particles that brought forth the X-rays.

The problem, here, is the latter question. Some ambiguities are left concerning the *acceptance* of the contemporary electron theories by the scientific community. What is certain is that, as was clarified by Lorentz and others, in order to explain several phenomena, including the dispersion of light, magneto-optical phenomena, and the emission of X-rays, electron theories were indispensable at that time. And, therefore, those who made the discoveries certainly did accept these electron theories. But, it takes a long while for a physical theory to be accepted by the contemporary scientific community at large. The actuality seems rather that the electron discoveries themselves convinced the scientific community to accept the electron theories. In other words, the discoveries played the role of the "justification" of the electron theories.

Therefore, the case of the discovery of the electron should be regarded as standing just at the middle point between the first and the second class of discoveries in Kuhn's categorization. Then, the discovery of the electron was, like many other discoveries, not an isolated single event, but has its own spatial and temporal extension, in which Lorentz was standing at the starting point.

As we have seen, there are ample reasons supporting the opinion of Leiden physicists that Lorentz was the "discoverer" of the electron, as reported by N.J. Nersessian (1986) who heard it from H.B.G. Casimir.[28] Nevertheless, for this matter, I am somehow inclined to Arabatzis' opinion that this view is also subject to the same problems as the attribution of the electron's discovery solely to Thomson.[29] Yet, in my opinion, Lorentz's contribution to the discovery should not be estimated less than that of Thomson. Thus, I dare say that Lorentz was the most distinguished character among the discoverers of the electron.

Therefore, the discovery of the electron should be regarded as a cumulative process of the discoveries by individual scientists. Around 1900, the European scientific community reached consensus with regard to the existence of the electron, and, at the same time, "Lorentz's electron theory" became accepted.[30]

[28] NERSESSIAN (1986).
[29] ARABATZIS (1996), p. 424.
[30] The delay in the acceptance of Lorentz's theory should be related to his isolation from the two mainstreams of the research tradition at that time; the Cavendish school and the Helmholtzian school.

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