The Man Who Shed Light on Electrons

The Story of Lorentz's Theory of Electrons

Neeraj Nandan Akella

(November 2025)

"Thoroughly conscious ignorance is the prelude to every real advance in science."

- James Clarks Maxwell

***

The idea of electrons is often attributed to J. J. Thomson due to his discovery of cathode rays in 1897. However, before any empirical evidence of electrons was found, it was Lorentz who produced a theory on electrons, making the idea accessible.

Hendrik Antoon Lorentz, a theoretical physicist in the 19th and 20th centuries, is mostly recognized for his work in formulating the equation of force from electric and magnetic fields as well as his equations relating space and time. Both works have proven to be highly insightful in the fields of electromagnetism and special relativity. However, his most significant contribution to physics might be his theory of electrons, which was able to explain various optical phenomena and even a quantum phenomenon known as the *Zeeman effect*.

Lorentz was drawn to science from an early age, on the other hand, he was also extremely quick at picking up new languages. This ability benefitted him when he worked on his dissertation from his home. During this time, he bought Fresnel's work, and soon began to admire him above any other physical scientist, due to the great sense of intuition he possessed, overcoming any shortcomings his mathematical ability had. Lorentz later borrowed Maxwell's work, where once again his linguistic proficiency helped.

Eventually he received his doctorate in 1875, with his dissertation based on the theory of reflection and refraction of light. Inspired by Fresnel's work, he chose to interpret them instead from the formalisms constructed by Maxwell and Helmholtz. While he contemplated whether to pursue theoretical or experimental physics, the University of Leiden offered him a chair for theoretical physics, which he accepted. This cemented his publications of the electron theory starting from 1892 and soon his work opened a new avenue of experimental and theoretical directions for physicists.

It is important to note that the idea of a base unit of charge was not *unique* to Lorentz's theory. By 1870s, the leading theory in electromagnetism, developed by Weber, considered an electric current to be consisting of two oppositely charged fluids, made of particles, moving in opposite directions. The attraction between electric particles was compared to gravitational force, acting *instantaneously at a distance*.

While this theory could explain all electric and magnetic phenomena, various developments were made to include retarded potentials (motivated by the similarity of speed of light and the ratio of electric and magnetic permittivity), and even considering only a single moving charged fluid (a modification made by Clausius). Therefore, there were a myriad of candidates to a definite electromagnetic theory, where some assumed either one or two electric fluids, some assumed action at a distance, and some assumed the presence of an ether. The bigger challenge was a theory which would also explain *all* optical phenomena under one framework. The closest one has come to such kind of a theory was Maxwell.

In 1850s and 1860s, Maxwell published several papers, eventually outlining a mathematical theory to explain electricity and magnetism in his treatise. In his work, he assumes the idea of ether, occupying vacuum and even the empty space between matter. While Maxwell constructed his equations based on the assumption of magnetic vortices and electric particles, he abandoned this idea to explain electromagnetic phenomena purely as a *mechanical state* of the ether. His theory also rejects action at a distance, primarily focusing on how the transverse vibrations of ether produce propagations at the speed of light.

With this set of ideas, Maxwell explored the optical phenomena predicted by his theory, to explain the origin of light through electricity, propagation of light in crystals, and more. Yet his theory still could not explain reflection and refraction of light, considered to be a failure of even its predecessor; the elastic-solid optical theories. Yet, for all its merits, Maxwell's Treatise often caused confusion among readers. He claimed, "While admitting electricity, as we have now done, to the rank of a physical quantity, we must not too hastily assume that it is, or is not, a *substance*, or that it is, or is not, a form of *energy*, or that it belongs to any known category of physical quantities" yet most found that the omission of a unit of charge made his idea of electricity vague.

The bridge between Maxwell's ideas and physicists was constructed by Helmholtz, who found that by assuming action at a distance, the electric displacement in a dielectric follows the same wave equations described by the elastic-solid theory. This shows that the vibration of ether could equally be explained by Maxwell's set of hypotheses or action at a distance and particulate electric fluids. This formalism helped make the Treatise of Electricity and Magnetism accessible to physicists, and Lorentz too followed the route paved Helmholtz even after reading Maxwell's work. Using this approach, Lorentz reproduced Helmholtz derivation for the wave equation, and formed an equation for Fresnel's work on light reflected at a dielectric's interface as his dissertation. His paper also showed how the electromagnetic theory of light more elegantly describes the same behaviour predicted by elastic-solid theory.

Hence, Maxwell's electromagnetic theory of light was preferred more than its predecessor. While being one of the first theories of optics with electromagnetism, Lorentz's work also helped separate the roles of the luminiferous ether and matter. In 1878, Lorentz produced another paper on matter, explaining the dispersion of light, where he further developed this distinction. In his paper, he uses the idea of charged harmonic oscillators present in the particles of the material, which highlights how an incident light causes the charges in the dielectric to vibrate, causing secondary waves which interfere with it.

The result of this effect is that the velocity of propagation of light in a medium is dependent on its frequency. He produced an equation of this relation by adding corrections to the Lorentz–Lorenz formula (independently developed by Lorenz in 1869):

$$\frac{n^2+2}{n^2-1} = \frac{A - \frac{B}{\lambda^2}}{\frac{C}{\lambda^2} - D}$$

Where n is the refractive index of the medium and λ is the wavelength of light.

This paper was the first one to establish the idea of *electrons*; a charged harmonic oscillator, in Lorentz's work, foreshadowing his future expeditions. This and Lorentz's subsequent paper in 1886 also worked towards showing that the electromagnetic field and ether are separate entities, independent of matter. In his following work from the 1890s, Lorentz assumed that the ether is stationary, unlike popular theories such as Hertz's which assumed an *ether drag*. Using this and his postulated behaviour of electrons, he was able to derive the field equations as well as the equation of motions for electrons in this field. He also assumed Fresnel's view that ether permeates all substances, including inter-molecular space, but once again rejected the idea that its density varies with the material. This completely separated the ether and matter, and Lorentz assumed that interactions between both happen solely due to the *negative* and *positive* electrons, existing in all matter.

Soon Lorentz also adopted Maxwell's point of view about action at a distance. He rejected this concept since he believed that the electromagnetic energy described by Maxwell is more intuitive and truer to nature. This led to his work towards showing that electric fluids with particles can be described with *contagious action*. Using this form of electrodynamics in 1892, Lorentz could explain optics in a similar fashion to his dissertation, considering the retarding of light as it enters a medium and the new vibrations produced by electrons in the medium interfering with the incident waves. Through this description, Lorentz was able to derive the *Fresnel drag coefficient*, which previously required the drag of ether to explain, making this demonstration of the theory a critical proof of credibility.

Soon Lorentz used the compact vector form of Maxwell's equations to find the force of ether, **E**, on matter containing electrons with a unit charge:

$$\mathbf{E} = 4\pi c^2\mathbf{D} + \mathbf{v} \times \mathbf{H}$$

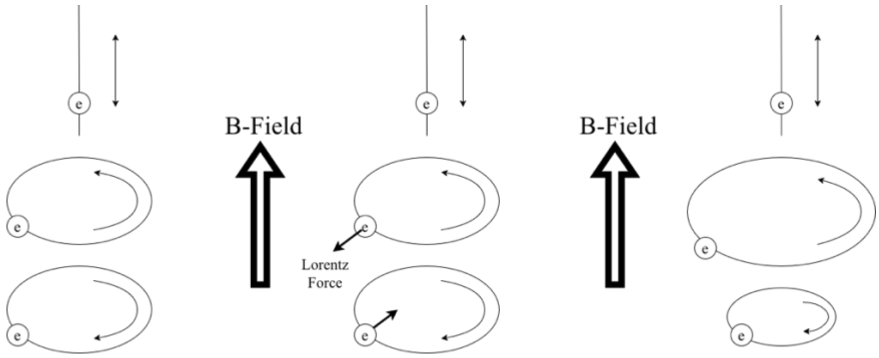
Where **D** is the dielectric displacement, **H** is the magnetic force and **v** is the velocity of the electric charge.

With this equation in 1895, known as the *Lorentz Force*, the theory of electrons is almost complete. Lorentz could now explain the origin of various optical phenomena and provide a succinct interaction relation between the luminiferous ether and electrons.

The theory particularly shines in its ability to explain the *normal* Zeeman effect. The effect was first observed by Pieter Zeeman in 1896 when he exposed a sodium flame to a strong magnetic field, with the help of electromagnets. He found that the spectrum lines emitted by the flame, which were previously defined, were now broadened. This hinted at more than one frequency of oscillation was present in the flame.

The effect remained small, yet it left Zeeman perplexed, since they have seemingly discovered that the frequency of light could be altered with magnetic fields. This was something previously thought to be impossible as Maxwell too believed that for light-radiating particles, "*no force in nature* can alter even *very slightly* either their mass or their *period* of oscillation".

Zeeman later realised that these observations perfectly align with Lorentz's theory of electrons. By considering the 3 kinds of oscillatory motion of electrons (two circular and a rectilinear motion), he was able to show that in the presence of a magnetic field, the periods of each motion would vary slightly to produce a triplet, the same pattern observed for the magnetic field in a perpendicular direction:



Similarly, Zeeman found that if the magnetic field instead acts parallel to the motion of the electrons, it produces a doublet. This aligned perfectly with the observations made by Zeeman and his colleagues with other elements, showing the power of Lorentz's classical theory in explaining a quantum phenomenon. Using this experiment, Zeeman found out that the electron must be *negatively* charged to explain the effect, and they must have a high *charge to mass* ratio. These deductions perfectly coincide with the *cathode ray experiment* in 1897 conducted by J. J. Thomson, once again validating Lorentz's theory.

Lorentz's work is still actively used to this day to simplify and provide a solid mathematical framework for optical phenomenon. Yet, it has been extended even further from its original scope, towards spectroscopy, probing atomic structures and more. The theory of electrons constructed by Lorentz remains as one of the most important and relevant classical theories to date, describing electrodynamics and explaining all behaviours of light through the fundamental particle of charge.

"Lorentz, Hendrik Antoon". Complete Dictionary of Scientific Biography. Retrieved (2025, 16 10) from Encyclopedia.com: https://www.encyclopedia.com/science/dictionaries-thesauruses-pictures-and-press-releases/lorentz-hendrik-antoon-0

Hirosige, T., (1969). *"Origins of Lorentz' Theory of Electrons and the Concept of the Electromagnetic Field"*. Historical Studies in the Physical Sciences, University of California Press, Vol. 1 pg. 151-209.

Zeeman, P., (1903, 02 05). *"Light Radiation in a Magnetic Field"*. Nobel Prize Lecture

Lorentz, H., A., (1902, 11 12). *"The Theory of Electrons and the Propagation of Light"*. Nobel Prize Lecture