Happy Birthday, Electron

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Happy Birthday, Electron

The Higgs gets the headlines, but the electron is really physicists’ favorite particle. The electron theory, developed 120 years ago, is an underappreciated bridge from classical to modern physics

By Frank Wilczek

Today electrons rule our world, but not so long ago they were only an idea. This month marks the 120th anniversary of the electron theory of Dutch physicist Hendrik Antoon Lorentz, a profound and influential creation. The electron was not just a hypothetized elementary particle but the linchpin of a unified theory of nature, itself a radical idea. Physicists are now accustomed to the notion that a complete description of nature can be built up from simple, beautiful equations, but in Lorentz’s time that was an almost mystic vision.

For most physicists today, the memorable peak of 19th-century physics was the theory of electrical and magnetic fields, beginning with Michael Faraday’s experimental discoveries and prophetic conceptions, culminating in James Clerk Maxwell’s mathematical synthesis of 1864. Then a haze intervenes, until the 20th-century massifs of relativity and quantum theory poke through. That foggy folk-history obscures the bridge between—a brilliant achievement itself, built through heroic labor.

To set the context, it is important to admit a blasphemy: Maxwell’s own exposition of Maxwell’s equations was a mess. You will not find, in his writings, the clean, compact, elegant structure that every physics student learns as “Maxwell’s equations.” Instead you discover a torrent of symbols and a sprawl of words and equations. Maxwell did not consider that he was producing the sort of thing we now consider “Maxwell’s equations,” poetry for the ages, suitable for engraving. Rather, he set out to summarize everything then known about electricity and magnetism. In his presentation, fundamental equations appeared mixed together with approximate expression; the system, such as it is, grew by accretion.

To oversimplify a complex history, Lorentz’s achievement was to purify the message of Maxwell equations—to separate the signal from the noise. The signal was four equations that govern the response of electric and magnetic fields to electric charge and current, along with one equation that specifies how those fields exert forces on charges. Everything else was noise.

His new perspective suggested new questions. Physicists now had definite equations for the behavior of tiny bodies with a given mass and charge. Could one rebuild the description of matter on a new foundation, starting from idealized “atoms” of charge? That was the burden of Lorentz’s electron theory. Starting with his 1892 paper, Lorentz and his followers explained one property after another—conduction of electricity and of heat, dielectric behavior, reflection and refraction of light, and more. Thus they laid the groundwork for the subjects we now call
electronics and materials science. In 1897 the experimentalist Joseph John Thomson showed that electrons really do exist.

Much of Lorentz’s 1892 paper deals with the seductive, though not unproblematic, idea that the mass of electrons could be a consequence of their electric charge. Charge generates electric fields; moving charge generates both electric and magnetic fields. Those fields resist change, so they back-react on the electron’s motion. Might this back-reaction account for the electron’s inertia, hence its mass?

Ideas of this sort have an ancient history: Aristotle wanted to account for the inertia through the back-reaction of air. Lorentz’s vision of electromagnetic mass was immensely influential. It inspired hard technical work, notably by Lorentz himself and by Henri Poincaré, that anticipated major parts of Albert Einstein’s special theory of relativity.

Quantum mechanics changed the rules of the game, and the idea that electromagnetic back-reaction alone is responsible for the mass of the electron no longer appears viable. Remarkably, however, my colleagues and I have come to understand the origin of the masses of protons, neutrons and other strongly interacting particles using a closely related idea. Their inertia arises from the back-reaction of the gluon fields of quantum chromodynamics, electromagnetism’s big brother. Although the Higgs particle is commonly credited with endowing matter with mass, the Higgs accounts for a fairly small fraction of the mass of ordinary matter. It is Lorentz’s idea, in a modern form, that explains the bulk.

Lorentz’s electron theory, though eventually superseded in detail, was a pivotal contribution to the progress of physics. By recognizing the right answers, and posing the right questions, he readied the path to the physics that we continue to travel on. Near the end of his own life, Einstein penned Lorentz a memorable tribute:

For me personally he meant more than all the others I have met on my life’s journey.

Frank Wilczek of the Massachusetts Institute of Technology received the 2004 Nobel Prize in physics for his role in developing quantum chromodynamics, the theory of the strong nuclear interaction. His 2008 book, The Lightness of Being, explains how this interaction explains the bulk of the mass in the universe.

Museum Boerhave. Leiden: Museum Boerhave, 1993. Includes a facsimile reproduction, a transcripion, and Dutch and English translations of the document. See also H.A. Lorentz; His Creative Genius and His Personality Mededeling no. 91 from the Rijksmuseum voor de Geschiedenis de Natuurwetenschappen, Leiden (1953)