The Discovery of the Electron

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At the end of the 19th century, there was no generally accepted model of the atom. Most physicists believed that the atom was indivisible, although the discovery of radioactivity cast doubt on that in the minds of some physicists. At the same time it was generally believed that electric charge, like mass, was infinitely divisible. For example, James Clerk Maxwell urged that electric charge represented a “strain in the electromagnetic ether”. However, there was also some evidence, deriving from Faraday’s studies of electrolysis, suggesting that charge might come in indivisible units. (Faraday himself did not believe this.) In 1891, G. Johnston Stoney introduced the term “electron” to describe this smallest unit of negative charge. Let us call these “Stoney-electrons”, for reasons that will become apparent below. J. J. Thompson proposed that Stoney-electrons were “negative corpuscles detached from atoms”. At that time neither he nor anyone else had any clear idea of what the structure of an atom might be or how Stoney-electrons, if there were such things, might be related to atoms.

Although these ideas were familiar by the beginning of the twentieth century, they resisted experimental confirmation until Robert Millikan performed his oil drop experiment in 1909. This experiment was taken to demonstrate that there is a smallest unit of negative charge, i.e., that Stoney-electrons exist. Millikan’s experiment consisted of suspending negatively charged oil drops in an electric field. By measuring the strength of the field that was required to suspend a particular oil drop, he could measure the charge on the oil drop. He discovered that all of the oil drops had charges that were integral multiples of 1.6×10^{-19} coloumbs, and concluded that that was the charge on a Stoney-electron. Millikan received the Nobel Prize in physics for this work.

Before continuing our brief history of atomic physics, let us consider these discoveries from the perspective of contemporary physics. Stoney-electrons are, by definition, the smallest unit of negative charge. According to contemporary particle physics, these exist, but they are not electrons — they are negatively charged quarks, which have 1/3 the charge of an electron. Millikan thought that he was measuring the charge on Stoney-electrons, but in fact, he was not. He was measuring the charge on electrons. He took his experiments to confirm that Stoney-electrons exist. He, and the physicists that followed him, were justified in believing this, and they were right, but they were right by accident because what Millikan was measuring was not Stoney-electrons. In other words, this is a Gettier example. The physicists had justified true belief that Stoney-electrons existed, but it was not knowledge.

Now let us return to our brief survey of the history of atomic physics. Having argued that Stoney-electrons exist, it remained to explain how they are related to atoms. J. J. Thompson proposed the “plum pudding” model according to which an atom is a sphere of uniform positive charge with Stoney-electrons somehow embedded in it. Note that this was just a hypothesis. There was no experimental evidence for the correctness of this model. The hope was to use this model to explain the patterns of spectral lines emitted from hot gases, but the model was not successful in doing this.

Between 1906 and 1918, Rutherford conducted experiments with the scattering of alpha particles passing through thin metal foils. This led him to propose the “nuclear model” of the atom, according to which the atom contained a very small positively charged nucleus surrounded at some distance by a cloud of Stoney-electrons. The evidence for this model pertained to the size of the nucleus that was required to explain the observed scattering, and did not directly pertain to Stoney-electrons. The Stoney-electrons were just there to balance the positive charge on the nucleus so that the overall charge on the atom was zero. In 1920, Rutherford introduced the term "proton" to refer to the nucleus of the hydrogen atom. The scattering experiments allowed him to compute that the charge on a proton was equal to the charge Millikan had (purportedly) measured for Stoney-electrons, and so he inferred that in a hydrogen atom there was just one proton and one Stoney-electron. This was a change from previous views, which often supposed that atoms contained thousands of electrons.

Of course, all this time people were using the term "electron", not "Stoney-electron", so let us continue in that vein. Thus far physicists believed (1) that electrons exist, i.e., they are the smallest unit of negative charge, and (2) that the atom consisted of a small positively charged nucleus surrounded by a cloud of electrons. The question remained how the nucleus and the electrons were tied together to form the atom. Progress towards answering this question came when Neils Bohr proposed the Bohr atom as the model of atomic structure. On this model, electrons are arranged around the nucleus in discrete shells, and energy is emitted or absorbed when electrons change orbit. The evidence for this theory was the data on specral emission lines that the plum pudding model tried unsuccessfully to explain.

Subsequent advances in atomic physics led to the discovery of the neutron by Cavendish in 1932, and the development of quantum mechanics by Schrödinger and Heisenberg in the 1930's. At that point all matter was supposed to be composed of electrons, proton, and neutrons — the *elementary particles*. However, subsequent work led to the discovery of a multitude of additional elementary particles, including pions, positrons, neutrinos, muons, and most recently, quarks and gluons. Quarks and gluons explain the "strong" or "nuclear" force that holds the nucleus together. Negatively charged quarks have a charge 1/3 that of an electron, and positively charged quarks have a charge 2/3 that of a proton. There are also anti-quarks whose charges are reversed. With the advent of the quark, neutrons and protons were downgraded from the status of elementary particles. They are now believed to be composed of quarks.

Now let us reflect upon this history. Something remarkable happened. The term "electron" was originally introduced to *mean* "Stoney-electron", i.e., smallest unit of negative charge. But according to contemporary particle physics, electrons are not Stoney-electrons. If we grant that when it was introduced, the term "electron" referred to quarks, and now it refers to electrons, it follows that the extension of the term has changed. How can this happen? It can only happen when a mistake is made and perpetuated by the relevant scientific community. In this case, the mistake happened early on. Millikan thought he was measuring electrons (i.e., Stoney-electrons), but he wasn't. Others accepted his value for the charge on the electron, and upon observing that the hydrogen nucleus has a positive charge of that same value, this led Rutherford to conclude that the hydrogen atom consisted of a single proton and a single electron. Accepting this, subsequent physicists were led to new conclusions about electrons. Eventually a huge body of beliefs about electrons built up and became entrenched. When Millikan's mistake was eventually discovered, the result was to maintain the bulk of the entrenched beliefs and reject the belief that electrons are Stoney-electrons.

This is a particularly clear and well-documented case of a quite general phenomenon. Consider "atom". Atoms were originally supposed to be the elementary and indivisible constituents of matter. This is the way the term "atom" was originally introduced. But now we believe that atoms have complex structure. As originally defined, "atom" referred to elementary particles, but now it refers to atoms. What this illustrates is that the extension of a scientific term can migrate, including different things at different times, without the world changing. In other words, the temporal extension can change, not just the current extension. Thus far, this is an observation about *words*. What should we conclude about *concepts*? If we take the words to express concepts, then we must conclude that either concepts change temporal extension, or the words change concepts.

It might be argued that "electron", as used by Millikan, never referred to quarks. It got its extension ostensively as the things Millikan was measuring. However, Millikan's conclusion was not that whatever he was measuring existed. That would be uninteresting. His conclusion was that Stoney-electrons existed. *That* is what people found remarkable, and that is why they gave him a Nobel Prize for his work.

One frequently hears the claim that natural kind terms like "electron" are introduced "ostensively". This is supposed to be analogous to introducing a proper name by pointing to its denotation. What makes the latter possible is that the denotation of the name is a single object, and hence you can literally point to it. But nothing similar is possible for concepts, because unlike the case of designators, you can never get direct access to the entire extension of a concept. For example, you cannot point to all the lions in the world, so how can you define "lion" ostensively? Suppose I point to a single lion, who happens to be large, dark-colored, and male, and say "This is a buto". What does my ostensive definition of "buto" ostend? Animals? Felines? Lions? Male lions? Dark-colored male lions? Large dark-colored male lions? The word might be intended to pick out any of these. Ostensive definitions of natural kinds make no sense.