Stoney's Electron

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George Johnstone Stoney, the man who named the electron, was led to the concept of a fundamental unit of electric charge by combining electro-chemistry with the kinetic theory of gases. But his understanding was incomplete (so the discovery of the electron is associated with JJ Thomson's determination of its charge to mass ratio in October 1897)

The suggestion of the name 'electron' (*amber* in Greek) for a hypothetical small unit of electric charge is generally attributed to George Johnstone Stoney, FRS, 1826-1911, born in Ireland, whose sister was the mother of George Francis Fitzgerald, famous scion of a distinguished scientific family. Stoney's career included work under Lord Rosse at Birr Castle and the chair of Natural Philosophy at what was then Queen's College, Galway, before he embarked on an administrative career that never quite suppressed his research. His many prescient publications tended to appear several years after the work had been done and the ideas had been honed down to a final form. While the name of the electron may have only first appeared in a paper of 1891, where it was linked to hypothetical processes of oscillations taking place among charged particles within atoms, Stoney's estimate of the value of the 'unit of electricity' and the very concept of the natural occurrence of such a unit, was due to work completed in 1874 – being presented at the British Association for the Advancement of Science meeting at Belfast in 1881.

According to Stoney's Royal Society obituary, Herman von Helmholtz independently drew attention to the existence of definite elementary charges which behave like atoms of electricity in 1881; also, it is well-known that Joseph John Thomson, in October 1897, published an account regarded as the announcement of the discovery of the electron (under another name) as a particle with a definite charge to mass ratio. Even so, it was not until 1899 when he read a paper 'On the existence of masses smaller than the atoms' before the British Association that his views really made headway outside the Cavendish Laboratory.

Stoney was able, by the 1870s, to comprehend a unit of electric charge being exchanged in electro-chemical processes involving molecules of water. The constituents of these molecules were hypothetically the same atoms that were so vividly invoked in the kinetic theory of gases and, particularly, through information on viscosity, where sizes of atoms, their number, and their mean free path were being estimated numerically. James G. O'Hara, now of Hamburg University, pointed out in 1974 that Stoney's derived estimate of the 'unit of charge', 10^{-20} Ampère (later called the Coulomb), was 1/16th of the correct value of the charge of the electron. Both O'Hara and the author of the Royal Society obituary noted that in his estimate Stoney availed himself of his determination of the number of molecules present in one cubic millimetre of gas at standard temperature and pressure: 10^{18}. It turns out that a substantial error in this figure was the only appreciable error in Stoney's work. That his result should suffer from such an error in the available data detracts nothing from the merit of Stoney's performance. It was pioneer work in an obscure and difficult line of research.

With one litre of H_2 gas weighing 0.1 gm, Stoney estimated that one H_2 molecule weighs 10^{-25} gm and that the chemical atom is half of this. He expressed the opinion that there is no advantage in retaining the coefficient of a half in such an estimate, as we are not even sure that we have assigned the correct power of ten. He therefore took 10^{-25} gm as being the value of the mass of an atom of hydrogen.

Stoney served for many years on a committee for defining electrical standards such as the Ampère, the volt and the ohm, and accordingly he quoted that committee in determining that an Ampère-second (or Coulomb) causes dissociation of 92×10^{-6} gm of H_2O. With oxygen having atomic weight 16 and hydrogen atomic weight 1, Stoney estimated that this quantity of water would contain: $92 \times 10^{-6} \times (2/16) \times (1/10^{-25}) = 1.15 \times 10^{20}$ H atoms.

Rounding this to 10^{20}, Stoney deduced that one chemical bond would correspond to 10^{-20} Coulombs (which he calls Ampères). However, without dropping a factor of 2, as explained above, and without other approximation, he could have arrived at the figure of 4.35×10^{-21} Coulombs for his 'unit of charge'.

The latter figure, as compared with a modern figure for the charge on the electron of 1.6018×10^{-19} Coulombs, is low by a factor of 36.8 (not 16 as was 10^{-20}). In tracking down this discrepancy we notice Stoney's use of the quantity 10^{18} for the number of molecules present in one cubic millimetre of gas at standard temperature and pressure. Using Avogadro's number 6.0238×10^{23}, and the volume of a gm-molecule (at s.t.p.) of 22.4146×10^{6} mm^3, we derive, instead of 10^{18}, the estimate 2.687×10^{16}, down by a factor of 37.22. If Stoney had started his calculations with this lower value his estimate, with all other assumptions except the dropped factor of 2 unchanged, would have agreed with a modern value for the charge of the electron within about 1%. Such agreement is spuriously close taking into account other approximations; however, this circumstance does not seem to have been noticed previously, partly because Stoney's delay from 1874 to 1881 in publication caused him to bring in a number of side-issues that led to a confusing situation over his estimates. It is apparent that his reasoning was correct except that simplistic and incorrect inferences had been drawn from the kinetic theory of gases. Modern values for the charge on the electron come either from radiation theory (Planck's Law and the Boltzmann Constant) or by virtually direct measurement in Millikan's famous oil-drop experiment. During his productive period Stoney was fully occupied professionally in university administration. It was only by rising at 5 am to work on science and by association with the physics 'giants' of Trinity College, Dublin (such as George Francis Fitzgerald, his nephew, John Joly; Thomas Preston, and Robert Ball) and other colleagues in the Royal Dublin Society, that he could produce his many valuable and highly ingenious contributions to physics and astronomy.