4.9: The Electron

Near the middle of the nineteenth century the English chemist and physicist Michael Faraday (1791 to 1867) established a connection between electricity and chemical reactions. He already knew that an electric current flowing into certain molten compounds through metal plates called **electrodes** could cause reactions to occur. Samples of different elements would deposit on the electrodes. Faraday found that the same quantity of electric charge was required to produce 1 mol of any element whose valence was 1. Twice that quantity of charge would deposit 1 mol of an element whose valence was 2, and so on.

Electric charge is measured in units called **coulombs**, abbreviated C. One coulomb is the quantity of charge which corresponds to a current of one ampere flowing for one second. In the image below, electrons (the blue particles) can be seen flowing through a metal wire. The coulomb then is the total charge of all electrons that flow through the wire in a given second.

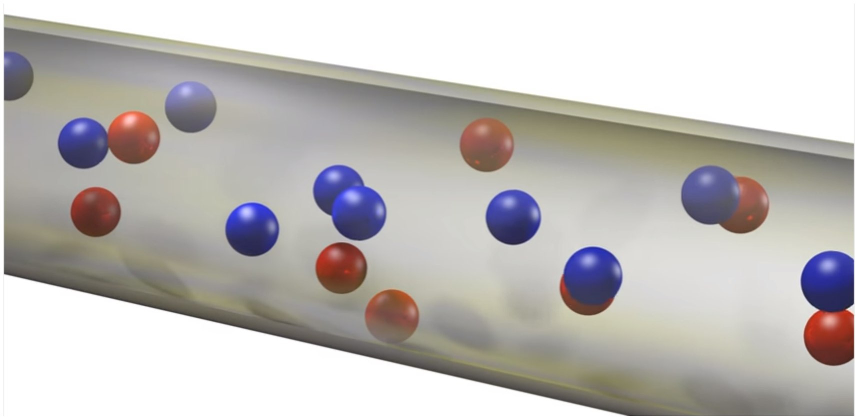

Image Credits: Physics Videos by Eugene Khutoryansky

The relationship between electricity and atomic structure was further clarified by experiments involving **cathode-ray tubes** in the 1890s. A cathode-ray tube can be made by pumping most of the air or other gas out of a glass tube and applying a high voltage to two metal electrodes inside. If ZnS or some other phosphor is placed on the glass at the end of the tube opposite the negatively charged electrode (**cathode**), the ZnS emits light. This indicates that some kind of rays are streaming away from the cathode. When passed between the poles of a magnet, these cathode rays behave the same way as the β particles described earlier. The fact that they were very small electrically charged particles led the English physicist J. J. Thomson (1856 to 1940) to identify them with the electrons of Faraday's experiments. Thus cathode rays are a beam of electrons which come out of the solid metal of the cathode. They behave exactly the same way no matter what the electrode is made of or what gas is in the tube. These observations allow one to conclude that *electrons must be constituents of all matter*.

In addition to being deflected by a magnet, the electron beam in a cathode-ray tube can be attracted toward a positively charged metal plate or repelled from a negative plate. By adjusting such electrodes to exactly cancel the deflection produced by a magnet of known strength, Thomson was able to determine that the ratio of charge to mass for an electron is 1.76×10^8 C/g. This is a rather large ratio. Either each electron has a very large charge, or each has a very small mass. We can see which by using Faraday's result that there are 96 500 C mol^{-1} of electrons

$$\frac{96\ 500\ \text{C mol}^{-1}}{1.76\ \times\ 10^{8}\ \text{C g}^{-1}} = 5.48\ \times\ 10^{-4}\ \text{g mol}^{-1}$$

Thus the molar mass of an electron is 5.48 × 10^{-4} g mol^{-1}, and if we think of the electron as an "atom"(or indivisible particle) of electricity, its atomic weight would be 0.000548—only $\frac{1}{1837}$ that of hydrogen, the lightest element known. In 1909 the American physicist Robert A. Millikan (1863 to 1953) was able to determine the charge on an electron independently of its mass. His value of 1.6 × 10^{-19} C can be combined with Thomson's charge-to-mass ratio to give an independent check on the molar mass for the electron

$$\frac{1.60\ \times\ 10^{-19}\ \text{C}}{1.76\ \times\ 10^{8}\ \text{C g}^{-1}}\ \times\ 6.022\ \times\ 10^{23}\ \text{mol}^{-1} = 5.47\ \times\ 10^{-4}\ \text{g mol}^{-1}$$

thus confirming that the electron has much less mass than the lightest atom. (The quantity 1.6 × 10^{-19} C is often represented by the symbol *e*. Thus the charge on a single electron is –*e* = –1.6 × 10^{-19} C. The minus sign indicates that the electron is a *negatively* charged particle.)