1.1.2: Discovery of Subatomic Particles

Subatomic Particles

Dalton's atomic theory stated that different elements were made of different atoms, but did not explain what made the atoms different. The answer is that atoms are composed of subatomic particles, protons, neutron, and electrons, and the number of the protons and electrons in an atom defines the element it represents. So after all, atoms are not so indivisible. However, an atom can still be seen as the smallest particle that represents the full properties of an element. If an atoms gets divided further into subatomic particles then these properties are being lost. To understand atoms further, we must therefore understand the subatomic particles they are made of. The first subatomic particle that was discovered was the electron. It was found through the investigation of so-called cathode rays which were a mysterious phenomenon at the time. Cathode rays occur when a high voltage of about 10-20 kV is applied to an evacuated tube (0.0001 mm Hg). You can see such a tube with a cathode ray going through in Figure 1.1.9. The big question was: What causes these rays?

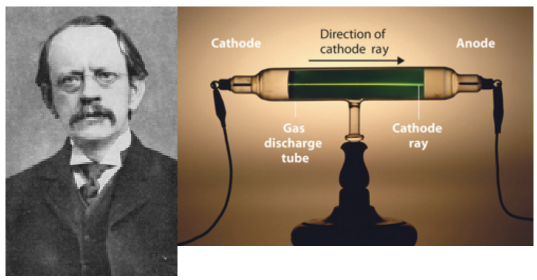

Figure 1.1.9 Joseph John Thomson (1856-1940) (Attribution: https://commons.wikimedia.org/wiki/F....J_Thomson.jpg, PD-US-expired)
and his experimental apparatus (Attribution: Chemlibetexts https://chem.libretexts.org/@api/dek...338&height=228, creativecommons.org/licenses/by-nc-sa/3.0/us/).

The answer was found by John Joseph Thomson. He applied electric and magnetic fields to these rays and found them deflected. When an electric field was applied the beam was deflected toward the positive pole. When an equally strong electric and magnetic field was applied, and the magnetic field was perpendicular to the electric field then these fields canceled out, and the rays were no longer deflected. Thomson concluded that these rays must consist of negatively charged particles emitted by the negatively charged electrode because they were attracted by the positive pole of the electric field: Electrons. Knowing the forces associated with the electrical and magnetic fields, he was able to calculate a mass to charge ratio of the electrons which is 5.6857 x 10E-9 g/C. After Thomson, Robert Millikan performed another experiment, the so-called oil drop experiment, that allowed to determine the charge and the mass of the electron. The charge of an electron is -1.6 x 10E-19 C, and its mass is 9.1 x 10E-28 g.

Thomson's plum pudding atomic model

The discovery of the electron led Thomson to the development of a first atomic model that would include a subatomic particle. It is named plum pudding model (Fig. 1.1.10). In the Thomson atom model electrons are embedded as little particles in a positively charged mass like raisins are embedded in a cake. This atom model is still far from the atom model that we accept today, but it represented an important step forward, because it introduced for the first time the idea that atoms are not indivisible, but contain subatomic particles.

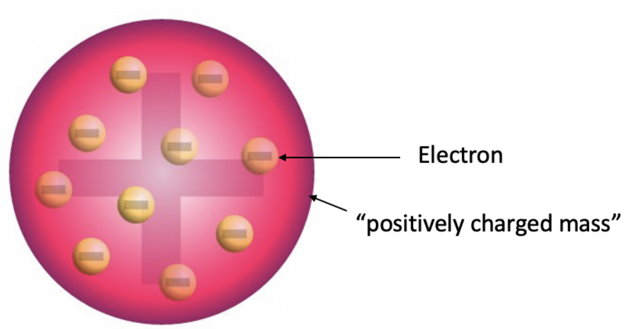

Figure 1.1.10 Thomson's plum pudding atomic model (Attribution: Fatfission (public domain) https://commons.wikimedia.org/wiki/File:Plum_pudding_atom.svg)

Rutherford's Atom Model

Ernest Rutherford (Fig. 1.1.11) wanted to test Thomson's plum pudding atom model by experiment. To do so, he placed a photographic film around a gold foil (Figure 1.1.12). In the following he bombarded the gold foil with alpha radiation. Alpha radiation is a form of radioactivity and consists of helium nuclei, also called alpha-particles. It was known at this time the alpha-particles were positively charged and had a large mass compared to an electron. Rutherford's hypothesis was that if Thomson's atom model was true, then the alpha particles should all go straight through the gold foil like a bullet going through a plum pudding. Therefore, a blackening of the photographic film, which served as the alpha radiation detector, should only occur directly behind the gold film.

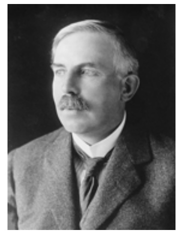

Figure 1.1.11 Sir Ernest Rutherford (1871-1931) who earned the Nobel prize for chemistry 1908. (Attribution: George Grantham Bain Collection (Library of Congress) [Public domain], commons.wikimedia.org/wiki/F...erford_LOC.jpg)

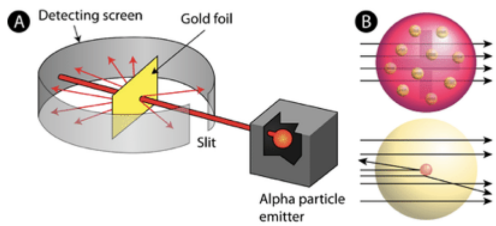

Figure 1.1.12 Rutherford's Gold Foil Experiment

However, what Rutherford observed was that while most of the alpha-particles went straight through the gold foil, some of them were deflected, and a few of them were even reflected. Rutherford concluded that Thomson's plum pudding model must be wrong. A bullet shot at a plum pudding would just never be reflected by the plum pudding and come back at you.

He suggested that the atom would be made of a positively charged nucleus where almost the entire mass of the atom would be concentrated. In the event of a collision between the alpha particle and that nucleus, the alpha particle would be reflected. In the event of an alpha particle passing by the nucleus close, the alpha particle would be deflected. In the event of an alpha particle passing the nucleus in larger distance, the alpha particle would pass the atom practically non-deflected. The observation that most of the alpha particles were not deflected led Rutherford to the conclusion that the overall atom must be much larger than the nucleus, in fact, the data allowed him to calculate that the radius of the atom would be about 10,000 times larger than the radius of the nucleus. This implies that the atoms would be mostly empty space. To explain the empty space, Rutherford assumed that the electrons would move in orbits around the nucleus like planets around the sun. This would be called the planetary model of the atom (Fig. 1.1.13).

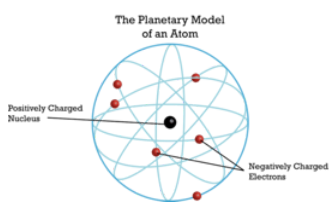

Figure 1.1.13 Rutherford's Atom Model