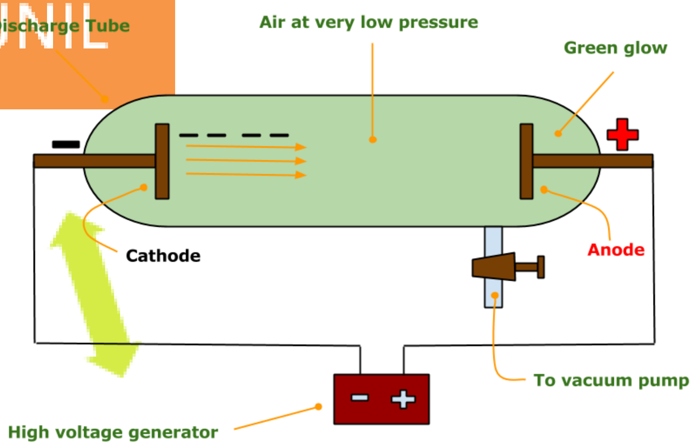
IX Structure of atom: Discovery of electrons, protons and neutrons

Discovery of Electron

Who discovered the electron? Electron was discovered by J. J. Thomson in 1897 when he was studying the properties of cathode ray.

What is cathode ray?

J. J. Thomson constructed a glass tube which was partially evacuated i.e. much of the air was pumped out of the tube. Then he applied a high electrical voltage between two electrodes at either end of the tube. He detected that a stream of particle (ray) was coming out from the negatively charged electrode (cathode) to positively charged electrode (anode). This ray is called cathode ray and the whole construction is called cathode ray tube. The schematic of a cathode ray tube



Production of cathode rays

Conclusion s:

- Cathode rays consist of electrons.
- Electrons are the basic unit s of all atoms.

Properties of cathode ray particle

1. They travel in straight lines.

2. They are independent of the material composition of the cathode.

3. Applying electric field in the path of cathode ray deflects the ray towards positively charged plate. Hence cathode ray consists of negatively charged particles.

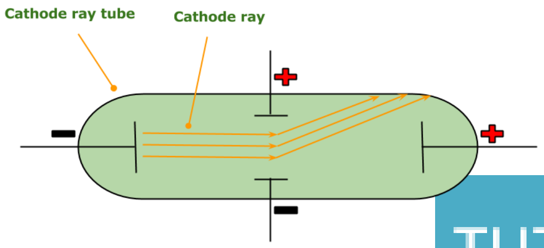


Figure : Deflection of cathode rays towards positively charged plates

J. J. Thomson measured the charge-by-mass-ratio (e/m) of cathode ray particle using deflection in both electric and magnetic field.

$e/m = -1.76 \times 108$ coulomb per gram

The cathode ray particle turned out to be 2000 times lighter than hydrogen.

Although we got e/m ratio for electron from J.J. Thomson's Cathode Ray Tube experiment, we still don't know the exact charge (e) for electron. American physicist Robert Millikan designed an experiment to measure the absolute value of the charge of electron which is discussed below.

Millikan Oil Drop Experiment

In 1909, American physicist R. Millikan measured the charge of an electron using negatively charged oil droplets. The measured charge (e) of an electron is $-1.60 \times 10-19$ Coulombs.

Using the measured charge of electron, we can calculate the mass of electron from e/m ratio given by J. J. Thomson's cathode ray experiment.

$e/m = -1.76 \times 108$ Coulomb-per-gram

$m = e - 1.76 \times 108$

Putting $e = -1.60 \times 10-19$ Coulomb,

$m = 9.1 \times 10-28$ gram.

What we have learned

Electron was discovered by J. J. Thomson in Cathode Ray Tube (CRT) experiment.

Electrons are negatively charged particles with charge-to-mass ratio -1.76×108 C/gm

The charge of an electron was measured by R. Millikan in Oil drop experiment.

Charge of an electron is $-1.60\times10-19$ C

Mass of an electron is $9.1\times10-28$ gram.

Electron is approximately 2000 times lighter than hydrogen.

Discovery of Proton

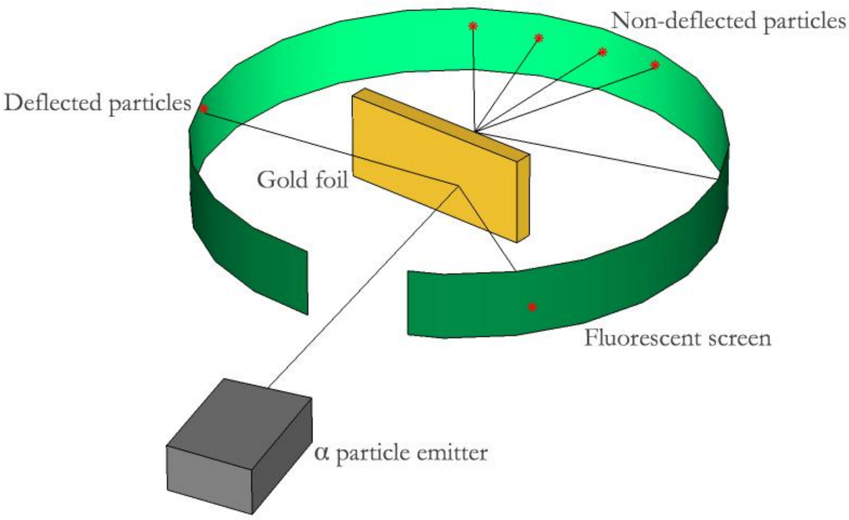


Figure 5. Schematic gold foil experiment

In 1909, Rutherford discovered proton in his famous gold foil experiment.

Gold Foil Experiment

In his gold foil experiment, Rutherford bombarded a beam of alpha particles on an ultrathin gold foil and then detected the scattered alpha particles in zinc sulfide (ZnS) screen.

Results

Most of the particles pass through the foil without any deflection.

Some of the alpha particles deflect at small angle.

Very few even bounce back (1 in 20,000).

Conclusion

Based on his observations, Rutherford proposed the following structural features of an atom:

Most of the atom's mass and its entire positive charge are confined in a small core, called nucleus. The positively charged particle is called proton.

Most of the volume of an atom is empty space.

The number of negatively charged electrons dispersed outside the nucleus is same as number of positively charge in the nucleus. It explains the overall electrical neutrality of an atom.

Discovery of Neutron

From the previous discussion, we can see that the gold foil experiment gave a clear picture of the structure of an atom which consists of protons (nucleus) and same number of electrons outside of the nucleus.

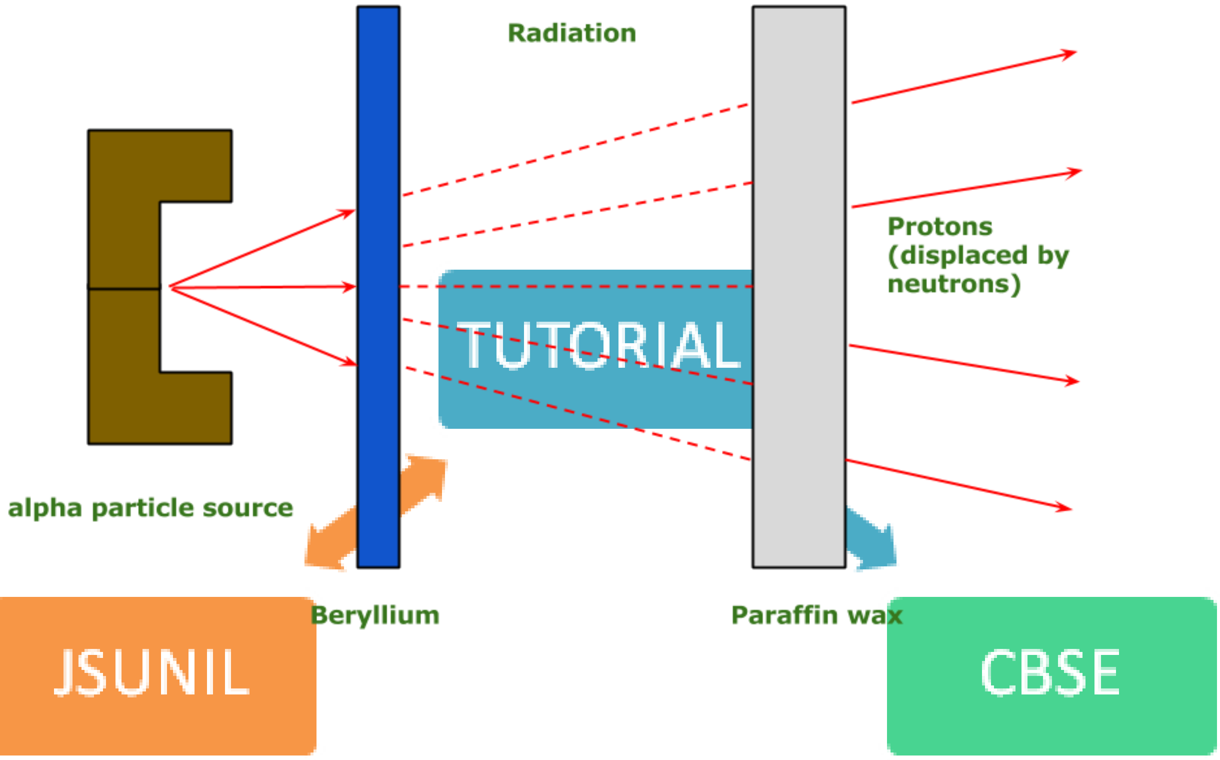


Figure Schematic diagram for the experiment that led to the discovery of neutrons by Chadwick.

$94Be+42\alpha\longrightarrow[136C]\longrightarrow[126C]+10n$

But scientists soon realized that the atomic model offered by Rutherford is not complete. Various experiments showed that mass of the nucleus is approximately twice than the number of proton. What is the origin of this additional mass? Rutherford postulated the existence of some neutral particle having mass similar to proton but there was no direct experimental evidence.

Several theories and experimental observations eventually led the discovery of neutron. We can summarize some of the scientific observations behind the discovery of neutron.

In 1930, W. Bothe and H. Becker found an electrically neutral radiation when they bombarded beryllium with alpha particle. They thought it was photons with high energy (gamma rays).

In 1932, Irène and Frédéric Joliot-Curie showed that this ray can eject protons when it hits paraffin or H-containing compounds.

The question arose that how mass less photon could eject protons which are 1836 times heavier than electrons. So the ejected rays in bombardment of beryllium with alpha particles cannot be photon.

In 1932, James Chadwick performed the same experiment as Irène and Frédéric Joliot-Curie but he used many different target of bombardment besides paraffin. By analyzing the energies of different targets after bombardment he discovered the existence of a new particle which is charge less and has similar mass to proton. This particle is called neutron. Beryllium undergoes the following reaction when it is bombarded with alpha particle.

$94Be + 42\alpha \longrightarrow [136C] \longrightarrow [126C] + 10n$

Here the symbol $^{X}_{Z}A$ is used where Z = atomic number and X = atomic mass of the element A.