Lecture Notes of B.Sc.(HONS.) PHYSICS ,Part-II, Paper -IV

By: Sonu Rani,
Assistant Professor ,
Department of Physics ,MMC,P.U.

TOPIC:-------Discovery of Neutron

In 1921 Ehrenfest Rutherford postulated that there were neutral massive particles in the nucleus of atoms. This conclusion arose from the despairing between an element's atomic no. and its atomic mass. In 1930 it was discovered that Beryllium when bombarded by α-particles ,emitted a very energetic stream of radiation . This stream was originally thought to be γ −radiation. However further investigation into the properties of the radiation revealed contradictory result. Like γ-ray these were extremely penetrating and were not deflected by electric field and magnetic field . However unlike γ-ray these rays did not discharge charged electroscope (the photoelectric effect). When a beam of this radiation hit a substance rich in proton for eg. Paraffin, protons were knocked which could be easily detected by the Geiger-Muller counter or ionisation chamber as shown in fig(1).

In 1932 Chadwick proposed that this particle were neutron. In 1932 he was awarded noble prize for his discovery.

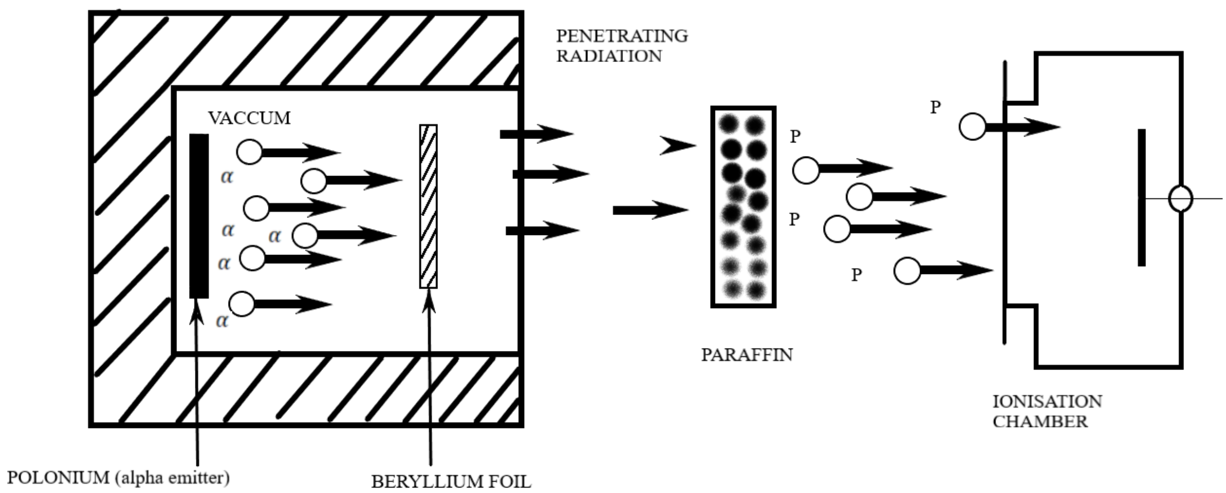

fig.(1)

In 1932 Chadwick performed a series of experiments on the recoil of many other nuclei (for example nitrogen) when struck by this penetrating radiation. He found that if this radiation consisted of γ-ray photons, then the energy of photons are obtained from experimental results varied with the nature of the recoiled nucleus. For example, protons ejected from paraffin had energies which required a γ-ray photon to have an energy of 55 MeV, while recoiling nitrogen nuclei had energies which required a γ-ray photon to have an energy of 90 MeV. This meant that the energy of supposed γ-ray photon increased with the mass of the recoiling atom, which was contrary to the conservation of energy and momentum in Compton collision.

Chadwick showed that these two difficulties disappeared if the radiation coming from beryllium bombarded with α-particles is supposed to consists of 'particles' (instead of massless γ-ray photons) of mass nearly equal to that of a proton, but having no charge. He called these particles **'neutrons'**. The nuclear reaction which produces these neutrons is given by:

$_4Be^9 + _2He^4 \rightarrow _6C^{12} + _0n^1$

Where $_0n^1$ is the symbol for the neutron .

<u>Determination of mass of Neutron:</u> Since neutron is not a charged particle, its mass cannot be determined directly by deflecting it in electric or magnetic field. Chadwick determined the mass of neutron by measuring the maximum velocities of recoiling nuclei of hydrogen and nitrogen struck be neutrons. Suppose a neutron of mass m and velocity v suffers head on collision with the stationary hydrogen nucleus of mass $m_{H..}$ Let the velocity of the neutron after the collision be v', and the (maximum) velocity of the recoiling hydrogen nucleus of $v_{H.}$

The equation of conservation of kinetic energy is given by:

$$\frac{1}{2}mV^2 = \frac{1}{2}mV'^2 + \frac{1}{2}m_H V_H{}^2$$

and the equation of conservation of momentum is given by:

$mv = mv' + m_H v_H$

Eliminating v' from these two equations, we get

$$V_H = \frac{2m}{m+m_H} v \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Again if a neutron with the same velocity v collides with a stationary nitrogen nucleus of mass m_N, the (maximum) velocity imparted to the recoiling nitrogen nucleus is given by

$$V_N = \frac{2m}{m+m_N} v \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Dividing eqn. (1) by (2),we get

$$\frac{V_H}{V_N} = \frac{m+m_N}{m+m_H}$$

m_N and m_H are known. If therefore v_H and v_N are found by measuring the maximum length of the cloud chamber tracks of the recoiling nuclei. The mass m of the neutron can be determined. Chadwick's result although approximate because of error in the determination of v_H and $v_{N,}$ showed that the mass of the neutron is slightly larger then that of photon.

Properties of Neutrons:

1. The neutron is a fundamental constituent of the nuclei of all atoms (except hydrogen atom). It has a mass of 1.00898 amu or 1.675×10^{-27} kg which is slightly greater than that of proton.
2. It is an uncharged particle, therefore it cannot be accelerated to high velocities by means of electric field as can be charged particle such as protons and electrons. For the same reason, the neutrons cannot be focused by means of magnetic field.
3. It is highly penetrating particle and can pass through thick sheets of lead.

4. Being chargeless, the neutron produces practically no ionization in a gas and hence no track in the cloud chamber.
5. Being uncharged, a neutron can easily enter the nucleus of an atom. It can therefore produce a nucleic excitation or nuclear disintegration far more readily then almost any other particle. (Other particles carrying a charge have to overcome the strong electrostatic repulsion offered by the nucleus.)
6. If the probability of nuclear excitation of nuclear disintegration is small, the neutrons, on striking matter are simply scattered by the atomic nuclei. On colliding with heavy nuclei, the neutrons are scattered with very little loss of energy. On colliding with light nuclei, however the neutron are slowed down in a few collisions. Light water (H_2O) heavy water(D_2O), paraffin wax and carbon are very effective in slowing down neutrons. These substances are called '**moderators'**. A slow neutron is more efficient in producing nuclear disintegration because it spends more time near a nucleus then a fast neutron and thus stands a greater chance of being captured.
7. Neutrons possessing energy of 1 MeV are known as fast neutrons. Those with energies below 1eV are described as slow neutron. The neutrons which have come with thermal equilibrium with a moderator at normal temperature and pressure are called thermal neutrons. Such neutrons have energies of approximately 0.03eV.

Detection of Neutrons: Neutrons are electrically neutral and therefore produce for negligible ionization in passing through matter. They cannot be detected directly be G-M counters, ionization chamber or similar devices which are based on detection by ionization. They does not produce a track in a cloud chamber. Hence, neutrons are detected by indirect process in which neutron produces charged particles.

(1.) **Detection of Slow Neutrons:** Slow neutrons can be detected by means of G-M tube or ionization chamber filled with Boron in fluoride gas (containing ${}_5B^{10}$). The neutrons passing through the gas disintegrate boron nuclei which thus emit α-particles:

$_5B^{10} + {_0n^1} \rightarrow {_3Li^7} + {_2He^4}$

The α-particle so produce cause ionization of the gas and are thus detected.

(2.) **Detection of Fast Neutrons:** G-M tube or ionization chamber containing hydrogen will detect fast neutrons. When a fast neutrons collides with hydrogen nucleus, it imparts energy to the hydrogen nucleus which in turn producers ionization in the surrounding gas and is detected.

Radioactive Decay of Neutron: A free neutron outside an atomic nucleus is unstable and decays into a Proton, emitting an electron and Antineutrino .

The reaction is: $_0n^1 \rightarrow {_1H^1} + {_{-1}e^0} + v$

(neutron) (proton) (electron) (antineutrino)

The half-life of the neutron has been estimated to be 12.8 minutes.

Uses of Neutrons:

1. Neutrons are used in medicine especially in the treatment of cancer.
2. Fast and slow neutrons are used for Artificial disintegration of nuclei and producing radio-isotopes.
3. Slow neutrons are used in nuclear fission.