

Chapter = 21

Nuclear Physics

Rutherford's Nuclear Model of Atom:

Ernest Rutherford developed a nuclear model of the atom from his α-particle scattering experiments.

According to his model an atom has a small, dense and positively charged nucleus with negative electrons orbiting about it.

In 1920 Rutherford suggested that there is probably another particle with in the nucleus, which is neutral. He gave it the name Neutron.

In 1932, James chadwick discovered Neutron.

21.1 Atomic Nucleus

Structure of the Nucleus:

At the centre of each atom, There is an extremely small nucleus. The entire positive charge of the atom and 99.9% of its mass is concentrated in the nucleus. The radius of the atom is 10^5 times greater than the radius of the nucleus.

Nucleons:

A nucleus consists of nucleons. "Protons and Neutrons are called nucleons." Proton has a positive charge. It is equal to 1.6×10^{-19} C. It is equal in magnitude to the charge on an electron. Neutron has no charge. It is a neutral particle.

The charge on the proton is positive, while that of an electron is negative. As an atom on the whole is electrically neutral, therefore we conclude that the number of protons inside the nucleus is equal to the number of electrons outside the nucleus.

Mass of proton $m_p = 1.673 \times 10^{-27}$ kg

Mass of Neutron m_n 1.675×10^{-27} Kg.

Proton and Neutron has nearly same mass.

Mass of electron m_e 9.1×10^{-31} Kg.

Unified Mass scale u:

Mass of atomic particles is generally expressed by using unified mass scale (u) in stead of Kilograms. "By definition 1u is exactly $\frac{1}{12}$ th of the mass of Carbon atom $^{12}_{6}C$."

$$1u = 1.6606 \times 10^{-27} \text{ kg}$$

On this scale

$$m_p = 1.007276 \text{ u}$$
$$m_n = 1.008665 \text{ u}$$
$$m_e = 0.00055 \text{ u}$$

Charge Number z:

"The number of protons inside a nucleus is called charge number z or Atomic number z."

Neutron Number N:

"The number of neutrons inside a given nucleus is called neutron number N."

Mass Number A:

"The total number of Protons and neutrons in a nucleus is called mass number A."

Mass Number = Number of protons + NO. neutrons

$$A = N + Z$$

Now we consider different elements of the periodic table.

Hydrogen:

Hydrogen is the simplest of all the atoms. Its nucleus has only one proton. so,

$$Z = 1 \quad , \quad A = 1$$

So, Hydrogen is represented by symbol $_1^1H$.

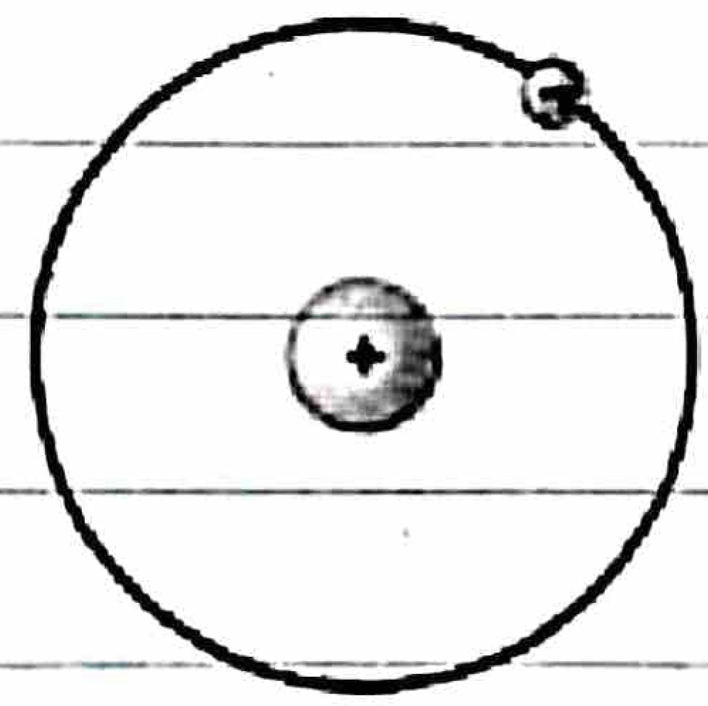
Helium:

Its nucleus has two Protons and two neutrons.

$A = N + Z$

$A = 2 + 2$

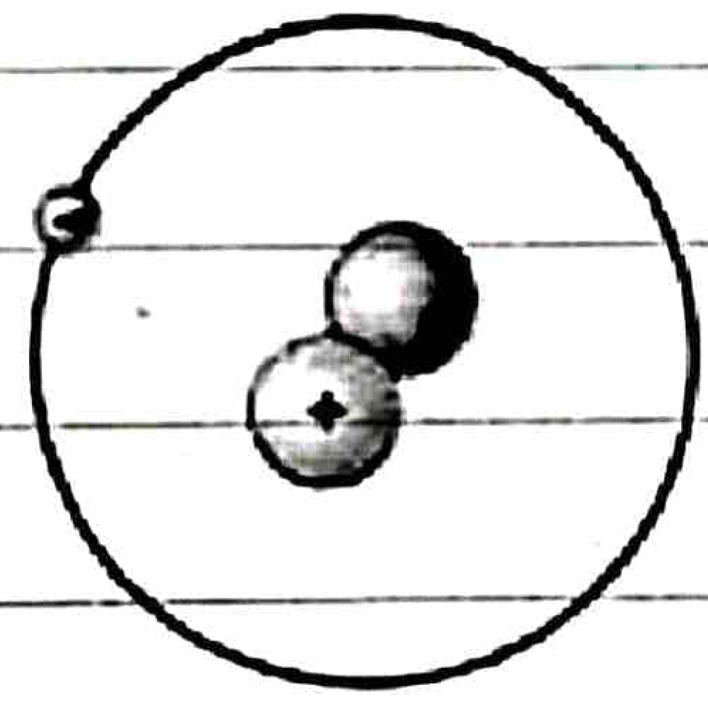
$A = 4$



$^{1}_{1}H$

(a) (Protium)

So, Helium is represented by $^{4}_{2}He$.



$^{2}_{1}H$

(b) (Deuterium)

<u>Uranium :</u>

It is a Heavy element.

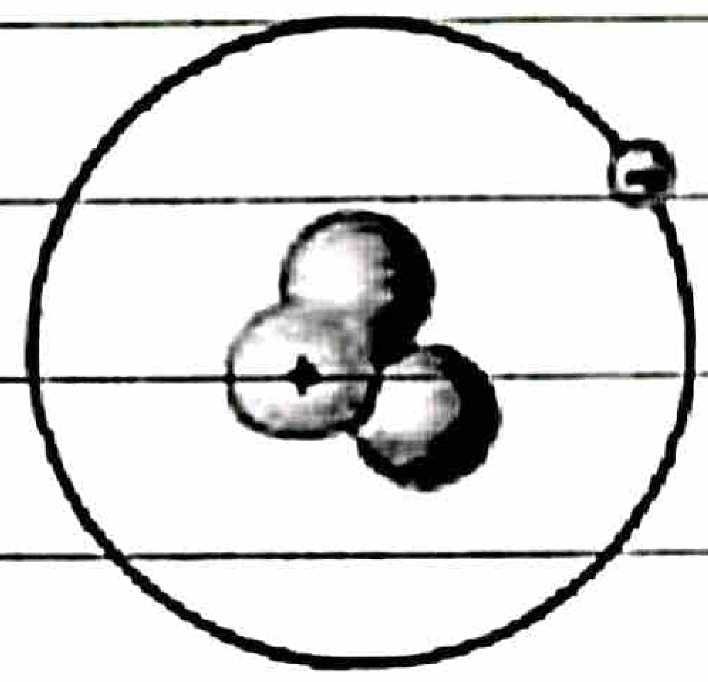
Its charge number $Z = 92$

Its Mass number $A = 235$

Its neutron number $N = A - Z$

$N = 235 - 92$

$N = 143$



$^{3}_{1}H$

(c) (Tritium)

$^{235}_{92}U$ In general for any element X. $^{A}_{Z}X$

→ In Light elements such as H, He, N, C, O the number of neutrons is same as that of number of protons.

In Heavy elements such as U, Pb (lead) neutron number than the number of Protons.

21.2 Isotopes

Definition:

"Isotopes are nuclei of an element having the same charge number "Z" but different mass number "A"."

Or,

"Atoms of an element having same number of Protons but different number of neutrons."

Examples:

Helium:

It has two Isotopes $^{3}_{2}He$, $^{4}_{2}He$

Both has the same charge number (number of protons) i.e $Z = 2$

In $^{3}_{2}He$ neutron number is,

$$N = A - Z$$
$$N = 3 - 2$$
$$N = 1$$

In $^{4}_{2}He$ neutron number is,

$$N = A - Z$$
$$N = 4 - 2$$
$$N = 2$$

Isotopes of Hydogen:

It has three isotopes ^1_1H, ^2_1H, ^3_1H.

Protium:

^1_1H $Z = 1$, $A = 1$

It has only one proton in the nucleus.

Deutrium:

^2_1H $Z = 1$, $A = 2$

It has one proton and one neutron in the nucleus.

Tritium:

^3_1H $Z = 1$, $A = 3$

It has one proton and two neutrons in the nucleus.

Chemical Properties:

The chemical properties of all the isotopes of an element are similar, because the chemical properties of an element depend on the number of electrons around the nucleus.

Isotopes of an element have

some number of electrons and same numbe r of protons.

 So, it is not possible to seperate the isotopes of an element by chemical methods.

Physical methods such as centrifugal Methods are used to seperate isotopes.

Mass Spectrograph:

It is a device which seperates the iosotopes and it determines the masses of iosotopes accurately.

Principle:

It uses electric and magnetic fields to sort out isotopes according to their masses.

Construction:

It consists of.

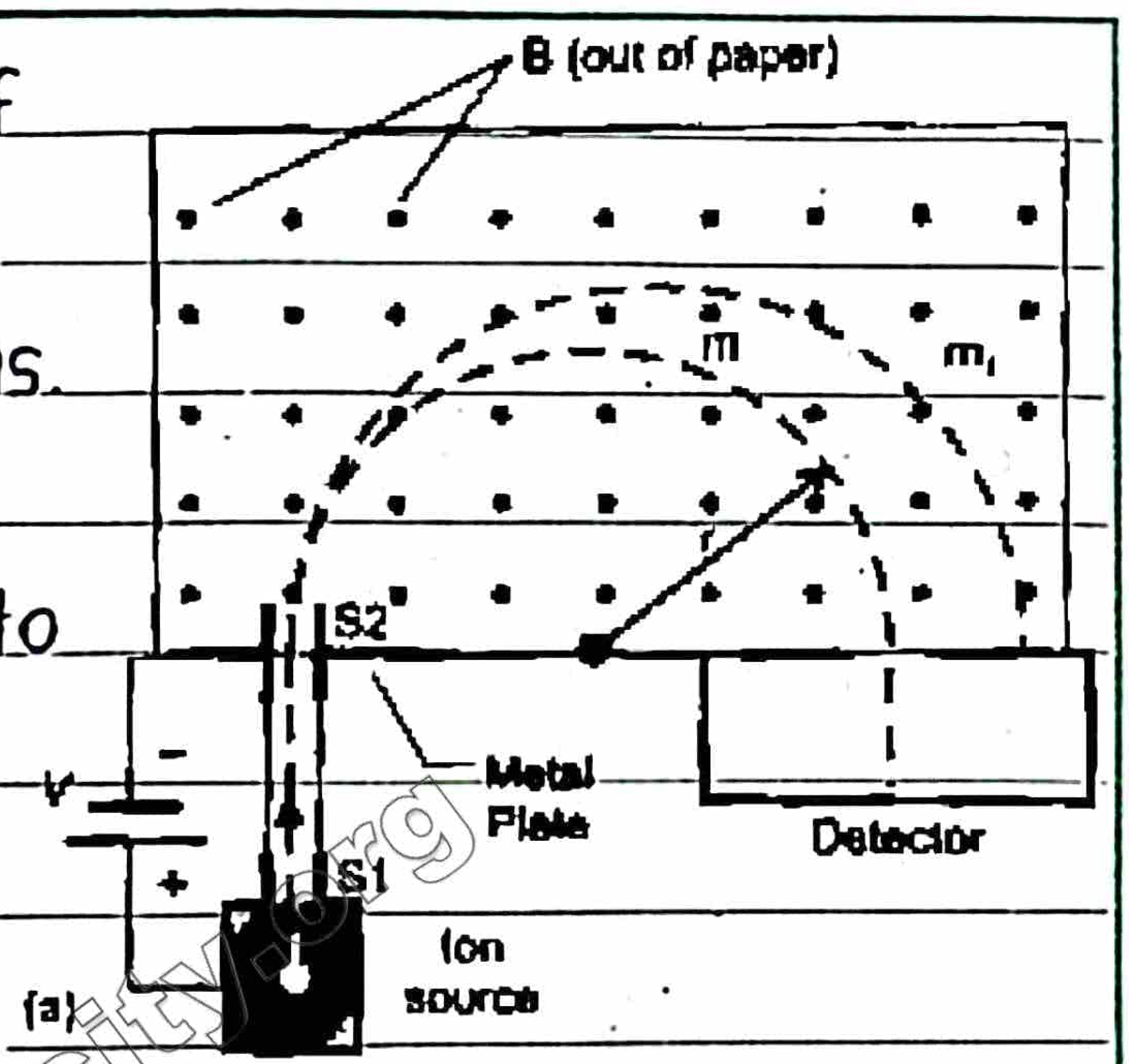
i). A vacuum chamber.

ii). An ion source.

iii). Two slits S_1 and S_2 connected to +ve and −ve terminals of voltage source.

iv). Detector to detect ions.

v). A magnetic field "B" applied perpendicular to vacuum chamber and out of the page.



Working:

In the ion source singly positive ions are produced in the vapour form. These ions having charge (+e) are accelerated through the potential difference "V" between the slits S_1 and S_2 on reaching S_2 they gain KE.

$$KE = Ve$$

$$\frac{1}{2}mv^2 = Ve$$

$$mv^2 = 2Ve$$

$$v^2 = \frac{2Ve}{m}$$

$$v = \sqrt{\frac{2Ve}{m}}$$

In the vacuum chamber the ions pass through uniform magnetic field "B". These ions are defelected in semicircular paths towards the detector. The detector records the number of ions reaching per second. The magnetic field provides centripetal force.

Magnetic force = centripetal force

$$F_m = F_c \qquad F_m = q(V \times B)$$

$$evB = \frac{mv^2}{r} \qquad F_m = qvB\sin 90^\circ$$

$$F_m = qvB$$

$$r = \frac{m}{eB} \times V \qquad F_m = evB$$

$$r = \frac{m}{eB} \times \sqrt{\frac{2Ve}{m}}$$

Taking squar on both sides.

$$r^2 = \frac{m^2}{e^2B^2} \times \frac{2Ve}{m}$$

$$r^2 = \frac{2mV}{eB^2} \longrightarrow (1)$$

$$r = \sqrt{\frac{2mV}{eB^2}}$$

$$r \propto \sqrt{m}$$

V = Potential difference.

This shows that radius "r" depends upon the mass "m" of ions since isotopes have different masses, so they have different radii. In this way we sort out ions.

By eq (1).

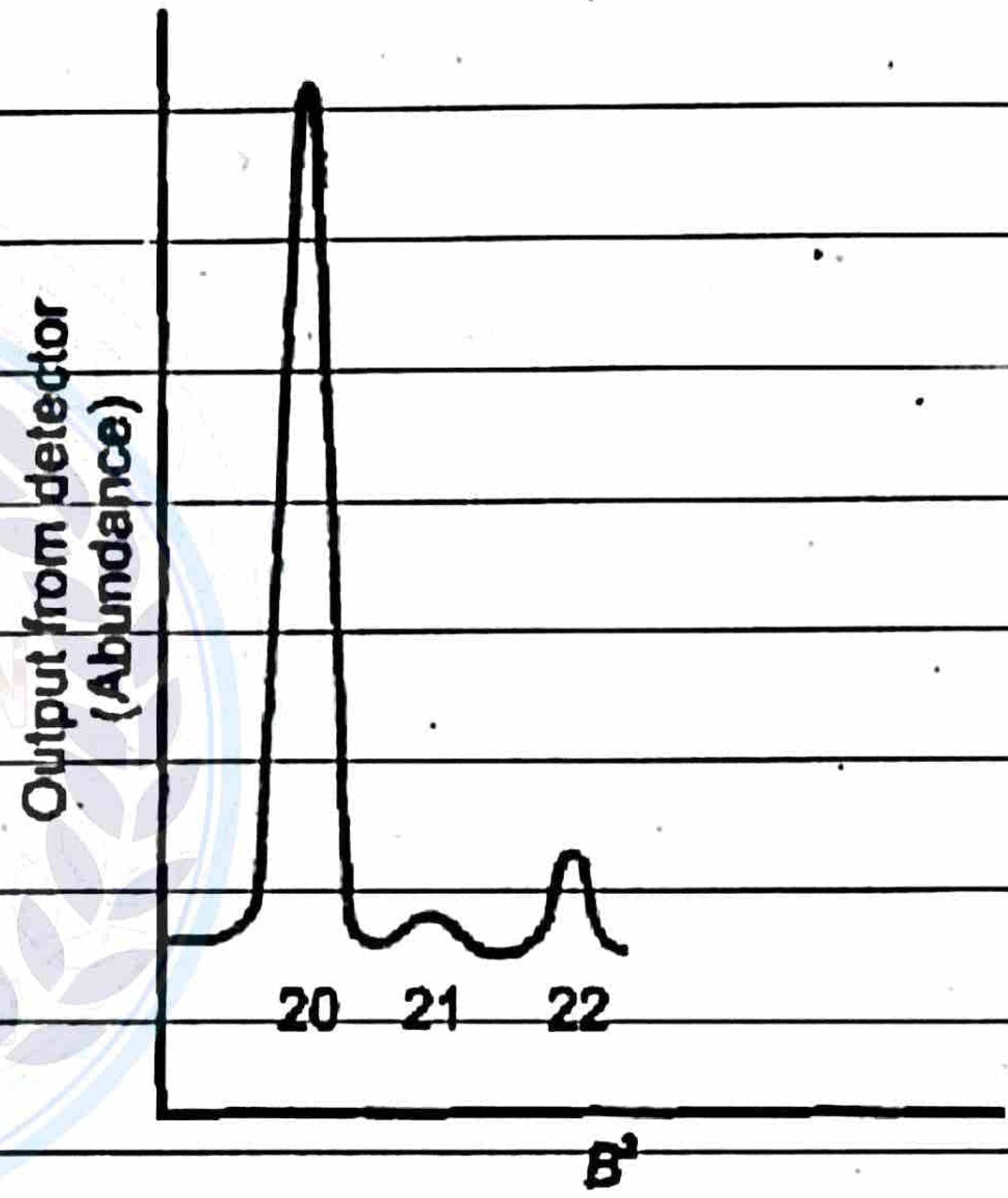
$$m = \left(\frac{er^2}{2V}\right)B^2 \longrightarrow (2)$$

radii "r" can be measured. So, masses of isotopes are determined with this relation. V and B are known.

Also $m \propto B^2$.

 By adjusting the value of 'B' and keeping $\left(\frac{er^2}{2V}\right)$ constant, the ions of different masses are allowed to enter the detector.

The graph of output of detector as a function of "B^2" gives an indication of what masses are present and the abundance of each mass.



(b) (Proportional to atomic mass)

Graph shows three naturally occurring iostopes of Neon gas having mass number 20, 21, 22. The most abundant isotope of Neon is Neon - 20.

21.3 Mass Defect and Binding Energy

Mass Defect:

"The mass of a nucleus always less than the total mass of its protons and neutrons. This difference in mass is called mass defect Δm." It is also called mass deficit.

$$\Delta m = Zm_p + (A - Z)m_n - m_{nucleus}$$

Here,

Z = Total number of protons in the nucleus.

m_p = Mass of one proton.

Zm_p = Total mass of all protons.

m_n = Mass of one neutron.

$(A-Z)m_n$ = Total mass of all neutrons.

$(A-Z)$ = Total number of all neutrons.

$m_{nucleus}$ = Experimental mass of entire nucleus.

or,

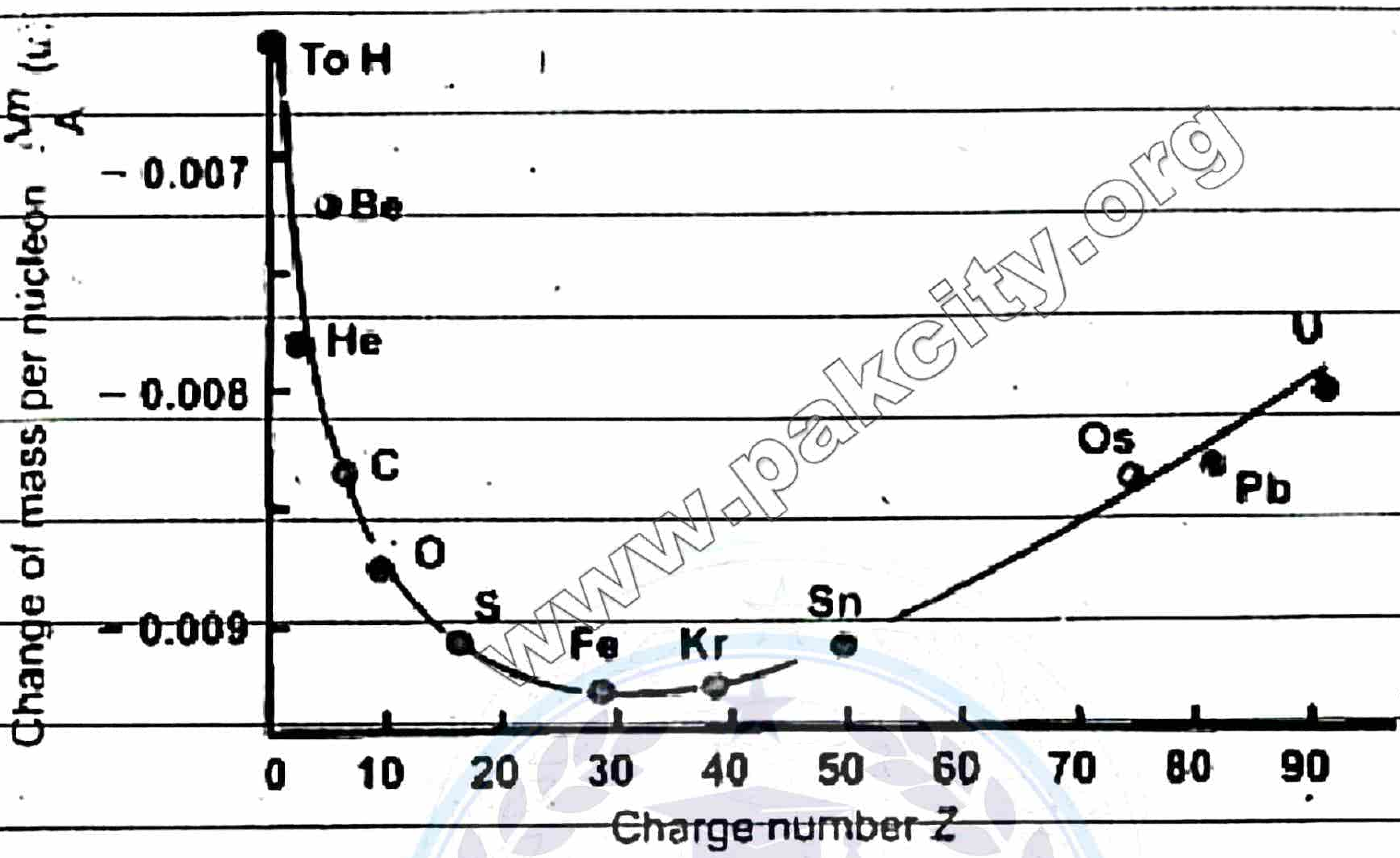
$$\Delta m = Zm_p + Nm_n - m_{nucleus}$$

$\because A - Z = N$

N = No of neutrons.

Mass Defect Per Nucleon:

Mass defect per nucleon is obtained by dividing the mass defect "Δm" by mass number A i.e $\frac{\Delta m}{A}$



$$\frac{\Delta m}{A} = \frac{m_{nucleus} - [Zm_p + (A-Z)m_n]}{A}$$

Fig. shows a graph between mass defect per nucleon $\frac{\Delta m}{A}$ and charge number or atomic number Z.

Binding Energy B.E:

The missing mass i.e. mass defect Δm is converted into energy during the formation of the nucleus and is called the binding energy B.E.

Definition:

The energy required to break the nucleus into its nucleons i.e. neutrons and protons is called binding energy.

According to Einstein's mass energy relation.

$$E = mc^2$$

$$B.E = \Delta mc^2$$

$$B.E = [Zm_p - (A - Z)m_n - m_{nucleus}] \times c^2$$

$$B.E = Zm_pc^2 - (A - Z)m_nc^2 - m_{nucleus}c^2$$

Calculation for the B.E of Helium ${}^4_2He$:

Mass defect.

$$\Delta m = Zm_p + Nm_n - m_{{}^4_2He}$$

$$\Delta m = 2m_p + 2m_n - m_{{}^4_2He}$$

$$\Delta m = 2 \times 1.007825u + 2 \times 1.008665u - 4.0028u$$

$$\Delta m = 4.03298u - 4.0028u$$

$$\Delta m = 0.03018u$$

Since.

$$1u = 1.66 \times 10^{-27} kg$$

$$\Delta m = 0.03018 \times 1.66 \times 10^{-27} kg$$

$$\Delta m = 5.0099 \times 10^{-29} kg$$

As.

$$B.E = \Delta m \times c^2$$

$$B.E = 5.0099 \times 10^{-29}\,kg \times (3 \times 10^8\,ms^{-1})^2$$

$$B.E = 4.5 \times 10^{-12}\,J \qquad \because 1eV = 1.6 \times 10^{-19}\,J$$

$$B.E = \frac{4.5 \times 10^{-12}}{1.6 \times 10^{-19}}\,eV \qquad 1J = \frac{1}{1.6 \times 10^{-19}}\,eV$$

$$B.E = 2.82 \times 10^{7}\,eV$$

$$B.E = 28.2 \times 10^{6}\,eV \qquad \because 10^6 = M$$

$$\boxed{B.E = 28.2\,MeV}$$

It means that when two neutrons and two protons fuse together to form a helium nucleus, 28.2 MeV energy is required to break the Helium nucleus into two protons and two neutrons.

In this manner B.E of each element can be calculated.

Binding Energy Per Nucleon:

It is obtained by dividing the binding energy B.E with total number of nucleons (i.e mass number A). So $\left(\frac{BA}{A}\right)$

For example. ${}^4_2He$; A = 4

$$\frac{B.E}{A} = \frac{28.2\,MeV}{4\,nucleon} = 7.05\,MeV/nucleon$$

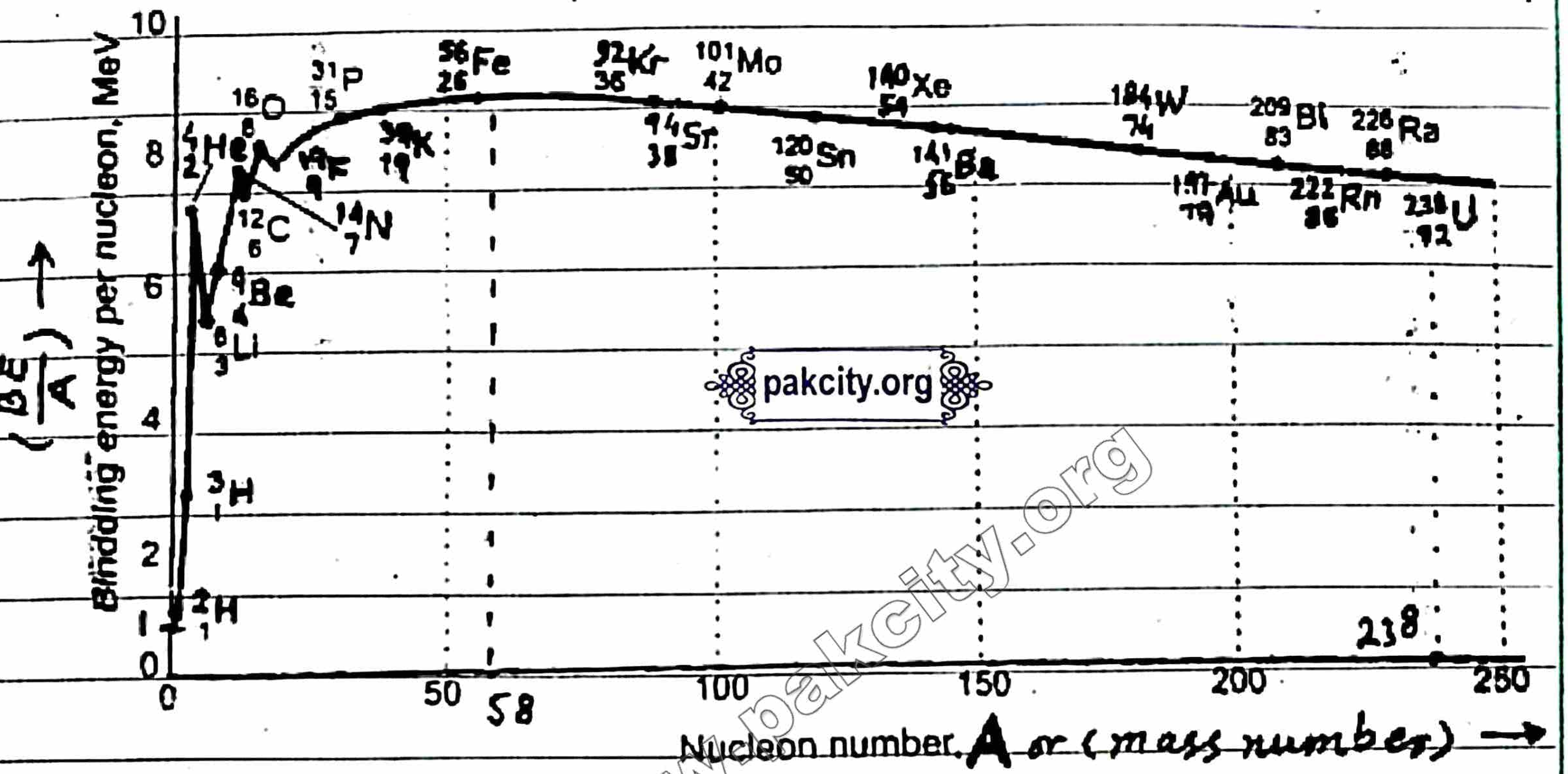


Fig. Shows a graph between B.E per nucleon $\frac{B.A}{A}$ and the mass number "A" of different elements.

The graph shows the Binding energy per nucleon increases with mass number till it reaches a maximum value of 8.8 MeV at mass number 58 and then it gradually decreases to a value of 7.6 MeV at mass number 238.

21.4 Radioactivity

The elements having charge number Z > 82 are unstable. They emit invisible radiation which effect the photographic plate. Such elements are called Radioactive and the proces is called Radioactivity.

The radiations emitte by radioactive elements are of three types.

(i) α alpha (ii) β beta (iii) γ gamma

Radioactivity is a purely nuclear phenomenon. It is not affected by any physical or chamical reaction. Radioactivity does not depend upon physical state of the radioactive material such as temperature, Pressure, density etc.

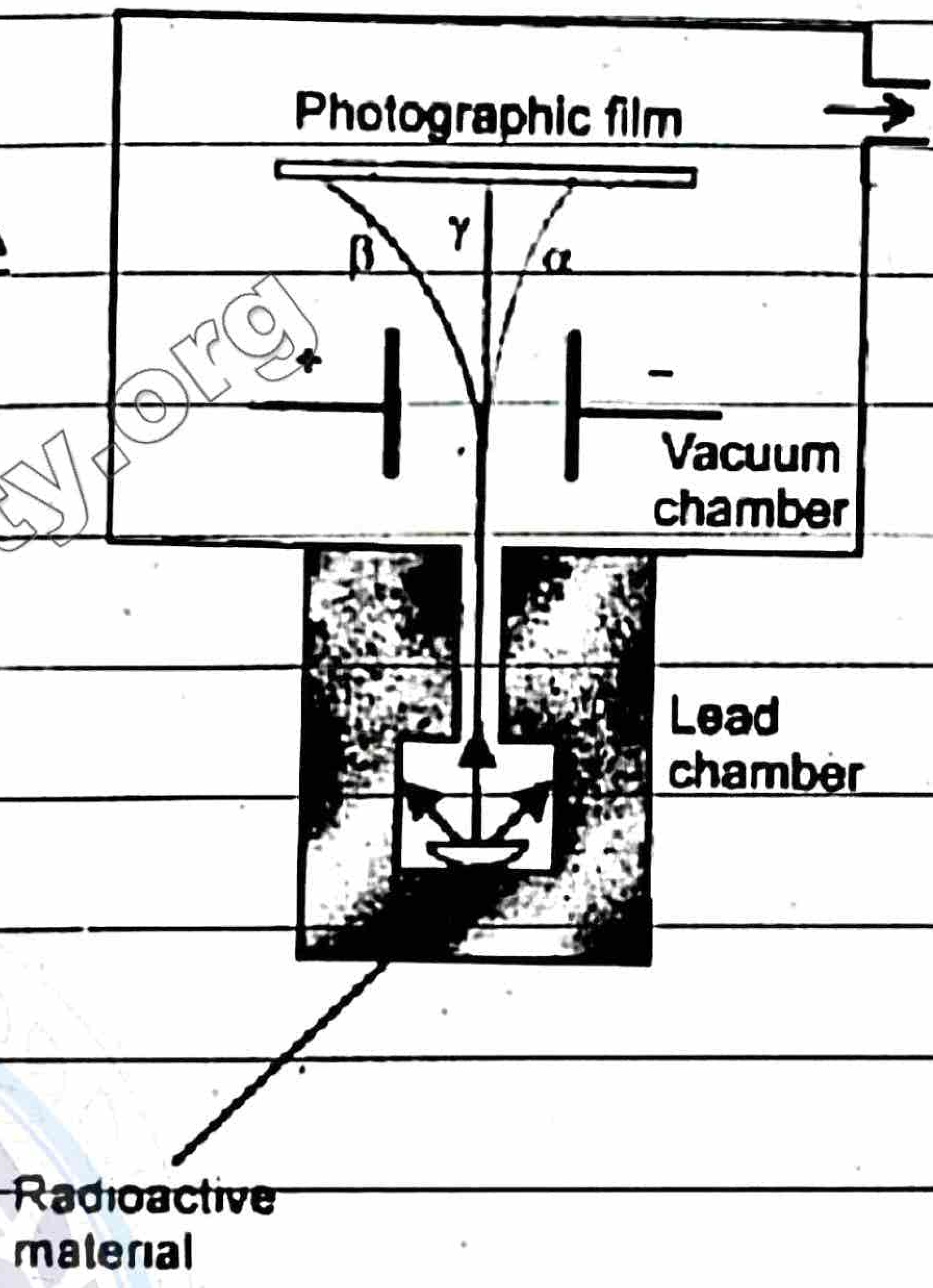
Discovery:

Radioactivity was discovered by Henri Becquerel in 1896. He found that an are containing Uranium (Z = 92) emits an invisible radiation which penetrates through a black paper wrapping a photographic plate, and affects the plate.

After Becquerels discovery Marie curie and Pierre curie discovered two new radioactive elements Polonium and Radium.

Explanation:

The radioactive material is placed at the centre of a block of Lead by drilling a hole in the block.



Radioactive radiations enter a vacuum chamber after emerging out of this hole. After passing between the two parallel charged plates. the radiations strike a photographic plate at three different points.

Conclusion:

From this experiment we conclude that.

i): All radiations from radioactive material are not alike (same).

ii): The radiations bending towards the -ve plate are positively charged particles, called α particles.

iii): The radiations bending towards the +ev plate are negatively charged particles, called β particles.

iv): The radiations that go straight without bending have no charge on them. These are called γ rays.

α Particles:

They are helium nuclei. Each α particle has 2 protons and 2 Neutrons. Their charge No. is 2 mass no is 4.

$Z = 2$; $A = 4$; ${}^{4}_{2}He$

β Particles:

They are fast moving electrons coming out of nucleus. Charge No. $Z = -1$ mass no $A = 0$ ${}^{0}_{-1}e$

γ Rays:

Like X rays. γ rays are electromagnetic rays coming out of nucleus. The wavelength of γ rays is much shorter then the X rays.

They have very high frequency.

Nuclear Transmutation or Radioactive Decay:

Whenever any particle or radiation is emitted out of a radioactive element, there is some change in the nucleus of the element. So, this element changes into a new element. This process is called radioactive decay.

Parent Element:

The orignal element is called parent element.

Daughter Element:

The element formed due to radioactive decay is called daughter element.

During radioactive decay Law of conservation of charge number, mass number, momentum and mass energy remain applicable.

Forms of Radioactivity:

1) Alpha Decay:

In an α decay the parent element loses 2 protons and 2 neutrons.

So, the charge number z (Atomic number) of daughter nucleus decreases by 2. The mass number A (number of protons plus neutrons) decreases by 4.

$$^{A}_{Z}X \longrightarrow ^{A-4}_{Z-2}Y + ^{4}_{2}He$$

Here:

$^{A}_{Z}X$ = Parent element

$^{A-4}_{Z-2}Y$ = Daughter element

Example:

$$^{226}_{88}Ra \longrightarrow ^{222}_{86}Rn + ^{4}_{2}He$$

$$^{238}_{92}U \longrightarrow ^{234}_{90}Th + ^{4}_{2}He$$

Ra – Radium
Rn – Radon gas
U – Uranium
Th – Thorium

β Decay:

Negative β particle is an electron. It comes out of the nucleus. As there is an electron present inside the nucleus. So, it is formed at the time of emission.

At the moment of emission "A neutron is converted into a proton and a negative β particle is emitted."

$$_{0}^{1}n \longrightarrow {}_{1}^{1}H + {}_{-1}^{0}e$$

(neutron) (proton) (β particle)

During β emission, No change in mass number A. Charge No. or Atomic number increases by 1.

Example:

$$_{90}^{234}Th \longrightarrow {}_{91}^{234}Pa + {}_{-1}^{0}e$$

$_{91}^{234}Pa$ Protactanium

Gamma Decay:

After the emission of α or β particle the nucleus is sometimes excited to a higher state. The excited state of the nucleus is unstable, so it comes back to the ground state by emitting γ radiation. γ Ray is simply photon (Packet of energy)

During γ emission, No change in charge number Z. No change in mass number A.

$$_{Z}^{A}X^{*} \longrightarrow {}_{Z}^{A}X - \gamma \text{ radiation}$$

$_{Z}^{A}X^{*}$ = Excited nucleus.

$_{Z}^{A}X$ = Ground state of Nucleus.

21.5 Half Life

Definition:

"The half life $T_{1/2}$ of a radioactive element is that period in which half of the atoms decay."

Whenever an α or β particle is emitted from the radioactive element, it is transformed into some other element. This radioactive decay process is quite random.

We cannot foretell about any particular atom as to when will it decay. It could decay immediately or it may remain unchanged for millions of years. Hence we do not talk about a single atom, but we talk about the group of atoms.

Example:

Consider a sample of 100,000 radioactive atoms. Suppose it Half $T_{1/2} = 1$ day. After 1 day 50,000 atoms decay into their daughter element. After 2 days 25000 atoms decay and 25000 are left undecayed. And so on, with the passage of every one day, the number of atoms remaining behind be-comes half of the number already present.

Conclusions :

★ ; No radioactive element can completely decay. It is due to reason that in any half life period only half of the nuclei decay and in this way infinite time is required for all the atoms to decay.

★ ; The number of atoms decaying in a particular period is proportional to the number of atoms present in the beginning of the period.

If the number of atoms to start with is large, then a large number of atoms will decay in this period and if the number of atoms present in the beginning is smell then less atom will decay.

Results in form of equation:

This result is expressed in the form of equation as follows.

Let,

N = Number of radioactive atoms present at any particular time.

ΔN = Number of atoms decaying in time Δt, ΔN is proportional to number of atoms N and time interval Δt.

$\Delta N \propto -N$ ∵ -ve sign shows that with the passage of time N decreases.

$\Delta N \propto \Delta t$

Combining these two

$\Delta N \propto -N\Delta t$

$\Delta N = (\text{constant}) - N\Delta t$ ∵ λ = constant

$$\Delta N = -\lambda N \Delta t \rightarrow (1)$$

Equation (1) shows that if the decay constant of any element is large then in a particular interval more of its atoms will decay and if the decay constant λ is small then in that very interval less number of atoms will decay.

Equation (1) can be written as.

$$\lambda = -\frac{\Delta N / N}{\Delta t}$$

Definition:

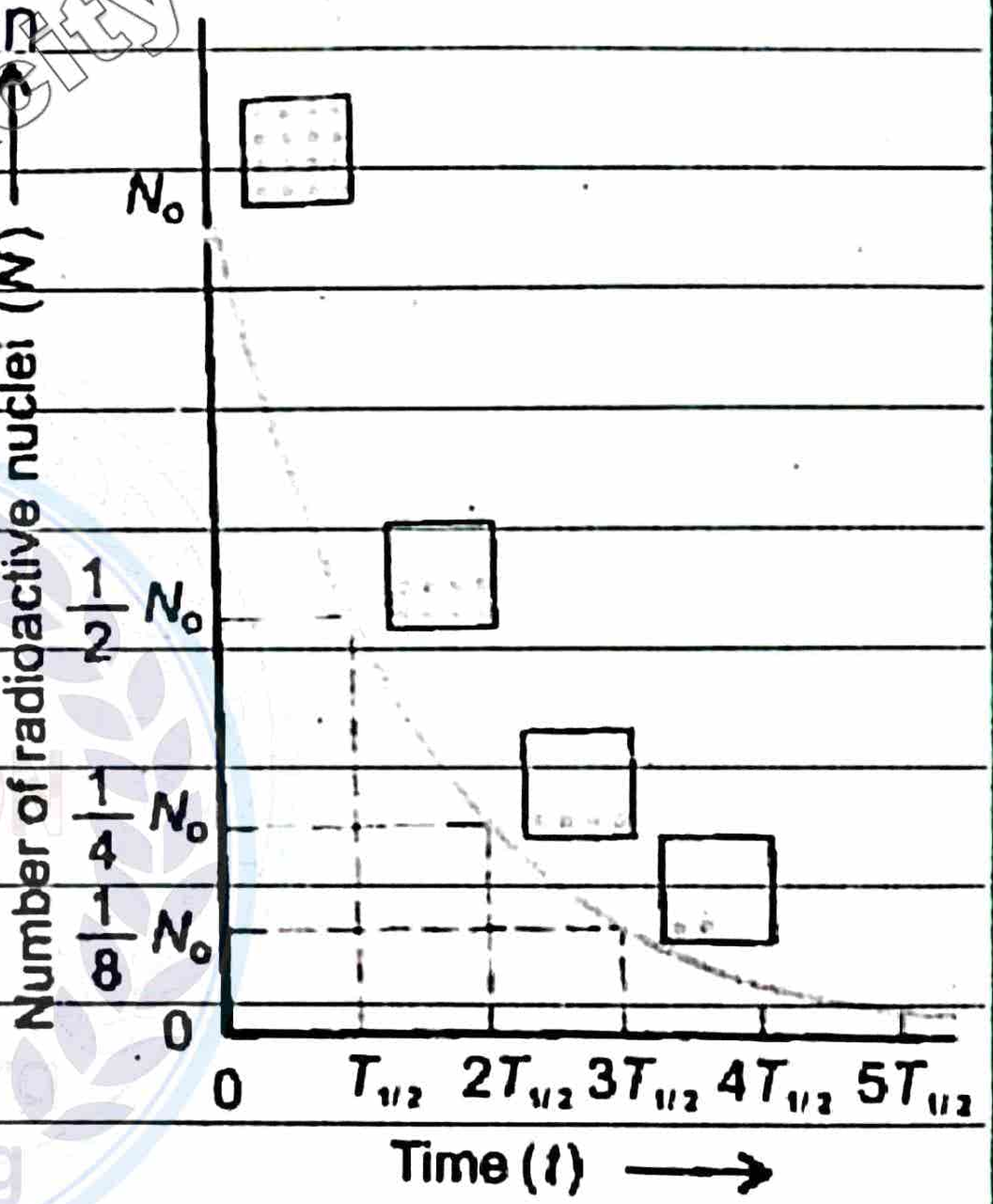
"The ratio of the fraction of decaying atoms per unit time is called decay constant."

Unit:

SI unit of decay constant is s^{-1}.

Decay Curve:

It is shown in fig. It is a graph between number of atoms in the sample of the radioactive element present at different times and the time.



The half life $T_{1/2}$ of a radioactive decay is the time in which one-half of the radioactive nuclei disintegrate.

At $t = 0$ the number of atoms in a given sample of radioactive element is N_0.

After one half life $T_{1/2}$ the remaining number of atoms is $= \frac{N_0}{2} = \frac{1}{2} N_0$

After 2nd half life $2T_{1/2}$

$$= \frac{N_0/2}{2} = \frac{1}{2} \times \frac{N_0}{2} = \frac{1}{4} N_0$$

$$= \left(\frac{1}{2}\right)^2 N_0$$

After 3rd half life $3T_{1/2} = \frac{N_o/4}{2} = \frac{N_o}{8} = \left(\frac{1}{2}\right)\left(\frac{1}{2}\right)^2 N_o$

$= \left(\frac{1}{2}\right)^3 N_o$

After n^{th} half life $nT_{1/2} = \left(\frac{1}{2}\right)^n N_o$

21.6 Interaction of Radiation with matter

1) Interaction of α-Particles with matter:

1): An α-particle travels a well defined distance in a medium before coming to rest. This distance is called the range of the particle.

2): As the particle passes through a solid, liquid or gas it loses energy due to exitation and ionization of atoms and molecules in the matter.

3): The ionization may be due to direct elastic collisions or through electrostatic attraction.

4): Ionization is the main interaction with matter to detect the particle or to measure its energy.

5): Range depends upon

i): Charge, mass and energy of the particle.

ii): The density of the medium and ionization potentials of the atoms of the medium.

2) Interaction of β Particle with matter:

1): β particles also lose energy by producing ionization.

2): Its ionization ability is 100 times less then that of α particles.

3): So its rang is 100 times more then α particles.

4): The rang of β particles is measured

by the effective depth of penetration in to the medium not by the length of erratic path.

5): The more dense the material through which β-particles pass, the shorter its range will be. (zig zag path)

∴ Both α and β-particles radiate energy as X-ray photons, when they are slowed by the electric field of the charged particles in a solid material.

3): Interaction of γ-Rays with matter:

1): γ-ray photons produce very litte ionization because it has no charge.

2): Photons are removed from a beam by either scattering or absorption in the medium.

3): γ-rays inter act with matter in three ways, depending on their energies.

a) At Low Energies: (less than about 0.5 MeV) The dominant process is Photoelectric Effect.

b) At Intermediate Energies: (between 0.1 MeV - 1 MeV)

The dominant process is Compton scattering.

c) At higher Energies: (more than 1.02 MeV)

The dominant process is pair production.

γ-ray Intensity:

In air γ-rays intensity "I" falls off as the inverse square of the distance from the source.

$$\left(I \propto \frac{1}{r^2} \right)$$

In solids, the intensity decreases exponentially with increasing depth of penetration into the material. The intensity "I_o" of a beam after passing through a distance "X" in the medium is reduced to intensity "I" given by the relation.

$$I = I_o e^{-\mu x}$$

μ = Linear absorption coefficient of the medium (solid). μ depends upon the energy of the photon as well as on the properties of the medium.

Fluorescence:

"Fluorescence is the property of absorbing radiant energy of the high frequency and re-emitting energy of low frequency in the visible region of electromagnetic spectrum." Charged particles α, β, and γ radiation produce Fluorescence or glow on striking some substance like zinc sulphide, sodium iodide or barium platinocyanide coated screens.

4): Ineraction of Neutrons with matter:

1): Being neutral particles their range is very large. They are extremely penetrating particles.

2): To be stopped or slowed, a neutron must under go a direct collision with a nucleus or some other particle that has a mass comparable to that of the neutron.

Materials such as water or plastic

which contain more low-mass nuclei per unit volume are used to stop neutrons.

3): Neutrons produce a very little indirect ioniztion when they interact with materials containing Hydrogen atoms and knock out protons.

Table : The summary of the nature of α, β & γ radiation

Characteristics	α–particles	β–particles	γ–rays
1. Nature	Helium nuclei of charge 2e	Electrons or positrons from the nucleus of charge ±e	E. M. waves from excited nuclei with no charge
2. Typical sources	Radon-222	Strontium-94	Cobalt-60
3. Ionization (Ion pairs mm^{-1} in air)	About 10^4	About 10^2	About 1
4. Range in air	Several centimetres	Several metres	Obeys inverse square law
5. Absorbed by	A paper	1~5 mm of Al sheet	1~10 cm of lead sheet
6. Energy spectrum	Emitted with the same energy	Variable energy	Variable energy
7. Speed	~ $10^7\ ms^{-1}$	~$1 \times 10^8\ ms^{-1}$	~$3 \times 10^8\ ms^{-1}$

21.7 Radiation Detectors

Nuclear radiations cannot be detected by our sences. Radiation detectors these radiations.

Most of the detectors uses the fact that radiations (α, β, γ) produce ionization in matter.

Wilson Cloud Chamber:

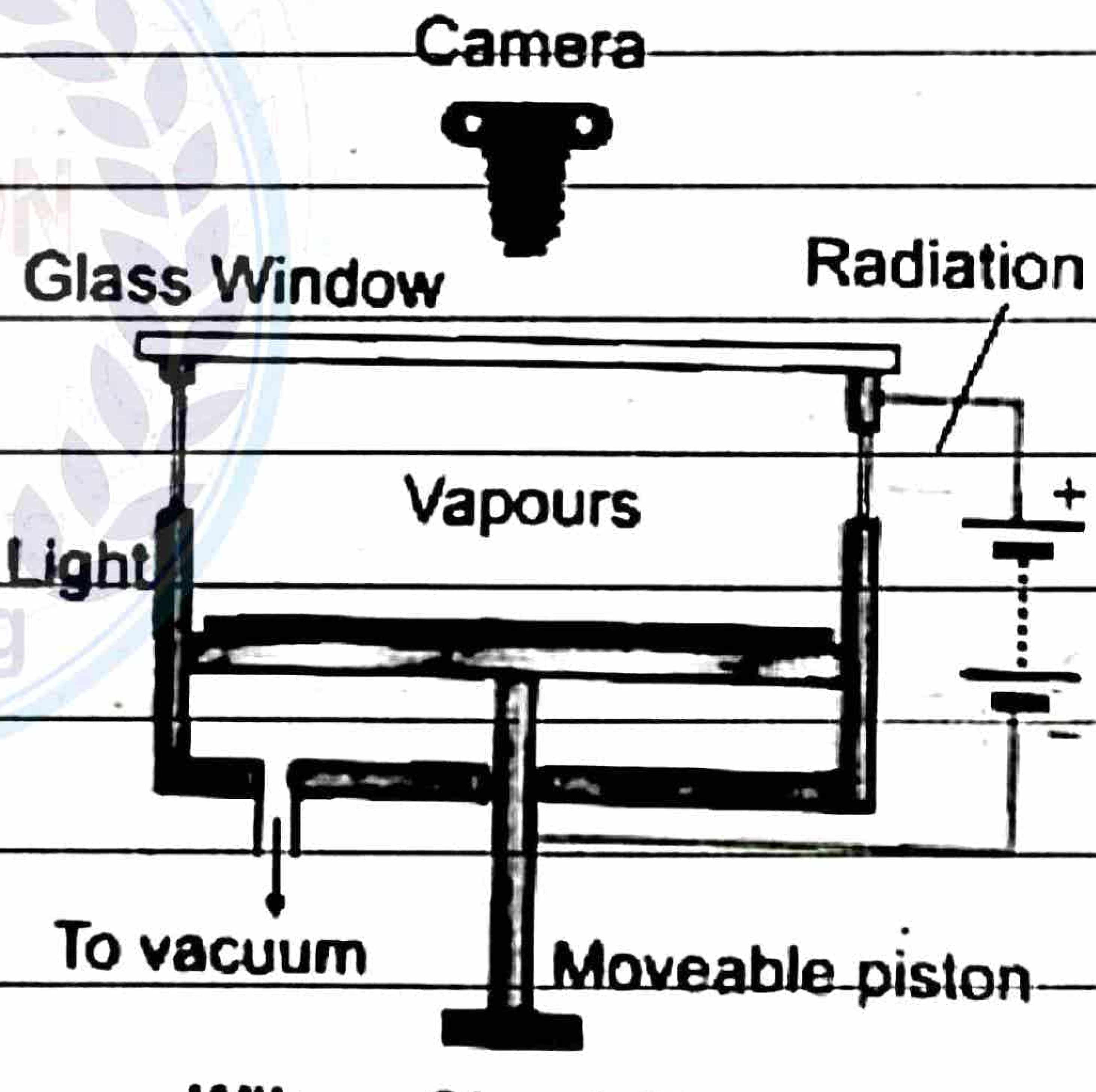
It is a device which shows the visible path of an ionizing particle.

Principle :

Super saturated vapours condense preferentially on ions. If an ionizing particle passes through a region in which cloud droplets are about to form, the droplets will be formed first along the particles path, showing the path as a trail of droplets.

Apparatus :

The apparatus consists of a cylinderical glass chamber closed at the upper end by a glass window and at the lower end by a movable piston. (Fig)



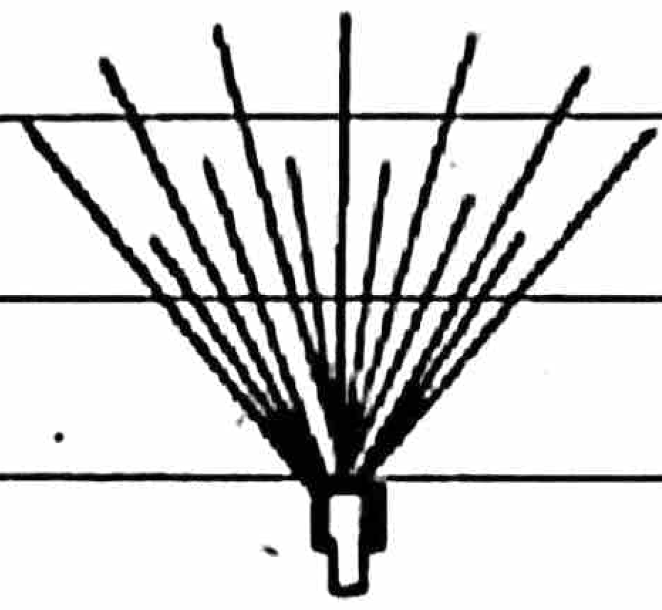
Wilson Cloud Chamber

A black felt pad soaked in alcohal is placed on a metal plate inside the chamber, alcohal vapours. A rapid expansion is produced by pulling quickly the piston. This adiabatic expansion produces sudden cooling which help to form super-saturated vapours.

Working:

As radiation pass through the chamber, ions are produced along the path. The tiny droplets of moisture condense on these ions and from vapour tracks showing the path of the radiation. The fog tracks are made visible with a lamp and may be seen or photographed through the glass window.

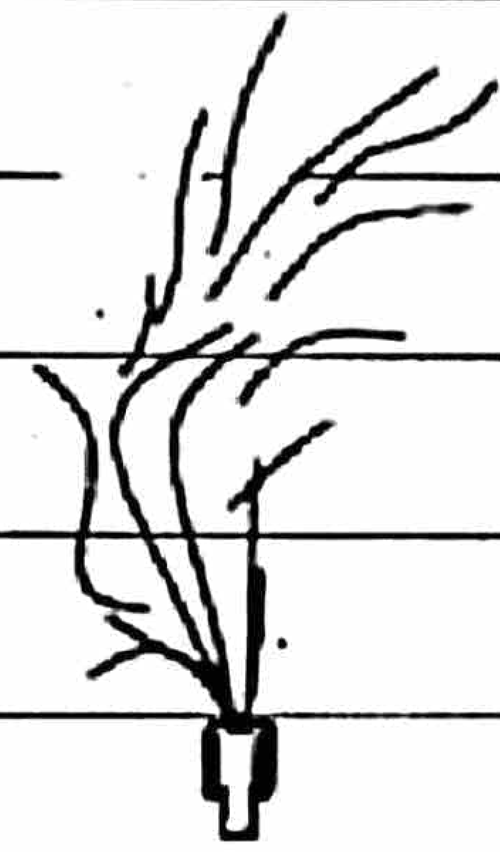
Tracks of:



(a) . α- Particle

i) α-Particles:

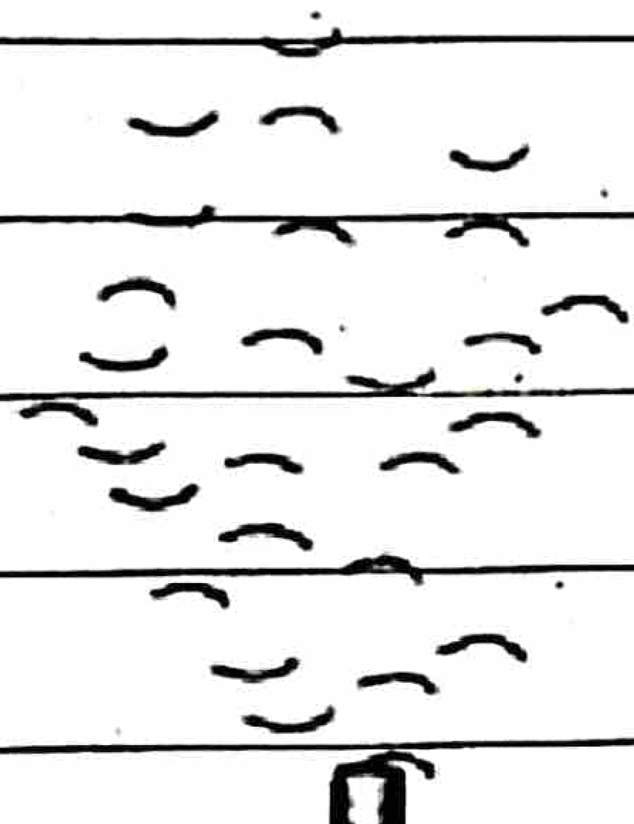
α-Particles leave thick, straight and continuous tracks due to intense ionization produced by them as shown in fig (a).



(b) β-Particle

ii) β-Particles:

They form thin and discontinuous tracks extending in erratic manner showing frequent deflections. (b).



(c) γ-Rays

iii) γ-Rays:

They leave no definite track along their path. The length of the tracks is proportional to the energy of the incident particle.

A high potential Difference:

A high potential difference of the order of 1 kV (1000 volts) between the top and bottom of the chamber provides an electric field which clears away all the unwanted ions from the chamber to make it ready for the next use.

A strong Magnetic Field:

Is applied inside the chamber which bends the paths providing information about the charge, mass and energy of the radiation particle. In this way it has helped in the discovery of new particles.

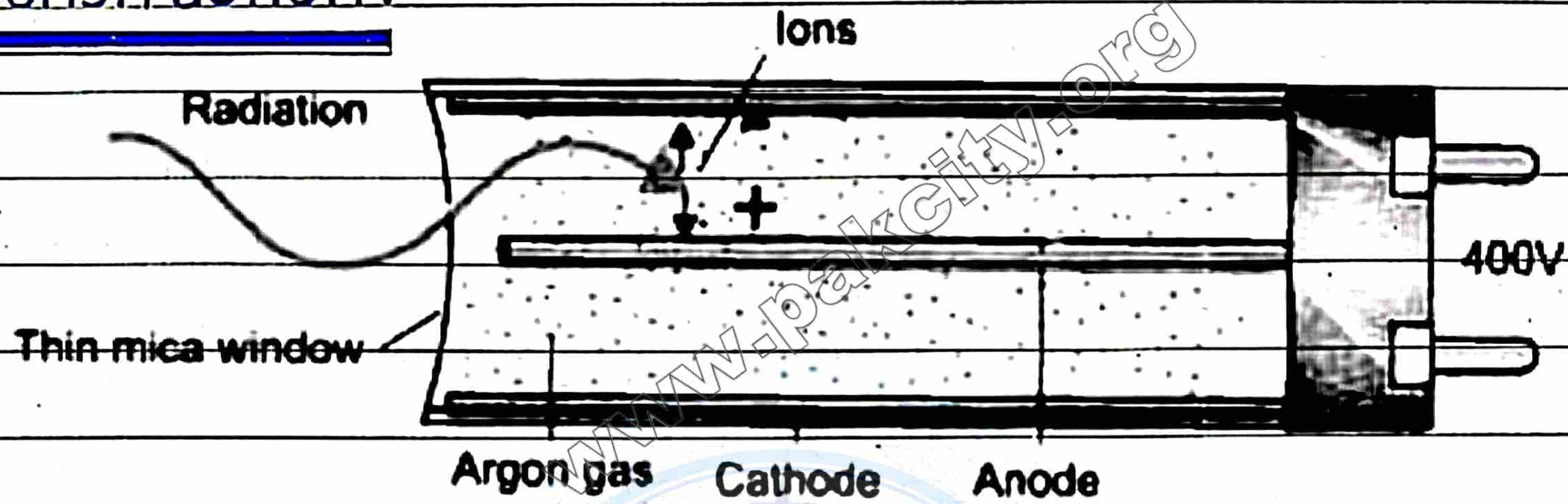
GeiGer-Muller counter:

It is a well known radiation detector.

Principle:

The discharge in the tube is produced due to the ionization produced by the incident radiation.

Construction:



Geiger – Muller Tube

It consists of stiff central wire acting as anode in a hollow metal cylinder acting as cathode. Suitable mixture of gas is filled in the cylinder (tube) at about $\frac{1}{10}$ th (0.1) of atmospheric pressure.

One end of the tube has a thin mica window through which α or β particles enter the tube and the other end is sealed by non-condcting material and carries the connecting pins for the two electrodes.

Working:

A high potential difference (about 400 volt for neon bromine filled tubes) but slightly less than that necessary to droduce discharge through the gas is maintained between the electrodes.

When radiation enters the tube, ionization is produced. The free electrons are attracted towards the positively charged central wire. As they are accelerated towards the wire by a strong electric field, they collide with other molecules of the gas and knock out more electrons which in turn do the same and produce a cascade of electrons that move towards the central wire.

This makes a short pulse of electric current to pass through an external resistor. It is amplified and registered electronically. The counter, which also provides the power is called a scaler.

The cascade of electrons produced by the entry of an ionizing particle is counted as a single pulse of approximately of the same size what ever the energy or path of particle may be. Thus, it cannot distinguish between the energies of the incident particle as output pulses are same. The entire electron puls takes less than 1 μs.

Dead time:

The positive ions take several hundred times as long to reach the outer cathode, because posite ions are very massive than the electrons. During this time further incoming particles cannot be counted. This time is called the dead time ($10^{-4}s$).

Spurious (false) counts:

When positive ions strike the cathode, secondary electrons are emitted from the surface. These electrons would be accelerated to give further spurious counts.

Quenching of the discharge:

i) Self Quenching:

The spurious counts

is prevented by mixing a small amount of quenching gas with the principal gas (Neon). The quenching gas must have an ionization potential lower then that of inert or principal gas.

Thus the ions of quenching gas reach the cathode before the principal gas ions. When they reach near the cathode, they capture electrons and become neutral molecules. Following neutralization, the excess energy of the quenching molecules is dissipated in dissociation of the molecules rather than in the release of electrons from the cathode.

Electronic Quenching:

For this purpose a large negative voltage is applied to the anode immediately after recording the output pulse. This reduos the electric field below the critical value for ionization by collision. The negative voltage remains untill all the positive ions are collected at cathode thus preventing secondary pulses.

Uses:

Geiger Counter can be used to determine the range or penetration power of ionizing particles. The reduction in the count rate by inserting metal plates between the source and the tube helps to estimate the penetration power of the incident radiation.

Solid State Detector:

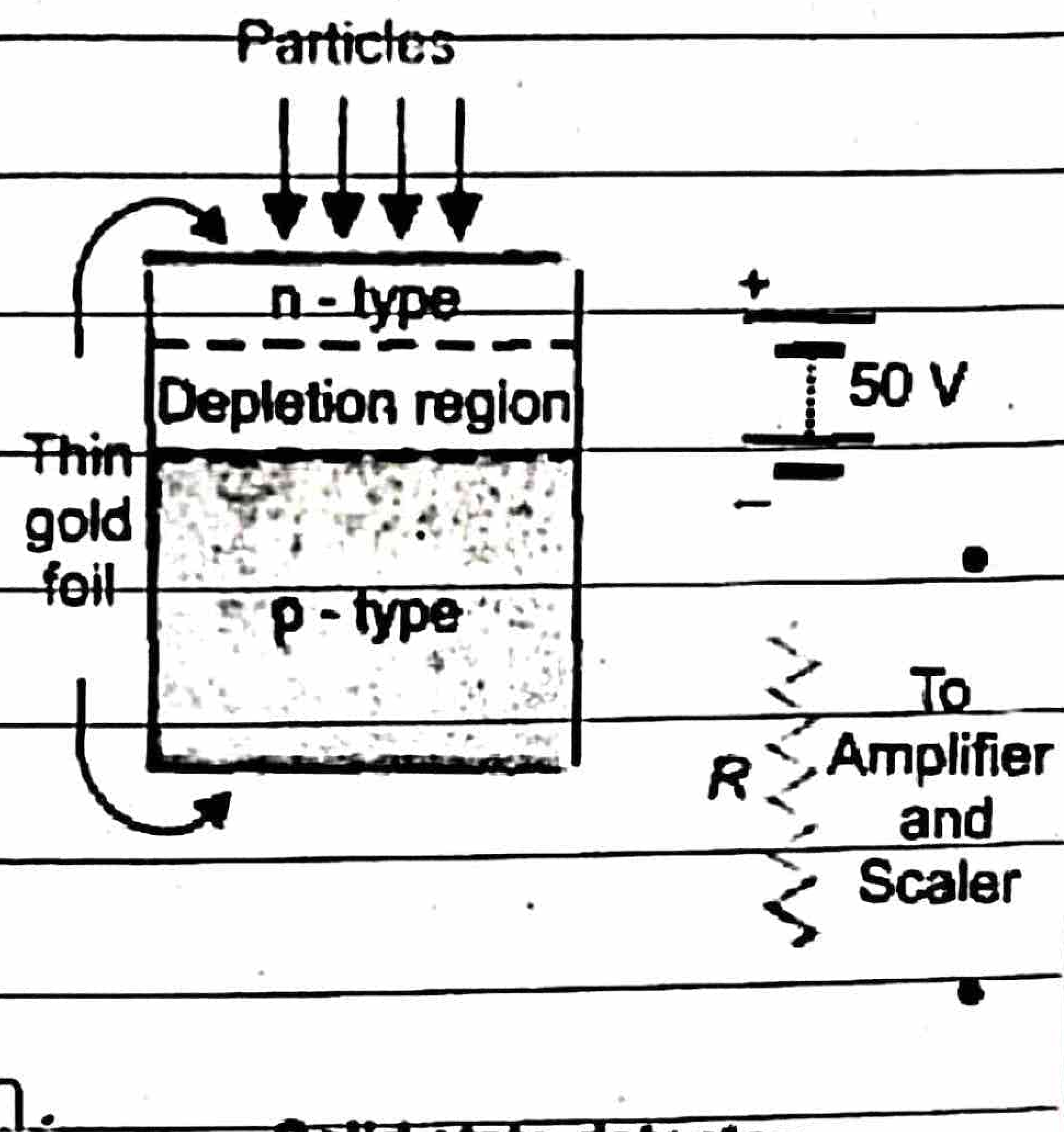
Solid state detectors are fast enough, more efficient and accurate, radiation.

Principle:

It is based upon the principle that when radiation is allowed to enter the depletion region, electron hole pairs are produced.

Construction:

A solid state detector is a specially designed pn-junction as shown in Fig. The detector is made from a P-type silicon or germanium.



Solid state detector

An n-type thin layer is produced by doping the top surface with doner impurity. The top and bottom surfaces are coated with a thin layer of gold to make good conducting contact with externa circuit.

Working:

A reverse bias is applied through the two conducting layers of gold. This enlarges the charge free region around the junction which is called the depletion region.

Normally no current flows through the circuit. When an incident particle peretrates through the depletion region, it produces electron hole pairs. These mobile charge carriers move towards the respective sides due to applied electric field. The arrival of these charges at the two surfaces produce a potential drop across the junction.

This gives rise to a current pulse through the external circuit which is amplified and registered by a scalar unit.

Uses:

★; The production of a current pulse requires a small amount of energy roughly 3.0 ev to 4.0 ev. So, the device is practically useful for detecting low energy particles.

★; It is small in size than any other detector and operates at low voltage.

★; The collection time of electrons and holes is much less than gas filled counters (such as Geiger counter) and hence solid state counter can count very fast.

21.8 Nucler Reactions

When α-Particle is emitted from Radium 226, Radon 222 gas is formed:

$$^{226}_{88}Ra \rightarrow \ ^{222}_{86}Rn + \ ^{4}_{2}He$$

This equation represents a nuclear reaction. This reaction takes place by it self.

Rutherford first of all proved that induced nuclear reactions are possible.

In general, if a particle "x" is bombarded on any nucleus "X" and this process gives a nucleus "Y" and a light object "y".

$$X + x \longrightarrow Y + y$$

The first nuclear reaction was performed by Rutherford in 1918. He bombarded an α-Particle on Nitrogen. As a result Oxygen is obtained and a proton is emitted.

$$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$$

Conditions for Nuclear Reaction:

1): Before and after the nuclear reaction the number of protons and number of neutrons must remain the same, because these cannot by destroyed or produced. In the above reaction.

Number of Protons $7 + 2 = 8 + 1$

Number of neutrons $7 + 2 = 9 + 0$

2): In a nuclear reaction the total energy including the rest mass energy before and after the reaction remains constant. Consider the nuclear reaction.

$$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$$

Total mass of reactants = $m_{^{14}_{7}N} + m_{^{4}_{2}He}$
= 14.0031 u + 4.0026 u = 18.0057 u

Total mass of products = $m_{^{17}_{8}O} + m_{^{1}_{1}H}$
= 16.9991 u + 1.0078 u = 18.0069 u

So.

mass of products > mass of reactants

Difference in mass = 0.0012 u

∵ 1u = 931 MeV

So, 0.0012 u mass must be supplied to the reactants to produce this reaction. or energy 0.0012 X 931 MeV = 1.13 MeV must be supplied to the reactants.

It may in the form of K.E of α-particle. So α-particle coming out of $^{214}_{84}Po$ with energy equal to 7.7 MeV may be used which makes the above reaction possible.

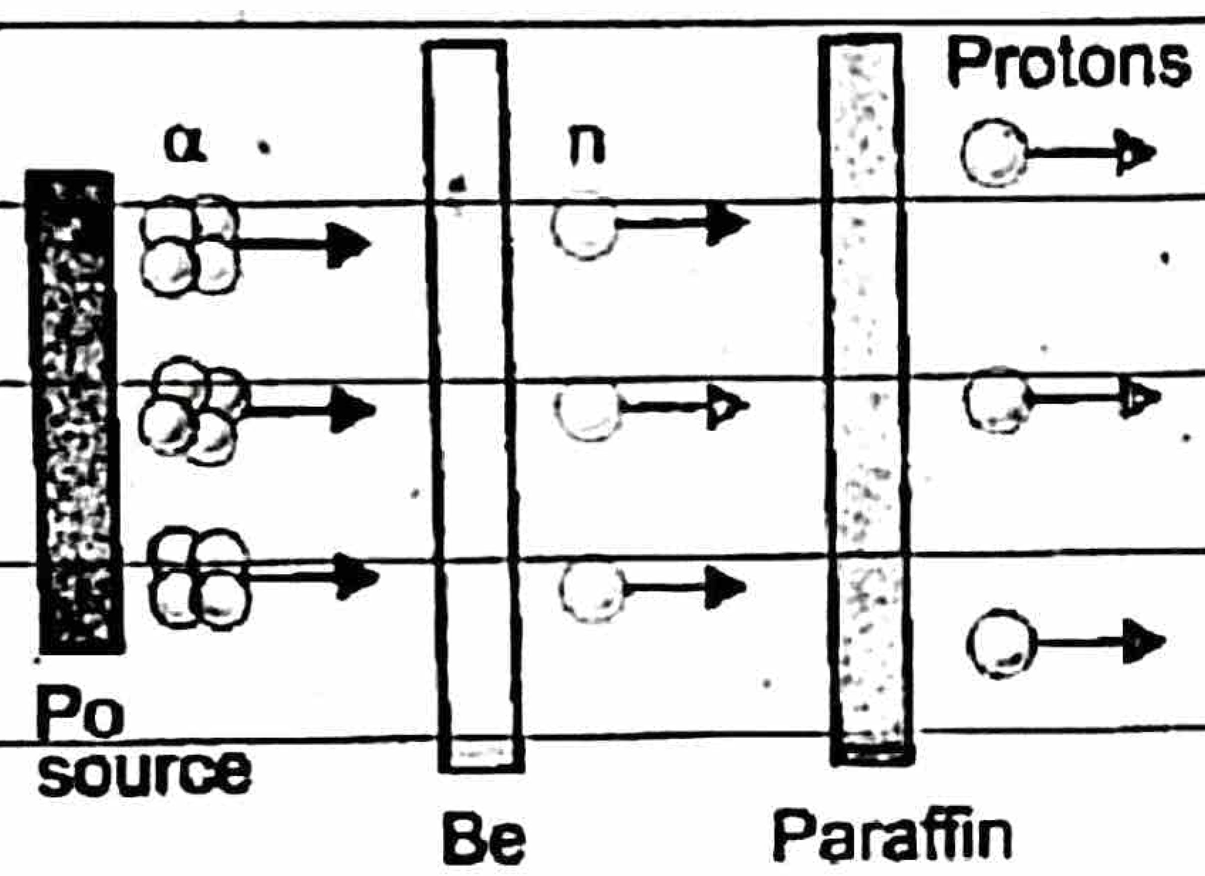
A nuclear reaction can take place in reverse direction. For example a proton accelerated to a very high velocity in a machine like cyclotron is bomborded on oxygen. Nitrogen is formed and an α-particle is liberated.

$$^{17}_{8}O + ^{1}_{1}H \longrightarrow ^{14}_{7}N + ^{4}_{2}He$$

In 1932 James Chadwick discovered Neutron with the help of following reaction. Chadwick bombarded α-particles on the nucleus of Beryllium $^{9}_{4}Be$ which is converted into carbon $^{12}_{6}C$ and a neutron was obtained.

$$^{9}_{4}Be + ^{4}_{2}He \longrightarrow ^{12}_{6}C + ^{1}_{0}n$$

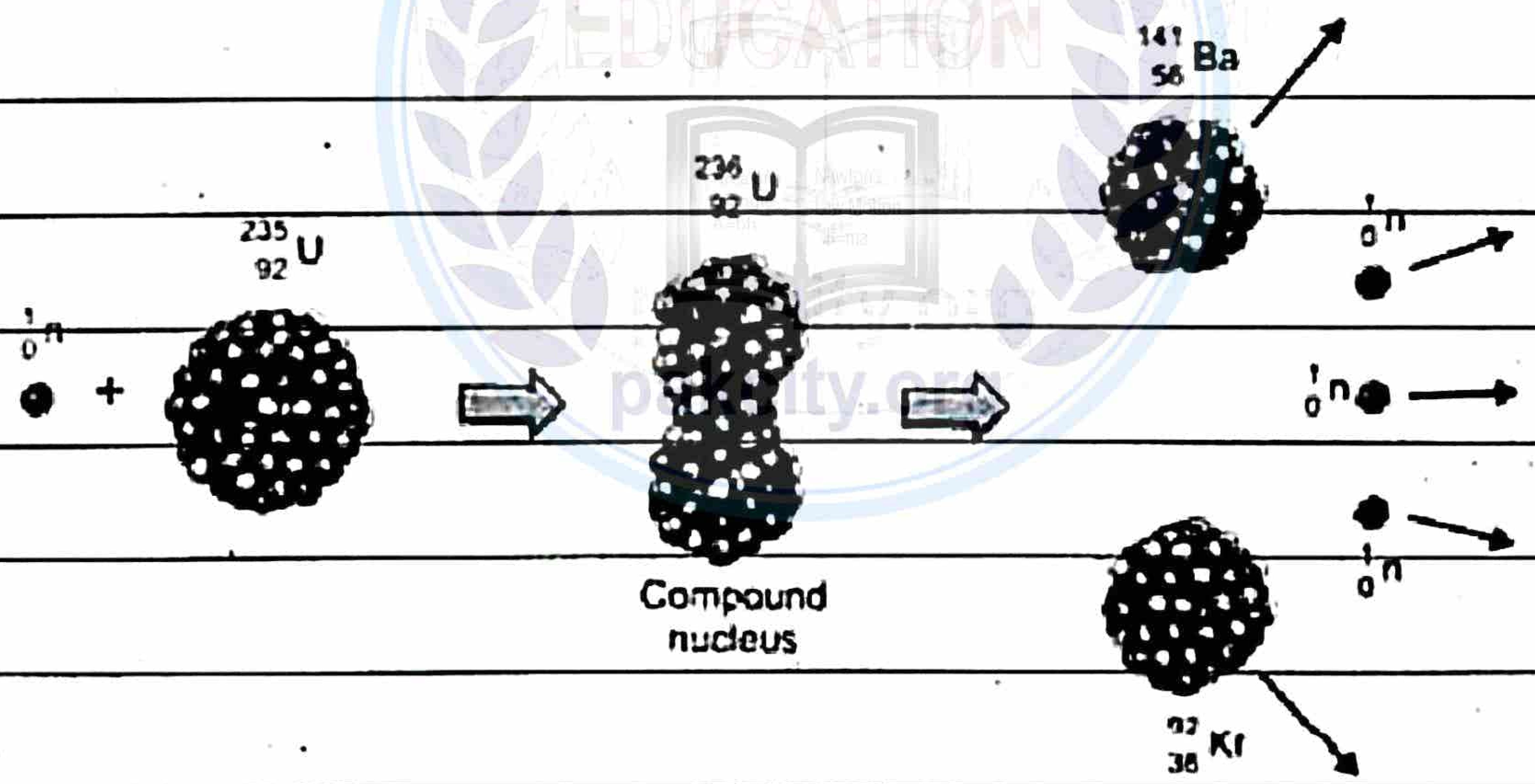
When neutrons are passed through a block of parafin, fast moving protons were ejected out of paraffin. This was so because the paraffin contains Hydrogen atoms whos nuclei are protons.



The mass of a proton is approximately equal to that of a neutron. A neutron makes an elastic collision with proton and knocks it out of paraffin.

21.9 Nuclear Fission

"Such a reaction in which a heavy nucleus like Uranium $^{235}_{92}U$ is broken into two nuclei of nearly equol size along with the emission of energy is called Fission Reaction."



Process of Fission reaction

Explanation:

In 1939 two German Scientists made a very important discovery. Their names are Otto Hahn and Fritz strassmann.

 They bombarded Uranium-235 $^{235}_{92}U$

with slow neutrons. A nuclear reaction took place. As a result, Barium $^{141}_{92}Ba$ and Krypton $^{92}_{36}Kr$ were formed and on the average 3 neutrons were released along with the release of 200 MeV energy.

This nuclear reaction is different from the other nuclear reactions in two way.

i): As a result of breakage of the Uranium nucleus two nuclei of almost equal size are obtained.

ii): A very large amount of energy is released.

Fission Reaction of $^{235}_{92}U$ is.

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + Q$$

$\because Q = 200$ MeV

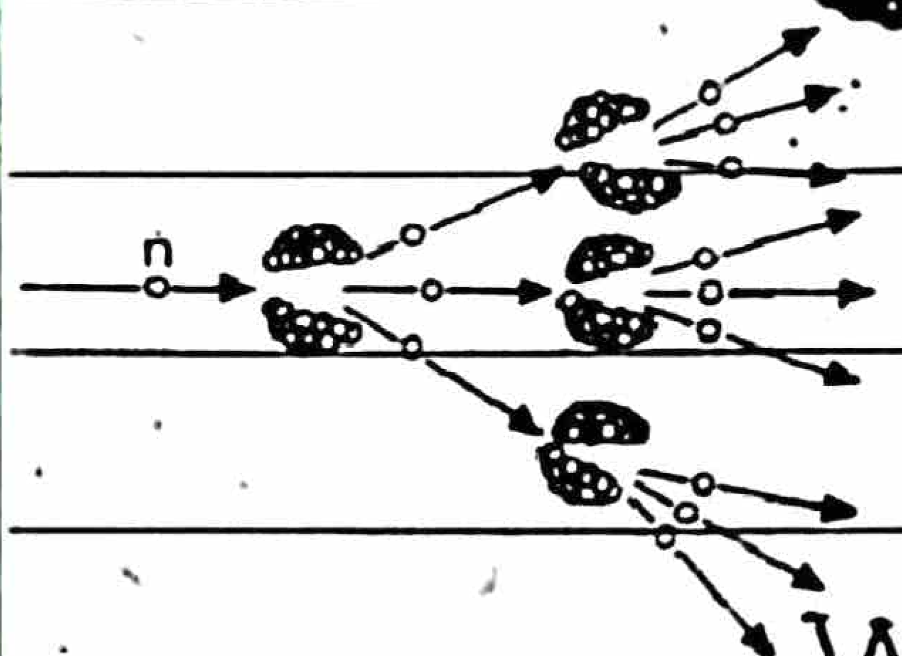
$Q = 200$ MeV of energy comes from the difference in the mass of reactants and mass of products.

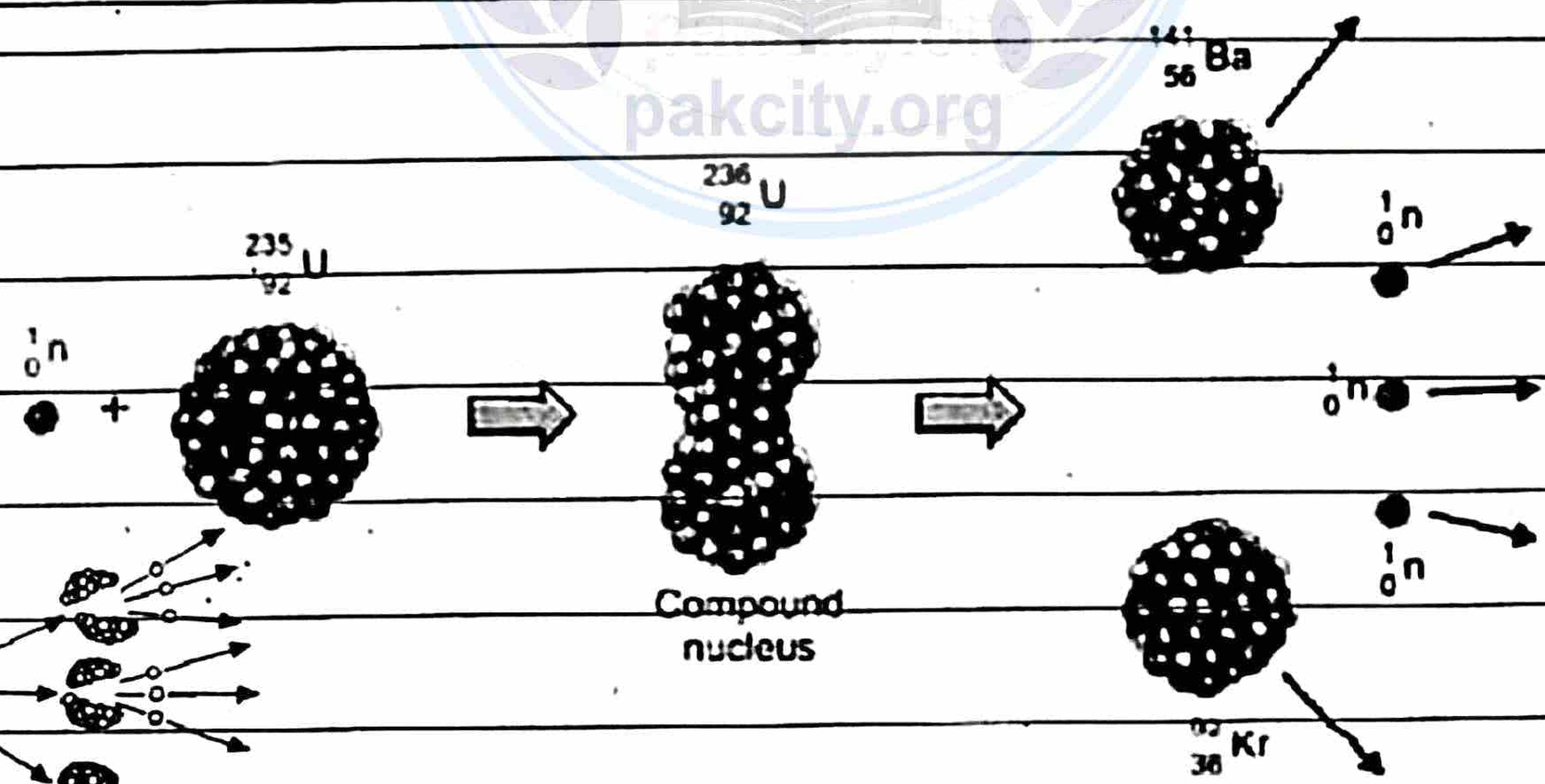
Fission Chain Reaction:

We Know that during a fission reaction a nucleus of U-235 absorbs a slow neutron and breaks into two nuclei of almost equal masses along with the emission of 2 or 3 neutrons By properly using these neutrons fission reaction can be produced in more Uranium atoms such that a fission reaction can continuously mantain itself. This process is called Fission Chain Reaction.

There are two types of Fission Chain Reaction.

1): Uncontrolled Fission Chain Reaction:





Process of Fission reaction

When $^{235}_{92}U$ is bombarded with a slow neutron. than $^{141}_{56}Ba$ and $^{92}_{36}Kr$ are fromed and three neutrons are emitted.

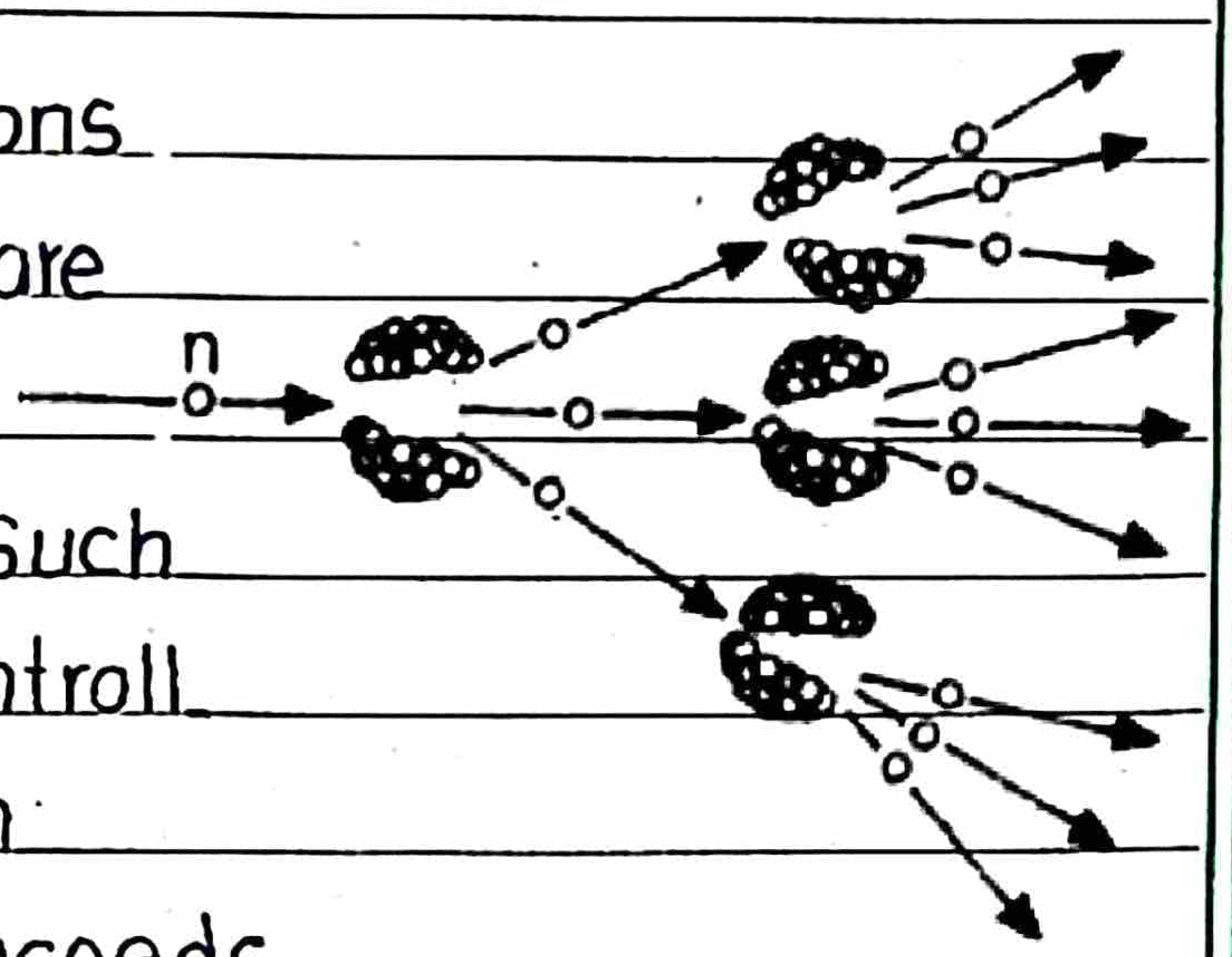
These 3 neutrons cause three more fission reactions in three $^{235}_{92}U$ atoms and 9 neutrons are produced. These 9 neutrons will cause additional fission. This way the process multiplies and is called uncontrolled Fission Chain Reaction as shown in fig.

This is the principle of the atom bomb. As a result of uncontrolled fission reaction in an atom bomb an atomic explosion takes place and a huge amount of energy is released.

2): Controlled Fission Chain Reaction:

It is possible to produce such condition in which only 1 neutron out of all the neutrons produced in one fission, produces further fission.

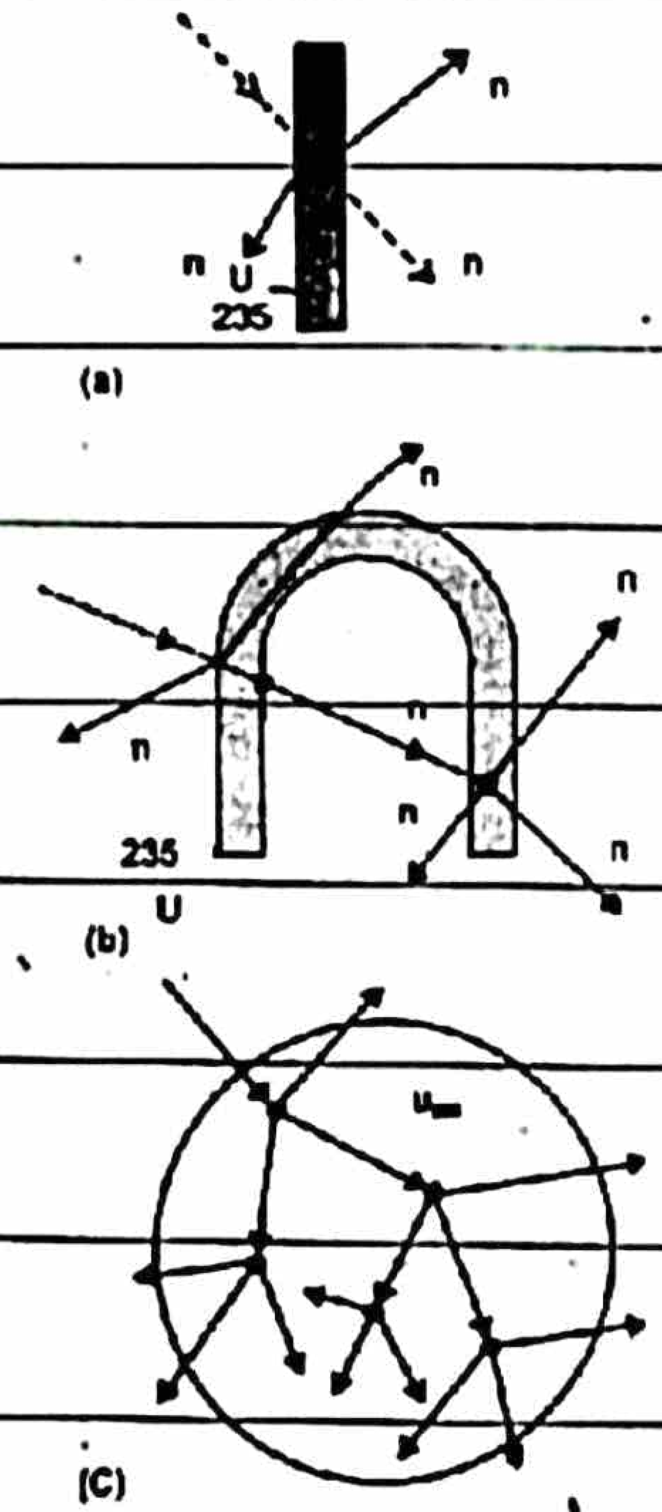
The other neutrons either escape out or are absorbed in some other medium except uranium. Such a reaction is called controlled fission chain reaction and Fission reaction proceeds



with constant initial speed.

In fig (a) a slow neutron is incident on a thin sheet of ${}^{235}_{92}U$. Fission takes place but three neutrons produced are scattered into air so no further fission can take place.

In fig (b) only two fission reaction take place. No further fission is possible. Hence chain reaction is not possible.



In fig (C) if the sphere of ${}^{235}_{92}U$ is big one then most of the neutrons produced due to fission reaction get absorbed in ${}^{235}_{92}U$ before escaping out of the sphere and produce a chain reaction.

Critical mass:

Such a mass of uranium which can sustain a chain reaction is called the critical mass.

Critical Volume:

Volume of the critical mass of Uranium is called critical volume.

Critical mass and Uranium mass:

1): If the mass of uranium is much greater than the critical mass, then the chain reaction proceeds at a rapid speed and a huge explosion is produced. Atom bomb works at this principle.

2): If the mass of uranium is less than the critical mass then the fission chain reaction does not proceed.

3): If the mass of uranium is equal to the critical mass, then chain reaction will proceed at its initial speed and in this way we gat a source of energy.

Energy in an atomic reactor is obtained according to this principle i.e, Controlled chain reaction.

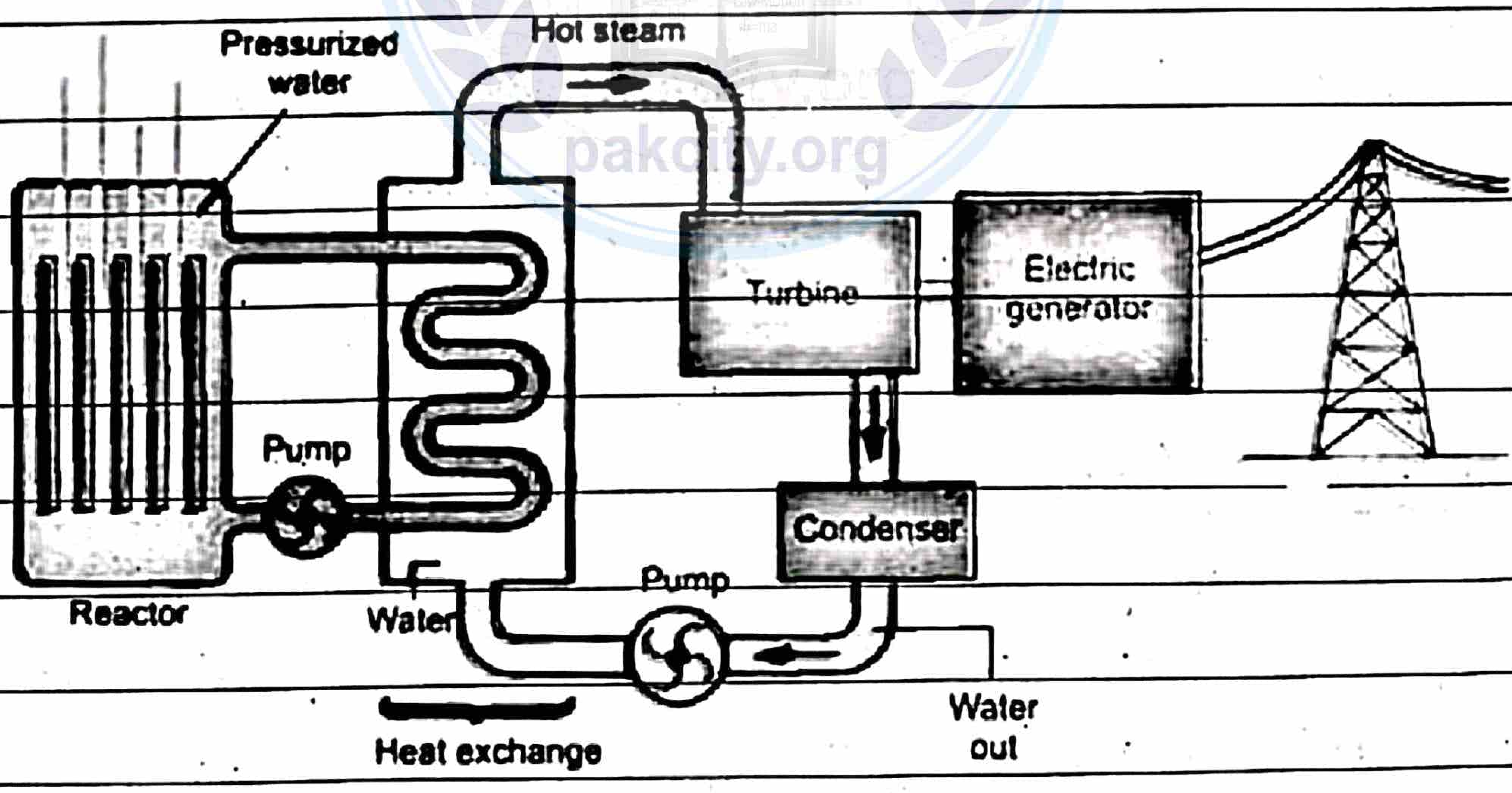
Nuclear Reactor:

It is a device in which nuclear fission chain reaction takes place at a constant rate in a controlled manner. It is used to produce nuclear energy for industrial and other useful purposes.

Principle:

Controlled fission chain reaction is the principle of a nuclear reactor.

Explanation:



The role of a reactor in a nuclear power station is the same as that of a furnace in a thermal power station. Heat energy is produced in fission reaction. This energy is used to rotate a turbine. The turbine rotates the generator which produces electricity. The sketch of a nuclear power station is shown in fig.

Construction:

1). Core:

It is main part of a nuclear reactor. Here fuel is kept in the form of cylinderical tubes. Reactor fuels are of various types.

Uranium was used as fuel in the elementary reactors. In this fuel the quantity of $^{235}_{92}U$ is increased from 2 % to 4 %. $^{235}_{92}U$ is only 0.7 % in naturally occuring uranium.

2). Moderator:

The fuel rods are placed in a substance of small atomic weight, such as water, heavy water D_2O, carbon or Hydrocarbons, etc. These substances are called moderators.

The function of these moderators is to slow down the speed of neutrons produced during fission process. Heavy water is made of $^{2}_{1}H$, a heavy isotope of Hydrogen instead of $^{1}_{1}H$.

The neutrons produced in the fission reaction are very fast and are not suitable for further fission in $^{239}_{92}U$ and $^{239}_{92}Pu$. For this purpose slow neutrons are more useful. To slow down the fast neutrons into slow neutrons moderators are used.

3). Absorbing Rods or Control Rods:

These are neutron absorbing rods which control the number of neutrons which produce nuclear fission reaction. For this purpose cadmium rods or Boron are used. These control rods are moved in or out of the reactor core to control neutrons that can initiate further fission. In this way speed of the Chain reaction is kept under control.

4). Heat Transfer:

When fission take's place in the core then heat is produced and temperature is, as high as 1200°C. Water is pumped into the reactor under high pressure to collect heat. When this very hot water is passed through the heat, exchanger where water is converted into steam to run the turbine and produce electricity with the help of a generator.

The temperature of the steam coming out of the turbine is 300°C. This is further cooled to water again. To cool this steam generally water from a river or sea is used.

In KANUPP Karachi nuclear power plant. heavy water is being used as moderator and also to transport energy from the core to the heat exchanger sea water is bing used to cool stream coming out from a turbine.

Disposal of the Nuclear waste:

The nuclear fuel once used for charging the reactor works for a faw months. The used fuel is then removed from the reactor and fresh fuel is fed into the reactor.

In the used fuel there is a large percentage of radioactive materials. There half life is about thousands of years. The radiations emitted from this used fuel are very injurious and harmful to the liring beings. Proper arrangement should be made to preserve this nuclear waste.

Salt mines:

The best place for the preservation is in the bottom of old salt mines, which are thousands of meters below the surface of the earth.

The nuclear waste material cannot be dumped into oceans or left in any place where they will contaminate the environement such as through soil or water.

Types of rectors:

Two main types of reactors.

1). Thermal Reactors:

The thermal reactors are one in which moderators are used to slow down the fast neutrons to thermal energies so that they can produce further fission. Either natural uranium or slightly enriched uranium as fuel.

Enriched uranium is one in which the % of $^{235}_{92}U$ is greater than its % in natural uranium.

There are many designs of thermal reactors but the most commonly used is the pressurized water Reactor (PWR) in which water is not allowed to boil due to a very high pressure.

2). Fast Reactors:

Fast reactors are one in which natural uranium $^{238}_{92}U$ is used as a fuel which is nearly 99% of uranium. $^{235}_{92}U$ absorbs a neutron and is converted into Plotonium - 239 i.e.

$${}^{238}_{92}U + {}^{1}_{0}n \longrightarrow {}^{239}_{93}Np + {}^{0}_{-1}\beta$$

(Neptunium)

$${}^{239}_{93}Np \longrightarrow {}^{239}_{94}Pu + {}^{0}_{-1}\beta$$

For neutrons can produce fission, so moderators are not requried in fast reactors.

Construction:

The core of a fast reactors contains a mixture of plotonium ${}^{239}_{94}P$ and uranium dioxide surrounded by a blanket of ${}^{238}_{92}U$. The neutrons which escape from the core, reacts with ${}^{238}_{92}U$ in the Blanket and finally produces Plotonium - 239. Thus more plstonium fuel is bred and so natural uranium is used more effectively. These fast reactors are also called fast breeder reactors.

21.10 Fusion Reaction

"Such a nuclear reaction in which two light nuclei merge to from a heavy nucleus is called fusion reaction."

In fission the energy released per nucleon is 0.90 MeV. It is due to the fact that binding energy per nucleon of fission fragments is greater than Uranium.

Energy from any nuclear reaction can be obtained provided the binding energy per nucleon of the products increases.

From the graph of binding energy per nucleon $\left(\frac{BA}{A}\right)$ and mass number (A), it is clear that binding energy per nucleon increases unit mass number (A) is 50. Hence two light nuclei when marged to form a heavy nucleus whose mass number is less than 50, then energy is released.

For example, when two protons and two neutrons are fused to from a helium nucleus then an energy of 28 MeV energy is given out.

During a fusion reaction, mass is lost which appears in the form of energy and this energy per nucleon is more than the energy released in fission. But at the same time, it is more difficult to start this reaction, because when two light nuclei are brought close to each other then a very large amount of energy is required to over come this repulsive Columb's force.

Where as in fission a neutron being neutral does not need large energy to reach a nucleus.

Example:

When two deuterons are (^2_1H) merge to form a helium nucleus, 24 MeV energy is released during this reaction.

$$^2_1H + ^2_1H \longrightarrow ^4_2He + Q\ (24\ MeV)$$

The probability of occuring this reaction is more when one proton or one neutron is produced.

$$^2_1H + ^2_1H \longrightarrow ^3_1H + ^1_1H + Q\ (4.0\ MeV)$$

$$^2_1H + ^2_1H \longrightarrow ^3_2H + ^1_0n + Q\ (3.3\ MeV)$$

In both of these reactions about 1.0 MeV energy per nucleon is produced which is equal to the energy produced during fission.

D-T Reaction (Deutrium ^2_1H - Tritium Reaction)

$$^2_1H + ^3_1H \longrightarrow ^4_2He + ^1_0n + Q\ (17.6\ MeV)$$

Different Methods for Producing Fusion

Reaction:

To produce fusion between two light nuclei, work has to be done to over come the repulsive force which exists between them. For this purpose the two nuclei, are moved towards one an other at a very high speed.

★: One method to do so is to give these nuclei a very large velocity with the help of an accelerator. This method has been used in the research study of nuclear fusion of (^3_1H). But this method cannot be used to obtain energy at large scale.

Nuclear Reaction in the Sun:

The sun is composed primerily of Hydrogen. It has a little amount of helium and a slight amount of other heavy elements. Sun is emitting large amount of energy continuously. The temperature of core of the sun is about 20 million °C and its surface sun. temperature is 5 million °C. Its energy is due to the fusion of two Hydrogen nuclei (i.e. 2 protons) (P.P. reaction) into deutron i.e

$$^{1}_{1}H + {}^{1}_{1}H \longrightarrow {}^{2}_{1}H + {}_{+1}e^{0} + \text{Energy} \quad \} \text{ Twice}$$

Deutron with proton forms $^{3}_{2}He$.

$$^{2}_{1}H + {}^{1}_{1}H \longrightarrow {}^{3}_{2}He + \gamma\text{ ray} + \text{Energy} \quad \} \text{ Twice}$$

Two $^{3}_{2}He$ fuse to from $^{4}_{2}He$.

$$^{3}_{2}He + {}^{3}_{2}He \longrightarrow {}^{4}_{2}He + {}^{1}_{1}H + {}^{1}_{1}H + \text{Energy}$$

In this reaction, 6 proton take part and finally a helium nucleus and two protons are formed. Nearly 25.7 MeV of energy is released i.e. 6.4 MeV $\left(\frac{25.7}{4}\right)$ per nucleon is obtained which is much greater than the energy per nucleon $0.9\ \frac{MeV}{nucleon}$ given out in fussion reaction.

21.11 Radiation Exposure

When a Geiger tube is used in any experiment, it records radiation even when a radioactive source is not there. This is caused by radiation called background radiation. It is partly due to cosmic radiation which comes to us from outer space and partly from naturally occuring radioactive substance in the earth's crust.

Cosmic Rays:

The cosmic radiations consists of high energy charged particles and electromagnetic radiation. The atomosphere acts as a shield to absorb some of these radiations as well as ultraviolet rays. In recent past, the depletion of ozone layer in the upper atmosphere has been detected which particularly filters ultraviolet rays reaching us.

This may result in increased eye and skin diseases. The depletion of ozone layer is suspected to be caused due to excessive release to some chemicals in the atmosphere such as chloroflouro carbons (CFC) used in refrigeration, aerosol spray and plastic from industry. Its use is now being replaced by environmentally friendly chemicals.

Building Materials:

Many building materials contain small amounts of radioactive isotopes. Radiactive radon gas enters buildings from the ground. It gets trapped inside the building which makes radiation levels much higher from radon inside than outside.

A good ventilation can reduce radon level inside the building. All types of food also contain a little radioactive substance. The most common are potassium 40 and carbon 14 isotopes.

Medical Radiation Exposure:

Some radiation in the environment is added by human activities. Medical practices, mostly diagnostic X-ray probably contribute the major portion to it. It is an unfortunate fact that may X-ray exposures such as routine chest X-ray and dental X-ray are made for no strong reason and may do more harm than good.

Every X-ray exposure should have a definite justification that outweighs the risks.

Other Sources:

The other sources include radioactive waste from nuclear facilities, hospitals, research and industrial establishments, colour television, luminous watches and tobacco leaves. A smoker not only inhales toxic smoke but also hazardous radiation. Low level background radiation from natural sources is normally considered to be harmless.

However, higher levels of exposure are certainly damaging. We cannot avoid exposure to radiation. However, the best advice to avoid unnecessary exposure to any kind of ionizing radiation.

21.12 Biological effects of Radiations

Activity:

"The strength of the radiation source is indicated by its activity."

A = No. of disintegrations per second.

Unit:

SI unit of activity is becquerel (Bq).

Becquerel:

"One disintegration per second is called becquerel."

$$1\ Bq = \frac{1\ \text{Disintegration}}{\text{second}}$$

Cuerie (ci):

"Older unit of activity is called cuerie. It is a large unit of activity."

1.0 cuerie is equal to 3.7×10^{10} disintegrations per second.

Absorbed Dose (D):

It is defined as, "The energy E absorbed from ionizing radiations per unit mass of the absorbing body."

$$D = \frac{E}{m}, \quad \text{Dose} = \frac{\text{Energy absorbed}}{\text{Mass}}$$

Gray (Gy):

SI unit of absorbed dose is gray.

1 Gray is equal to Joule per Kilogram.

$$1\ Gy = \frac{1\ \text{Joule}}{1\ kg}$$

Rad:

"An older unit of absorbed dose is called rad." Rad is an acronym of radiation absorbed dose.

$$1\ \text{rad} = 0.01\ Gy$$

$$1\ \text{rad} = \frac{1}{100}\ Gy$$

$$1\ Gy = 100\ \text{rad}$$

Note:

Equal doses of different radiations

do not produce same biological effect.

For the same absorbed dose alpha particles are 20 times more damaging than x-rays. The effect also depends on the part of the body absorbing the radiations.

Example:

Neutrons are particularly more damaging to eyes than other parts of the body.

Equivalent Dose (De):

The equivalent dose of any absorbed radiations is defined as the product of the absorbed dose "D" and "RBE" of the kind of radiations being absorbed.

$$De = D \times RBE$$

$De = D \times (Q.F)$

Here RBE stands for Relative Biological Effectiveness (a quality factor) (Q.F).

Sievert (Sv):

Sievert is the SI unit of

the equivalent dose.

$$1\,Sv = 1\,Gy \times RBE$$

Rem:

It is an old unit of equivalent dose (De).

$$1\ rem = 0.01\ Sv$$

$$1\ rem = \frac{1}{100}\ Sv$$

$$1\ Sv = 100\ rem$$

Chapter = 21

Questions

Question: 21.1

Answer:

A Isotopes are those nuclei which have the same atomic number but different mass number. Isotopes have same number of protons but different number of neutrons.

Question: 21.2

Answer:

Heavy nuclei are unstable due to large number of protons and large electrostatic force of repulsion between them. The strong nuclear force cannot balance these repulsive Coulamb forces, so the heavy neuclei are unstable.

Question: 21.3

Answer:

No.

It will not completely decay after 2 years. 75% of it will have decayed and 25% will be left undecayed.

Infinity time is required for a radioactive element to completely decay.

Question: 21.4

Answer:

$n = 2$ for two half lives.

$$\therefore N = \left(\frac{1}{2}\right)^n N_o = \left(\frac{1}{2}\right)^2 N_o = \frac{1}{4} N_o$$

So $\frac{1}{4}$ of radioactive sample is left.

$N_o - \frac{1}{4} N_o = \frac{3}{4} N_o$ is decayed in 2 half lives.

$\frac{3}{4}$ is decayed i.e. 75% is decayed in 2 half lives.

Question: 21.5

Answer:

The half life of $^{226}_{88}Ra$ is 1.6×10^3 years, but its total life time is infinity. It is a common property of all the radio active elements that infinity time is required to decay completely. So $^{226}_{88}R$ is still found in nature although the Earth is 5 billion years old.

Question: 21.6

Answer:

Interaction of radiations with matter are three types.

i): Interaction of α particle.

For long or detail see page (27).

ii): Interaction of β particle.

For long or detail see page (28).

iii): Interaction of γ particle.

For long or detail see page (29).

Question: 21.7

Answer:

α and β are charged particles. So they produce ionization with out hitting an atom by attaracting or repelling the electrons.

Difference:

α particles produce indirect ionization by attracting the electrons.

β particles produce indirect ionization by repelling the electrons.

Question: 21.8

Answer:

A particle which produces more ionization interacts strongly with matter. In each such interaction it loses energy and hence comes to rest soon. Thus it has less penetrating power.

Question: 21.9

Answer:

In a wilson's cloud chamber, α particles leave small, thick (Dense) and straight tracks. It shows that α particles produce greater ionization, they have small range. β particles From thin and discontinuous tracks extending in erratic manner showing frequent collission β particles produce smaller ionization than α.

γ rays have no definite tracks. They have very small ionizing power.

Question: 21.10

Answer:

α particles have very small range. So the window of GM tube should by very thin. γ rays are highly penetrating so there is no need of such a window.

Question: 21.11

Answer:

For answer of this question see at page number (40).

Question: 21.12

Answer:

The minimum mass of fissionable material such as $^{235}_{92}U$ in which fission can take place in an uncontrolled manner producing explosion is called critical mass.

Question: 21.13

Answer:

Advantages:

i): The fuel has small cost.
ii): The cost of electricity is cheap.
iii): It does not produce smoke.
iv): Waste products can be reprocessed.

Disadvantages:

i): It has radiation hazards.
ii): Its wast products are strongly radioactive and is difficult to handle.
iii): Its fuel is not easily available.
iv): Its waste products is dangerous and cannot be easily dumped.

Question: 21.14

Answer:

i): Fusion reaction takes place at very high temperature of about 10^7 K.

ii): Great amount of energy is required

to fuse the positively charged nuclei. For this purpose accelerators must be present to accelerate the nuclei to very high speed.

Question: 21.15

Answer:

Advantages:

i): Fusion reaction is free from radioactive waste.

ii): Energy or nucleon liberated in fusion reaction is large as compared fission reaction.

iii): It will be safe from pollution and resources.

Disadvantages:

i): It is difficult to control this reaction.

ii): It is difficult to start the fusion reaction.

Question: 21.16

Answer:

The radiations present due to comic rays and due to the presence of radioactive materials under the crest of Earth are called back ground radiations.

Question: 21.17

Answer:

α-source is more dangerous than β-source because α-source produces high ionization than that of β-source.

Question: 21.18

Answer:

As,

$$1\,Gy = \frac{1\,J}{1\,kg}$$

$$10\,m\,Gy = 10 \times 10^{-3}\,Gy = 10^{-2}\,\frac{J}{kg}$$

$$1\,m\,Gy = 1 \times 10^{-3}\,Gy = 10^{-3}\,\frac{J}{kg}$$

So,

$$10\,mGy > 1\,mGy$$

Question: 21.19

Answer:

The radioactive isotope acts as an indicator or tracer that makes it possible to follow the course of a chemical or biological process.

Uses of Tracers:

In medicine:

The tracers are used in medicine to detect the malignant tumors.

In understanding of photosynthesis:

This techniqes has helped to understand more clearly the complex process of photo synthesis.

Question: 21.20

Answer:

Radioactivity with γ-rays from cobalt 60 is often used in the treatment of cancer. The γ-rays are carefully focused on the malignant tissue similarly radioactive iodine 131 is used to combat cancer if the thyroid gland.

Chapter = 21

Solved Examples

Example: 21.1

Solution:

Mass defect can be calculated as.

$$m = (m_p + m_n) - m_2$$
$$= 1.6726 \times 10^{-27} + 1.6749 \times 10^{-27} - 3.3435 \times 10^{-27}$$

$$m = 3.9754 \times 10^{30}\ kg$$

Now Binding energy can be calculated as.

$$B.E = mc^2 = (3.9754 \times 10^{-30})\ 9 \times 10^{16}$$
$$B.E = 3.5729 \times 10^{-13} J$$
$$B.E = \frac{3.5729 \times 10^{-13}}{1.6 \times 10^{-19}}$$
$$B.E = 2.33 \times 10^6\ ev$$

$$B.E = 2.33\ Mev$$

Example: 21.2

Solution:

As the half life of iodine is 8 days, therefore, in 8 days half of the iodine decays given below in the table is the amount of iodine present after every 8 days.

Interval in days.	Quantity of iodine.	Interval in days.	Quantity of iodine.
0	20 mg	32	321.25 mg
8	10 mg	40	0.625 mg
16	5 mg	48	0.3125 mg
24	2.5 mg		

Example: 21.3

Solution:

RBE factor = 10

$D_e = 400 \text{ rem} = 400 \times 0.01 Sv$

$D_e = 4 Sv$

$D = ?$

Using equation.

$$D = \frac{D_e}{RBE}$$

$$D = \frac{4 Sv}{10} = 0.4 Gy$$

Since 1 Gy is 1 J Kg^{-1}, hence total energy absorbed by the whole body

$= mD = 80 \times 0.4\, Gy = 32\, J$

It is a very small amount of thermal energy.

Second Method of example 21.2

$T_{1/2} = 8$ days

time $= 48$ days

The number of half lives past

$$n = \frac{48\, day}{8\, day} = 6$$

Remaining Quantity $= \left(\frac{1}{2}\right)^n \times$ Initial Quantity

$= \left(\frac{1}{2}\right)^6 \times 20$ mg

$= \frac{1}{64} \times 20$ mg

Remaining Quantity $=$ 0.3125 mg

Chapter = 21

Problems with Solutions

Problem: 21.1

Solution:

Atomic mass of tritium = m = 3.016049 u
Mass defect = Δm = ?
Binding energy for tritium = ΔE = ?

As we know that ∵ In tritium, $Z=1, N=2$

$$\Delta m = Zm_p + Nm_n - m \longrightarrow (1)$$

$$m_p = 1.007276\,u$$
$$m_n = 1.008665\,u$$

Put these valuse in eq (1)

$$\Delta m = 1\times1.007276 + 2\times1.008665 - 3.016049$$

$$\boxed{\Delta m = 0.008557\,u}$$

∵ $c = 931\frac{MeV}{u}$

$$B.E = \Delta mc^2$$
$$B.E = 0.008557\,\cancel{u} \times 931\,\frac{MeV}{\cancel{u}}$$

B.E = 7.97 MeV

Problem: 21.2

Solution:

$T_{1/2} = 9.70\ hrs$

$= 9.70 \times 60 \times 60\ S$

$T_{1/2} = 34920\ s$

Decay constant $\lambda = ?$

$$T_{1/2} = \frac{0.693}{\lambda}$$

$$\lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{34920s}$$

$$\lambda = 1.98 \times 10^{-5}\ S^{-1}$$

Problem: 21.3

Solution:

Decay equation for β_ emission is

$${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta$$

So,

$${}^{234}_{91}Pa \longrightarrow {}^{235}_{92}U + {}^{0}_{-1}\beta$$

$${}^{234}_{92}U = \text{Daughter nuclei}$$

Problem: 21.4

Solution:

$$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$$

ΔE or Q = ?

So,

$$\Delta m = (m\,^{14}_{7}N + m\,^{4}_{7}He) - (m\,^{17}_{7}O + m\,^{1}_{1}H)$$

Since,

Mass of $^{14}_{7}N$ = 14.0031 u

Mass of $^{4}_{2}He$ = 4.00264 u

Mass of $^{17}_{7}O$ = 16.9996 u

Mass of $^{1}_{1}H$ = 1.0073 u

$$\Delta m = (14.0031 + 4.00264) - (16.9996 + 1.0073)$$

$$\Delta m = 18.00574 - 18.0069$$

$$\boxed{\Delta m = -0.0012\,u}$$

For energy

$$\Delta E = -0.0012\,u \times 931\ \frac{MeV}{u}$$

$$\Delta E = -1.117$$

$$\boxed{\Delta E = -1.12\ MeV}$$

Negative sign shows that the energy is required for this reaction.

Problem: 21.5

Solution:

$$^{14}_{6}C \longrightarrow ^{14}_{7}N + ^{0}_{-1}e$$

$$E = ?$$

$$m^{14}_{7}C = 14.0077U$$

Since

$$\Delta m = m^{14}_{7}C - (m^{14}_{7}N + m^{0}_{-1}e)$$

$$\Delta m = 14.0077 - (14.0031 + 0.00055)$$

$$\Delta m = 14.0077 - 14.00365$$

$$\boxed{\Delta m = 4.05 \times 10^{-3} u}$$

So,

$$E = \Delta m \times c^2$$

$$E = 4.05 \times 10^{-3} \cancel{u} \times 931 \frac{MeV}{\cancel{u}}$$

$$\boxed{E = 3.77 \text{ MeV}}$$

Problem: 21.6

Solution:

For α decay

$$^{A}X \longrightarrow ^{A-4}_{Z-2}Y + ^{4}_{2}He$$

1st α decay

$$^{233}_{92}U \longrightarrow ^{229}_{90}Th + ^{4}_{2}He$$

2nd α – decay

$$^{229}_{90}Th \longrightarrow {}^{225}_{88}Ra + {}^{4}_{2}He$$

Resulting Isotope = $^{225}_{88}Ra$

Problem: 21.7

Solution:

$$^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n$$

Energy released

$E = ?$

$\Delta m = (m\,{}^{2}_{1}H + m\,{}^{3}_{1}H) - (m\,{}^{4}_{2}He + m\,{}^{1}_{0}n)$

$\Delta m = (2.014102 + 3.01605) - (4.002603 + 1.008665)$

$\Delta m = 5.030152\ u - 5.011268\ u$

$\Delta m = 0.018884\ u$

So,

$E = \Delta m \times c^2$

$E = 0.018884\ u \times 931\ \frac{MeV}{u}$

$E = 17.6\ MeV$

Problem: 21.8

Solution:

Thickness of sheet $= X_1 = 5mm$

$= 5 \times 10^{-3} m$

Reduction in intensity of beam $= I_1 = 0.4 I_o$

Reduction of intensity in lead sheet $= I_2 = 0.5 I_o$

Thickness of lead sheet $= X_2 = ?$

By formula.

$$I = I_o e^{-\mu X}$$

For 1st case.

$$I_1 = I_o e^{-\mu X_1}$$

$$0.4 \cancel{I_o} = \cancel{I_o} e^{-\mu X_1}$$

$$0.4 = e^{-\mu X_1}$$

Taking ln

$$\ln 0.4 = -\mu X_1 \ln e \qquad \because \ln e = 1$$

$$\ln 0.4 = -\mu X_1 \longrightarrow (1)$$

For 2nd case,

$$I_2 = I_o e^{-\mu X_2}$$

$$0.5 I_o = I_o e^{-\mu X_2}$$

$$0.5 = e^{-\mu X_2}$$

Taking ln

$$\ln 0.5 = -\mu X_2 \ln e$$

$$\ln 0.5 = -\mu X_2 \longrightarrow (2)$$

Divide eq (1) by eq (2).

$$\frac{\ln 0.4}{\ln 0.5} = \frac{-\mu x_1}{-\mu x_2}$$

$$\frac{-0.916}{-0.693} = \frac{x_1}{x_2}$$

$$\frac{0.916}{0.693} = \frac{x_1}{x_2}$$

$$x_2 = \frac{0.693\, x_1}{0.916}$$

$$x_2 = \frac{0.693 \times 5 \times 10^{-3}}{0.916}$$

$$x_2 = 3.7827 \times 10^{-3}\, m$$

$$\boxed{x_2 = 3.78\, mm}$$ Thickness of lead sheet

Problem: 21.9

Solution:

1st distance = r_1 = 1.0m

Count rate at 1m = I_1 = 360 C/min

Count rate at 3.0m = I = ?

Since count rate obeys inverse square law

$$I \propto \frac{1}{r^2}$$

$$I = \frac{K}{r^2}$$

K is constant

For 1st count

$$I_1 = \frac{K}{r_1^2} \rightarrow (1)$$

For 2nd count

$$I_2 = \frac{K}{r_2^2} \rightarrow (2)$$

Divide eq (1) by eq (2)

$$\frac{I_1}{I_2} = \frac{K/r_1^2}{K/r_2^2}$$

$$\frac{I_1}{I_2} = \frac{K}{r_1^2} \times \frac{r_2^2}{K}$$

$$\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}$$

$$I_2 = \frac{I_1 \times r_1^2}{r_2^2} \rightarrow (3)$$

Putting the values in eq (3)

$$I_2 = \frac{1}{3^2} \times 360 = \frac{360}{9}$$

$$I_2 = 40\ C/min$$ Count rate at 3.0 m

Problem: 21.10

Solution:

Mass = m = 75 Kg

Dose = D = 24 m rad

= 24×10^{-3} rad

Since,

$1\ rad = 0.01\ Gy$

$D = 24 \times 10^{-3} \times 0.01$

$= 0.24 \times 10^{-3}\ Gy$

$RBE = 12$

Energy in Joules = $E = ?$

Dose in rem = $De = ?$

(A) As we know that the absorbed energy

$E = m \times D$

$E = 75 \times 0.24 \times 10^{-3}$

$E = 18 \times 10^{-3}$ Joule

$E = 18m$ Joule

∵ Unit of De is Sv, Sv = Sievert

(B) Since,

$De = Dose \times RBE$

$De = 0.24 \times 10^{-3} \times 12\ Sv$

$De = 2.88 \times 10^{-3}\ Sv \longrightarrow (1)$

As, $1\ rem = 0.01\ Sv$

$\frac{1}{0.01}\ rem = 1\ Sv$

$100\ rem = 1\ Sv$

From eq. (1)

$De = 2.88 \times 10^{-3} \times 100\ rem = 0.288\ rem$

$De = 0.29\ rem$

Equivalent Dose in rem.