ATOMIC NUCLEUS :→ It is the central area of the atom where the entire +ve charge and most of the mass of the atom are concentrated in a small volume.

It is composed of two kinds of subatomic particles :→
(i) protons and (ii) neutrons

In 1911, **Rutherford** postulated the existence of nucleus inside an atom.

⇒ From α-particle scattering experiment nuclear size was found to be of the order of 10^{-14} m and the diameter of an atom is of the order of 10^{-10} m.

⇒ Researches on artificial radioactivity revealed that many particles like α-particles, protons, neutrons, positrons, β-particles, etc. enter into the constitution of nuclei in one way or other.

COMPOSITION OF A NUCLEUS

Protons and Neutrons are the main building blocks of the nuclei of all atoms.

(i) **Proton** ⇒ It is the fundamental particle with a +ve charge of 1.6×10^{-19} C and rest mass of 1.6726×10^{-27} kg.
Its rest mass is 1836 times the rest mass of e⁻

(ii) **Neutron** ⇒ It is chargeless fundamental particle having mass slightly greater than that of proton. 1.6749×10^{-24} kg.

The following terms are used to describe the composition of an atomic nucleus :→

(a) **Nucleons** ⇒ Protons and Neutrons in the nuclei of an atom are collectively known as **Nucleons**.

(b) **Atomic Number** ⇒ The no. of protons in the nucleus is called the atomic no. of the element.

Denoted by ⇒ Z

(c) Mass Number ⇒ It is the total no. of protons and neutrons present in a nucleus. **Denoted by** ⇒ A

(d) Nuclear Mass ⇒ 'The total mass of the protons and neutrons present in a nucleus is called Nuclear Mass.'

(e) **Nuclide** ⇒ 'It is a specific nucleus of an atom characterised by its atomic number Z and mass number A.'

Symbolically it is represented as :- $^{A}_{Z}X$ or $_{Z}X^{A}$

X ⇒ chemical symbol of element

eg ⇒ Gold nucleus is represented as $^{179}_{79}Au$.

For a neutral atom we have the following relations :→

No. of protons in an atom = Z
No. of electrons in an atom = Z
No. of nucleons in an atom = A
No. of neutrons in an atom = N = A − Z

ISOTOPES, ISOBARS, ISOTONES and ISOMERS :→

Isotopes ⇒ 'The atoms of an element which have the same atomic no. but different mass no. are called Isotopes.'

Such atoms contain same no. of protons and electrons but different no. of neutrons. Isotopes of an atom occupy same position in Periodic Table.

eg:) Hydrogen has 3 isotopes :→ (i) Hydrogen (protium) [^1_1H] (ii) Deuterium [^2_1H] and (iii) Tritium [^3_1H]

Lithium has 2 isotopes ⇒ ^6_3Li and ^7_3Li,

The different isotopes have different relative abundances. So, the weighted average of the atomic masses of all the isotopes of an element is taken as its average atomic mass. For example, normal chlorine contains 75% of $^{35}_{17}Cl$ and 25% of $^{37}_{17}Cl$

∴ Average atomic mass of chlorine $= \frac{(35 \times 75) + (37 \times 25)}{75 + 25}$

$= 35.50$

Isobars :→ The atoms having the same mass number but different atomic number are called isobars.

Such atom contains different no. of protons and electrons. They occupy different positions in the periodic table.

eg ⇒ (i) ^3_1H and ^3_2He (ii) $^{37}_{17}Cl$ and $^{37}_{16}S$

(iii) $^{40}_{20}Ca$ and $^{40}_{18}Ar$

Isotones :→ 'The nuclides having the same no. of neutrons are called isotones.

eg :) (i) $^{37}_{17}Cl$ and $^{39}_{19}K$ (ii) $^{198}_{80}Hg$ and $^{197}_{79}Pu$

X **Isomers** :→ 'These are the nuclei with same atomic number and same mass number but existing in different energy states.'

eg :) a nucleus in its ground state and the identical nucleus in metastable excited state are isomers.

DISCOVERY OF NEUTRONS :->

The neutrons were discovered by James Chadwick in 1932.

⇒ Chadwick performed an experiment in which α-particles from a radioactive Polonium source were used to bombard **beryllium nuclei.**

⇒ Highly penetrating rays were found to come out of the beryllium metal, which could not be deflected by electric and magnetic fields.

⇒ These radiations were used to bombard hydrocarbons like paraffin wax. High energy protons were knocked out from the paraffin wax. The energy of the ejected protons was found to be too high to be accounted for γ-ray photons.

⇒ By using the laws of conservation of energy and momentum Chadwick concluded that the penetrating radiation consisted of neutral particles, each having a mass nearly that of a proton. These particles were called neutrons.

The reaction may be written as :->

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

↳ neutron having zero charge & mass nearly same as that of a proton.

PROPERTIES OF NEUTRONS :->

(1) Neutron is an elementary particle present in the nuclei of all elements except of hydrogen.

(2) It has no charge and its mass is slightly more than that of a proton.

$$m_n = 1.00866\ \text{amu} = 1.6749 \times 10^{-27}\ \text{kg}.$$

(3) Inside a nucleus, neutron is stable. But outside a nucleus, it is unstable. A free neutron spontaneously decays into a proton, electron and antineutron (an elementary particle with zero charge and zero rest mass) with a mean life of about 1000 s.

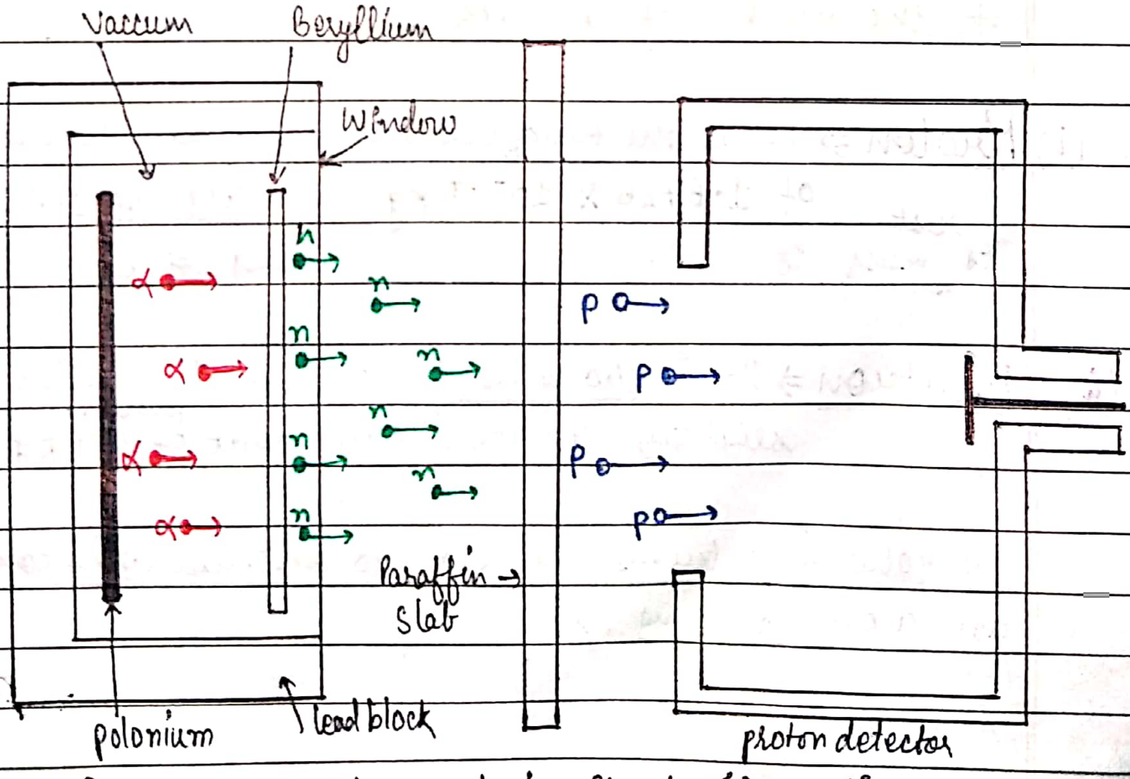
$${}^1_0n \rightarrow {}^1_1H + {}^0_{-1}e + \bar{\nu} + Q$$

(4) Being neutral, they do not interact with electrons. So neutrons have low ionising powers.

(5) Being neutral, neutrons are not repelled or attracted by the nucleus and the e⁻'s of an atom. They can easily penetrate heavy nuclei and induce nuclear reactions.

(6) They induce radioactivity in many elements.

(7) In heavier nuclei, the no. of neutrons is more than that of protons. Protons being +vely charged, repel each other and in order to maintain the stability of nucleus, more neutrons become necessary for heavier nuclei.



Experimental set up used by Chadwick to discover neutrons.

After Discovery of Neutron

SIZE OF THE NUCLEUS

A nucleus is not a solid object. Its surface is not a well defined boundary. Assuming nuclei to be spherical, their volumes can be estimated.

Experimental observations show that :-

'Volume of nucleus is directly proportional to the no. of nucleons (mass number) constituting nucleus.'

$\therefore$ Volume of Nucleus $\propto A$

$$\frac{4}{3}\pi R^3 \propto A$$ [R ⇒ radius of nucleus

$$\text{or} \quad R^3 \propto A$$

$$\boxed{R = R_0 A^{1/3}}$$

↳ R_0 a constant called **Nuclear Unit Radius.**

$$\boxed{R_0 = 1.2 \times 10^{-15}\, m = 1.2\, fm}$$

↳ Its value depends upon the nature of probe particles.

ATOMIC MASS UNIT (amu) :-

'One atomic mass unit is defined as $\frac{1}{12}$th of the actual mass of carbon-12 atom.'

$$\boxed{1\text{ amu }(u) = \frac{1}{12}\text{th of the mass of one } C^{12} \text{ atom}}$$

$$1\,\text{amu} = \frac{1}{12} \times 1.992678 \times 10^{-26}\ \text{kg}$$

$$\boxed{1\,\text{amu} = 1.660565 \times 10^{-27}\ \text{kg}}$$

Mass of electron (m_e) = 0.00055 amu = 9.11×10^{-31} kg
" " proton (m_p) = 1.0073 amu = 1.6726×10^{-27} kg
" " neutron (m_n) = 1.0086 amu = 1.6749×10^{-27} kg

It is measured by an instrument called Spectrometer

NUCLEAR DENSITY

As the volume of nucleus is directly proportional to its mass number A, so the density of nuclear matter is independent of the size of the nucleus (or mass no. A).

Consider a nucleus with a mass no. 'A' amu

$\therefore$ mass of nucleus = A amu

" " " $= A \times 1.660565 \times 10^{-27}$ kg

Volume of Nucleus $= \frac{4}{3}\pi R^3$ [R → radius of nucleus]

as density $= \frac{\text{mass}}{\text{Volume}}$

$$\therefore \text{Density of nucleus} = \frac{A \times 1.660565 \times 10^{-27}}{\frac{4}{3}\pi R^3}$$

$$= \frac{A \times 1.660565 \times 10^{-27}}{\frac{4}{3}\pi [R_0 A^{1/3}]^3}$$

$$= \frac{A \times 1.660565 \times 10^{-27}}{\frac{4}{3}\pi R_0^3 A}$$

$$= \frac{3 \times 1.660565 \times 10^{-27}}{4 \times 3.14 \times [1.1 \times 10^{-15}]^3}$$

$$\boxed{\text{Density of Nucleus} = 2.97 \times 10^{17}\ \text{kg/m}^3}$$

NOTE:→ ⟨1⟩ Density of nuclei is independent of mass number (A).

⟨2⟩ Nucleus has a very high density.

⟨3⟩ Density of nucleus is maximum at centre and decreases gradually to zero as we move away from the centre.

"The effective value of nuclear radius is taken as the distance from the centre, at which the density decreases to half of its value at the centre."

FORCES BETWEEN NUCLEONS

Following two forces are supposed to be acting b/w the nucleons :->

(1) Gravitational force of attraction
(2) Electrostatic force of repulsion → (due to charge on protons)

Consider two protons at a distance 'r' apart, then Gravitational force of attraction b/w them

$$F_G = \frac{G m_p m_p}{r^2} \quad [m_p \Rightarrow \text{mass of proton}]$$

$$F_G = \frac{6.67 \times 10^{-11} \times (1.67 \times 10^{-27})^2}{r^2} \text{ —— ①}$$

$$F_G =$$

Electrostatic force of repulsion b/w them

$$F_e = \frac{k q_p q_p}{r^2}$$

$$F_e = \frac{9 \times 10^9 \times (1.6 \times 10^{-19})^2}{r^2} \text{ —— ②}$$

$$\boxed{\frac{F_e}{F_G} \approx 10^{36}}$$

i.e., electrostatic force b/w two protons is 10^{36} times stronger than Gravitational force b/w them at same distance.

NUCLEAR FORCE

If gravitational and electrostatic forces are the only forces acting within the nucleus then the electrostatic repulsive force b/w the protons would tear off the nucleus. But even a heavy nucleus containing a large no. of protons is stable, this is the evidence of the fact that there must exist a third kind of the force between the nucleons which is responsible to hold the nucleons together known as Nuclear Force which is basically a strong attractive force and is about 100 times stronger than the electrostatic force.

The relative strength of gravitational, electrostatic and nuclear force is :→

$$\boxed{F_G : F_e : F_n = 1 : 10^{36} : 10^{38}}$$

Properties of Nuclear Force :→

(1) Strongest force in nature that holds the nucleons together.

(2) Short range force which operates only upto 2–3 fm from a nucleon.

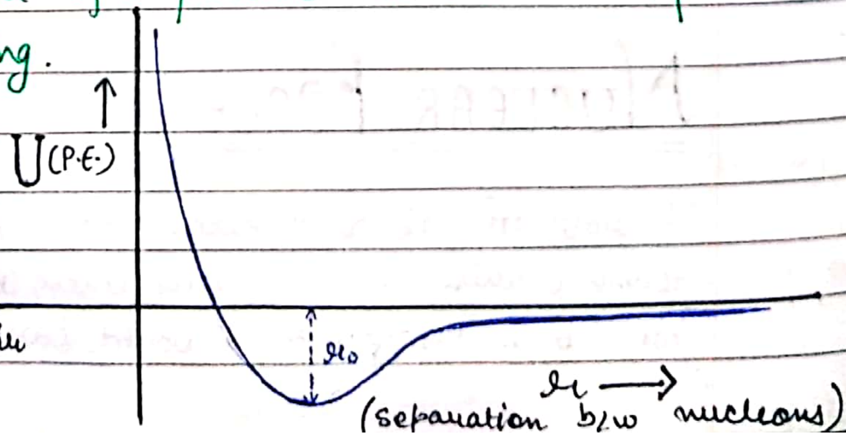
(3) Charge independent force.

(4) Non-Central Force :→ The nuclear force b/w two nucleons does not act along the line joining their centres.

(5) Saturated Force :→ A nucleon experiences a force only due to its nearest neighbouring nucleons.

\# Imp (6) Nuclear forces are strong attractive forces but contain a small component of repulsive nature which prevent the nucleus collapsing.

variation of P.E. of a pair of nucleons as a function of their separation b/w them (r).



If $r > r_0$ force is attractive
If $r < r_0$ force is repulsive

NOTE:→ Japenese physicist H. Yukawa suggested that the nuclear force b/w two nucleons arises from the constant ~~exchang~~ exchange of particles called mesons, b/w them.

NUCLEAR STABILITY

The stability of a nuclide is intimately connected to the relative no. of neutrons and protons present in it. If the attractive force b/w nucleons is less than the electrostatic repulsion then it makes the nucleus unstable and results in decay.

Following factors determine the stability of the nucleus:→

(i) Binding Energy per nucleon ⇒ More its value more is the stability.

(ii) Neutron-Proton Ratio (N/Z) ⇒ For a stable nucleus, generally its value is more than 1.

Elements having same no. of protons and neutrons have N/Z = 1 (atomic no. less than 20). The no. of neutrons increases as the atomic no. increases and the ratio N/Z increases and becomes more than 1. More neutrons overcome the electrostatic force b/w protons and makes the nuclide stable.

There are No Stable Nuclides for Z > 83. Thus, the heaviest stable nuclide is $_{83}Bi^{209}$.

(iii) Type of Nucleus ⇒ Even-Even nuclei (even protons & even neutrons) are found to be most stable.

Only 4 stable nuclides have both odd Z and odd N :

^{2}H , ^{6}Li , ^{10}Bi , ^{14}N (These are called odd-odd nuclides)

The mass of a particle measured in a frame of reference in which the particle is at rest, is called rest mass.

MASS ENERGY EQUIVALENCE :→

According to EINSTIEN mass can be converted into energy.

Mass 'm' is equivalent to energy 'mc^2'.

$$\therefore E = mc^2$$

above eqⁿ can also be written as :-

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

Law of Conservation of mass-energy :→ It states that - 'the sum of the mass-energy of a system of particles is the same before and after their interaction.'

ENERGY EQUIVALENCE OF ONE amu :→

[Relation b/w amu and MeV]

$$1 \text{ amu} = 1.660565 \times 10^{-27} \text{ kg}$$

$$c = 2.998 \times 10^{8} \text{ m/s}$$

using, $E = mc^2$

$$E = (1.660565 \times 10^{-27}) \times (2.998 \times 10^{8})^2$$

$$E = 1.4925 \times 10^{-10} \text{ J}$$

$$E = \frac{1.4925 \times 10^{-10}}{1.6 \times 10^{-19}} \text{ eV}$$

$$E = \frac{1.4925 \times 10^{-10}}{1.6 \times 10^{-13}} \text{ MeV}$$

$$\therefore \boxed{1 \text{ amu} = 931.5 \text{ MeV}}$$

∴ mass of 1 amu is equivalent to 931.5 MeV of energy.

Scanned with CamScanner

MASS DEFECT

It is found that the mass of a stable nucleus is always less than the total mass of its constituent nucleons.

'The difference b/w the sum of the masses of the nucleons constituting the nucleus and the rest mass of the nucleus is known as Mass Deffect.'

Denoted by :-> Δm.

$$\boxed{\text{mass defect} = \text{mass of nucleons} - \text{rest mass of the nucleus}}$$

Consider nucleons of an atom ${}_{Z}X^{A}$

$\therefore$ no. of protons $= Z$

no. of neutrons $= (A-Z)$

Let $m_p \Rightarrow$ mass of one proton

$m_n \Rightarrow$ mass of one neutron

$m_N \Rightarrow$ mass of ${}_{Z}X^{A}$ nucleus

$\therefore$ mass defect = mass of nucleons − rest mass of ${}_{Z}X^{A}$ nucleus

$\Delta m = [\text{mass of } Z \text{ protons} + \text{mass of } (A-Z) \text{ neutrons}] - \text{mass of } {}_{Z}X^{A} \text{ nucleus.}$

$$\boxed{\Delta m = Zm_p + (A-Z)m_n - m_N} \text{ ——— ①}$$

In this atom, no. of electrons $= Z$

If $m_e \Rightarrow$ mass of one e^-

then on adding and subtracting mass of Z electrons in RHS of eq^n ①

$$\Delta m = Zm_p + Zm_e + (A-Z)m_n - m_N - Zm_e$$

$$\Delta m = [Z(m_p + m_e)] + (A-Z)\,m_n - [m_n + Zm_e] \text{ ②}$$

Here $[m_p + m_e]$ = mass of one ${}_1H^1$ atom say $m({}_1H^1)$
and $[m_N + Zm_e]$ = mass of one ${}_ZX^A$ atom say $m({}_ZX^A)$

∴ eq^n ② becomes,

$$\boxed{\Delta m = Zm({}_1H^1) + (A-Z)m_n - m({}_ZX^A)} \text{ — ③}$$

BINDING ENERGY

When a nucleus is formed from free nucleons, the decrease in the mass of the nucleons is released as the equivalent energy (as per $E = mc^2$).

'The energy equivalent to the mass defect is used in Binding the nucleons and is known as binding energy of the nucleus.'

In order to break the nucleus or to completely separate the nucleons from each other an equal amount of work has to be done.

B.E. of nucleus = energy equivalent to mass defect

$$\boxed{B.E. = \Delta mc^2}$$ [In Joules provided m is in kg and c in m/s]

or $$\boxed{B.E. = \Delta mc^2 \times 931.5}$$ [in MeV provided Δm is in amu]

Expression for Binding Energy :->

as $\Delta m = Zm({}_1H^1) + (A-Z)m_n - m({}_ZX^A)$ — ①

And $B.E = \Delta mc^2$ — ②

$$\therefore \boxed{B.E. = [Zm({}_1H^1) + (A-Z)m_n - m({}_ZX^A)]c^2} \text{ — ③}$$

BINDING ENERGY PER NUCLEON :-

'It is the average energy required to extract one nucleon from the nucleus.'

$$\boxed{\text{Binding Energy per nucleon} = \frac{B.E.}{\text{Total nucleons}} = \frac{B.E.}{A}}$$

PACKING FRACTION :- 'It is mass defect per nucleon'.

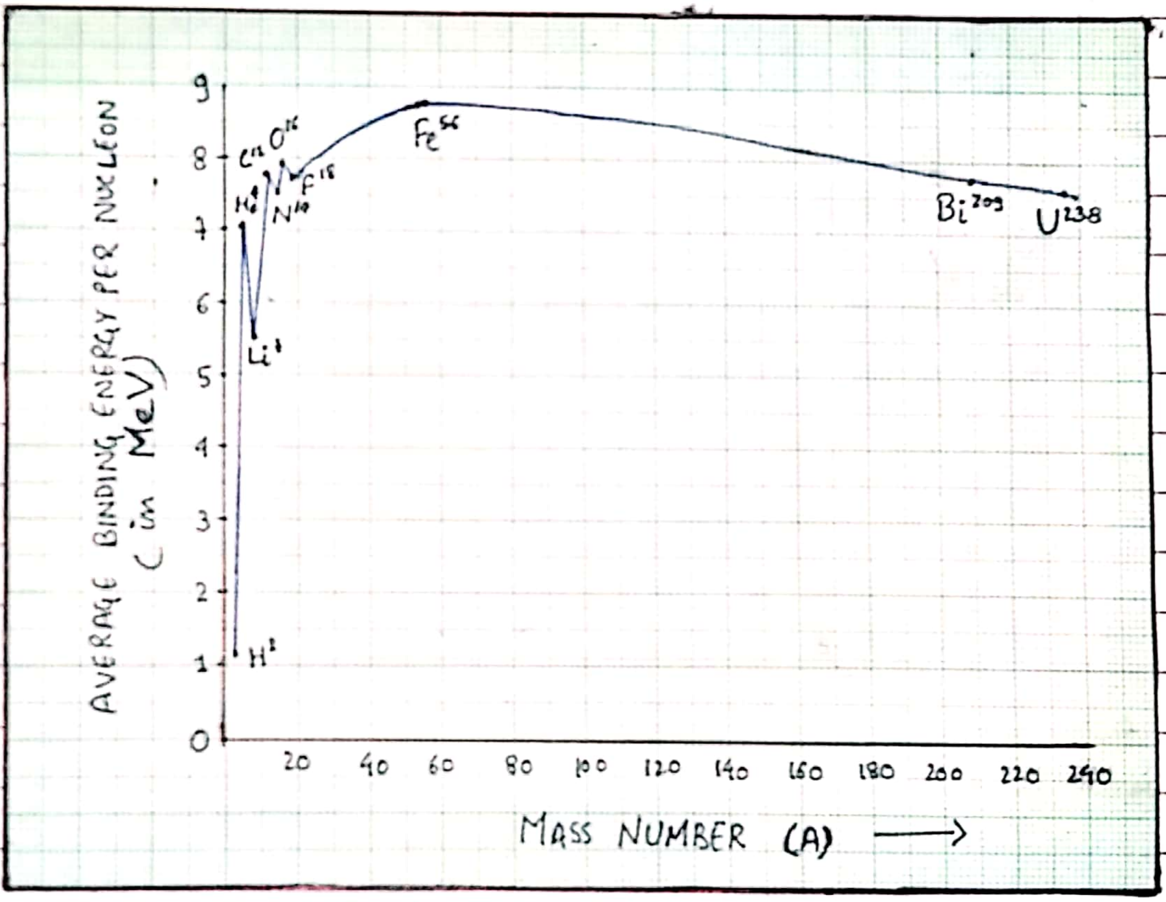
Thus, $\boxed{\text{Packing Fraction of a nucleus} = \frac{\text{Mass defect}}{\text{Total nucleons}} = \frac{\Delta m}{A}}$

nucleon and packing fraction

BINDING ENERGY CURVE

The B.E. per nucleon of a nucleus gives a measure of the stability of that nucleus. Greater is the B.E. per nucleon of a nucleus, more stable is the nucleus.

'The graph between average binding energy per nucleon and the mass number A of different nuclei is a curve, called binding energy curve.'



Inferences from the curve :-

(1) From $A = 50$ to $A = 80$ curve is almost flat (avg. $B.E./A \approx 8.5\,MeV$) so the nuclei of mass number b/w $A = 50$ and $A = 80$ are most stable.

(2) For iron ($_{26}Fe^{56}$, i.e. $A = 56$) $B.E./A$ is maximum ($\approx$ ($\approx 8.8\,MeV$), hence it has maximum stability.

3. For nuclei of $A > 80$, avg. B.E./A decreases slowly and drops to about 7.6 MeV for $_{92}U^{238}$. This lower value of B.E./A fails to overcome repulsion among protons in nuclei having large no. of protons. For this reason nuclei of heavier atoms, beyond $_{83}Bi^{209}$ are radioactive.

4. For nuclei of $A < 50$, avg. B.E./A decreases and below $A=20$ it decreases sharply. Hence nuclei of $A < 20$ are comparatively less stable.

5. Below $A < 50$, the curve does not fall continuously. The curve has peaks at $_8O^{16}$, $_6C^{12}$ and $_2He^4$. This shows that even-even nuclei are more stable than their immediate neighbours.

6. Both very heavy and very light nuclei have a lower average Binding Energy per nucleon (B.E./A).

7. Heavier nuclei (such as $_{92}U^{238}$) have a tendency to split into two lighter nuclei (near flat maximum of the curve) to increase avg. B.E./A by releasing the energy. [NUCLEAR FISSION].

8. The lighter nuclei (such as $_1H^2$) have a tendency to combine to form a heavier nucleus ($_2He^4$) to increase avg. B.E./A (by much greater amount than in fission) by releasing larger amount of energy [NUCLEAR FUSION].

RADIOACTIVITY

'Radioactivity is the phenomenon of spontaneous transformation of an element into another with the emission of some particles (α-particles, β-particles) or radiations (γ-rays) is called natural radioactivity.'

The substance capable of emitting radiations are called radioactive substance.

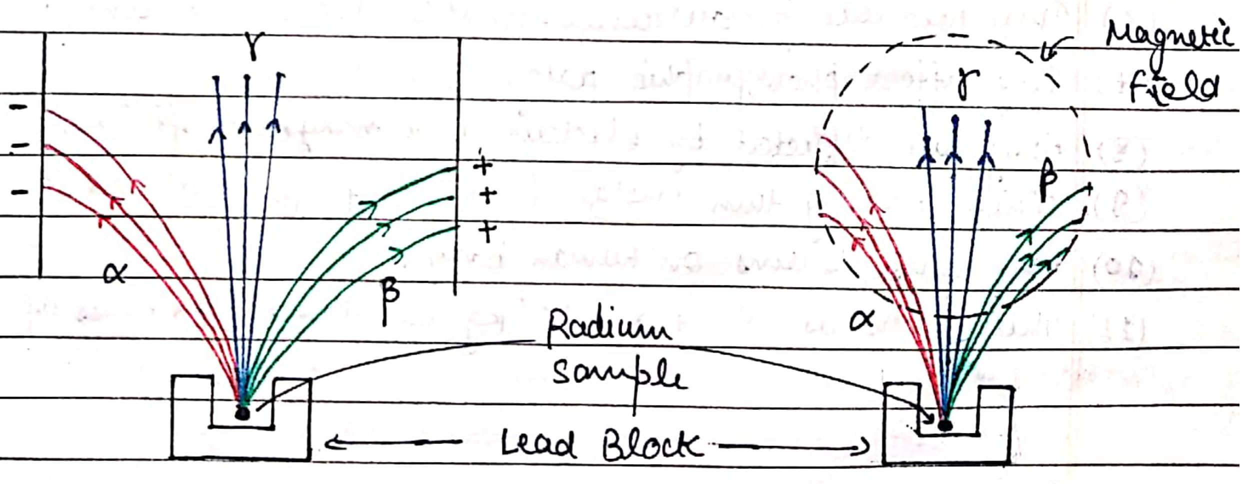
e.g. of radioactive substance :- uranium, polonium, radium thorium, actinium, etc. It is seen that all naturally occuring elements with atomic number greater than 82 show radioactivity

Discovery :-> The phenomenon of radioactivity was discovered accidently by Henry Becquerel in 1896.
Pierre Curie and Marie Curie, two years later the discovery of radioactivity by Bequerel, discovered two more radioactiv substance - Polonium and Radium.

NUCLEAR RADIATIONS :->

'Nuclear radiation refers to the particles and photon emitted during the disintegration of a radioactive substance.'
They are also known as Ionising Radiations.
Nuclear radiations includes :->
(i) α-Rays (ii) β-Rays (iii) γ-Rays
These three rays are called Becquerel Rays

Rutherford and Villiard were the 1st to analyse the radiation emitted by radium. This radiation was found to consist of three components :-> α-Rays, β-rays and γ-Rays.



(i) In electric field (ii) In magnetic field

A sample of radioactive element is placed in small cavity drilled in a lead block. The radiations coming out of the cavity are subjected to an electric field provided by two plates or magnetic field as shown in fig.

In both cases, the narrow beam splits into 3 components

(1) The component which bends towards the negative plate consists of +vely charged particles, called α-rays.

(2) The component which bends towards the +ve plate consists of -vely charged particles, called β-rays.

(3) The component which remains undeflected consists of neutral photons, called γ-rays.

Properties of α-particles :->

(1) An α-particle is equivalent to helium nucleus ($_2He^4$) consisting of two protons and two neutrons.
(2) It has a +ve charge equal to +2e where $e = 1.6 \times 10^{-19}$ C.
(3) Velocity of α-particle is of the order of $\frac{1}{10}$th of velocity of light
(4) Because of large mass, penetrating power of α-particles is very small. α-particles can be easily stopped by an Al sheet of 0.02 mm thickness.
(5) Because of large mass & velocity, they have large ionizing power.
(6) They produce fluorescence in substances like zinc sulphide.
(7) They affect photographic plate.
(8) They are deflected by electric and magnetic fields.
(9) While passing thin metal foils, they get scattered.
(10) They cause burns on human body.
(11) Their mass is 6.67×10^{-27} kg or 4amu (4× mass of proton)

Properties of β-particles :-)

(1) They consists of fast moving electrons of nuclear origin.

(2) It carries the charge of an e^- i.e. 1.6×10^{-19} C of -ve charge.

(3) Their velocity ranges from 33% to 99% of velocity of light.

(4) Because of small mass, the penetrating power of β-particles is very large. They are absorbed by Al sheet of 5mm thickness. Their penetrating power is 100 times that of α-particle.

(5) They ionise the gas through which they pass, but their ionising power is 1/100th that of α-particles.

(6) They can also produce fluorescence in certain substances like ZnS.

(7) They affect photographic plate more strongly than α-particle.

(8) They are deflected by electric and magnetic field.

(9) Due to their small masses, β-particles are easily scattered by atomic nuclei when passed through matter.

(10) Their mass is same as that of $e^- = 9.1 \times 10^{-31}$ Kg.

Properties of γ-Rays :-)

(1) They are electromagnetic waves which have wavelength less than of X-rays.

(2) γ-rays are not deflected by electric & magnetic fields showing that they do not have any charge.

(3) γ rays travel with the speed of light. The rest mass of γ-photon is zero.

(4) γ rays have very large penetrating power. Their penetration power is 10000 times of α-particles. They can pass through several cm's of iron & lead sheet.

(5) They ionise gases very slightly. Their ionising power is $\frac{1}{10000}$ times that of α-particles.

(6) They can produce fluorescence in substances like ZnS (very least).

(7) They affect a photographic plate more than β-particles.

(8) They eject β-particles from substance on which they fall.
(9) They can produce nuclear reactions.

Comparision Between the properties of α, β and γ-rays.

Property	α-Rays	β-Rays	γ-Rays
1. *Nature*	Helium nuclei	Electrons of nuclear origin	High energy e.m. radiations
2. *Mass*	6.67×10^{-27} kg or 4 amu	9.11×10^{-31} kg	Rest mass is zero
3. *Charge*	$+2e$	$-e$	0
4. *Deflection by $\vec{E}$ and $\vec{B}$*	Deflected towards –ve pole	Deflected towards +ve pole	Nil
5. *Speed*	$\approx 10^7$ ms^{-1}	$\approx 10^8$ ms^{-1} but variable	3×10^8 ms^{-1}
6. *Ionising power*	10^4 times that of γ-rays	10^2 times that of γ-rays	Minimum
7. *Penetrating power*	Minimum	10^2 times that of α-rays	10^4 times that of γ-rays
8. *Effect on photographic plate and ZnS phosphor*	Strong effect	Less effect	Least effect

LAWS OF RADIOACTIVE DECAY :-

(1) Radioactivity is a spontaneous phenomenon and one can not predict when a particular atom in a given radioactive sample will undergo disintegration.

(2) When a radioactive atom disintegrate, either an α-particle (the nucleus) or a β-particle (e^-) is emitted.
The new atom so formed (called daughter atom) may emit a γ-ray photon if nucleus is left in excited state on emitting α or β-particle.
The α and β particle are never emitted simultaneously.
Further, a radioactive atom can never emit more than one α-particle or β-particle at a time.

(3) On emitting α-particle, the atomic no. and mass no. of daughter nucleus are respectively 2 and 4 less than that of their corresponding values for parent nucleus.

$$\boxed{{}_{Z}X^{A} \xrightarrow{-\alpha} {}_{Z-2}Y^{A-4}}$$

(4) On emitting β-particle, the atomic no. of the daughter nucleus increases by 1 whereas the mass no. remains same as compared to their corresponding values for parent nucleus.

$$\boxed{{}_{Z}X^{A} \xrightarrow{-\beta} {}_{Z+1}Y^{A}}$$

(5) The emission of a γ-particle does not change the mass no. or the atomic no. of the radioactive nucleus.

Imp

(6) RADIOACTIVE DECAY LAW :->

'The number of nuclei disintegrating per second of a radioactive sample at any time is directly proportional to the no. of undecayed nuclei present at that time.'

OR

'The Instantaneous rate of disintegration of a radioactive sample is directly proportional to the no. of atoms present at that time.'

i.e., $\boxed{-\frac{dN}{dt} \propto N}$ ——— ①

The –ve sign indicates that the no. of undecayed nuclei (N) decreases with time.

Let at $t = 0$, no. of nuclei present $= N_0$
Let at $t = t$, no. of nuclei becomes $= N$
Let at $t = t + dt$, no. of nuclei becomes $= N - dN$

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∴ No. of atoms disintegrated $= dN$, in a time dt

Acc. to Radioactive Decay Law,

$$-\frac{dN}{dt} \propto N$$

$$\therefore \quad \boxed{\frac{dN}{dt} = -\lambda N} \quad \text{———} ②$$

↳ a constant called RADIOACTIVE DECAY CONSTANT or DISINTEGRATION CONSTANT or TRANSFORMATION CONSTANT

So, $$\frac{dN}{dt} = -\lambda N$$

$$\Rightarrow \frac{dN}{N} = -\lambda dt$$

∴ on Integrating both sides.

$$\int \frac{dN}{N} = -\int \lambda dt$$

$$\int \frac{1}{N} dN = -\lambda \int dt$$

Integration constant

$$\log_e N = -\lambda t + C \quad \text{———} ③$$

at, $t = 0$, $N = N_0$

$$\log_e N_0 = -\lambda \times 0 + C$$

$$\Rightarrow \boxed{C = \log_e N_0} \quad \text{———} ④$$

∴ From eqⁿ ③ & ④, we get

$$\log_e N = -\lambda t + \log_e N_0$$

$$\log_e N - \log_e N_0 = -\lambda t$$

$$\log_e \left(\frac{N}{N_0}\right) = -\lambda t$$

$$\therefore \quad \frac{N}{N_0} = e^{-\lambda t} \quad \text{———} ⑤$$

$$\boxed{N = N_0 e^{-\lambda t}} \quad \text{———} ⑥$$

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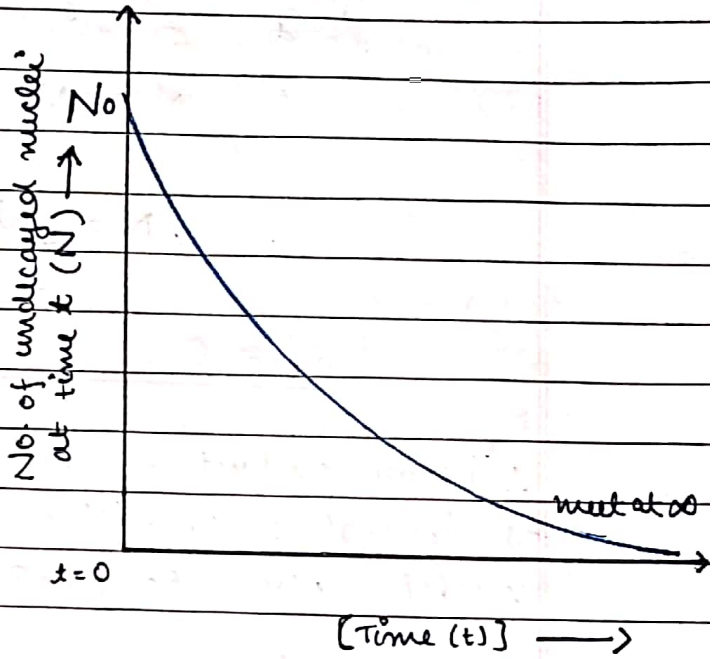
NOTE:-> ~~At~~ Eqn ⑥ gives the no. of radioactive nuclei left after time 't'.

The graph b/w N and t is shown in fig.

(1) The no. of active nuclei decreases rapidly in the begining and the rate of decay becomes slower and slower with the passage of time.



(2) The slope of the graph at any instant gives the instantaneous rate of disintegration.

(3) The larger the value of decay constant λ, the higher is the rate of disintegration.

(4) A radioactive sample will take infinitely long time to disintegrate completely.

DECAY CONSTANT :->

as $\frac{dN}{dt} = \lambda N$ (in magnitude)

$$\therefore \boxed{\lambda = \frac{dN/dt}{N}} \quad \text{——} ①$$

∴ 'Decay constant of a radioactive nuclei is numerically equal to the ratio of its instantaneous rate of disintegration to the no. of undecayed atoms present at that time.'

=> The value of λ depends on the nature of the radioactive substance.

as, $N = N_0 e^{-\lambda t}$ —— ②

If $\lambda = \frac{1}{t}$ then from eq.^{n} ② $N = N_0 e^{-1}$

$$\therefore \quad N = \frac{N_0}{e}$$

$$N = \frac{N_0}{2.718}$$

$$\boxed{N = 0.368\, N_0} \qquad \boxed{N = 36.8\% \text{ of } N_0}$$

∴ 'Decay constant of radioactive nucleus is equal to the reciprocal of that time in which the no. of undecayed nuclei reduces to 36.8% of their initial value.'

HALF - LIFE :→ 'The half life of a radioactive substance is the time in which it reduces to half of its initial value.'

Denoted by :→ $T_{1/2}$

Relation b/w $T_{1/2}$ and λ :→

As, $N = N_0 e^{-\lambda t}$

If $t = T_{1/2}$, $N = \frac{N_0}{2}$

∴ from above eq.^{n}, $\frac{N_0}{2} = N_0 e^{-\lambda T_{1/2}}$

$$\frac{1}{2} = e^{-\lambda T_{1/2}}$$

$$e^{\lambda T_{1/2}} = 2$$

Taking natural logarithm,

$$\lambda T_{1/2} = \log_e 2$$

$$\lambda T_{1/2} = 2.303 \log_{10} 2$$

$$\lambda T_{1/2} = 2.303 \times [0.3010]$$

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

$$\boxed{T_{1/2} = \frac{0.693}{\lambda}} \quad \text{———} \ ②$$

NOTE:- After 1^{st} half life, $N = \frac{N_0}{2} \Rightarrow \frac{N}{N_0} = \frac{1}{2} \Rightarrow \frac{N}{N_0} = \left(\frac{1}{2}\right)^1$

" 2^{nd} " " , $N = \frac{1}{2}\left(\frac{N_0}{2}\right) \Rightarrow \frac{N}{N_0} = \cancel{N_0} \frac{1}{4} \Rightarrow \frac{N}{N_0} = \left(\frac{1}{2}\right)^2$

" 3^{rd} " " , $N = \frac{1}{2}\left(\frac{N_0}{4}\right) \Rightarrow \frac{N}{N_0} = \frac{1}{8} \Rightarrow \frac{N}{N_0} = \left(\frac{1}{2}\right)^3$

— — — — — — — — — — —

— — — — — — — — — —

— — — — — — — — —

" n^{th} " " , ~~N~~ — — — — — — — — $\frac{N}{N_0} = \left(\frac{1}{2}\right)^n$

i.e., No. of radioactive nuclei left undecayed after n half lives -

$$\boxed{\frac{N}{N_0} = \left(\frac{1}{2}\right)^n} \quad \text{———} \ ①$$

If total time lapes in 'n' half lives is 't'

then $n = \frac{t}{T_{1/2}}$

$\therefore$ from eq^n ①

$$\boxed{\frac{N}{N_0} = \left(\frac{1}{2}\right)^{t/T_{1/2}}} \quad \text{———} \ ②$$

$\Rightarrow$ Significance of half-time :- 'The value of half-life of a radio isotope gives an idea of the relative stability of that isotope. An isotope having longer half life is more stable than the isotope with shorter half-life.'

MEAN LIFE or AVERAGE LIFE

'Mean life is the average time for which the nuclei of a radioactive substance exist.'

It is denoted by 'T_a'.

$$\boxed{\text{Mean Life } (T_a) = \frac{\text{Sum of the lives of all the nuclei}}{\text{Total number of nuclei}}}$$

Relation b/w MEAN LIFE AND DECAY CONSTANT

Let ⇒ N_0 ⇒ no. of nuclei at $t = 0$

N ⇒ no. " " at $t = t$

and $N + dN$ ⇒ no. " " at $t = t + dt$

As dt is small, so the life of each of the dN nuclei can be approximately taken equal to 't'.

∴ Total life of dN nuclei $= t\,dN$

Total life of N_0 nuclei $= \int_0^{N_0} t\,dN$

$$\text{Mean Life} = \frac{\text{Total life of all } N_0 \text{ nuclei}}{N_0}$$

or $$T_a = \frac{1}{N_0}\int_0^{N_0} t\,dN$$

as $N = N_0 e^{-\lambda t}$

$dN = -\lambda N_0 e^{-\lambda t}\,dt$ (Differentiating both sides).

When $N = N_0$, $t = 0$ and when $N = 0$, $t = \infty$

changing the limits in terms of time, we get

$$T_a = \frac{1}{N_0}\int_0^{\infty} t\lambda N_0 e^{-\lambda t}\,dt$$

Here we ignored -ve sign which tells that N decreases with passage of time (Magnitude only).

$$T_a = \lambda\int_0^{\infty} \underset{\text{I}}{\underset{\Downarrow}{t}}\,\underset{\text{II}}{\underset{\Downarrow}{e^{-\lambda t}}}\,dt$$

Now, using integration by parts.

$$T_a = \lambda \left[\left\{ t \int e^{-\lambda t} dt \right\}_0^{\infty} - \int_0^{\infty} \left(\frac{dt}{dt} \int e^{-\lambda t} dt \right) dt \right]$$

$$T_a = \lambda \left[\left\{ \frac{t e^{-\lambda t}}{-\lambda} \right\}_0^{\infty} - \int_0^{\infty} \frac{e^{-\lambda t}}{-\lambda} dt \right]$$

$$T_a = 0 + \frac{\lambda}{\lambda} \int_0^{\infty} e^{-\lambda t} dt = \left[\frac{e^{-\lambda t}}{-\lambda} \right]_0^{\infty}$$

$$T_a = -\frac{1}{\lambda} \left[e^{-\infty} - e^{0} \right] = -\frac{1}{\lambda} [0 - 1]$$

$$\boxed{T_a = \frac{1}{\lambda}}$$

Also,

$$\boxed{T_{1/2} = \frac{0.693}{\lambda} = 0.639\, T_a}$$

$$\boxed{T_a = \frac{T_{1/2}}{0.693} = 1.44\, T_{1/2}}$$

∴ Average life of a radioactive sample is equal to the reciprocal of its decay constant.

ACTIVITY OF A RADIOACTIVE SUBSTANCE

'Activity of a radioactive Substance is its instantaneous rate of disintegration.'

or

'The no. of disintegrations of radioactive sample per second is called activity of radioactive substance.'

Decay Rate or activity R of a radioactive sample at time t is

$$\boxed{R = -\frac{dN}{dt}} \quad \text{———} ①$$

-ve sign indicates that activity decreases with passage of tim

Also, as $\frac{dN}{dt} = -\lambda N$ —— ②

from ① & ② $\boxed{R = \lambda N}$

hence $R_0 = \lambda N_0$ (Decay Rate at $t = 0$)

as $N = N_0 e^{-\lambda t}$

$$\frac{R}{\lambda} = \frac{R_0}{\lambda} e^{-\lambda t}$$

$$\boxed{R = R_0 e^{-\lambda t}} \quad \text{—— ③}$$

Similarly,
It can be proved that $\boxed{\frac{R}{R_0} = \left(\frac{1}{2}\right)^{t/T_{1/2}}}$ —— ④

UNITS OF ACTIVITY :-

S.I. Unit ⇒ Becquerel (Bq)

'One bequerel is defined as the decay rate of one disinitegration per second.'

$$\boxed{1\ \text{Bq} = 1 \text{ decay per second (dps)}}$$

Other Units ⇒ (a) Curie (Ci)

'Decay rate of 3.7×10^{10} disintegrations per second

$$\boxed{1\ \text{Ci} = 3.7 \times 10^{10}\ \text{dps} = 1\ \text{Bq}}$$

(b) Rutherford (rd) ⇒ 'Decay rate of 10^6 disintegration per second.'

$$\boxed{1\ \text{rd} = 10^6\ \text{dps} = 10^6\ \text{Bq}}$$

$$\boxed{1\ \text{Ci} = 3.7 \times 10^4\ \text{rd}}$$

1 mCi (milli curie) = 3.7×10^7 Bq
1 μCi (micro curie) = 3.7×10^4 Bq

Q ⇒ How many α and β-particles are emitted in the following decay process.

$$_{92}U^{238} \longrightarrow {}_{82}Pb^{206}$$

Sol^n as in given process, mass no. is reduced by 32.

∴ no. of α-particles emitted = $\frac{32}{4} = 8$

$_{92}U^{238} \xrightarrow{-8\alpha} Y^{206}_{92-16}$ | $_{92}U^{238} \xrightarrow{-8\alpha} {}_{76}Y^{206}$

as atomic no. after emitting 8α particles should be 76 but ATQ, it is 82.

∴ increase in Z = 82 − 76 = 6

no. of β-particles emitted = $\frac{6}{1} = 6$

ALPHA DECAY :→

'Alpha decay is a process in which an unstable nucleus transforms itself into a new nucleus by emitting an alpha particle (a helium nucleus $_2He^4$).'

The nuclei that contain more than about 210 nucleons are so large that the short range nuclear force holding them together becomes insufficient to counter balance the long range electrostatic repulsive force b/w the protons. Such nuclei may achieve greater stability by emitting α-particle ($_2He^4$). As α-particle has large value of binding energy nearly equal to (≈ 28 MeV). Therefore, by emitting α-particle, the Binding Energy per nucleon of the residual nucleus increases and hence tends towards the greater stability.

α- decay can be expressed as

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

here $E_\alpha = \Delta m c^2$

where $\Delta m = \left[m_X - (m_Y + m_{He}) \right]$

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

NOTE:-> Speed of emitted α- particle :-> suppose parent nucleus ${}_{Z}X^{A}$ be at rest before decay.

Let v_{He} => velocity of α- particle

v_Y => " " daughter nucleus Y

Applying Law of conservation of momentum.

$$m_Y v_Y = m_{He} v_{He} \quad \text{———} \; ①$$

As E_α appears in the form of K.E. of α- particle & daughter nucleus

So,

$$\frac{1}{2} m_{He} v_{He}^2 + \frac{1}{2} m_Y v_Y^2 = E_\alpha \quad \text{———} \; ②$$

Substitute the value of v_Y from ①

$$\frac{1}{2} m_{He} v_{He}^2 + \frac{1}{2} \frac{m_{He}^2 v_{He}^2}{m_Y^2} = E_\alpha$$

$$\frac{1}{2} m_{He} m_Y v_{He}^2 + \frac{1}{2} m_{He}^2 v_{He}^2 = m_Y E_\alpha$$

$$\frac{1}{2} (m_Y + m_{He}) m_{He} v_{He}^2 = m_Y E_\alpha$$

$$\underbrace{\frac{1}{2} m_{He} v_{He}^2}_{\Downarrow \; K_{He}} = \frac{m_Y}{m_Y + m_{He}} \cdot E_\alpha$$

Now, $m_Y \approx (A-4)$ amu & He = 4 amu

∴

$$\boxed{K_{He} = \frac{1}{2} m_{He} v_{He}^2 = \frac{(A-4) \cdot E_\alpha}{A}}$$

$$\boxed{v_{He} = \sqrt{\frac{2K_{He}}{m_{He}}} = \sqrt{\frac{2(A-4) \cdot E_\alpha}{A m_{He}}}}$$

* **BETA DECAY** :-> 'The process of spontaneous emission of an electron (e^-) or a positron (e^+) from a nucleus is called β-decay.'

Beta Decay generally occurs in the nuclei having neutron to proton ratio higher or lower than that of a stable nuclei.

It may occur in following two cases :->

(1) **Beta Minus (β^-) Decay** :-> In this decay a neutron in a nucleus is converted into a proton and electron. In this process a new particle called antineutrino is also originated.

$$n \longrightarrow p + e^- + \bar{\nu}$$

or

$${}_0n^1 \longrightarrow {}_1H^1 + {}_{-1}e^0 + \bar{\nu}$$

As neutron no. is reduced by 1 and proton no. is increased by 1. Therefore, in this case neutron to proton ratio decreases.

$$\boxed{\begin{array}{l} {}_ZX^A \longrightarrow {}_{Z+1}Y^A + {}_{-1}e^0 + \bar{\nu} \\ {}_ZX^A \longrightarrow {}_{Z+1}Y^A + \beta^- + \bar{\nu} \end{array}}$$

or

anti neutrino

beta minus particle

(2) **Beta Plus (β^+) Decay** :-> In this decay, a proton is converted into a neutron by ejecting a positron and neutrino as-

$$p \longrightarrow n + e^+ + \nu$$

or

$${}_1H^1 \longrightarrow {}_0n^1 + {}_{+1}e^0 + \nu$$

In such case, neutron no. increases by 1 whereas proton no. decreases by 1.

β particle → electron

β^+ particle → positron.(anti particle of e^-)

β^+ decay is represented as –

$$\boxed{{}_{z}X^{A} \longrightarrow {}_{z-1}Y^{A} + {}_{+1}e^{0} + \nu}$$

OR

$$\boxed{{}_{z}X^{A} \longrightarrow {}_{z-1}Y^{A} + \underset{\text{Beta Plus } \beta^+ \text{ particle}}{\beta^+} + \nu} \text{ neutrino.}$$

NOTE :-

(1) A nucleus does not contain any electron, positron, neutrino or antineutrino, yet it can eject these particles.

In β^- decay, neutron transforms into a proton inside the nucleus as –
$$n \rightarrow p + e^- + \bar{\nu}$$

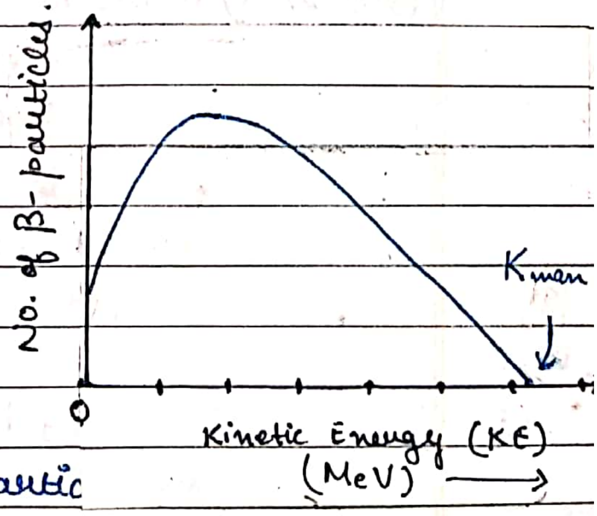
In β^+ decay, proton transforms into a neutron inside the nucleus as –
$$p \longrightarrow n + e^- \nu$$

It shows that a beta decay process involves the conversion of a neutron into a proton or vice-versa. These nucleons have nearly equal mass. That is why the mass number (A) of a nuclide undergoing beta decay does not change.

(2) The graph b/w energy of β-particles & their number is shown in fig.

⇒ Most of the β-particles emitted carry small energies.

⇒ Only very few β-particles carry maximum energy called end point energy.



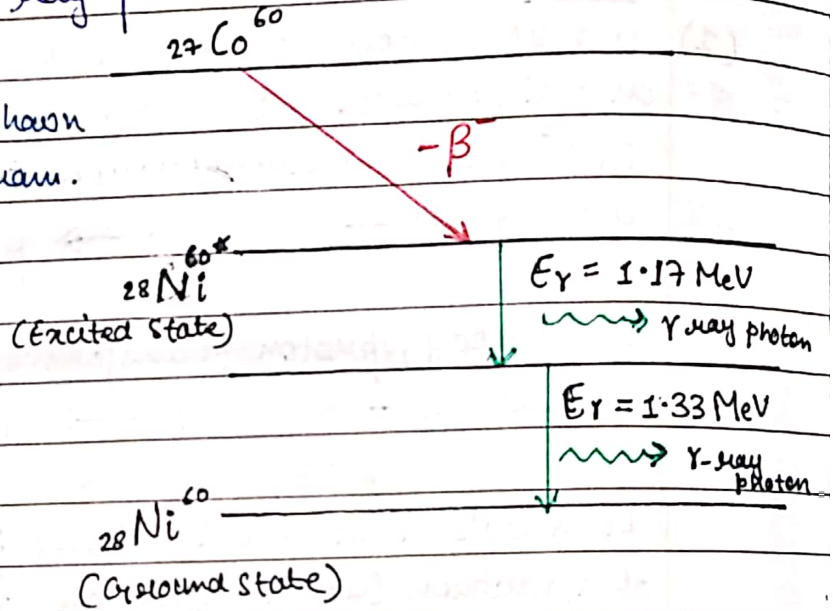
⇒ The energy spectrum of emitted β-particles is continuous i.e., β-partic can carry all possible energies from zero to maximum.

GAMMA DECAY :-

'It is the process of emission of Gamma Ray photon from a radioactive nucleus.'

During the radioactive decay, the emission of α or β- particle usually leaves the nucleus in an excited state which is found to go some other excited state or ground state by emitting γ-ray photons.

eg.⇒ of γ-decay is shown through energy diagram.



NUCLEAR REACTIONS

'The nuclear transmutations (formation of nuclei of new elements) which are carried out by artificial means (by bombarding the target nuclei with some particle called projectile) are called Nuclear Reactions.'

Examples :-

① $_7N^{14} + {}_2He^4 \longrightarrow {}_8O^{17} + {}_1H^1$

(α - particle used as projectile)

② $_{13}Al^{27} + {}_1H^1 \longrightarrow {}_{12}Mg^{24} + {}_2He^4$

(Proton used as projectile)

③ $_7N^{14} + {}_0n^1 \longrightarrow {}_5B^{11} + {}_2He^4$

(neutron [illegible] projectile)

④ $${}_3Li^7 + {}_1H^2 \longrightarrow {}_3Li^8 + {}_1H^1$$

(Deutron used as projectile)

SYMBOLIC REPRESENTATION OF A NUCLEAR REACTION

$${}_{Z_1}X^{A_1} + {}_{Z_2}P^{A_2} \longrightarrow {}_{Z_3}Y^{A_3} + {}_{Z_4}O^{A_4} + Q$$

Target Nucleus — Projectile — Residual Nucleus — Outgoing Particle — Q. Value of Nuclear Reaction (Energy)

All Nuclear Reactions obey :-

(1) Law of Conservation of nuclear number.

$$A_1 + A_2 = A_3 + A_4$$

(2) Law of Conservation of charge number.

$$Z_1 + Z_2 = Z_3 + Z_4$$

(3) Law of Conservation of mass and energy.

Total energy (K.E. + rest mass energy) of product particles = Total energy of the reactant particles.

(4) Law of Conservation of Momentum.

Total momentum of particles entering into reaction = Total momentum of products after the reaction.

COMPOUND NUCLEUS :-

Nuclear reaction proceed in two stages :-

(1) In 1st stage the bombarding particle strikes the target nucleus to form a new nucleus called Compound Nucleus.

(2) In 2nd stage, the compound nucleus decays into a new nucleus by emitting a particle or a group of particles (it is because the compound nucleus is unstable).

$$\underbrace{X + P \longrightarrow}_{\text{Stage I}} \underset{\text{(unstable)}}{\underset{\text{Compound Nucleus}}{[C]}} \underbrace{\longrightarrow Y + O}_{\text{Stage II}}$$

Q-Value of Nuclear Reaction :→

[Nuclear Reaction Energy]

In the reaction $X + P \longrightarrow Y + O + Q$

$Q \Rightarrow$ represents Q. Value of nuclear reaction.

'It is equal to the difference b/w the sum of the rest masses of reacting particles and the sum of the rest masses of the product particles.'

If Q is +ve ⇒ Reaction is exoergic.
If Q is −ve ⇒ Reaction is endoergic.

NOTE:→ Whenever an element with a smaller B.E. is transmuted into an element with a larger B.E., a tremendous amount of energy is released. This is due to the conversion of some mass into energy in accordance with Einstein's mass-energy relation.
The energy released due to the decrease in mass is given by

$$\boxed{Q = -\Delta m c^2}$$

∴ The nuclear reactions which can be exploited to produce energy are of two broad types :→

(1) Nuclear Fission
(2) Nuclear Fusion.

NUCLEAR FISSION

'The process of splitting of a heavy nucleus into two nuclei of nearly comparable masses with liberation of energy is called Nuclear Fission.'

eg :→

$$_{92}U^{235} + {}_0n^1 \longrightarrow [_{92}U^{236}] \longrightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_0n^1 + 200\ \text{MeV}$$

slow neutron

compound Nucleus (unstable)

Mass defect in this reaction = 0·2153 amu

Energy released per fission of $_{92}U^{235}$ = $0{\cdot}2153 \times 931 \approx 200$ MeV

Each of the 3 neutron carries an energy of about 2 MeV as such the fast neutrons will escape and can not cause the fission of other uranium nuclei. To utilise them for the fission of the other 3 uranium nuclei they have to be slowed down.

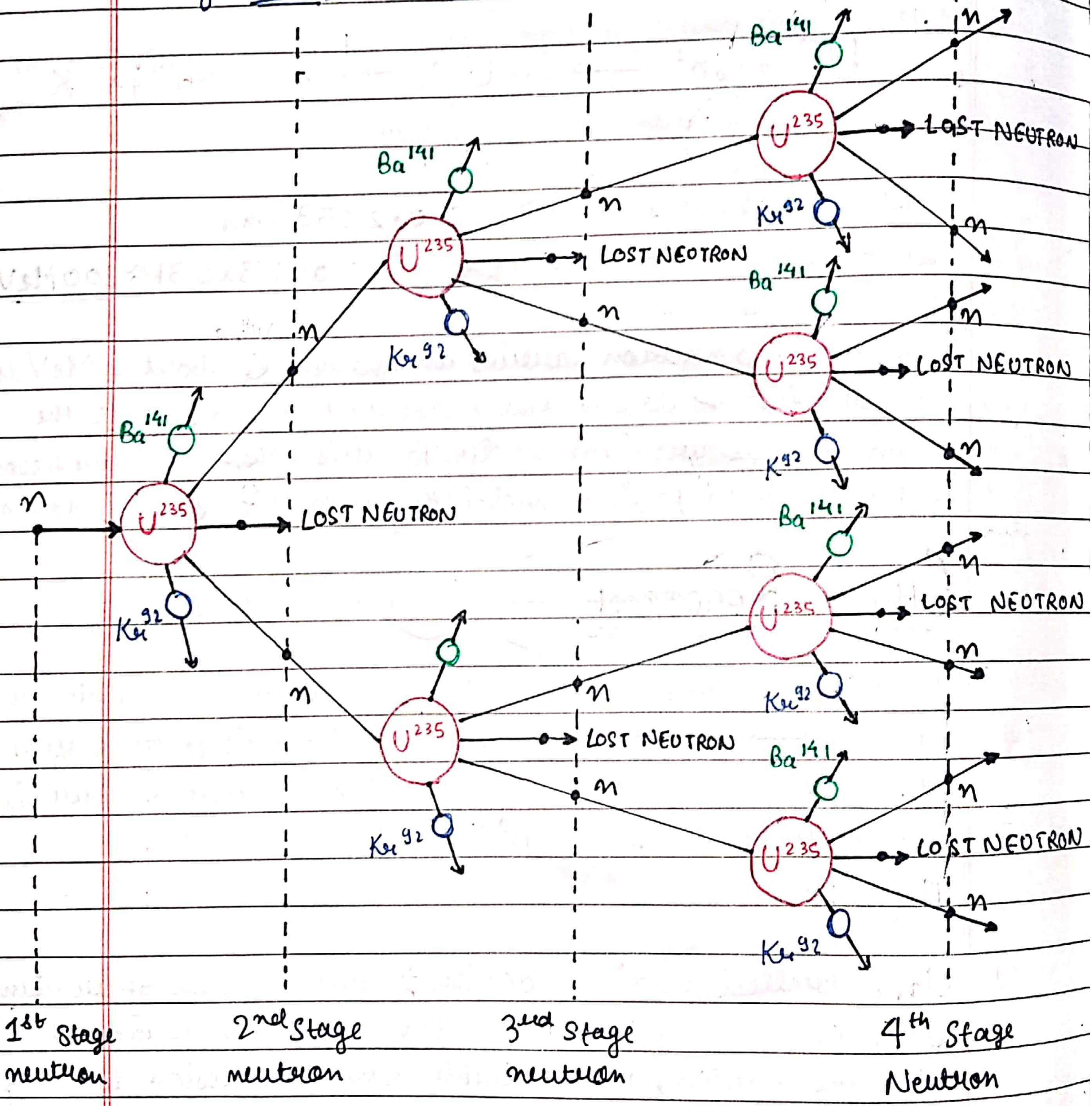
CHAIN REACTION

'A nuclear chain reaction is that reaction in which the particle that initiates the reaction is also produced after the reaction and can carry on the reaction further is known as Chain Reaction.'

Types :→

(1) Uncontrolled Chain Reaction ⇒ Such a fission of uranium atom in which all the neutrons which are produced after the reaction, are available after the fission to carry out the fission further is called Uncontrolled chain Reaction. eg ⇒ in atomic bomb.

<u>Controlled Chain Reaction</u> ⇒ In these type of reactions partial absorption of neutrons is done after each fission. <u>eg</u> ⇒ Such reactions are carried out in Nuclear Reactors. In nuclear reactors such absorption is done using <u>Boron</u> or <u>Cadmium</u> rods.



⇒ The slow moving neutrons of energies 0.0235 eV are called <u>Thermal Neutrons</u>.

NEUTRON REPRODUCTION FACTOR (K) :-

(Multiplication factor).

'It is defined as the ratio of rate of production of neutrons to the rate of loss of neutrons.'

$$\boxed{K = \frac{\text{Rate of production of neutrons}}{\text{Rate of loss of neutrons.}}}$$

If K > 1 ⇒ The reaction is accelerated.
If K = 1 ⇒ Reaction is steady.
If K < 1 ⇒ Reaction is retarded.

CRITICAL SIZE AND CRITICAL MASS :-

'The uranium/any other fissionable material block is said to be of critical size if the no. of neutrons lost per second is just equal to the no. of neutrons produced per second in the block.'

'The mass of such a block is said to be a critical mass.'

NUCLEAR REACTOR/ATOMIC PILE

'It is a device in which sustained and controlled chain reactions are carried out.'

Principle ⇒ Controlled Nuclear Fission Reaction.

Construction ⇒ Its essential parts are :-

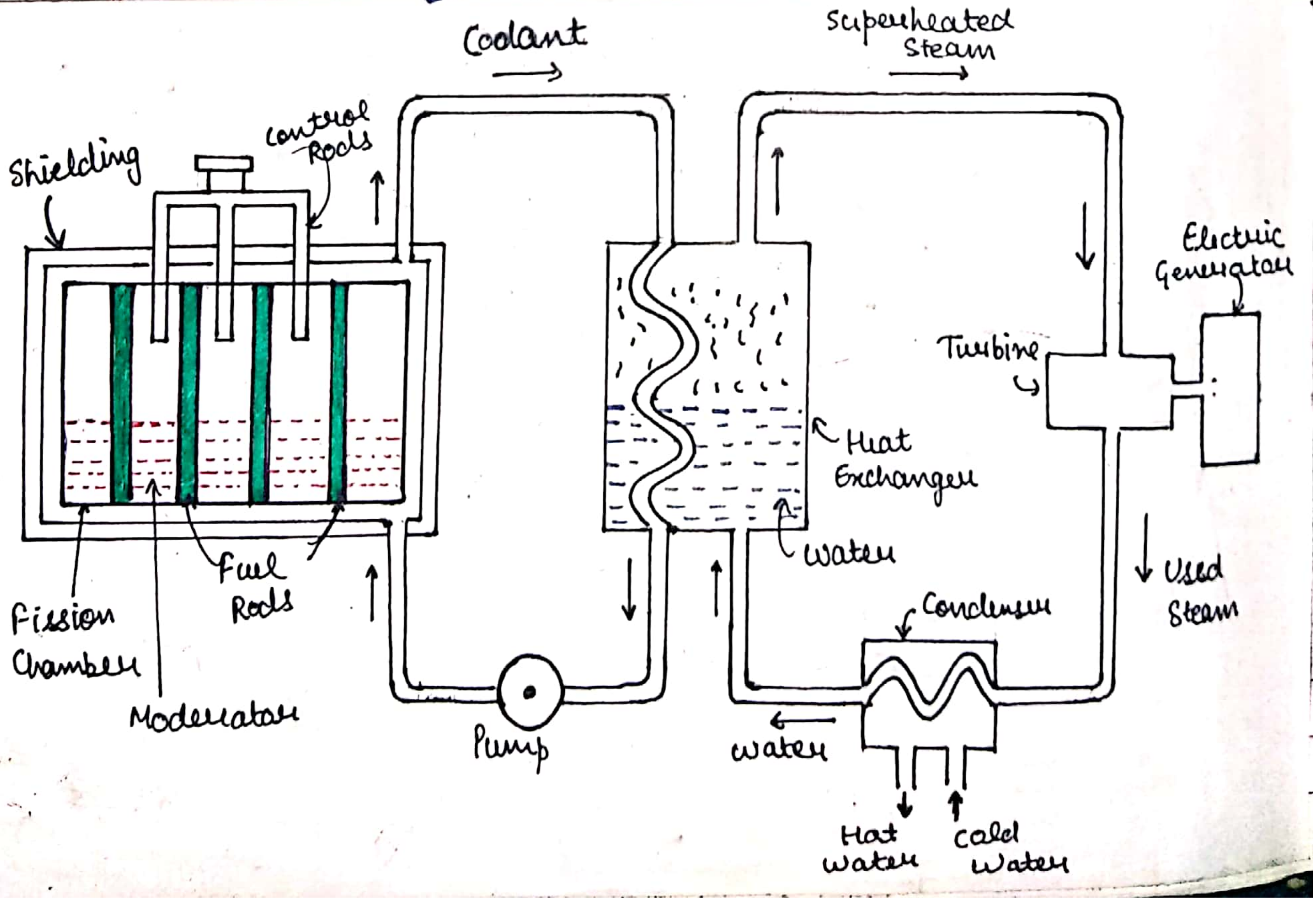
(1) **Nuclear Fuel** ⇒ A fissionable material such as U-235, Th-232, and Pu-239 is used as fuel and is taken in the form of rod. These rods are placed in the core of the reactor.

(2) **Moderator** ⇒ A material used to slow down the fast moving neutrons is called a Moderator. Fast neutrons have more tendency to escape while slow neutrons are more efficient in inducing fission. e.g ⇒ D_2O (heavy water), graphite, etc.

(3) **Control Rods** ⇒ It is a material used to absorb the neutrons to control chain reaction and maintain a stable rate of reaction. Cadmium or Boron rods are used as Control Rods.

(4) **Coolant** ⇒ It is a material used to absorb the heat generated in the reactor. It releases the heat to water which then convert it into steam and this steam is used to run the turbine. The coolant must have high boiling point and high specific heat. Heavy water and Liquid Sodium are used as coolants.

(5) **Protective Shields** ⇒ The reactor is enclosed in a thick concrete chamber to prevent spreading of radioactive effect of the surroundings known as Protective Shields.



WORKING :- A few $_{92}U^{235}$ nuclei undergo fission liberating fast neutrons. These fast neutrons are slowed down by surrounding moderator. The cadmium rods are used to control the chain reaction. The fission produces heat in the nuclear core. The coolant transfers this heat from the core to the heat exchanger, where steam is formed. This steam produced at very high pressure runs a turbine and electricity is obtained at the generator. The dead steam from the turbine condenses into water and is returned into the heat exchanger. The process repeats and continuous supply of electrical energy is obtained.

In addition to production of electricity, nuclear reactor is also used to produce radioactive isotopes.

NUCLEAR FUSION

'When two or more than two light nuclei fuse together to form a heavy nucleus with the liberation of energy, the process is called Nuclear Fusion.'

e.g. =)

$$_1H^2 + {_1H^2} \longrightarrow {_2He^4} + 24\ MeV$$

$$_1H^1 + {_1H^1} \longrightarrow {^2_1H} + e^- + \nu + 0.42\ MeV$$

Fusion of the two light nuclei takes place in an attempt to achieve greater stability.

To carry out the fusion of the two nuclei they must be brought so much close so that they overcome electrostatic repulsion and come within the attractive range of the Nuclear forces. This is best achieved by raising the temp. of two nuclei about $10^7 K$ due to which these reactions are also called **Thermonuclear reactions**.

It is very difficult to achieve such a high temperature but this can be triggered by atomic explosion involving fission.

Once the fusion begins, the energy liberated can maintain the minimum required temperature and the fusion continues.

Thermonuclear fusion reactions are the source of energy in sun as well as other stars.

If we compare the above energy outcome with the energy released in the fission of U-235 (as discussed earlier), the fusion reactions seems to be less energetic than fission. However, for the same mass in the two cases, if we calculate the energy released, then we found that the energy released in the fusion reaction is about 7 times as large as in case of the fission reaction.

Necessary Conditions for Nuclear Fusion :-

(1) **High Temperature** is necessary for the light nuclei to have sufficient kinetic energy so that they can overcome mutual coulombic repulsions and come closer than the range of nuclear force.

(2) **High Density** or pressure increases the frequency of collision of light nuclei and hence increases the rate of fusion.

Nuclear Fission versus Nuclear Fusion

	Nuclear Fission	Nuclear Fusion
(1)	Here a heavy nucleus when excited gets split up into 2 smaller nuclei of nearly comparable masses.	Here two lighter nuclei fuse together to form a heavier nucleus.
(2)	Neutrons are the link particles in this process.	Protons are the link particles in this process.

(3)	The conditions of high temp. and pressure are not necessary for its occurrence. It can be carried on the earth.	The conditions of extremely high pressure and temp. are necessary for its occurrence. So it can't be easily carried in laboratory.
(4)	Here the energy available per nucleon is small, about 0.85 MeV.	Here the energy available per nucleon is large, about 6.75 MeV.
(5)	The energy obtained from a unit mass of fissionable material is smaller than that obtained in case of fusion.	The energy obtained from a unit mass of a fusible material is large.

Q=) A neutron is absorbed by a $_3Li^6$ nucleus with subsequent emission of an α-particle. Write the corresponding nuclear reaction and calculate the energy released in the reaction. Mass of $_3Li^6$ = 6.015126 amu. Mass of $_1H^3$ = 3.016049 amu. Mass of $_2He^4$ = 4.002604 amu. Mass of neutron = 1.008665 amu.

Sol^n

$$_3Li^6 + {}_0n^1 \longrightarrow {}_1H^3 + {}_2He^4 + \text{Energy}$$

$$\Delta m = \left[m(_3Li^6) + m(_0n^1)\right] - \left[m(_1H^3) + m(_2He^4)\right]$$

$$\Delta m = [6.015126 + 1.008665] - [3.016049 + 4.002604]$$

$$\Delta m = 7.023791 - 7.018653$$

$$\Delta m = 0.005138 \text{ amu}$$

Now, 1 amu = 931.5 MeV

$\therefore$ Energy released = 0.005138×931.5

= 4.786047 MeV

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