4/12/23

CHAPTER-12

NUCLEI

★ NUCLEUS

An atom consists of central region called nucleus which has positively charged particles called protons and neutral particles called neutrons.

- ATOMIC MASS UNIT

Atomic mass unit is defined as $\frac{1}{12}^{th}$ the mass of carbon-12 atom (i.e. ${}_6C^{12}$)

- AVAGADRO'S HYPOTHESIS

According to Avagadro's hypothesis, 1 mole of a substance contains atoms equal to Avagadro's number

$$N = 6.022 \times 10^{23}$$

Mass of 6.022×10^{23} atoms = 12g

Mass of 1 atom of $C^{12} = \frac{12}{6.022 \times 10^{23}}$ g

$$1 \text{ amu} = \frac{1}{12} \times \text{mass of 1 carbon atom } {}_6C^{12}$$

$$= \frac{1}{12} \times \frac{12}{6.022 \times 10^{23}}$$

$$= 1.66 \times 10^{-24} \text{ g}$$

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

- ENERGY EQUIVALENT TO 1 AMU

According to mass-energy equivalence $E = mc^2$

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

$$c = 3 \times 10^8 \text{ m/s}$$

$$E = 1.66 \times 10^{-27} \times 9 \times 10^{16} \text{ J}$$

$$= 1.49 \times 10^{-10} \text{ J}$$

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

$$E = \frac{1.49 \times 10^{-10}}{1.6 \times 10^{-19}}$$

$$= 931.25 \times 10^{6} \ eV$$

$$1 \ amu = 931.25 \ MeV \simeq 931 \ MeV$$

- NUCLEONS

Atomic number of protons and neutrons in a nucleus are collectively known as nucleons.

- ATOMIC NUMBER

The number of protons in a nucleus is known as atomic number. It is represented by z.

- ATOMIC MASS NUMBER

The sum of number of protons (z) and number of neutrons (N) is called mass number. It is denoted by A.

$$A = Z + N$$

$$N = A - Z$$

Representation

$$^{A}_{Z}X$$

- PROPERTY OF NUCLEUS

1. Nucleus is located at the centre of atom.
2. Nucleus contains positively charged protons and neutrons which is neutral.
3. Nuclear density is same for all atoms.
4. Size of nucleus depends on mass number.
5. Charge on every nucleus is $+Ze$.

- PROPERTY OF NUCLEAR FORCE

1. Nuclear forces are short range forces (1 fermi)
2. Nuclear forces are attractive in nature.
3. Nuclear force is similar between protons and neutrons.
4. This forces can exert between protons and protons, neutrons and protons or neutrons or neutrons.
5. Thus forces are charge independent.

- SIZE OF THE NUCLEUS

Distance of closest approach for 5.5 MeV KE

$$r_0 = 4 \times 10^{-14} \text{ m}$$

$$KE \propto \frac{1}{r_0}$$

$$KE \uparrow \qquad r_0 \downarrow$$

For further decrease in r_0, attractive nuclear forces start affecting the coulombic repulsion.

→ Nuclear size was found to vary linearly with mass no. (A)
→ It means volume of nucleus is directly proportional to mass no.

$$V\left(\frac{4}{3}\pi R^3\right) \propto A$$

$$R \propto A^{1/3}$$

$$R = \underbrace{R_0}_{\substack{\to \text{empirical constant.} \\ \to 1.2 \text{ fm}}} A^{1/3}$$

Q Calculate the radius of a nucleus of mass number 8. Given $R_0 = 1.2 \times 10^{-15}$ m.

Sol. $R = R_0 A^{1/3}$

$R_0 = 1.2 \times 10^{-15}$

$= 1.2 \times 10^{-15} (8)^{1/3}$

$= 1.2 \times 10^{-15} \times 2$

$= 2.4 \times 10^{-15}$ m

- NUCLEAR DENSITY

Mass per unit volume of a nucleus is called nuclear density.

$$\rho = \frac{\text{Mass of nucleus}}{\text{Volume of nucleus}}$$

$$= \frac{(1.67\times10^{-27})A}{\frac{4}{3}\pi R^3}$$

$$= \frac{1.67\times10^{-27}\cancel{A}}{\frac{4}{3}\pi R_0^3\cancel{A}}$$

$$= \frac{3\times1.66\times10^{-27}}{4\times3.14\times(1.2\times10^{-15})^3}$$

$$= 2.38\times10^{17}\ kg/m^3$$

ρ is independent of A

ρ is constant.

- ISOTOPES, ISOBARS AND ISOTONES

* ISOTOPES

These are the atoms of same element having same atomic number (Z) but different mass number (A).

For example: $^{10}_{6}C$, $^{11}_{6}C$, $^{12}_{6}C$, $^{14}_{6}C$

Isotopes have same number of electrons and protons but different no. of neutrons.

* AVERAGE ATOMIC MASS

Average atomic mass of an element is equal to the weighted average of the masses of these isotopes based on the occurence of each isotope in nature.

$$A_1 \times \%\ \text{abundance} + A_2\ \%\ \text{abundance}$$

$$\frac{A_1 x_1 + A_2 x_2 \ldots}{100}$$

* ISOBARS

The atoms of different chemical elements having same mass number (A) but different atomic no. (Z) ~~is~~ are called isobars.

For example: ^3_1H and ^3_2He

^7_3H and ^7_4Be

* ISOTONES

The atoms of different chemical elements having same number of neutrons but different atomic number.

For example: ^9_4Be and $^{10}_5B$

$^{13}_6C$ and $^{14}_7N$

Q Given the mass of iron nucleus as 55.85 u and A = 56. Find nuclear density.

Sol. $m = 55.85u = 55.85 \times 1.67 \times 10^{-27}$ kg

$$V = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi R_0^3 A$$

$$\text{Nuclear density} = \frac{m}{V} = \frac{3m}{4\pi R_0^3 \times A}$$

$$= \frac{3 \times 55.85 \times 1.67 \times 10^{-27}}{4 \times 3.14 \times (1.2 \times 10^{-15})^3 \times 56}$$

$$= 2.29 \times 10^{17} \text{ kg/m}^3$$

☆ MASS-ENERGY EQUATION AND NUCLEAR BINDING ENERGY

- MASS ENERGY EQUATION

This equation merges two principles namely the law of conservation of energy and law of conservation of mass into single law of conservation of relativistic energy.

$$E_T = mc^2 \text{ (Total energy)}$$

$$E_T = \underbrace{m_0c^2}_{\text{Rest mass energy}} + KE$$

$$KE = mc^2 - m_0 c^2$$
$$= (m - m_0) c^2$$
$$= \Delta m c^2$$

KE of a particle = $\underset{\text{particle}}{\text{change in mass}}$ of × $(\underset{\text{in air}}{\text{speed of light}})^2$

Q Calculate the energy equivalent to 1mg in eV.

Sol. $E = mc^2$
$= 10^{-6} \times 9 \times 10^{16}$
$= 9 \times 10^{10}$ J
$= \dfrac{9 \times 10^{6}}{1.6 \times 10^{-19}}$ eV = 5.625×10^{29} eV.

- **MASS DEFECT**

Mass defect is defined as the difference between the mass of constituent nucleons of a nucleus in free state and mass of nucleus.

Nucleus contains Z-protons
A − Z Neutrons

$$\text{Mass defect} = (m_p Z + m_n (A - Z) - \underset{\hookrightarrow \text{ Mass of nucleus}}{M})$$

- **NUCLEAR ~~BOND~~ BINDING ENERGY**

→ Binding energy is the energy required to hold the nucleons in a nucleus.

→ The mass of the nucleus is less than sum of masses of nucleons.

→ This decrease in the mass of nucleons (equal to mass defect) is converted into energy $(E = \Delta m c^2)$

↳ Responsible to hold nucleons in the nucleus.

"The total energy required to disintegrate the nucleus into its constituent particles is called nuclear binding energy"

(OR)

The energy equal to mass defect is the binding energy of the nucleus.

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

$$\{[m_p Z + (A - Z) m_n] - m\} c^2$$

→ BE in Joule and Δm in kg

If Δm is in amu $E_b = \Delta m$ amu

$$1 \text{ amu} = 931 \text{ MeV}$$

$$E_b = \Delta m \times 931 \text{ MeV}$$

Q Calculate the binding energy of $^{16}_{8}O$ nucleus. Given mass of $^{16}_{8}O$ = 15.994914 amu.

Mass of proton = 1.007825 amu

Mass of neutron = 1.008665 amu

Sol. $\Delta m = [(8 \times 1.007825 + 8 \times 1.008665) - 15.99491]$ amu

$= 0.137$ amu

1 amu = 931 MeV

BE = 0.137×931 MeV = 127.55 MeV.

- NUCLEAR BINDING ENERGY PER NUCLEON

The average energy required to release a nucleon from a nucleus is called binding energy per nucleon.

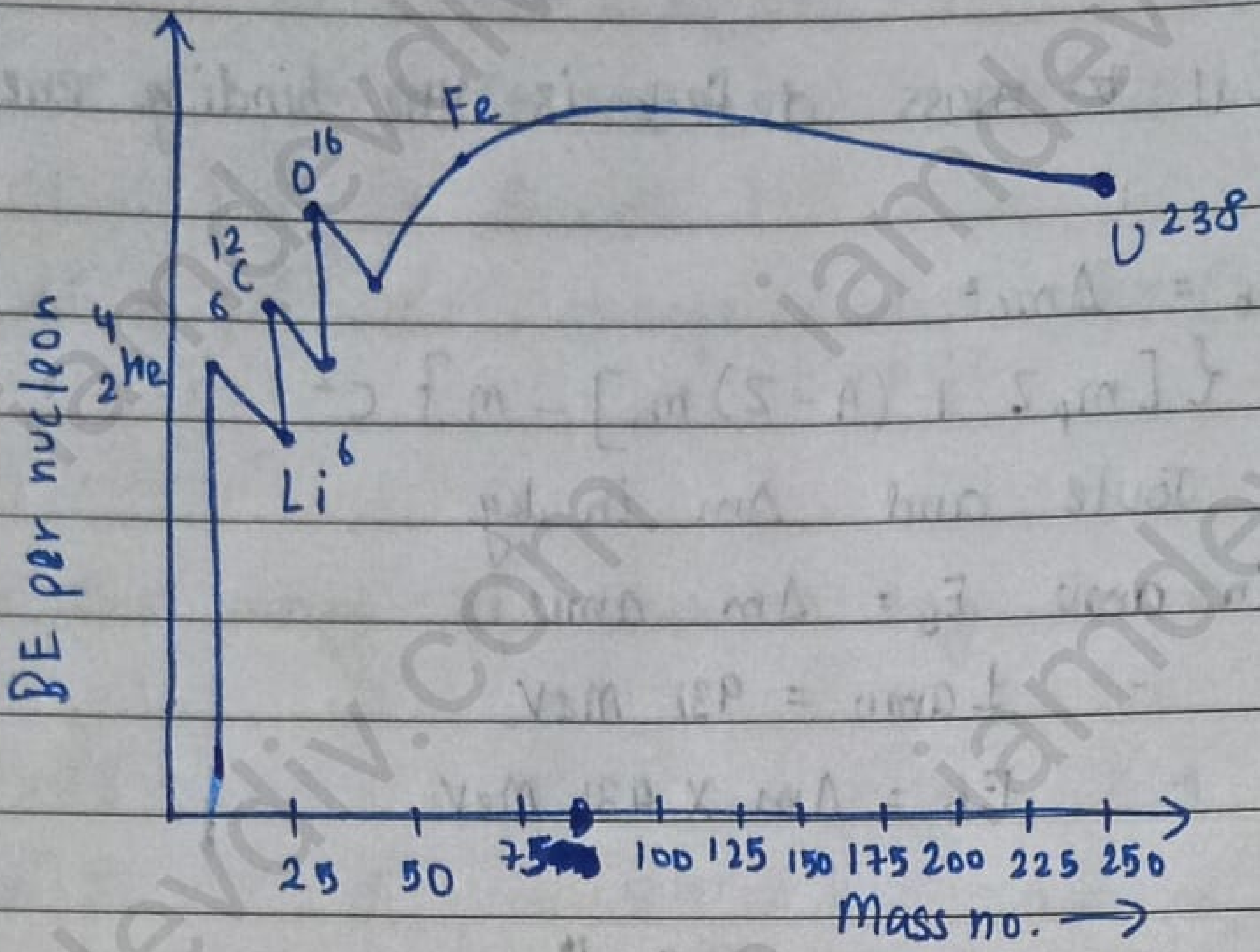
$$\text{BE per nucleon} = \frac{\text{Binding energy}}{\text{Total no. of nucleons}}$$

$$E_b = \frac{\Delta m \times 931}{A}$$

- SIGNIFICANCE OF BINDING ENERGY PER NUCLEON

→ Binding energy per nucleon determines the stability of a nucleus.

→ If the BE per nucleon of a nucleus is less, the nucleus is less stable whereas nucleus is more stable, if its binding energy per nucleon is higher.



* ANALYSIS FROM GRAPH

(i) Average binding energy per nucleon for mass no. < 3 is very small.

(ii) $3 < A < 20$

Some nuclie in this range have large BE per nucleon than their neighbouring nuclie.

Nuclie have ↑ BE are more stable.

(iii) For $30 < A < 62$

BE per nucleon increases gradually till it attains a maximum value 8.8 MeV per nucleon corresponding to $A = 56$.

Iron, Nickel are stable elements.

(iv) For nuclie having $A > 62$, BE per nucleon gradually decreases. For Uranium ($A = 238$) the BE per nucleon is 7.5 MeV.

* CONCLUSION

(i) The intermediate nuclie have larger values of BE per nucleon, so they are more stable.

(ii) The BE per nucleon has low value for both light and heavy nuclei. So they are unstable nuclei.

(iii) When a heavy nucleus splits into lighter nuclei, then BE per nucleon of lighter nuclei is more than original heavy nucleus (Nucleons of lighter nuclei are more tightly bound). This process is nuclear fission.

☆ PROPERTIES OF NUCLEAR FORCE

1. STRONGEST INTERACTION

Nuclear force is the strongest interaction known in nature that holds the nucleons together.

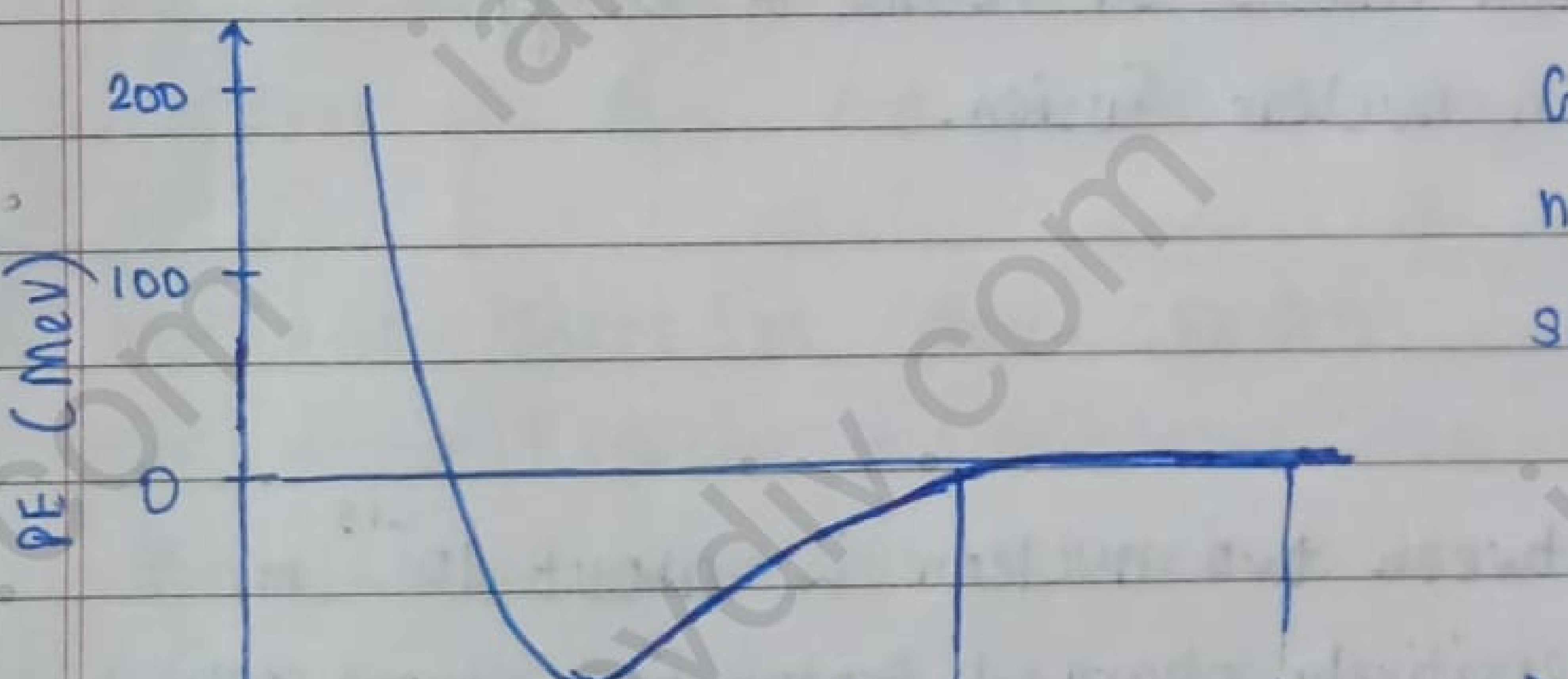
$$F_g : F_e : F_n = 1 : 10^{36} : 10^{38}$$

(The relative strength of gravitational, electrostatic and nuclear forces).

2. SHORT RANGE FORCE

Unlike gravitational and electrostatic forces, nuclear force is a short-range force. It operates only upto a very short distance of about 2-3 fm from a nucleon.

3. VARIATION WITH DISTANCE



Graph of PE of a pair of nucleons as a function of their separation r

PE is minimum at $r_0 = 0.8$ fm.

(i) for $r < r_0$, PE increases rapidly with decreasing r
(It indicates strong repulsive nuclear force)

(ii) for $r > r_0$, PE decreases to zero gradually with increasing r
(indicates attractive nuclear forces) (max attraction at $r = r_0$)

(iii) It varies inversely on some higher power of distance.

(iv) for $r \simeq 4$ fm, the nuclear force becomes zero.

(Nuclear force → short range)
Negative PE → attractive in nature)

* IMPORTANCE OF BE CURVE

(A) NUCLEAR FISSION

(i) BE per nucleon is smaller for heavier nuclei then middle ones (heavier nuclei are less stable).

(ii) When a heavier nucleus splits into lighter nuclei, B E/nucleon changes from 7.6 MeV to 8.4 MeV.

(iii) Greater BE of the product nuclei results in the liberation of energy. (This is what happens during nuclear fission).

(B) NUCLEAR FUSION

(i) The BE per nucleon is small for lighter nuclei (they are less stable).

(ii) When two light nuclei combine to form a heavy nucleus, the higher binding energy per nucleon results in release of energy.

(iii) This is what happens in nuclear fusion.

* NUCLEAR FORCE

(i) Average separation between two nucleon is about 10^{-15} m.

(ii) At this separation, positively charged proton feel strong coulombic repulsion.

(iii) Gravitational force (weaker force) between two nucleons is 10^{-36} times smaller than electrostatic repulsion. (so cannot hold the nucleons together).

~~Thes~~ There is some strong attractive force acting between nucleons that overcome the electrostatic repulsion.

This strong attractive force that binds the protons and neutrons together inside a tiny nucleus.

4.* CHARGE INDEPENDENT CHARACTER

Attractive force between two neutrons (nn force) is nearly equal to that between two proton (pp force) or between a proton and neutron (pn force).

(Nuclear force does not depend on the charge of particles).

NOTE → In case of pp nuclear force, there is a repulsive force between two protons, but this is weak compared to strong nuclear force.

5. SATURAION EFFECT

(i) Nuclear Forces show saturation effect

(ii) Nucleon interacts only with nearest neighbours and has no influence on other nucleons.

(iii) It quickly becomes zero when distance between two nucleus is just about 3 fm.

6. NUCLEAR FORCE IS AN EXCHANGE FORCE

Nuclear force are due to exchange of π mesons between two nucleons, so they are called exchange forces.

7. NUCLEAR FORCE IS NON-CENTRAL

The force between two nucleons does not act along the line joining their centres and is therefore non-central force.

8. NUCLEAR FORCE IS SPIN DEPENDENT

It has been found that nuclear force between nucleons having parallel spins is greater than the force between nucleons having anti-parallel spins. They are spin dependent.

★ NUCLEAR INSTABILITY

There are two major forces in a nucleus.

(i) Electrostatic force of repulsion between the protons.

(The proton inside the nucleus try to fly about due to this force)

(ii) The nuclear force being attractive holds the nucleons (i.e protons and neutrons) inside the nucleus.

Q Why larger nuclei are unstable.

SOL. (i) Nuclear force is a short-range force i.e it is effective only if nucleons are about 10^{-15} m apart).

(ii) Also nuclear force between neighbouring nucleons is more than between two nucleons lying on opposite edges of a nucleus).

(iii) Electrostatic force of repulsion is long-range force.

(iv) In small or light nucleus, nuclear force is large as compared to electrostatic force of repulsion, so light nuclei are stable.

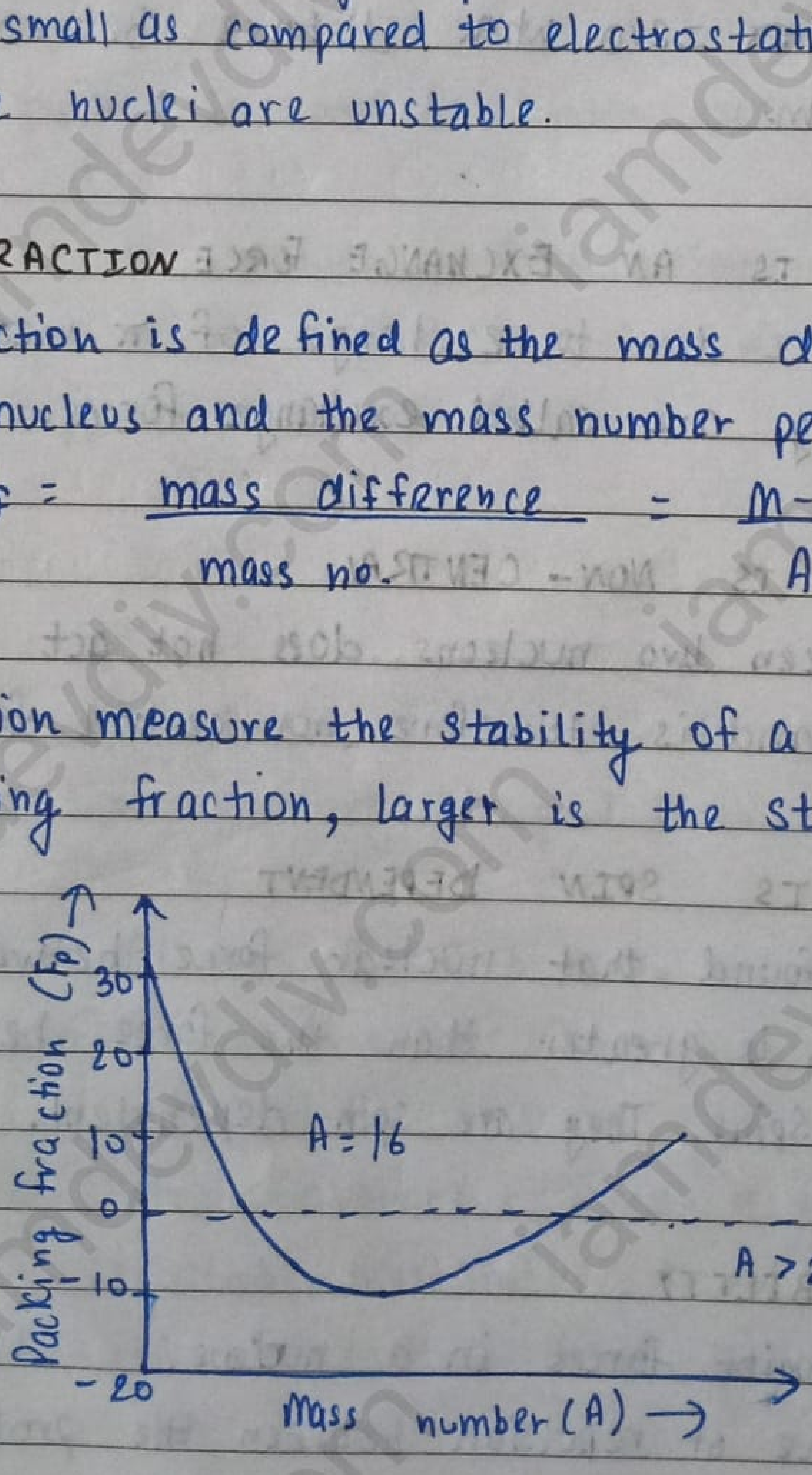
(v) In large nucleus (having large no. of nucleons) the nuclear force is small as compared to electrostatic force of repulsion. Hence large nuclei are unstable.

☆ PACKING FRACTION

Packing fraction is defined as the mass difference between the mass of nucleus and the mass number per nucleon.

$$P_f = \frac{\text{mass difference}}{\text{mass no.}} = \frac{M-A}{A}$$

Packing fraction measure the stability of a nucleus. Smaller the value of packing fraction, larger is the stability of the nucleus.



NUCLEAR REACTIONS

When a beam of energetic particles (α-rays or neutrons) collide with stable nucleus, the original nucleus is converted into nucleus of new element. This process is called nuclear reaction.

$$a + X \longrightarrow Y + b$$

a → incident energetic particle
X → target nucleus
Y → Residual nucleus
b → Outgoing particle.

First nuclear reaction was performed by Rutherford in 1919

* He bombarded Nitrogen with α-particle and obtain oxygen and a proton.

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

* Following Physical Quantities are conserved in a Nuclear Reaction

(i) Atomic no. is conserved

$$\Sigma Z = 0$$

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

$Z = 2 + 7 = 9$ (Before)
$Z = 8 + 1 = 9$ (After)

(ii) Mass number is conserved

Atomic mass (A) before and after the nuclear reaction is conserved

$$\Sigma A = 0$$

$A = 4 + 14 = 18$ (Before)
$A = 17 + 1 = 18$ (After)

(iii) Linear momentum is conserved

Linear momentum of the ~~particles~~ particles before the reaction is equal to linear momentum of the particle after the reaction, $\Sigma p = 0$

(iv) Angular momentum is conserved

Angular momentum of particles before the nuclear reaction is equal to angular momentum of particles after the reaction.

$$\Sigma L = 0$$

- Q-VALUE OR ENERGY OF NUCLEAR REACTION

Energy absorbed or released during nuclear reactions is known as Q- value of nuclear reaction.

(i) It is equal to the difference between KE of products & reactants

Q-value = KE of products − KE of reactants

(ii) Q-value of nuclear reaction can also be defined as the difference between mass of reactants and mass of product.

Q-value = (mass of reactants − mass of product) c^2

* ENDOTHERMIC REACTION ($Q < 0$)

For endothermic reaction to proceed, energy is supplied from outside.

* EXOTHERMIC REACTION ($Q > 0$)

During exothermic reaction, energy is released.

Q Find Q value of the following nuclear reaction:

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

Given mass of ${}_7N^{14}$ = 14.003 amu

mass of ${}_2He^4$ = 4.002 amu

mass of ${}_8O^{17}$ = 16.999 amu

mass of ${}_1H^1$ = 1.008 amu

SOL. Mass of reactants = mass of ${}_7N^{14}$ + mass of ${}_2^4He$

= 14.003 + 4.002 = 18.005 amu

Mass of products = mass of ${}_8^{17}O$ + mass of ${}_1^1H$

= 16.999 + 1.008 = 18.007 amu

Q-value

$18.005 - 18.007 = -0.002\ amu = -0.002 \times 931\ MeV = -1.862\ MeV$

$Q < 0 \Rightarrow$ Endothermic

- NUCLEAR ENERGY

The energy obtained from the conversion of nuclear mass is known as Nuclear energy.

- NUCLEAR FISSION

Nuclear fission is a process of splitting a heavy nucleus into two lighter nuclei releasing large amount of energy.

$${}_{92}U^{235} + {}_{0}n^{1} \longrightarrow \underbrace{{}_{92}U^{236}}_{\text{Unstable}} \longrightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_{0}n^{1} + Q$$

Q = 200 meV (due to mass defect of 0.215 amu)

* THEORY OF NUCLEAR FISSION

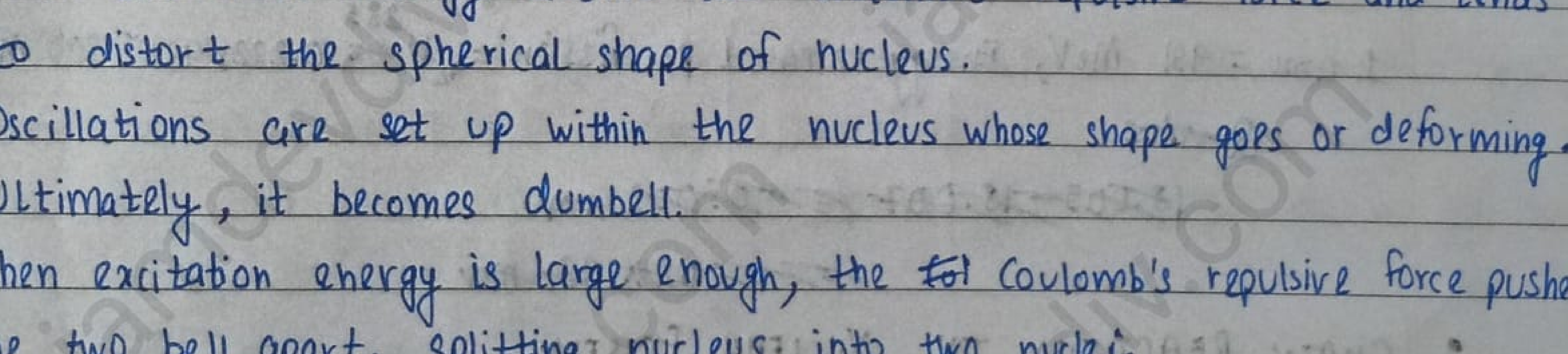
→ When the nucleus is bombarded with a neutron, the neutron is captured by nucleus.

→ This provides an excitation energy to the nucleus.

→ This excitation energy favours the coulomb's repulsive force and tends to distort the spherical shape of nucleus.

→ Oscillations are set up within the nucleus whose shape goes or deforming. Ultimately, it becomes dumbell.

→ When excitation energy is large enough, the ~~tot~~ Coulomb's repulsive force pushes the two bell apart, splitting nucleus into two nuclei.



- RADIOACTIVE CAPTURE

If excitation energy is not enough, the nucleus simply emits energy in the form of γ-rays equal to excitation energy and surface tension like nuclear force restores the spherical shape of nucleus.

The sum of masses of product nuclei is found to be less than mass of reactants. The difference in mass (mass defect) is converted into energy which is about 200 MeV per fission.

↳ energy released per fission

$$ {}_0n^1 + {}_{92}U^{235} \longrightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_0n^1 + \underset{\text{(Energy)}}{Q} $$

Mass of ${}_{92}U^{235}$ = 235.124 amu

Mass of ${}_0n^1$ = 1.009 amu

Total mass of reactants = 236.133 amu

Mass of ${}_{56}Ba^{141}$ = 140.958 amu

Mass of ${}_{36}Kr^{92}$ = 91.926 amu

Mass of $3\,{}_0n^1$ = 3.027 amu

Total mass of products = 235.911 amu

Difference in mass = mass of reactants − mass of products

= 236.133 − 235.911

= 0.222 amu

1 amu = 931 MeV, Energy released per fission = ${}_{92}U^{235}$ = 0.222 × 931 ≃ 200 MeV

~~Q value~~

~~18.005 − 18.007 = 0.002 amu~~

~~= 0.002 × 931 MeV~~

- CHAIN REACTION IN NUCLEAR FISSION

(i) In nuclear fission, three neutrons are produced along with release of large amount of energy.

(ii) Thus newly produced neutrons can cause further fission of more nuclei, producing large amount of energy.

(iii) The process continues and no. of fission taking place at each stage goes on increasing at a fast rate. This process is called uncontrolled chain reaction.

Q How to sustain uncontrolled chain reaction?

Ans. ~~Sol~~. Uranium consists of three isotopes

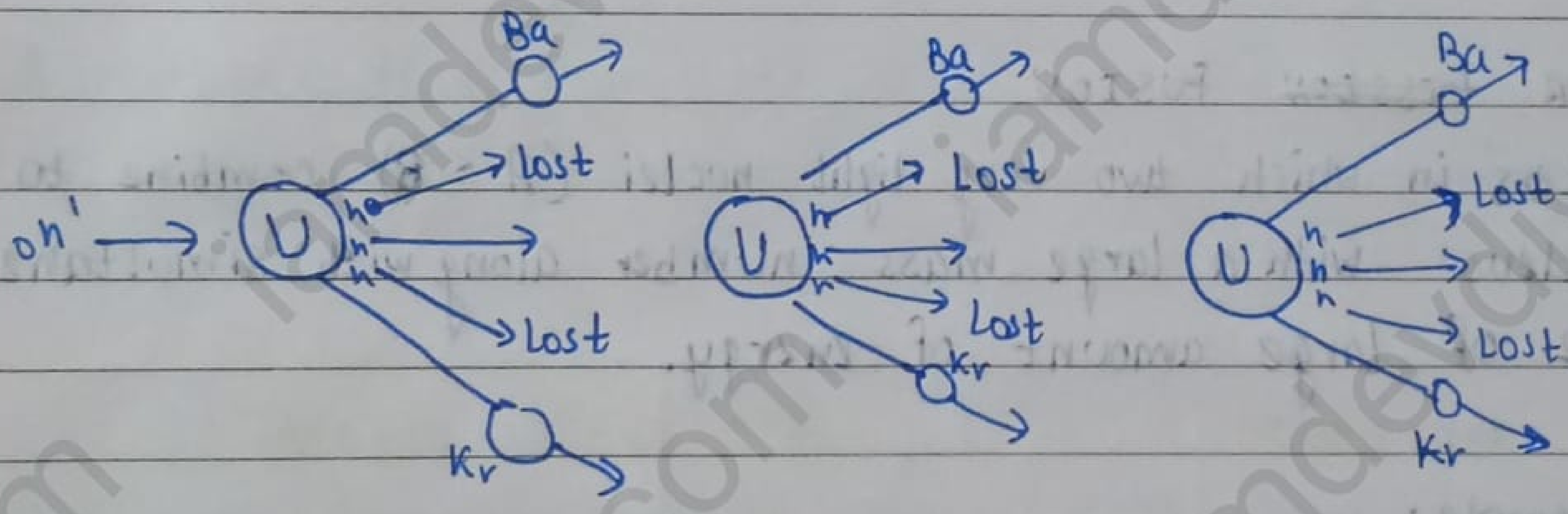
$_{92}U^{238}$ $_{92}U^{236}$ $_{92}U^{235}$

$_{92}U^{238}$ → abundance (99.3%)
(can only be fusioned by fast neutrons of energy ~ 1 MeV and more) because neutrons having low energy are absorbed by $_{92}U^{238}$ and hence chain reaction cannot be sustained

$_{92}U^{235}$ → (can ~~only~~ be fissioned even by slow neutrons. To sustain chain reaction $^{235}_{92}U$ is separated from ordinary uranium).
Uranium $^{235}_{92}U$ so obtained is called enriched uranium (fissionable materials)

✫ TYPES OF CHAIN REACTIONS

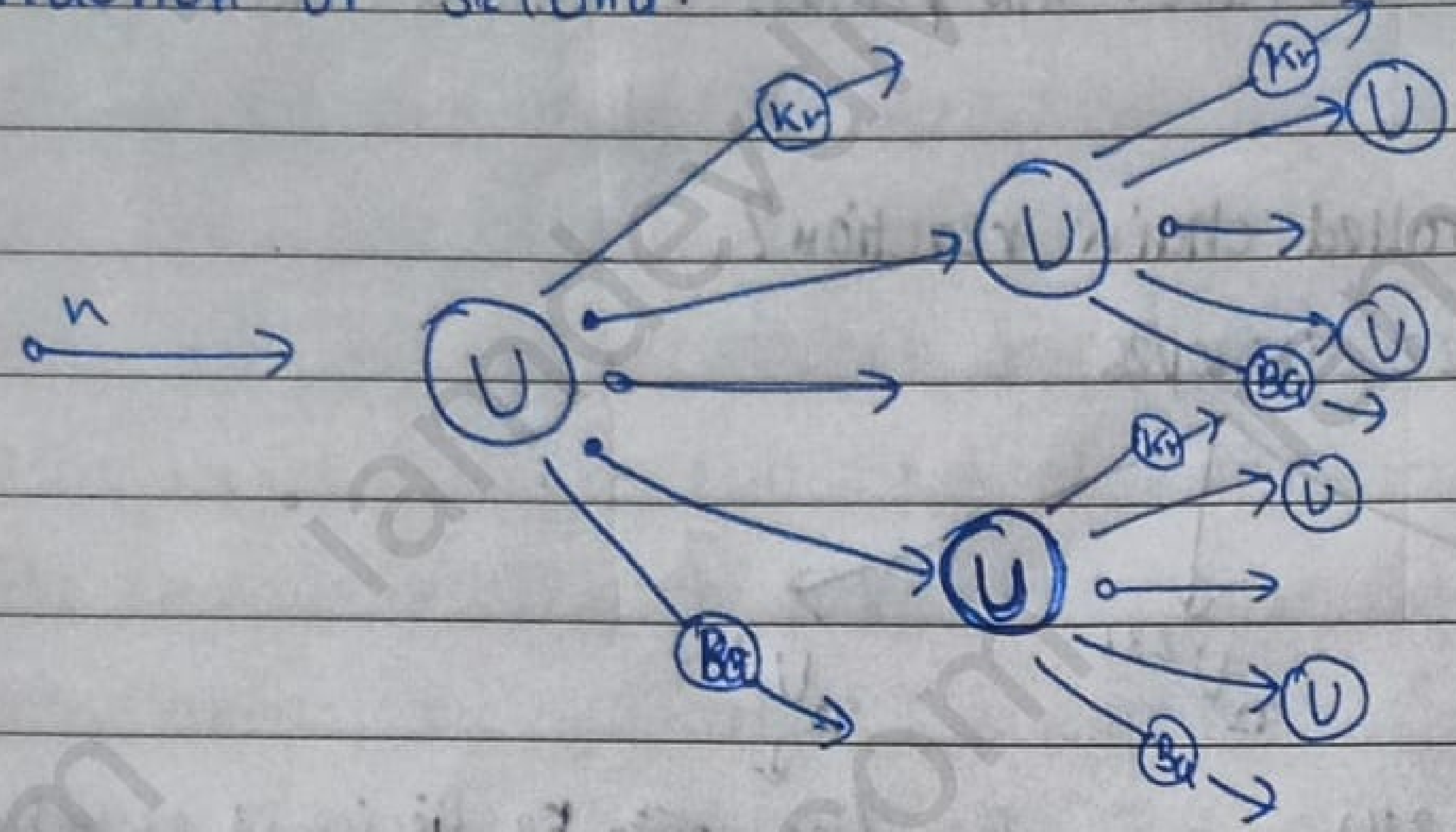
- CONTROLLED CHAIN REACTION



If only one neutron is available to cause further fission at each stage, then constant amount of energy is released.
The controlled chain reaction take place in a nuclear ~~reaction~~ reactor and energy obtained from such reaction is used for purposeful work such as producing electricity.

- UN-CONTROLLED CHAIN REACTION

If more than one neutron ~~are~~ produced in a fission cause further fissions at each stage, then no. of fissions and energy released multiply rapidly. In such chain reaction, huge amount of energy is released within a fraction of second.



☆ **MODERATORS**

The chance of causing fission of $_{92}U^{238}$ by slow neutrons or very small and hence neutrons are available for fission of $_{92}U^{235}$ isotope.

The fast neutrons can be slowed down by certain materials called moderators.

☆ **NUCLEAR ~~FISSION~~ FUSION**

A process in which two very light nuclei ($A \leq 8$) combine to form a nucleus with a large mass number along with simultaneous release of large amount of energy.

For example:

(i) When two nuclei of deterium ($_1H^2$) fuse together $_1H^2 + {}_1H^2 \longrightarrow {}_2He^3 + {}_0n^1 + Q$

(ii) when four hydrogen ($_1H^1$) nuclei fuse together,

$$4\,{}_1H^1 \longrightarrow {}_2He^4 + 2\,{}_{+1}e^0 + 2\nu + Q$$

↳ 26.7 MeV

Energy released due to the fusion of 4 hydrogen nuclei is given by

$$Q = [\text{mass of } 4\,{}_1H^1 - \text{mass of } {}_2He^4]\,c^2$$

$$= (4 \times 1.007825 - 4.002603)\,u$$

$= 0.028697\,\mu$

$= 0.028697 \times 931.5$ MeV

$= 26.7$ MeV

- EXPLANATION

1) BE per nucleon of very light nuclei is less than that of intermediate nuclei.
(Light nuclei are less stable that of intermediate nuclei)

2) Sum of masses of individual nuclei is more than the mass of nucleus formed by their fusion.
(The difference in mass is released in the form of energy)

→ Nuclear fusion is exothermic nuclear reaction.

Q Why nuclear fusion is known as thermonuclear reaction?

Ans. i) When two light nuclei brought close to each other, they exert a repulsive force on each other due to positive charges.

ii) These nuclei can fuse together if they have enough kinetic energy to overcome the force of repulsion between them.

iii) High KE means high temperature. Thus nuclear fusion can be achieved at a very temperature and hence is known as thermonuclear reaction.

NOTE → A ~~te~~ temperature of the order of 10^8 K is required to trigger nuclear fusion.
→ Much temperature is available in the core of the sun and other stars (where nuclear fusion occurs)

- COMPARISON OF ENERGY RELEASED IN NUCLEAR FISSION AND NUCLEAR FUSION

Consider of 1 kg of $_{92}U^{235}$ undergoing a nuclear fission.

Number of atoms in 1 kg of U^{235}

$$= \text{No. of nuclei} = \frac{\text{Avagadro no.} \times \text{mass in g}}{\text{Atomic weight}}$$

$$= \frac{6.022 \times 10^{23} \times 10^{3}}{235}$$

$$\approx 2.56 \times 10^{24}$$

Since energy released per fission ≈ 200 MeV

Energy released by the fission of 2.56×10^{24} nuclei (i.e 1 kg of U^{235})

$$= 2.56 \times 10^{24} \times 200$$

$$\approx 5.12 \times 10^{26} \text{ MeV}$$

* Nuclear fusion

(i) Nuclear fusion occurs in the interior of the sun.

(ii) 4 hydrogen nuclei fuse to give a helium nucleus.

(iii) Energy released due to fusion of 1 kg hydrogen in the sun.

No. of atoms in 1 kg of four ^1_1H $= \frac{6.02 \times 10^{23} \times 10^{3}}{4}$

$$\approx 1.505 \times 10^{26}$$

Energy released due to one fusion of 4 hydrogen nuclei = 26.7 MeV

Energy released by the fusion of 1.505×10^{26} nuclei (i.e 1 kg of ^1_1H) $= 1.505 \times 10^{26} \times 26.7$

$$= 40.2 \times 10^{26} \text{ MeV}$$

∴ Energy released by fusion is greater than energy released by fission.

★ STELLAR ENERGY (Energy source of stars)

Hans Bethe in 1939 suggested that the source of stellar energy is thermo-nuclear reactions.

It follows two different series of processes:

1. PROTON-PROTON CYCLE

It is a thermo nuclear reaction in which direct collisions of protons results in the formation of heavy nuclei.

$$^1_1H + ^1_1H \longrightarrow {}_1H^2 + {}_{+1}e^0 + \nu + 0.42 \text{ MeV}$$
$$^2_1H + ^1_1H \longrightarrow {}_2He^3 + \gamma + 5.49 \text{ MeV}$$
$$^3_2He + ^3_2He \longrightarrow {}^4_2He + 2\,^1_1H + 12.86 \text{ MeV}$$

Total energy released in this cycle
= (0.42 + 5.49 + 12.86) MeV
= 18.77 MeV

(Two protons produced in the last step of the cycle repeat the proton-proton cycle)

2. CARBON NITROGEN CYCLE

It is a thermo nuclear reaction in which carbon nuclei absorbs a succession of protons until they emit alpha particles to become carbon nuclei once more to repeat the cycle indefinitely.

$$_6C^{12} + ^1_1H \longrightarrow {}^{13}_7N + Q_1 \text{ (MeV)}$$
$$^{13}_7N \longrightarrow C^{13}_6 + {}_{+1}e^0 + \nu$$
$$^{13}_6C + ^1_1H \longrightarrow {}^{14}_7N + Q_2 \text{ (MeV)}$$
$$^{14}_7N + ^1_1H \longrightarrow {}^{15}_8O + Q_3 \text{ (MeV)}$$
$$^{15}_8O \longrightarrow {}^{15}_7N + {}_{+1}e^0 + \nu$$
$$^{15}_7N + ^1_1H \longrightarrow C^{12}_6 + He^4_2$$

Total energy released in the cycle = 24.68 MeV

Thermo-nuclear reactions take place in the ~~sun~~ Sun and other stars and hence they are source of energy of Solar system.

- UNCONTROLLED FUSION

(i) Temperature required for nuclear fusion $\sim 10^7$ K, to achieve this temperature ($\sim 10^7$ K)
(ii) To achieve this much temperature, an atom bomb employing the process of nuclear fission is exploded.
(iii) Atomic explosion triggers the fusion process and simultaneous release of tremendous amount of energy.
(It is the principle of hydrogen bomb)

- RADIATION HAZARDS

(i) Radiation damage to the chromosomes in the reproductive organs can cause genetic disorder.
(ii) Long exposure to ~~rad~~ radiation causes cancer.
(iii) Long exposure to radiation causes blindness.

- USE OF RADIATION

(i) Dangerous disease like cancer is cured by radiation therapy (γ rays from Co^{60} is used).
(ii) Radiations are used to induce plant mutations which improves the varieties of many crops.
(iii) Radiations are also used to eliminate agricultural pests.
(iv) Radiation like X-rays are used to detect the fracture in the bone and presence of foreign material in the human body.
(v) Gamma rays or X-rays are used to detect the defects in metals. ~~casting~~ ~~cating~~ ~~and~~ ~~wet~~