# Ch.13 → Nuclei

## ⇒ Nucleus

→ Composition [Overall charge → +ve]

Proton (+ve) + Neutron (Neutral)

# Member of nucleus are called nucleons

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★ **Atomic Mass unit (amu)** → One atomic mass unit is defined as one by 12th $\left(\frac{1}{12^{th}}\right)$ of the mass of an atom of $^{12}_{6}C$ isotope.

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

→ $1 \text{ amu} = 931 \text{ MeV}$ $\left[{}^{A}_{Z}X\right]$

★ **Atomic number (Z)** → It is the no. of protons present in the nucleus of an atom

★ **Mass number (A)** → of an element is the total no. of protons and neutrons present in the nucleus of an atom.

\# {
Atomic no. = Z = no. of protons
Mass number = A = no. of protons & neutrons
No. of neutrons = A − Z
}

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# ISOTOPES → These are the atoms of the same element which have same atomic number but different atomic masses.

→ Isotopes of hydrogen : $^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$
[Protium : Deuterium : Tritium]

→ Isotopes of carbon : $^{12}_{6}C$ $^{14}_{6}C$

# ISOBARS → These are the atoms ~~whose~~ of different elements which have same mass number but different atomic number.

- Examples : $^{14}_{6}C$ $^{14}_{7}N$ / $^{40}_{20}Ca$ $^{40}_{18}Ar$

# ISOTONES → These are the atoms whose nuclei have the same number of neutrons [A − Z]

- Examples : $^{4}_{2}He$ $^{3}_{1}H$ / $^{10}_{8}O$ $^{14}_{6}C$

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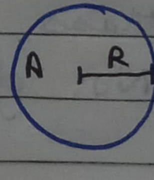
# NUCLEAR SIZE → Rutherford's α - particle scattering experiment shows that volume of the nucleus is directly proportional to its mass number. If 'R' is the radius of the nucleus then its volume is :

$$\Rightarrow \frac{4}{3}\pi R^3 \propto A$$




$$\Rightarrow R^3 \propto A$$

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★ $R \propto A^{1/3}$

★ $R = R_0 A^{1/3}$

⊙ Where, $R_0 \rightarrow$ constant

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

# $\frac{R_1}{R_2} = \left(\frac{A_1}{A_2}\right)^{1/3}$

Q1) Two nuclei A and B are in ~~same~~ atomic mass ratio 1 : 8. Find ratio of radii.

Ans:- $\left(\frac{A_1}{A_2}\right)^{1/3} = \frac{R_1}{R_2}$

$\Rightarrow \left(\frac{1}{8}\right)^{1/3} = \frac{R_1}{R_2}$

$\Rightarrow \left[\frac{(1)^3}{(2)^3}\right]^{1/3} = \frac{R_1}{R_2}$

★ $\frac{R_1}{R_2} = \frac{1}{2}$ ans

Q2) Two nuclei have mass number in the ratio 27 : 125. What is the ratio of their radii?

Ans:- $\frac{A_1}{A_2} = \left(\frac{27}{125}\right)^{1/3}$

$\Rightarrow \left[\frac{(3^3)}{(5^3)}\right]^{1/3} = \frac{R_1}{R_2}$ ★ $\frac{R_1}{R_2} = \frac{3}{5}$ ans

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# NUCLEAR DENSITY → It is defined as mass per unit volume. It is calulated as:

$$\Rightarrow \quad N.D = \frac{A}{\frac{4}{3}\pi R^3} \quad \text{— (1)}$$

$$\rightarrow \quad \text{Using, } R = R_0 A^{1/3} \quad \text{— (2)}$$

⇒ Put (2) in (1)

{ N.D → is constant → is independent of atomic mass }

$$\Rightarrow \quad N.D = \frac{A}{\frac{4}{3}\pi R_0^3 A}$$

$$\Rightarrow \quad N.D = \frac{3}{4\pi R_0^3}$$

★ $N.D = 2.3 \times 10^{17}\ kg/m^3$

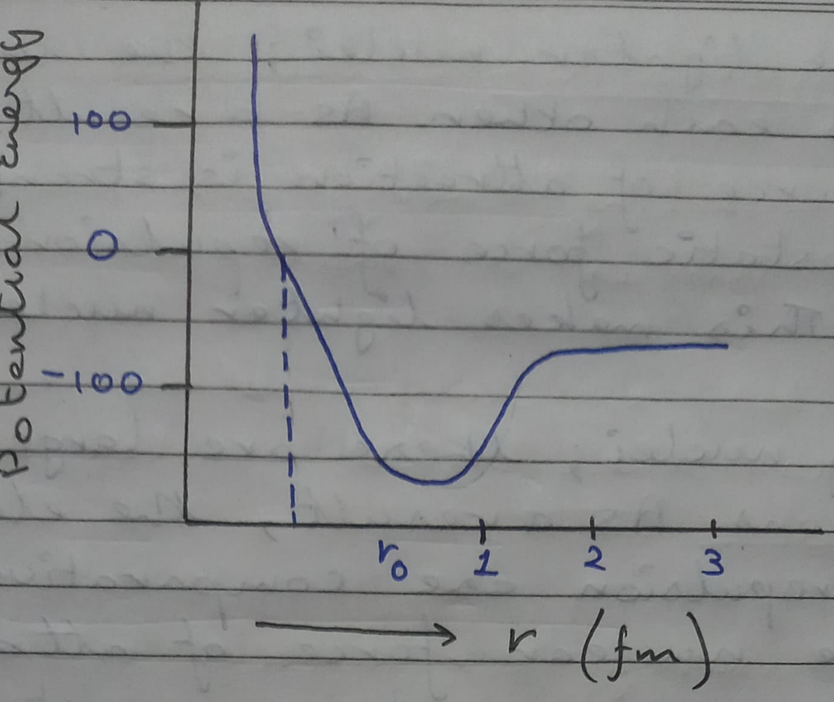
Q3) Two nuclei A and B are in atomic mass ratio 1: 8. Find ratio of their nuclear density.

Ans :-

$$\frac{A_1}{A_2} = \frac{1}{8}$$

★ $N.D = \frac{1}{1}$ ans

# NUCLEAR FORCES → These are the strong forces of attraction which hold together the nucleons in the nucleus of an atom.




## ⇒ Properties of Nuclear Forces

→ They act b/w the pair of neutrons, a pair of protons and also b/w a neutron and a proton.

→ They are the strongest forces in nature.

→ They are nearly 100 times that of electrostatic force & $10^{38}$ times the gravitational force.

→ They are very short range forces which means they act over very small distances.

→ They don't obey inverse square law.

→ These forces are negligible, when distance b/w nucleons is more than 10 fermi.

Q) Why are heavy nuclei unstable?

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Ans:- In the lighter nuclei; the nucleons are close to each other. As a result, the nuclear force of attraction is stronger than the electrostatic force of repulsion between protons. This makes lighter nuclei stronger.

In heavy nuclei; there are large distances b/w nucleons. As a result, the electrostatic force of repulsion are comparatively stronger than the nuclear force of attraction. This makes the nucleus unstable.

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# MASS DEFECT → When mass of all the nucleons in a nucleus is calculated; it is found to be more than the actual mass of the nucleus. This difference b/w the mass of the nucleons is called mass defect.

★ Consider a nucleus of mass $M_n$ having atomic no. Z and mass number A. Let $m_n$ be the mass of neutron & $m_p$ be the mass of each proton;

∃ Mass of Z protons = $Z \cdot m_p$

∃ Mass of all neutrons = $(A-Z) m_n$

→ Sum of masses of all nucleons = $Z \cdot m_p + (A-Z) m_n$

★ Mass of defect; $D_m = [Z \cdot m_p + (A-Z) m_n]$

# BINDING ENERGY → It is found that the rest mass of the nucleus is always slightly less than the sum of the masses of free neutrons and protons composing the nucleus. This difference b/w the masses is converted to energy which is responsible for binding the nucleons together in the nucleus.

★ Binding Energy of the nucleus is the energy with which the nucleons ~~and~~ are held together in the nucleus and is equal to the amount of work done in separating the nucleons an infinite distance apart so that they don't influence each other.

$$\Rightarrow \quad B.E = \Delta m c^2$$

$$\Rightarrow \quad B.E = \left[Z \cdot m_p + (A-Z) m_n - M_n\right] \cdot c^2$$

# BINDING ENERGY CURVE

## ⇒ Characteristics

1) Average Binding Energy per nucleons for lighter nuclei is small.

2) The peaks in the binding energy curve represents that these nuclei are highly stable.

3) Binding energy per nucleon is maximum for Fe and is nearly equal to 8.8 MeV. Beyond Fe; Binding energy per nucleon decreases with increase in mass number.

4) The binding energy per nucleons; $E_{bn}$ is practically constant i.e partially independent of the atomic no. for nuclei of middle mass no. $[30 < A < 170]$.

5) The curve have a maximum of about 8.75 MeV for A = 56 and has a value of 7.6 MeV for A = 238.

6) $E_{bn}$ is lower for both light nuclei $[A < 30]$ and heavy nuclei $(A > 170)$.

7) The constancy of the binding energy in the range $30 < A < 170$ is the consequence of the fact that the nuclear force is short-ranged.

## ⇒ Nuclear Fission

★ The phenomenon in which a heavy nucleus

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($A > 230$) when excited splits into two smaller nuclei of nearly comparable masses is called nuclear fission.

# Nuclear fission reactⁿ for uranium nucleus:

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

⊙ Q value for this reactⁿ is about 200 MeV.

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# Fission

Controlled Fission Reaction | Uncontrolled Fission Reaction

## → Uncontrolled Chain Reaction

★ If chain reactions start with a fissionable material and the material which initiates the reaction is also present as a product then the reaction will continue to occur & produce a tremendous amount of energy which is an underlying principle of atomic bomb.

## → Controlled Chain Reaction

The chain react$^n$ can be controlled if some amount of neutrons are absorbed and removed from the system so that one out of three on an average is available for further fission and nuclear fission reaction takes place in a controlled way.

## ⇒ Fusion

★ The process in which two light nuclei combine (at extremely high temperature) to form a single heavier nucleus is called nuclear fission.

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Ex :- $^{1}_{1}H + ^{1}_{1}H \longrightarrow ^{2}_{1}H + e^{+} + \nu + 0.42\ MeV$

# High temperature is necessary for the light nuclei to have sufficient kinetic energy so that they can overcome their mutual coulombic repulsions and come closer than the range of nuclear force.

# High density or pressure increases the frequency of collision of light nuclei & hence increases the rate of fusion.

⇒ **Difference B/W Nuclear Fission & Nuclear Fusion**

| Nuclear Fission | Nuclear Fusion |
|---|---|
| 1) Here a heavy nucleus when exited gets split up into two smaller nuclei of nearly comparable masses. | 1) Here two lighter nuclei fuse together to form a heavier nucleus |
| 2) The conditions of high temperature & pressure are not necessary for its occurence. It can be carried on the earth. | 2) The conditions of extremely high pressure & temperature are necessary for its occ-urence. So it cannot be easily carried in a laboratory. |
| 3) Neutrons are the link particles of this process. | 3) Protons are the link particles of this process. |

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| | |
|---|---|
| 4) It is a quick process. | 4) It occurs in several steps. There is sufficient time gap b/w initial & final steps. |
| 5) Here the energy available per nucleon is small, about 0.85 MeV. | 5) Here the energy available per nucleon is large, about 6.75 MeV. |
| 6) The energy obtained from a unit mass of a fissionable material is smaller than the obtained in case of fusion. | 6) The energy obtained from a unit mass of a fusible material is large. |
| 7) It produces very harmful radioactive wastes. | 7) The products of fusion are harmless |
| 8) The stock of fission-able fusion is limited. | 8) The fuel required for fusion is available in plenty. |

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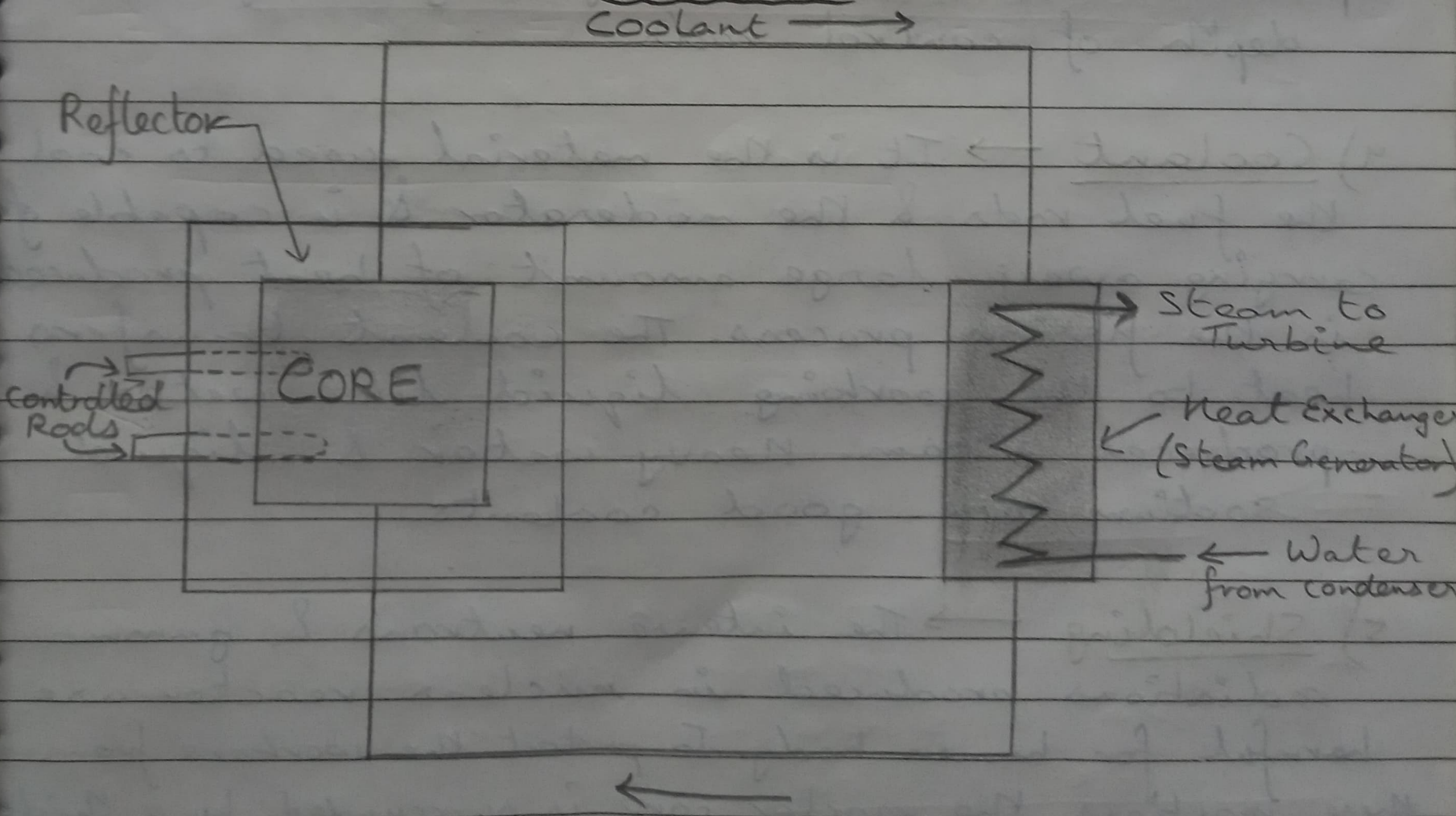
## ⇨ Nuclear Reactor

★ It is a device in which a nuclear chain reaction is initiated, maintained and controlled. It works on the principle of controlled chain reaction and provides energy at a constant rate.

### ⟹ Schematic Diagram Based On Thermal Neutron Fission

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## Main Parts of Nuclear Reactor

1) **Nuclear fuel** → It is the material that can be fissioned by neutrons. The isotopes like U-235, Th-232 & Pu-239 can be used as the reactor fuel.

2) **Moderator** → By the use of moderator, the fast neutrons are slowed to thermal velocities. Usually, heavy water, graphite & beryllium oxide are used as moderators.

3) **Control rods** → To start, stop or control the chain reaction, rods of neutron absorbing material like cadmium or boron are inserted into the reactor core. The rate of neutron production is controlled by adjusting the depth of control rods.

4) **Coolant** → It is the material used to cool the fuel rods & the moderator & is capable of carrying away large amount of heat produced in the fission process. The coolant transfers heat to the working liquid like water & produces steam. Heavy water & liquid sodium are good coolants.

5) **Shielding** → The intense neutrons & gamma radiations produced in nuclear reactor are harmful for human body. To protect the workers from these reactions, the reactor core is surrounded by a thick concrete wall, called a reactor shield.

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## ⇒ Uses of Nuclear Reactor

(1) In preparation of radio-isotopes, which find extensive use in scientific research, medicine, agriculture & in industry.
(2) In generation of electric power.
(3) In production of fast neutrons which are needed in nuclear bombardment.
(4) In producing fissile material like plutonium which is used in atomic bombs.

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## ⇒ Working

★ In a nuclear reactor, neutrons are put which strike with uranium rod & nuclear fission reaction starts. The energy produced by fission is absorbed by coolant and is given to water in heat exchange. Water boils to produce steam which runs turbine to produce electricity.

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