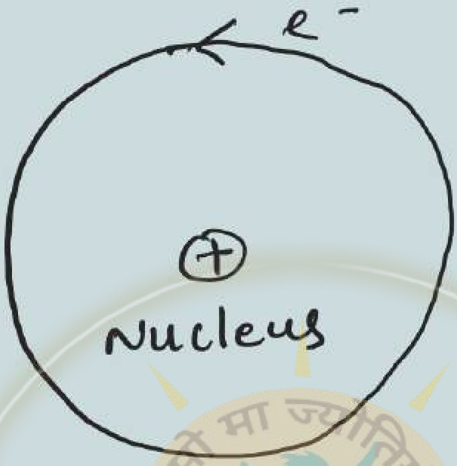
Nuclei



→ The positive charge & entire mass of atom is concentrated at it's centre called Nucleus.

→ Nucleus is made up of proton's & neutrons, these are called nucleons.

→ Proton : charge = $+1.6 \times 10^{-19}\, C = +e$

mass = $1.6726 \times 10^{-27}\, kg = 1\, amu$

symbol → $_1H^1$

→ Neutron : charge = 0

mass = $1.6749 \times 10^{-27}\, kg$

symbol = $^1_0 n$

mass number

↑

$$^A_Z X \rightarrow \text{element} \qquad \text{eg} \Rightarrow {}^{16}_{8}O$$

↓

Atomic Number

no. of protons = Z

no. of neutrons = $A - Z$

Classification of nuclei

1) Isotopes :

$Z \rightarrow$ Atomic Number $\longrightarrow$ same

$A \rightarrow$ mass Number $\rightarrow$ different

eg $^{1}_{1}H$, $^{2}_{1}H$, $^{3}_{1}H$

$^{35}_{17}Cl$, $^{37}_{17}Cl$

(2) Isobars :

$A \rightarrow$ mass number $\rightarrow$ same

$Z \rightarrow$ Atomic Number $\rightarrow$ different

eg. $^{3}_{1}H$ & $^{3}_{2}He$

$^{14}_{6}C$ & $^{14}_{7}N$

③ Isotones :

$A \rightarrow$ different

$Z \rightarrow$ different

$A-Z \rightarrow$ same

eg. $^{7}_{3}Li$ & $^{8}_{4}Be$

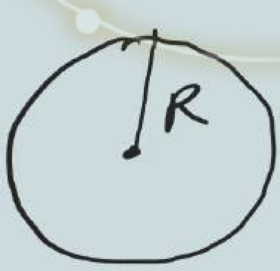
3p   4p

4n   4n

Nuclear shape, size & Density

Shape: Nuclei are regarded spherical for almost all purposes.

Size:



$$R = R_0 (A)^{1/3}$$

R → Radius of Nucleus

R_0 → constant

A → mass number

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

$= 1.2$ fermi

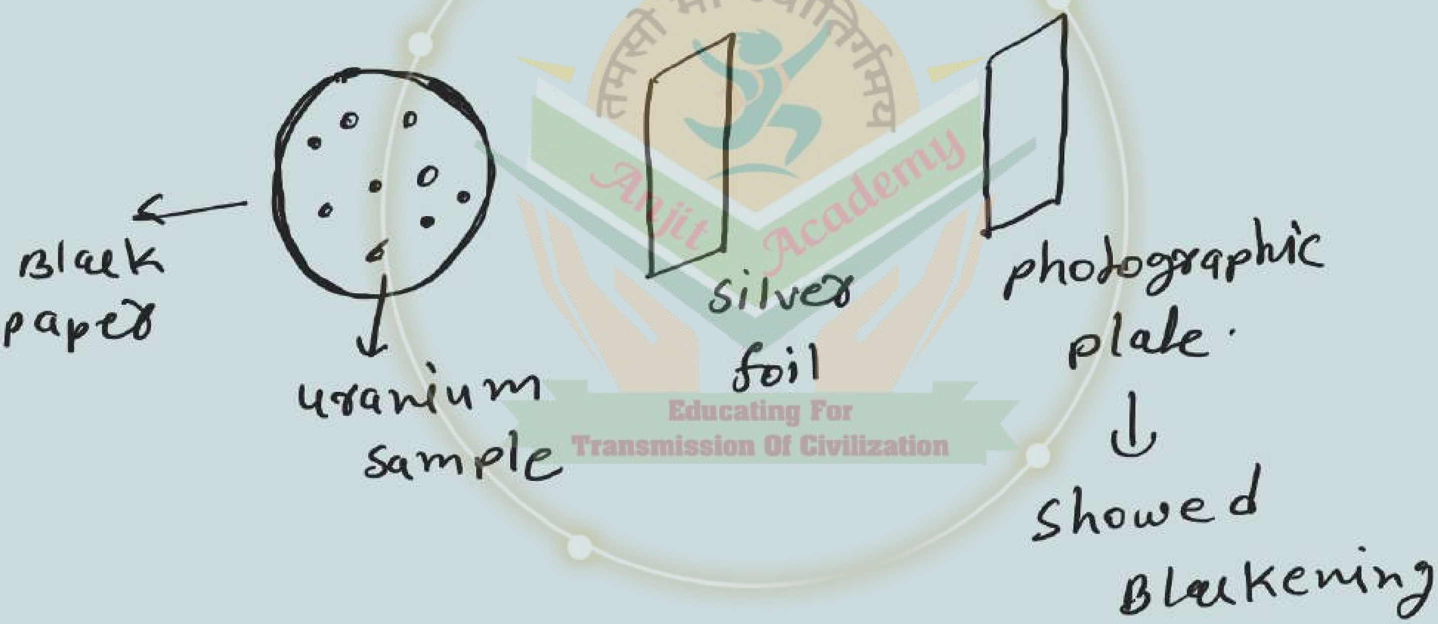
Nuclear Density:-

$$\rho = \frac{\text{mass of Nucleus}}{\text{Volume of Nucleus}}$$

$\rho \approx 2 \times 10^{17}\ kg/m^3$

Radioactivity :-

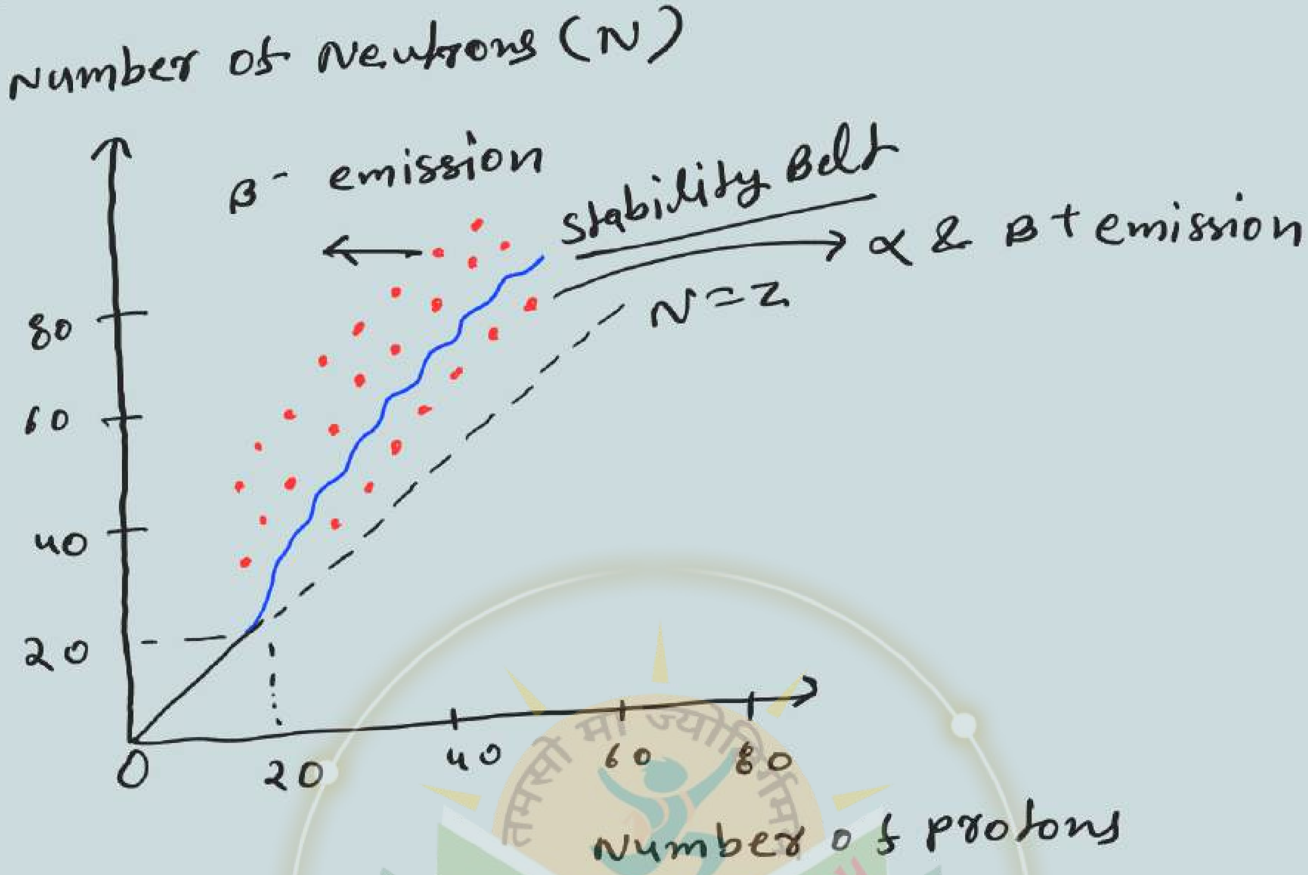
→ Radioactivity was discovered accidentally in 1896 by H. Becquerel.



→ Amongst 1500 Nuclides, less than 260 are stable

→ The unstable nuclides gain stability by emitting α- particles or β- particles and γ-waves. (Radioactivity)

Stability Belt



→ stability of nuclei depends on $\frac{n}{p}$ ratio

→ Nuclei lying on stability belt are stable.

→ for $Z \leq 20 \Rightarrow \frac{n}{p} \approx 1$

→ for $Z \geq 20 \Rightarrow 1 \leq \frac{n}{p} \leq 1.6$

→ Nuclei above & Below stability belt emits α- particles,

β^- particles (electrons), β^+ particles (positron) to reach stability belt.

→ No nuclei are stable after $z = 83$, $\left({}^{209}_{83}Bi\right)$ after $z = 83$ all nuclei are radioactive.

Alpha Decay $\left({}^{4}_{2}He\right)$

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

(parent nucleus) (Daughter Nucleus)

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

$\left(\frac{n}{p} = 1.58\right)$ $\left(\frac{n}{p} = 1.6\right)$

→ For Spontaneous α- particle emission

$$\begin{pmatrix} \text{Rest mass of} \\ \text{Daughter Nucleus} \\ + \text{ Rest mass} \\ \text{of } \alpha\text{- particle} \end{pmatrix} < \begin{pmatrix} \text{Rest mass} \\ \text{of parent} \\ \text{nucleus} \end{pmatrix}$$

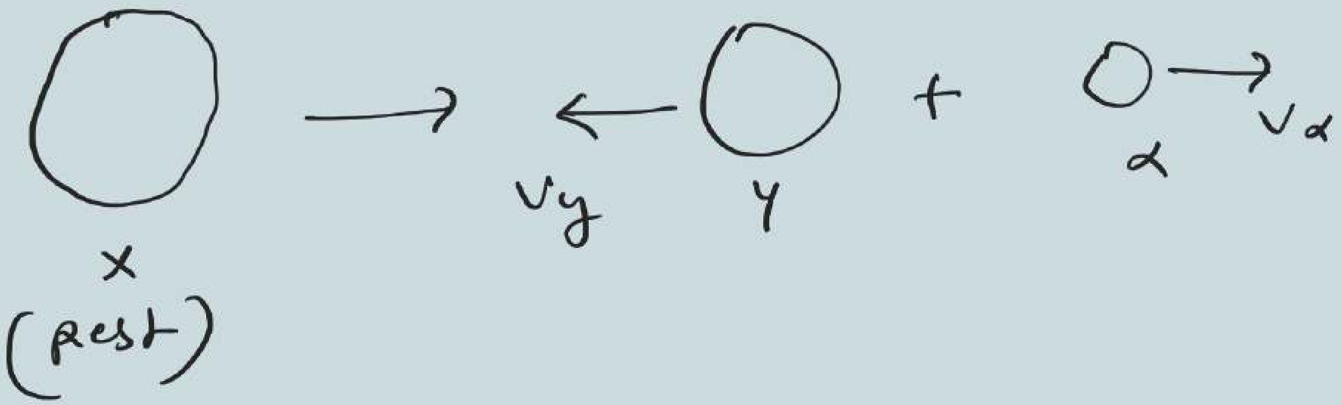
Energy of Reaction :-

$$X \longrightarrow Y + \alpha$$

$$Q = \underbrace{[m_X - (m_Y + m_\alpha)]}_{\text{mass defect}} c^2$$

$$Q = \underbrace{\Delta m}_{\text{in a.m.u.}} \times 931.5 \text{ MeV}$$

⇒



$$m_y v_y = m_\alpha v_\alpha$$

Momentum conservation $\boxed{P_y = P_\alpha}$

⇒ Kinetic Energy of Emitted α-particle –

$$K_\alpha = \frac{Q\, m_y}{m_\alpha + m_y} = \frac{P^2}{2m_\alpha}$$

$$K_y = \frac{Q\, m_\alpha}{m_\alpha + m_y} = \frac{P^2}{2m_y}$$

<u>β – Decay</u>

↙ ↘

$\beta^{\ominus}$ Decay (electron)

$\beta^{\oplus}$ Decay (positron)

$\beta^{\ominus}$ Decay: $\rightarrow$ electron emission

$({}^{0}_{-1}e)$ $({}^{0}_{-1}\beta)$

$${}^{A}_{Z}X \longrightarrow {}^{0}_{-1}\beta + {}^{A}_{Z+1}Y + \underset{\substack{\downarrow \\ \text{Antineutrino}}}{\bar{\nu}}$$

eg. $${}^{14}_{6}C \longrightarrow {}^{0}_{-1}\beta + {}^{14}_{7}N + \bar{\nu}$$

→ Actually $\beta^{\ominus}$ decay is conversion of a neutron to proton inside the nucleus.

$${}^{1}_{0}n \longrightarrow {}^{1}_{1}p + {}^{0}_{-1}e + \bar{\nu}$$

→ $\bar{\nu}$ has zero charge & zero Rest Mass, travels at speed of light (c) & have highest penetrating Power.

$\beta^{\oplus}$ Decay $\rightarrow$ positron emission

$$({}^{0}_{+1}e) \quad ({}^{0}_{+1}\beta)$$

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

eg $${}^{12}_{7}N \longrightarrow {}^{12}_{6}C + {}^{0}_{1}\beta + \nu$$

Actually $\beta^{\oplus}$ Decay is the conversion of a proton to neutron inside the nucleus.

$${}^{1}_{1}p \longrightarrow {}^{1}_{0}n + {}^{0}_{+1}e + \nu$$

Electron capture :

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

→ proton inside nucleus catches a 'K' shell electron like a Lizard catches flying insects. when Nucleus do not provide energy required for $\beta^{\oplus}$ decay.

γ — Decay : Electromagnetic wave

$$^{A}_{Z}X^{*} \longrightarrow {}^{A}_{Z}X + {}^{0}_{0}\gamma$$

excited state   ground state

Law of Radioactive Decay

→ Rutherford & Soddy

Let there be 'N' nuclei in a sample

Let dN nuclei decay in time dt

Rate of Decay $= -\dfrac{dN}{dt}$

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

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

Law of Radioactive Decay.

Disintegration constant / Decay constant / Radioactive constant

$$\int_{N_0}^{N} \frac{dN}{N} = \int_{0}^{t} -\lambda \cdot dt$$

$$\left[\log_e N\right]_{N_0}^{N} = -\lambda (t)_0^t$$

$$\left[\log_e N - \log_e N_0\right] = -\lambda t$$

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

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

$$\boxed{N = N_0 e^{-\lambda t}} \rightarrow \text{time}$$

N → number of Nuclei left

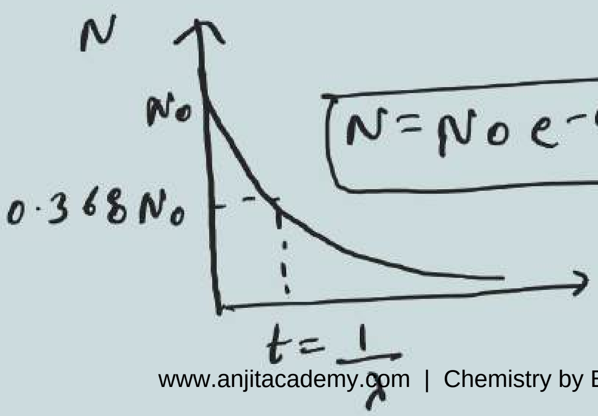
N_0 → initial number of Nuclei

$t \to 0,\ N \to N_0$

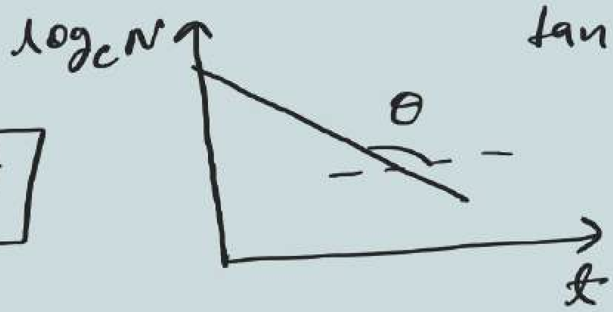
$t \to \infty,\ N \to 0$

Graph :

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



$\tan\theta = -\lambda$



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

Half Life of Decay : ($t_{1/2}$)

time in which number of nuclei decays to half of initial value

$t = 0 \quad ; \quad N = N_0$

$t = t_{1/2} \quad ; \quad N = \frac{N_0}{2}$

$$\log\left(\frac{N}{N_0}\right) = -\lambda t_{1/2}$$

$$\log_e\left(\frac{1}{2}\right) = -\lambda t_{1/2}$$

$$\log_e(2^{-1}) = -\lambda t_{1/2}$$

$$-\log_e(2) = -\lambda t_{1/2}$$

$$t_{1/2} = \frac{1}{\lambda}\log_e(2)$$

$$\boxed{t_{1/2} = \frac{0.693}{\lambda}}$$

Activity of a Radioactive Substance

Activity → Number of nuclei decays per unit time

$$\boxed{R = -\frac{dN}{dt}}$$

R → activity

from Rutherford and Soddy's law

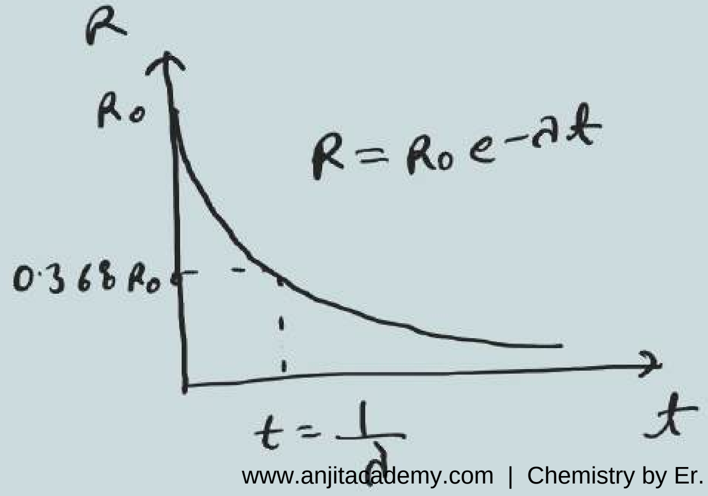
$$-\frac{dN}{dt} = \lambda N$$

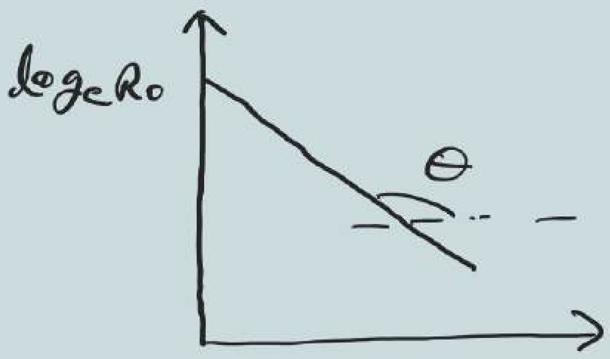
$$\boxed{R = \lambda N}$$

$$\boxed{R = \lambda N_0 e^{-\lambda t}}$$

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

$$\boxed{\log_e\left(\frac{R}{R_0}\right) = -\lambda t}$$





$$\log_e R = \log_e R_0 - \lambda t$$

Mean / Average Life of a Radioactive substance (τ)

average of the lives of all the atoms in a sample.

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

$$\tau = \frac{1}{\frac{0.693}{t_{1/2}}}$$

$$\boxed{\tau = 1.443\, t_{1/2}}$$

$$\boxed{\tau > t_{1/2}}$$

Nuclear Fission

- It is a Nuclear Reaction in which a heavy nucleaus splits into two or more smaller, Lighter Nuclei.
- Fission produce Large amount of energy & γ photon.

fission

Spontaneous fission

↓

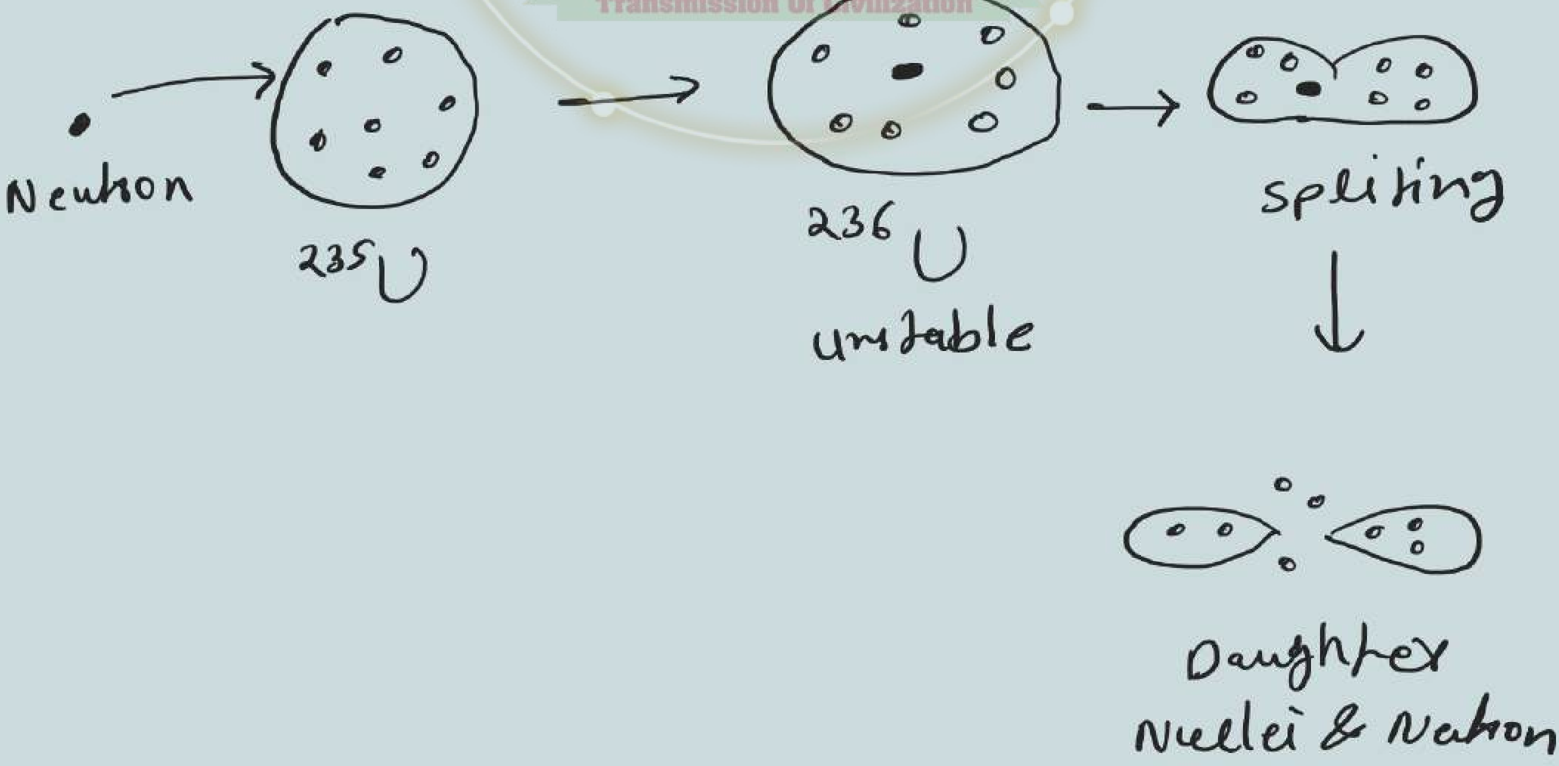
Radioactivity

induced fission

↓

spliting of Nuclei by neutron, proton or α- particle

Induced fission (By neutron)



The composition of daughter nuclei is unpredictable.

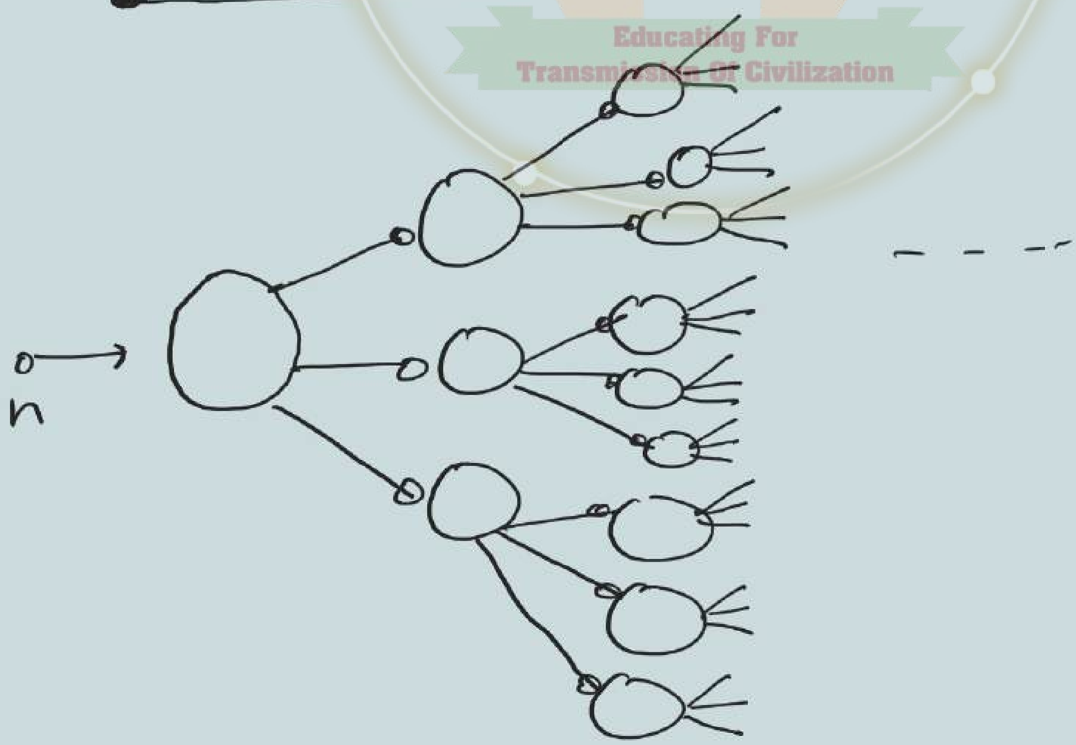
$$^{235}_{92}U + ^{1}_{0}n \longrightarrow \underset{\text{(unstable)}}{^{236}_{92}U} \longrightarrow ^{144}_{56}Ba + ^{89}_{36}Kr + 3\,^{1}_{0}n$$

or

$$^{236}_{92}U \longrightarrow ^{133}_{51}Sb + ^{99}_{41}Nb + 4\,^{1}_{0}n$$

$$^{236}_{92}U \longrightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2\,^{1}_{0}n$$

Chain Nuclear Reaction



chain Nuclear Reaction

uncontrolled

↓

Energy keeps multiplying in μs. (216 meV per fission)

↓

Atom Bomb (50 kg of Uranium can liberated 10^{15} J of energy)

Like → Hiroshima & Nagasaki

controlled

↓

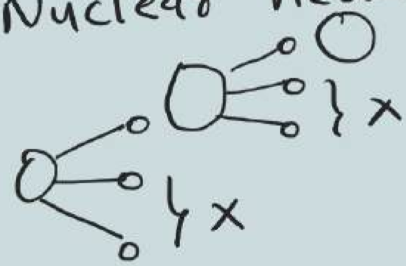
only one out of 3 neutron is allowed to cause further fission

↓

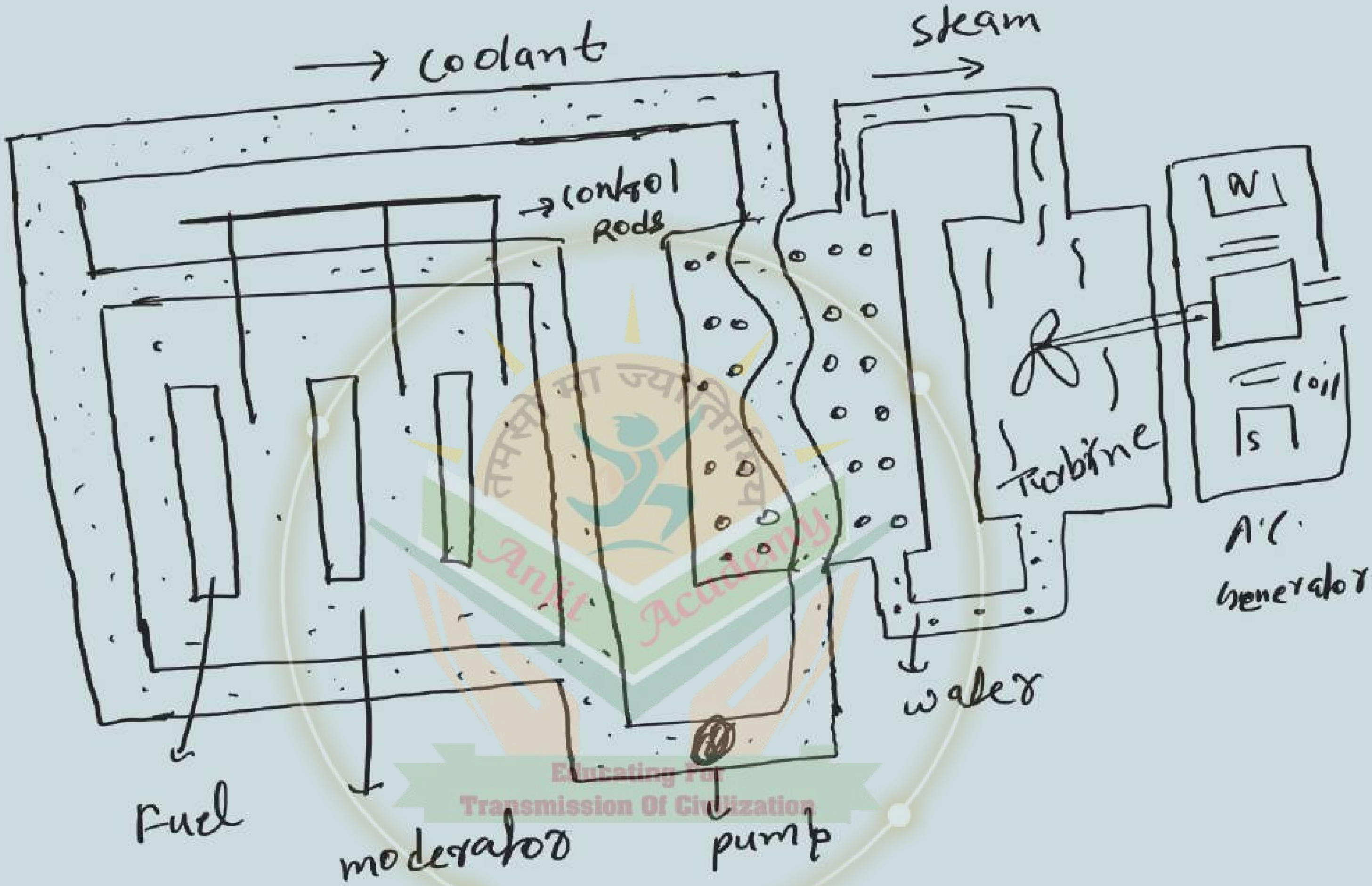
one fission causes one fission in next generation

↓

Nuclear Reactor



Nuclear Reactor



Nuclear fusion :-

A process in which two lighter nuclei combine to form a heavier nucleus alongwith simultaneous release of large amount of energy.

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