Modern Physics → $\boxed{\text{Planck}}$

Photon Theory → Packet of Energy

→ Rest Mass = 0

→ Speed of Light $c = 3 \times 10^{8}$ m/s

→ $\boxed{E = \frac{hc}{\lambda} = h\nu}$

$[h] = 6.626 \times 10^{-34}$ J-s $= [ML^{2}T^{-1}]$

→ $E = mc^2$

[m → moving of photon]

Matter $m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$

m_0 = Rest Mass

$$\left[E^2 = p^2c^2 + m_0^2c^4\right]$$

$\boxed{v = 10^{8} \text{ m/s}}$

$\frac{v^2}{c^2} = \frac{1}{9}$

→ Momentum of Photon $\boxed{p = \frac{E}{c} = \frac{h}{\lambda}}$

→ $E = \frac{hc}{\lambda} = \frac{12420\ (eV\text{-}\mathring{A})}{\lambda\ (\text{in } \mathring{A})} = \frac{1242\ (eV\text{-}nm)}{\lambda\ (\text{in } nm)}$ [photon]

→ Bulb Power $P = n\left(\frac{hc}{\lambda}\right) = \frac{N}{t}\left(\frac{hc}{\lambda}\right)$

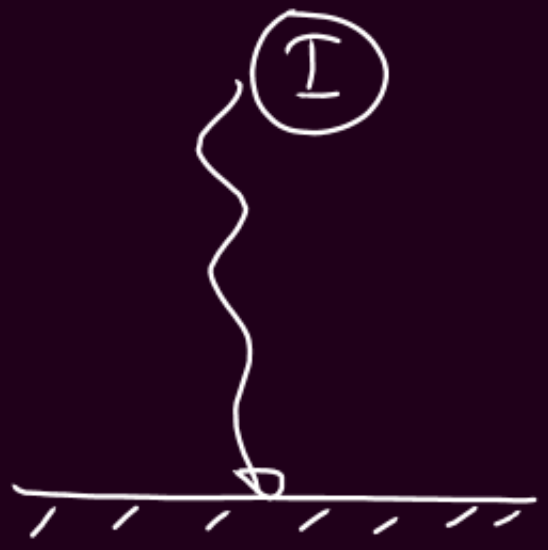
N → no of photons in time t

n → no. of photons per sec.

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

Radiation Pressure

① Completely Absorb

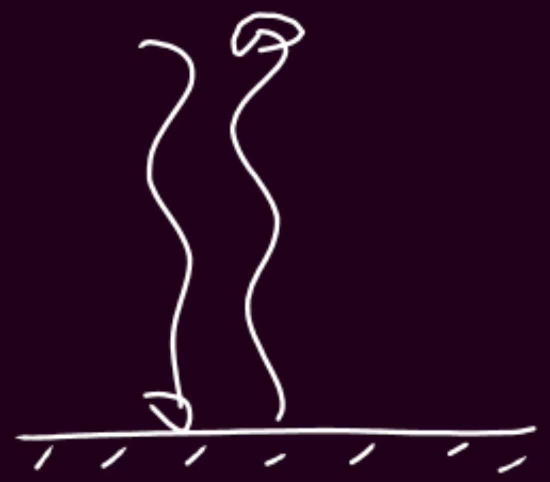


$$R.P. = \frac{I}{c}$$

$$\Delta p = \frac{E}{c}$$

② Reflecting Surface

(I) Normal Incidence



$$R.P. = \frac{2I}{c}$$

$$\Delta p = \frac{2E}{c}$$

(II) Oblique Incidence

$$R.P. = \frac{2I\cos\theta}{c}$$

$$\Delta p = \frac{2E\cos\theta}{c}$$

1 $$\text{Power} = \frac{\text{Energy}}{\text{time}}$$

2 $$\text{Intensity} = \frac{\text{Power}}{\text{Area}}$$

4 $$\text{Force} = (\text{Radiation Pressure}) \times (\text{Area})$$

Q. 200 W

80 %

6000 Å

$n = ?$

$$\boxed{\eta P = n\left(\frac{hc}{\lambda}\right)}$$

$$n = \frac{\eta P \lambda}{hc} = \frac{0.8 \times 200 \times 6 \times 10^{-7}}{6.6 \times 10^{-34} \times 3 \times 10^{8}}$$

$= 5 \times 10^{20}$ per sec

Q. 5000 Å

momentum of photon?

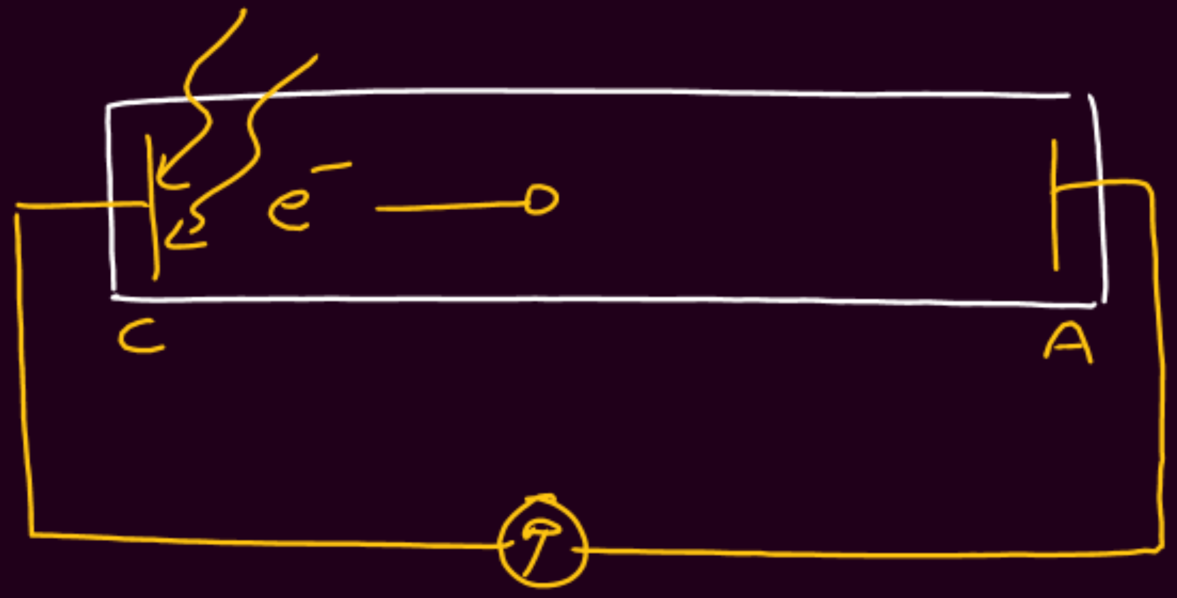
$$p = \frac{h}{\lambda} = \frac{6.6 \times 10^{-34}}{5 \times 10^{-7}} \quad N\text{-}s$$

Q. 10 W/m^2 light

normally on perfectly Reflecting Surface

$$R.P. = \frac{2I}{c} = \frac{2 \times 10}{3 \times 10^{8}} \quad N/m^2$$

Photoelectric Effect



→ Discovery → Hertz

→ Explain → Lenard & Hallwach

Cathode → UV (generally)

→ e^- (photo e^-)

① Instantaneous — wave theory (time-lag)

② $\nu \geq \nu_0$ — [All frequency]

③ V_s doesn't depend on intensity — (It should depend on I)

Work function (ϕ) $\boxed{\phi = \frac{hc}{\lambda_0} = h\nu_0}$

λ_0 → threshold wavelength

ν_0 → — " — freq.

for PEE
$$\left\{\begin{array}{l} E_{ph} \geq \phi \\ \nu \geq \nu_0 \\ \lambda \leq \lambda_0 \end{array}\right.$$

$$0 \le (KE) \le KE_{max}$$

$$E_{ph} > \phi$$

① $e^- \rightarrow \times$

② $e^- \rightarrow 0$

③ $e^- \rightarrow (KE) \le KE_{max}$

$C_s \rightarrow 2.14\ eV$

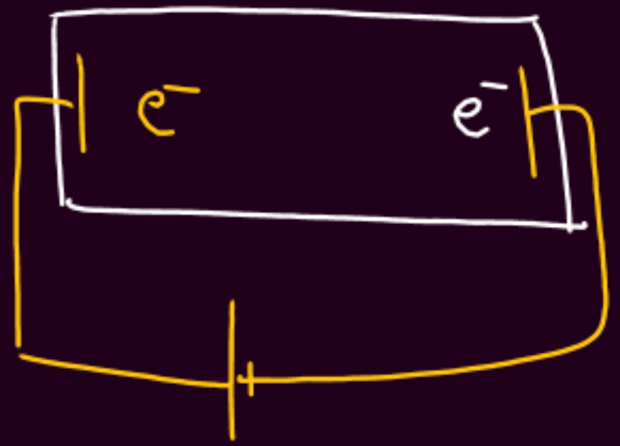
$$\boxed{eV_s = KE_{max} = E_{ph} - \phi}$$

$$eV_s = KE_{max} = h\nu - h\nu_0$$

$$eV_s = KE_{max} = \frac{hc}{\lambda} - \frac{hc}{\lambda_0}$$

Saturation Current $\boxed{i_s = ne}$ $n \rightarrow$ no. of photo e^- emitted per sec.

Quantum Efficiency $\boxed{\eta = \dfrac{\text{no. of photo } e^- \text{ emitted}}{\text{no of photons incident}}}$



Stopping Potential (V_s) $\rightarrow$ Min potential diff. to stop e^- reaching Anode

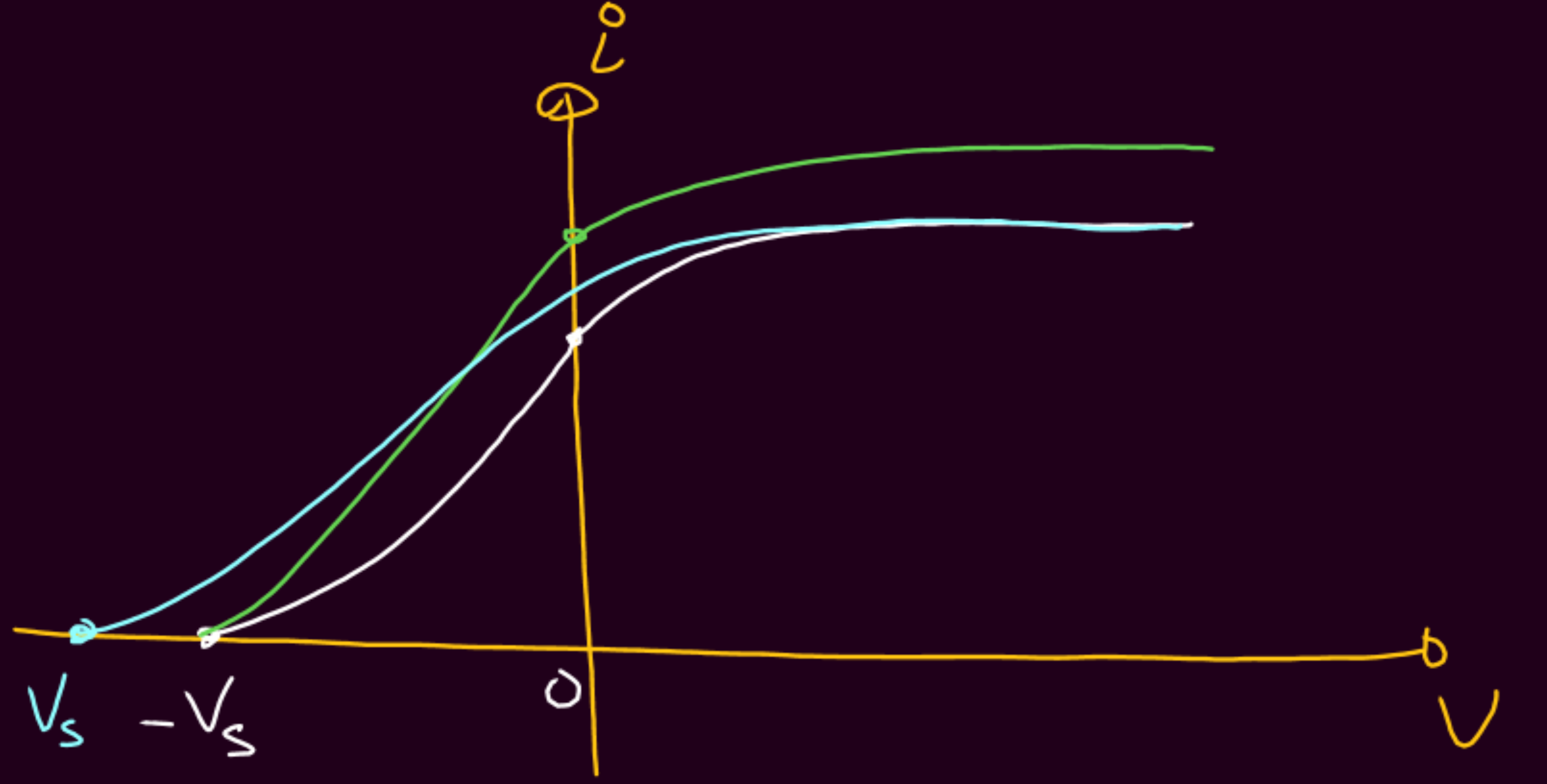
$\begin{pmatrix}\text{no. of photons} \\ \text{incident}\end{pmatrix} \propto (\text{Intensity})$

$(\text{no. of photo } e^-) \propto (\text{---}''\text{---})$

$(\text{Saturation Current } i_s) \propto (\underset{I}{\text{Intensity}})$

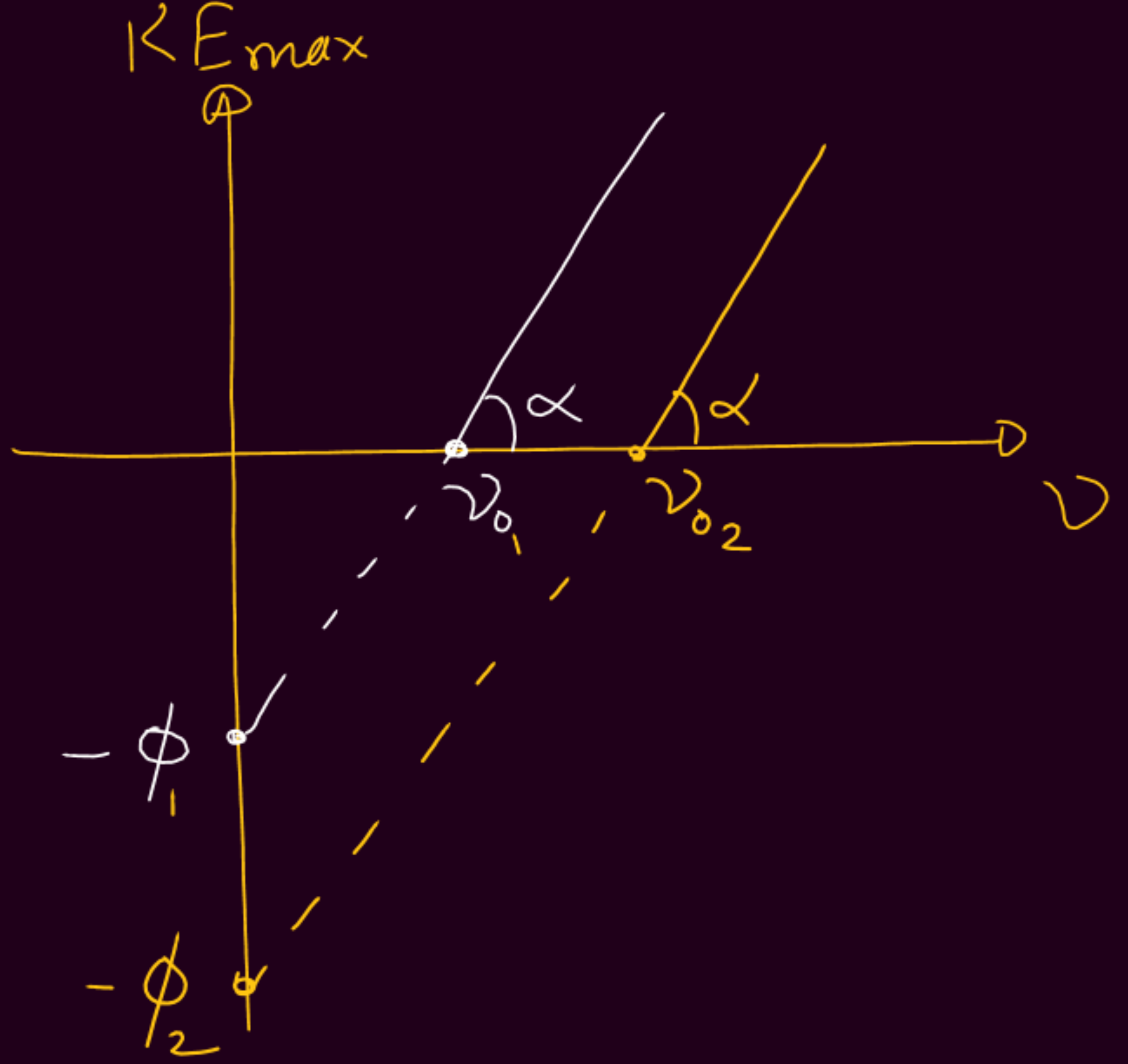
$$\boxed{\frac{i_{s_2}}{i_{s_1}} = \frac{I_2}{I_1} = \left(\frac{r_1}{r_2}\right)^2}$$

$r \rightarrow$ distance of Source from Cathode



Intensity ↑

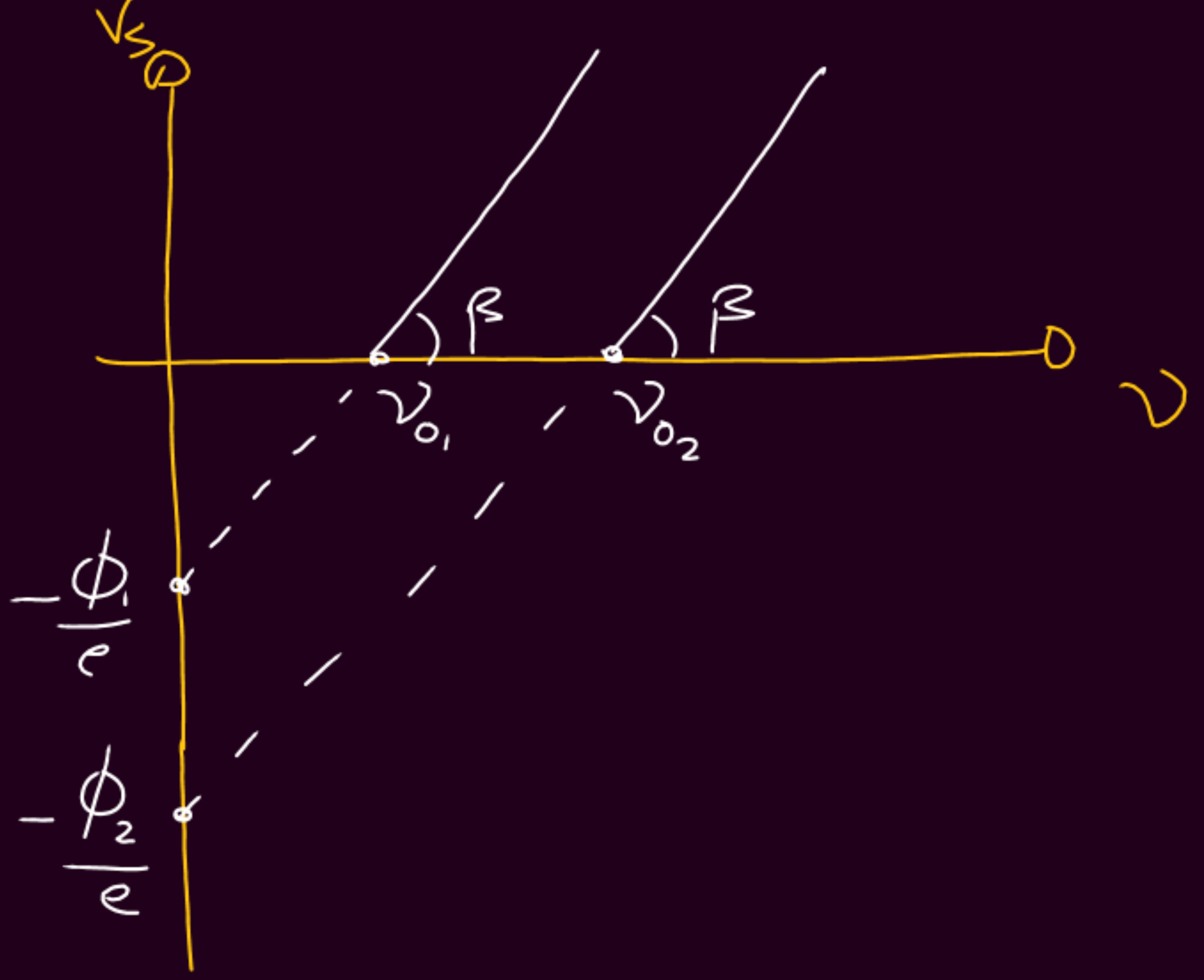
E_{ph} ↑



$$KE_{max} = h(\nu) - \phi$$

$$y = mx + c$$

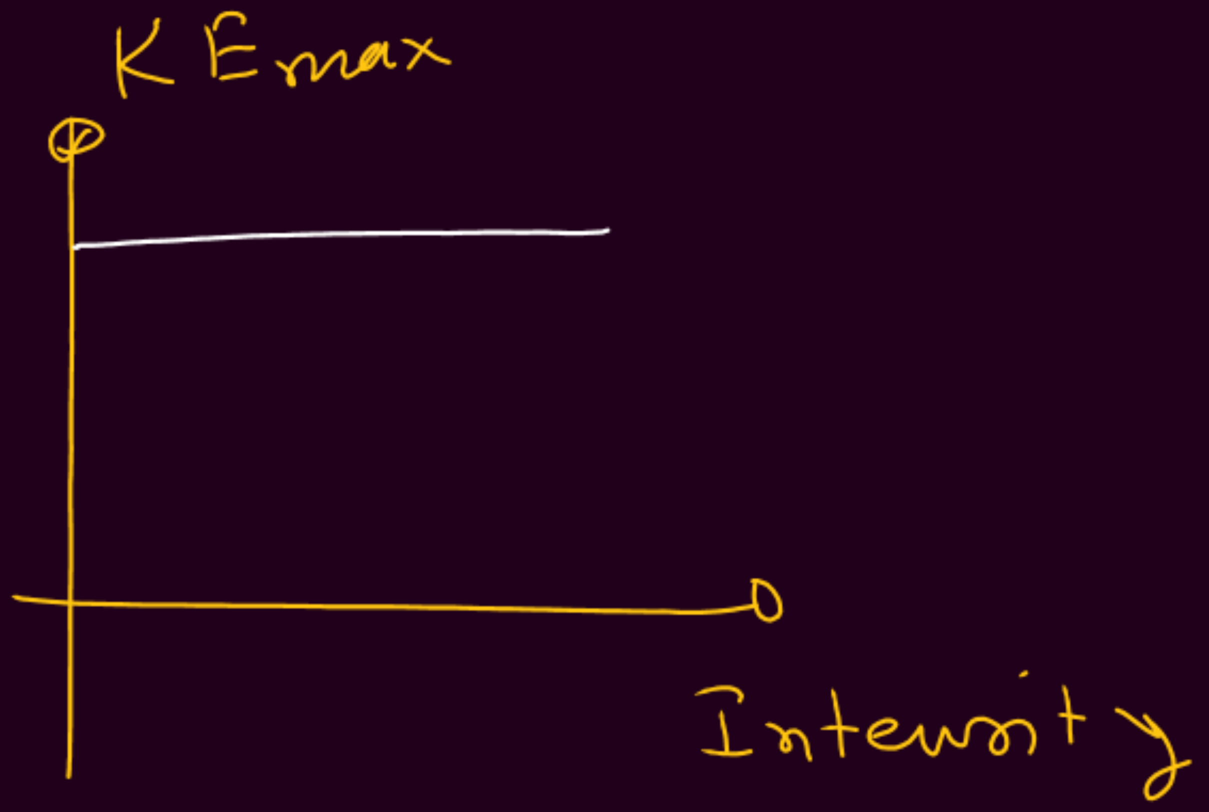
$$\boxed{\text{Slope} = \tan\alpha = h}$$

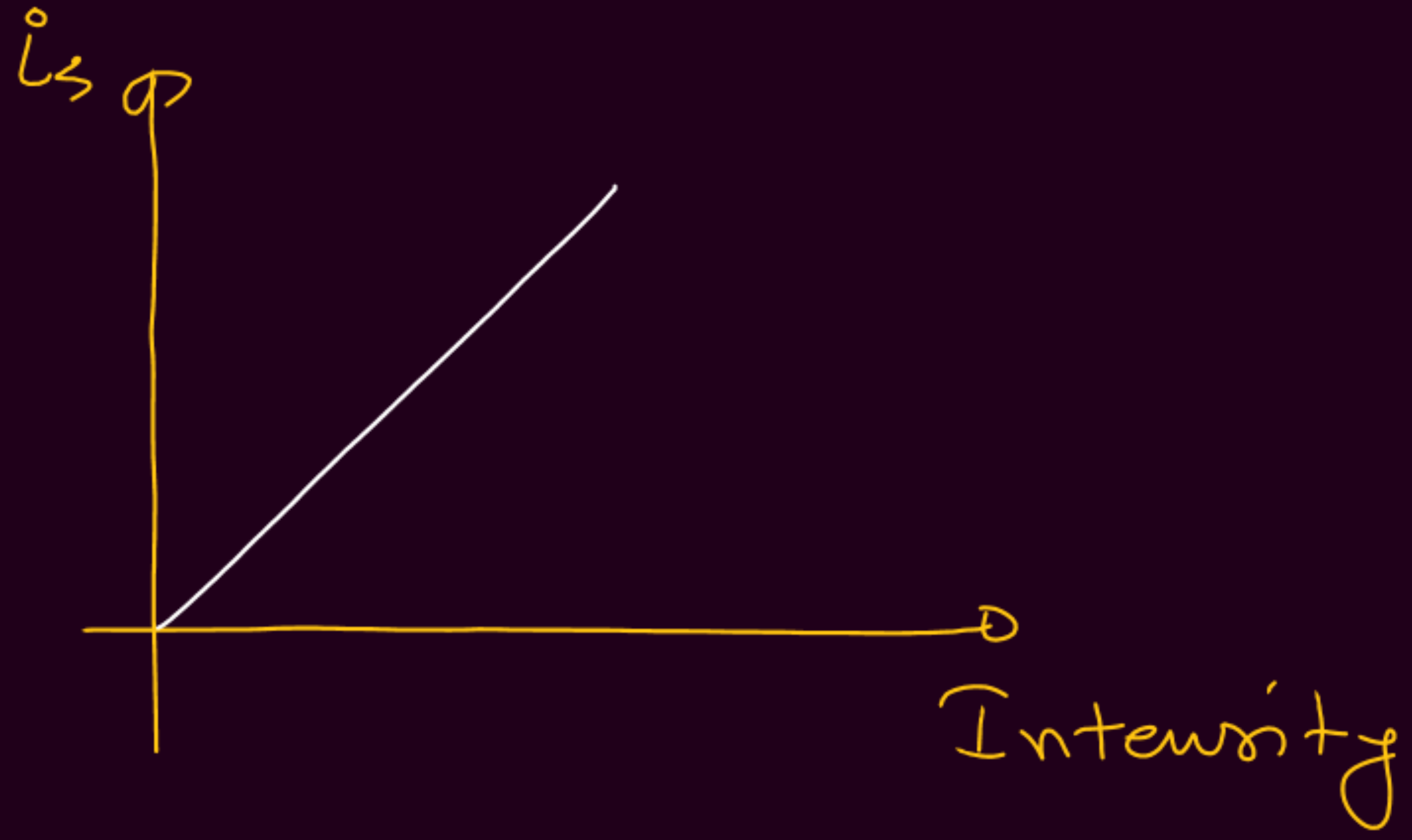


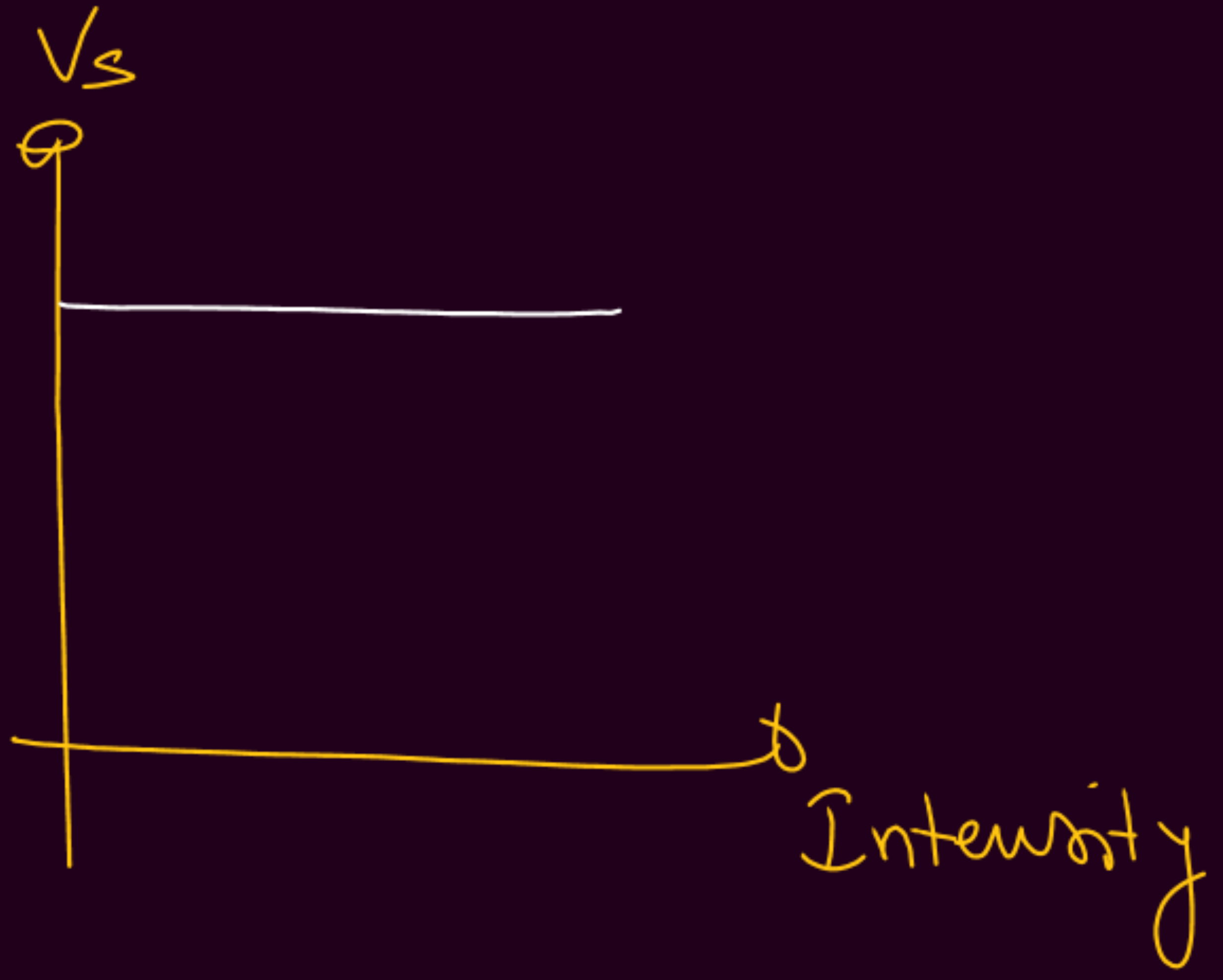
$$eV_s = h\nu - \phi$$

$$V_s = \left(\frac{h}{e}\right)\nu - \left(\frac{\phi}{e}\right)$$

$$\boxed{\text{Slope} = \tan\beta = \frac{h}{e}}$$


KEmax
Intensity


i_s
Intensity


V_s
Intensity

Q. $\phi = 4eV$

$$\lambda_0 = \frac{12420}{4} = 3105\ \mathring{A}$$

Q. $\phi = 5eV$

$\nu_0 = ?$

$$\phi = h\nu_0$$

$$5\times1.6\times10^{-19} = (6.6\times10^{-34})\nu_0$$

$$\boxed{\nu_0 = 1.2\times10^{15}\ Hz}$$

Q. $\phi = 3eV$

$E_{ph} = 4.5eV$

$$KE_{max} = 4.5 - 3 = 1.5\ eV = \cancel{e}V_s$$

$$\boxed{V_s = 1.5\ V}$$

Q. $\lambda_0 = 5000\ \mathring{A}$ $\qquad V_s = ?$

$\lambda = 4000\ \mathring{A}$

$$eV_s = \frac{12420}{4000} - \frac{12420}{5000}$$

$$\boxed{V_s = 0.62\ V}$$

Q. $\lambda_1 = 2000\ \text{Å} \rightarrow 6.$

$\boxed{\lambda_2 = 4000\ \text{Å}} \rightarrow \boxed{3.}$ ✓

$\boxed{\lambda_3 = 6000\ \text{Å}} \rightarrow \boxed{1.}$ ✓

① if $\phi = 5\,eV$

$$\lambda_0 = \frac{12420}{5} =$$

$$\lambda \leq \lambda_0$$

$$\boxed{\lambda_1}$$

② If only $\boxed{\lambda_1\ \&\ \lambda_2}$ PEE

max possible $\nu_0 = ?$

$$\nu_0 = \frac{c}{\lambda_0} = \frac{3\times10^8}{4000\times10^{-10}}$$

$$= 7.5\times10^{14}\ Hz$$

Q. $\phi = 3eV$

photon $\rightarrow$ $KE_{max} = 7eV$

$\nu \rightarrow 2\nu$ $\rightarrow$ $KE_{max} = ?$

① $7 = E_{ph} - 3$

$E_{ph} = 10eV$

② $E_{ph} = 20eV$

$KE_{max} = 20 - 3$

$= 17eV$

Q. $\phi = 3eV$

$KE_{max} = 2eV$

if $\lambda \rightarrow 2\lambda$

$KE_{max} = ?$

① $2 = E_{ph} - 3$

$E_{ph} = 5eV$

② $E_{ph} = 2.5eV < \phi$

PEE not possible

$\boxed{0}$

Q. $\lambda = 4050\ \mathring{A}$ then $KE_{max} = 1\ eV$

$\lambda = 2050\ \mathring{A}$ then $KE_{max} = ?$

$$KE_{max} = \frac{12420}{2050} - \phi$$

$$1 = \frac{12420}{4050} - \phi$$

$$KE_{max} - 1 = 6.2 - 3.1$$

$$\boxed{KE_{max} = 4.1\ eV}$$

Q. Source → 30 cm $i_s = 24\ mA$

Source → 20 cm $i_s = ?$

$$\frac{i}{24} = \left(\frac{30}{20}\right)^2$$

$$\boxed{i = 54\ mA}$$

Q. $\phi = 3eV$

$\lambda = 3000\ \mathring{A}$

then max. speed of photo e^-?

$$KE_{max} = \frac{12420}{3000} - 3 = 1.14\,eV = \frac{1}{2}\left(9.1\times10^{-31}\right) v_{max}^2$$

$$v_{max} = \sqrt{\frac{2\times1.14\times1.6\times10^{-19}}{9.1\times\cancel{10^{-31}}}\times10^{11}}$$

$$= \frac{4}{3}\times10^{5}\sqrt{22}$$

$$= (1.3\times4.7)\times10^{5}$$

$$v_{max} = 6.2\times10^{5}\ m/s$$

Case

$$\frac{1}{2} m v_{max}^2 = KE_{max} = eV_s = E_{ph} - \phi$$

① if $E_{ph} \rightarrow$ Doubled then

- KE_{max} / V_s more than Double
- v_{max} more than $\sqrt{2}$ times

$3 = 5 - 2$

$8 = 10 - 2$

② If $KE_{max} \rightarrow$ Doubled, $v_{max} \rightarrow \sqrt{2}$ times, then E_{ph} less than double

$3 = 5 - 2$

$6 = E - 2$

Matter wave

de-Broglie Hypothesis

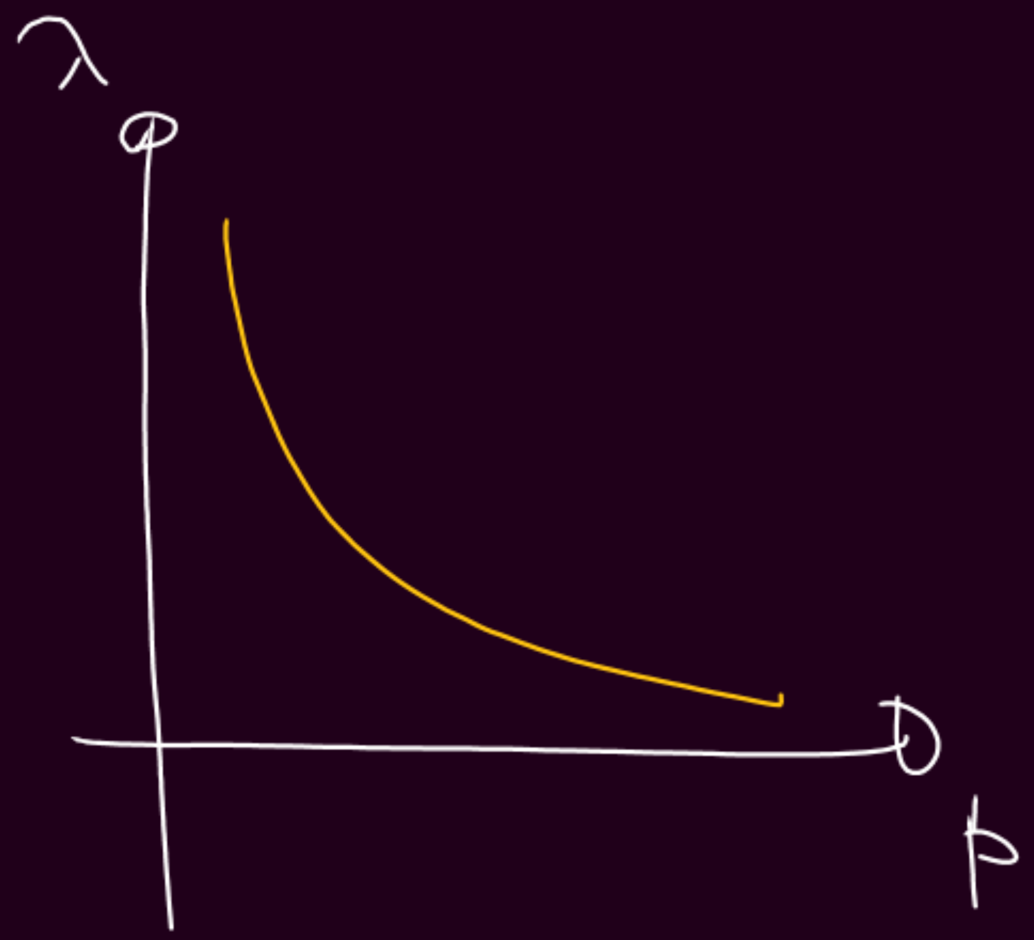
$$\boxed{\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mK}}} = \frac{h}{\left(\frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}\right)v}$$

(de-Broglie wavelength)

YDSE → Stream of e^-

$\boxed{V_a\ ?}$

fringe → Shrink



de-Broglie wavelength of charged Particles

→ $KE = qV_a$

$$\lambda = \frac{h}{\sqrt{2mqV_a}}$$

$$\boxed{\lambda_e = \frac{12.27}{\sqrt{V_a}}\ \text{Å}} = \sqrt{\frac{150}{V}}$$

$$\boxed{V_a = \frac{150}{\lambda^2}} \quad (\lambda \text{ in Å})$$

→ $\bar{e}$ is acc. through 100 V

$KE = 100\ eV$

→ α is acc. through 150 V

$KE = (2e)(150) = 300\ eV$

$\left(m_p = m_n = 1.67 \times 10^{-27}\ kg\right)$ $\alpha = He^{2+}$ p n n p

de-Broglie Wavelength of Neutron

[Thermal Neutron]

$$\boxed{\lambda = \frac{h}{\sqrt{3mk_BT}}}$$

$$KE = \frac{3}{2}k_BT$$

$$k_B = 1.38 \times 10^{-23}\ J/K = \frac{R}{N_A}$$

Q. If KE of e^- $\rightarrow$ Doubled then find % change in de-Broglie wavelength?

$$\lambda = \frac{h}{\sqrt{2mK}}$$

$K \rightarrow 2K$

$$\lambda \rightarrow \frac{1}{\sqrt{2}}\lambda = 0.7\lambda$$

$$\boxed{-30\%}$$

Q p ↑ by 50%

% in λ?

$$\lambda = \frac{h}{p}$$

$$p \rightarrow \left(1 + \frac{50}{100}\right) p = 1.5p$$

$$\lambda \rightarrow \frac{\lambda}{1.5} = \frac{2}{3}\lambda = 0.67\lambda$$

$$\boxed{-33\%}$$

Q. e^- Acc. through 100V

$$\lambda_e = \frac{12.27}{\sqrt{100}} = 1.227\ \mathring{A}$$

Q. $e^- \rightarrow \lambda_e = 10\,nm$

$$V_a = ?$$

$$V_a = \frac{150}{\lambda^2} = \frac{150}{(100)^2}$$

$$\boxed{V_a = 15 \times 10^{-3}\ V}$$

Q λ of neutron at 300K

$$\lambda = \frac{h}{\sqrt{3 m k_B T}}$$

$$\lambda = \frac{\overset{2.2}{\cancel{6.6}} \times \cancel{10^{-34}}\ \ 10^{-10}}{\sqrt{\cancel{3} \times 1.67 \times \cancel{10^{-27}} (1.38 \times \cancel{10^{-23}})(\cancel{300})}}$$

$$\lambda = \frac{2.2}{\sqrt{1.67 \times 1.38}}\ \mathring{A}$$

$$\lambda = \frac{2.2}{1.5}\ \mathring{A} = 1.47\ \mathring{A}$$

Q. de-Broglie wavelength of e^- ?, which has same energy as photon of λ.

$$E_{ph} = E_e$$

$$\lambda_e = \frac{h}{\sqrt{2mE_e}}$$

$$\frac{hc}{\lambda} = \frac{h^2}{2m\lambda_e^2}$$

$$\boxed{\lambda_e^2 = \frac{h\lambda}{2mc}}$$

For Same Energy of photon & e^-

1. $\lambda_{ph} \propto \lambda_e^2$

2. $\lambda_{ph} = \dfrac{2mc\lambda_e^2}{h}$

Case

For same de-Broglie wavelength, Total energy of e^- is more than photon

$$\lambda_e = \frac{h}{mv}$$

$$E_e = mc^2 = \frac{h}{\lambda_e v} c^2$$

$$E_{ph} = \frac{hc}{\lambda}$$

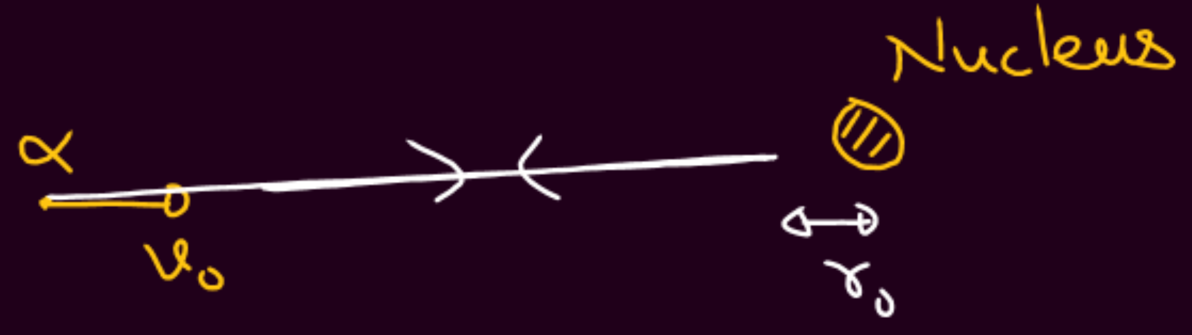
$$\boxed{\frac{E_e}{E_{ph}} = \frac{c}{v}} > 1$$

Atom

→ Rutherford's

① $N \propto \dfrac{1}{\sin^4\left(\frac{\theta}{2}\right)}$

②



Closest distance of Approach $= r_0$

$$\frac{k Z_1 Z_2 e^2}{r_0} = \frac{1}{2} m v^2$$

③ $\dfrac{mv^2}{r} = \dfrac{k Z e^2}{r^2}$

"Maxwell" → Acc. q ⇒ radiates EMW

Bohr's Atomic Model

Postulate

→ Stable − e^- (does not radiate)

→ $L = \dfrac{nh}{2\pi}$ (Quantization principle)

→ Transitions $\boxed{\Delta E = h\nu = \dfrac{hc}{\lambda}}$

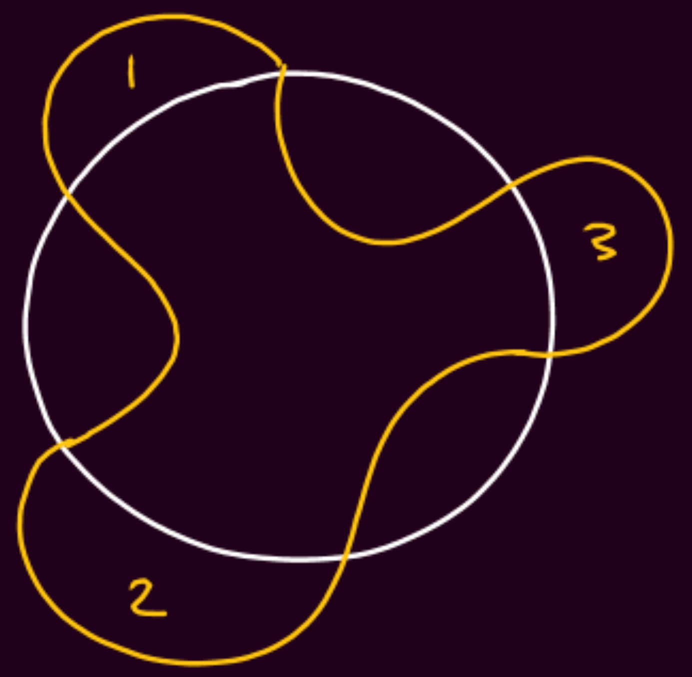
de-Broglie's Exp. of Bohr's Quantization Principle

→ e^- → wave
↳ standing wave

$$\boxed{2\pi r_n = n\lambda}$$

$$2\pi r = n\frac{h}{mv}$$

$$L = mvr = n\frac{h}{2\pi}$$



3^{rd} orbit

H-like Atom (Single e^-)

① $\dfrac{mv^2}{r} = \dfrac{kZe^2}{r^2}$

② $L = mvr = \dfrac{nh}{2\pi}$

③ $PE = -\dfrac{kZe^2}{r}$

$TE = -\dfrac{kZe^2}{2r}$

$KE = \dfrac{kZe^2}{2r}$

④ $PE = 2(TE)$

$KE = -(TE)$

⑤ $E = -(13.6\,eV)\dfrac{Z^2}{n^2} = -(Rhc)\dfrac{Z^2}{n^2}$

⑥ Rydberg Const. $\dfrac{1}{R} = 912\ \text{Å}$

⑦ $r = (0.53\ \text{Å})\dfrac{n^2}{Z}$

⑧ $v = (2.18\times10^6)\dfrac{Z}{n} = \left(\dfrac{c}{137}\right)\dfrac{Z}{n}$

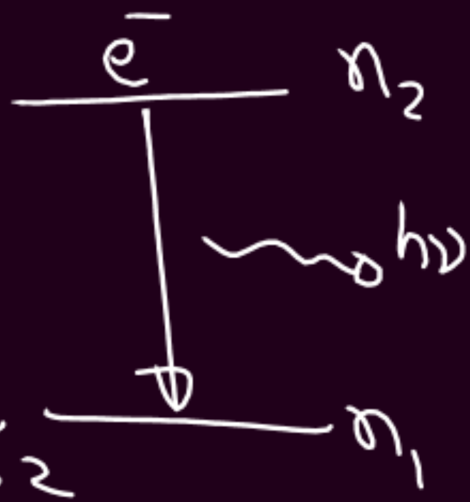
⑨ e^- - Transitions $\Delta E = h\nu = \dfrac{hc}{\lambda} = (Rhc)Z^2\left(\dfrac{1}{n_1^2} - \dfrac{1}{n_2^2}\right)$

(Mass of atom)

⑩ Recoil ① Momentum $= Mv = \dfrac{\Delta E}{c} = \dfrac{h}{\lambda}$

(v = recoil speed)

② Recoil Energy $= KE = \dfrac{1}{2}Mv^2 = \dfrac{p^2}{2M} = \dfrac{h^2}{2M\lambda^2} = \dfrac{\Delta E^2}{2Mc^2}$



Proportionality

① Energy $\propto \left(\frac{Z^2}{n^2}\right)$

② radius $\propto \left(\frac{n^2}{Z}\right)$

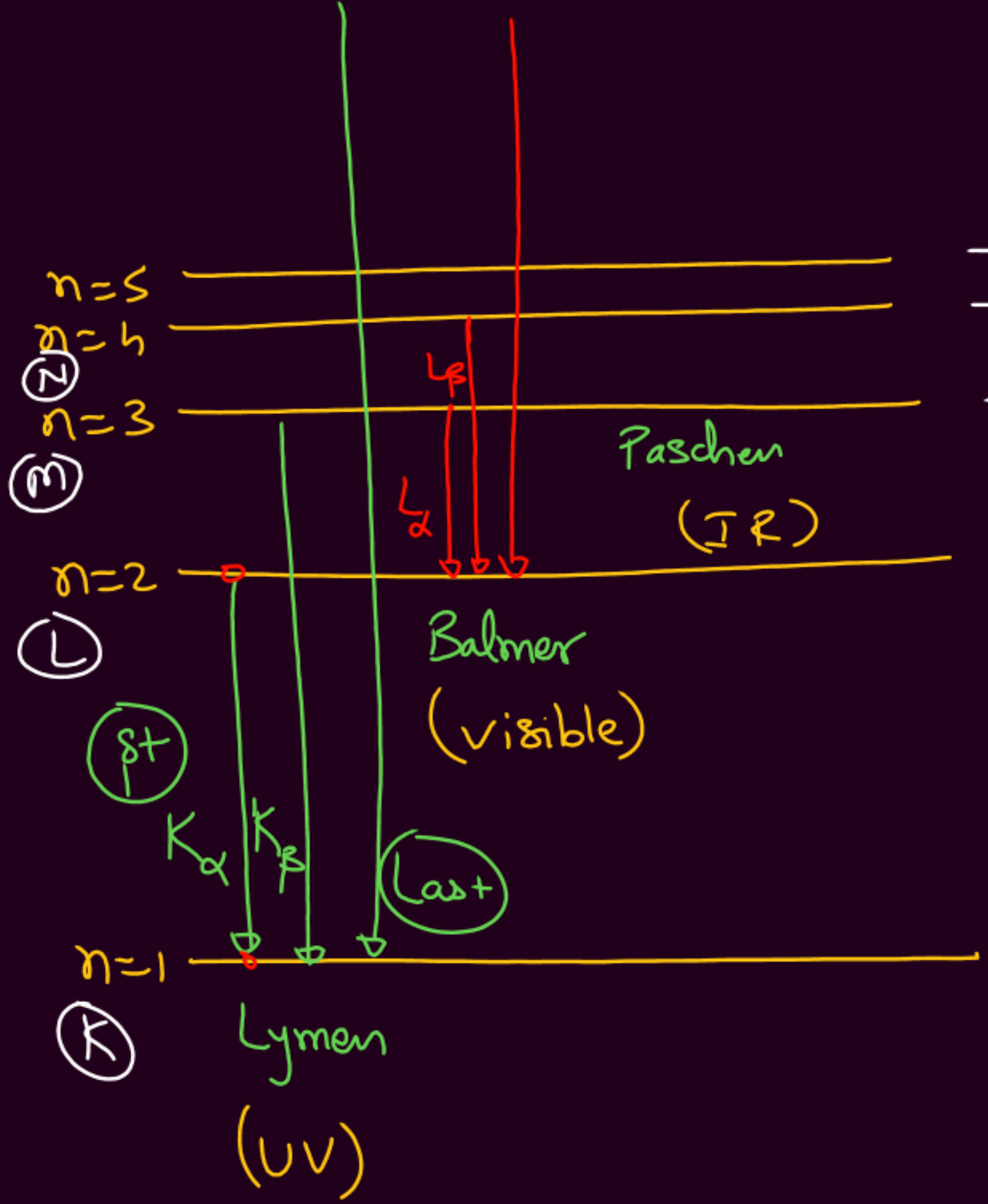
③ speed / momentum (e^-) $\propto \left(\frac{Z}{n}\right)$

④ Ang. momentum $\propto n$

⑤ Time Period $\left(T = \frac{2\pi r}{v}\right)$ $\propto \left(\frac{n^3}{Z^2}\right)$

⑥ freq $\propto \frac{1}{\text{Time period}} \propto$ current

⑦ Current $i = qf = \frac{q}{T} = \frac{q\omega}{2\pi} = \frac{qv}{2\pi r}$



TE	PE	KE	
-0.54			
-0.85			
-1.51			2nd Excited
-3.4	-6.8	3.4	1st Excited
-13.6	-27.2	13.6	ground

(1) Min energy req. for excitation is $10.2\,eV$ ($n=1$ to $n=2$)

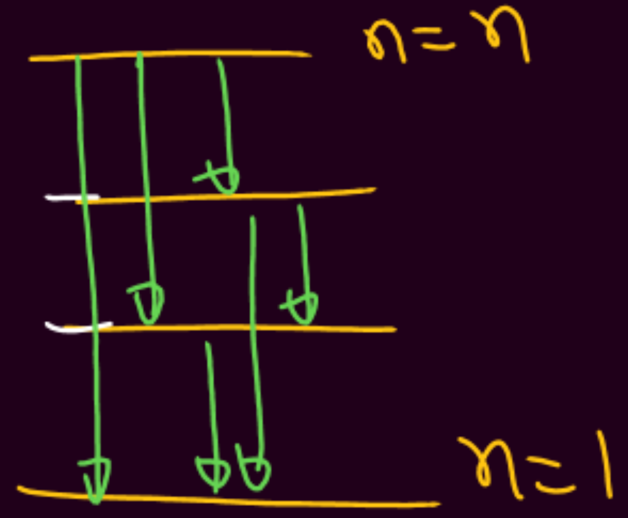
(2) If $E_{ph} = 11\,eV \rightarrow$ no excitation $\rightarrow$ collision $\rightarrow$ [Elastic]

(3) Min. energy req. for ionisation is $13.6\,eV$

(4) $E_{ph} = 15\,eV$ $\rightarrow$ Ionise

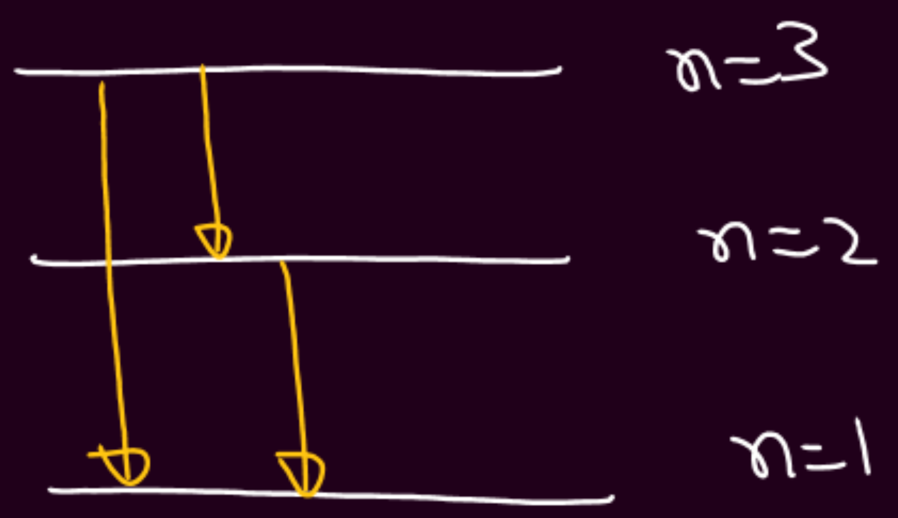
$\rightarrow$ $15 - 13.6 = 1.4\,eV = KE$

(5) no. of spectral lines $= \dfrac{n(n-1)}{2}$



$n=3$: no. of lines $= 3$

$n=4$: no. of lines $= 6$



Q. Energy of Li^{2+} in first excited $= (13.6 eV) \frac{(3)^2}{(2)^2}$

Q. 3^{rd} Excited → ground ⇒ wavelength of photon ?

(H-atom)

① $\frac{hc}{\lambda} = Rhc \left(\frac{1}{1^2} - \frac{1}{4^2}\right)$

$\lambda = \frac{16}{15R}$

$\lambda = 912\left(1 + \frac{1}{15}\right)$

$\lambda = 912 + 60 = \underline{972 \text{ Å}}$

② $\lambda = \frac{12420}{13.6 - 0.85}$ Å

Q. Find the ratio of wavelength of 1st Line of Lymen (λ_1) & 2nd of Balmer (λ_2)

$$\frac{1}{\lambda_1} = R\left[\frac{1}{1^2} - \frac{1}{2^2}\right] = \frac{3R}{4}$$

$$\frac{1}{\lambda_2} = R\left[\frac{1}{2^2} - \frac{1}{4^2}\right) = \frac{3R}{16}$$

$$\boxed{\frac{\lambda_1}{\lambda_2} = \frac{1}{4}}$$

Q. H-atom → ground to get 6 Lines in emission spectrum $\lambda = ?$ of incident radiation should be?

6 Lines ⟶

$$\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{4^2}\right] = \frac{15R}{16}$$

$$\boxed{\lambda = \frac{16}{15R}}$$

Q. In Rutherford Exp. scattered at 60° is x then find at 120°?

$$\frac{y}{x} = \left[\frac{\sin\left(\frac{60^\circ}{2}\right)}{\sin\left(\frac{120^\circ}{2}\right)}\right]^4$$

$$\frac{y}{x} = \left(\frac{1}{\sqrt{3}}\right)^4 = \frac{1}{9}$$

$$\boxed{y = \frac{x}{9}}$$

Q. Ang. momentum of e^- in H-atom depends on orbital radius as

1) r^0 2) $\sqrt{r}$ 3) $\frac{1}{\sqrt{r}}$ 4) r

① $L = \frac{nh}{2\pi} \propto \sqrt{r}$

$r \propto n^2$

② $\frac{mv^2}{r} = \frac{k q_1 q_2}{r^2}$

$v \propto \frac{1}{\sqrt{r}}$

$vr \propto \sqrt{r}$

$L = (mvr) \propto \sqrt{r}$

Q. Find de-Broglie wavelength of e^- 3^{rd} orbit of H-atom

(1) $n\lambda = 2\pi r$

$$3\lambda = 2\pi(0.53)(3)^2$$

$$\lambda \simeq 10\,\mathring{A}$$

(2) $$\lambda = \frac{h}{mv} = \frac{6.6\times10^{-34}}{9\times10^{-31}(2.18\times10^6)\left(\frac{1}{3}\right)}$$

$$\simeq 10\,\mathring{A}$$

Q If PE in ground state is taken zero Then find PE, KE, TE in 1^{st} Excited?

Ref PE = 0 at ∞

PE	KE
-6.8	3.4
-27.2	13.6

20.4

$27.2 - 6.8 = \underline{20.4\,eV}$

Ref PE = 0 at $n=1$

$\underline{PE}$ +	$\underline{KE}$ =	TE
$+20.4$	3.4	$\underline{23.8}$
0	13.6	$\underline{13.6}$

20.4

Q. If wavelength of Series limit of Balmer λ_0 then series limit of Lymen?

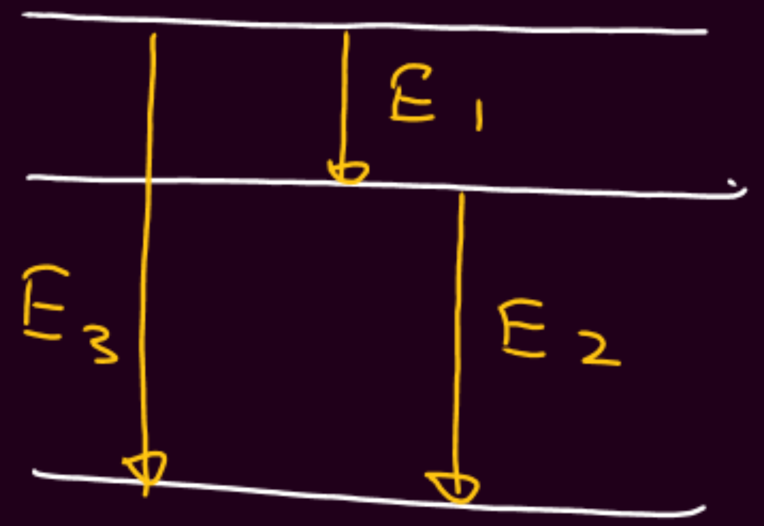
$$\frac{1}{\lambda_0} = R\left[\frac{1}{2^2} - \frac{1}{\infty}\right] = \frac{R}{4}$$

$$\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{\infty}\right] = R$$

$$\boxed{\lambda = \frac{\lambda_0}{4}}$$

Q. H-atom → 3 lines

λ_1 (max), λ_2, λ_3 (min)



① $E_3 = E_1 + E_2$

② $\nu_3 = \nu_1 + \nu_2$

③ $$\frac{1}{\lambda_3} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$$

Hypothetical

given $F = -\frac{k}{r^m}$

$$\boxed{F = -\frac{dU}{dr}}$$

✓ (1) $\frac{mv^2}{r} = -\frac{k}{r^m}$

✓ (2) $mvr = \frac{nh}{2\pi}$

Q $U = ar^2$

(1) $F = -2ar = \frac{mv^2}{r}$

(2) $mvr = \frac{nh}{2\pi}$

$$2ar = \frac{m}{r}\left(\frac{n^2h^2}{4\pi^2 m^2 r^2}\right)$$

$$r^4 = \frac{n^2h^2}{8\pi^2 am}$$

Orbital magnetic Moment $= \frac{eL}{2m} = \frac{n\,eh}{4\pi m}$

Nuclei

$m_p = m_n \approx 1.67 \times 10^{-27}$ kg

$m_e \approx 9.1 \times 10^{-31}$ kg

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

Z = no. of protons

A = Mass Number

A = no. of nucleons

$$\boxed{A = Z + N}$$

N = no. of neutrons

Density of Nucleus ~ 10^{17} kg/m^3

↳ nearly same for all nuclei

$$(\text{Volume}) \propto A$$

$$R^3 \propto A$$

R = Radius of Nucleus

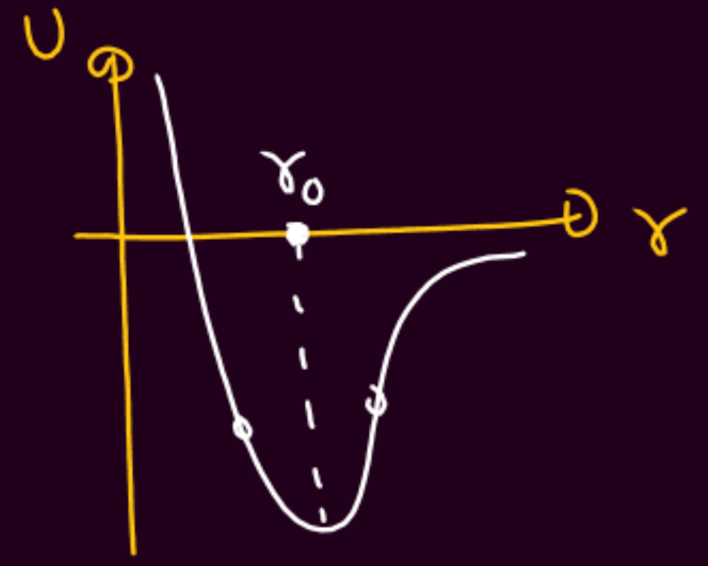
$$\boxed{R = R_0 A^{1/3}}$$

$R_0 \approx 1.2$ fermi

[1 fermi = 10^{-15} m]

Strong Nuclear Force

- Strongest
- Short Range force
- $\left.\begin{array}{l} p-p \\ n-n \\ p-n \end{array}\right\}$
- Attractive & Repulsive



- Not a Central force
- Spin dependent → {Stronger if same spin}
- $[\pi^+ / \pi^- / \pi^0]$
- Dog - bone Theory

$$p \rightarrow n + \pi^+$$
$$\pi^+ \rightarrow e^+ + \nu$$
$$\overline{p \rightarrow n + e^+ + \nu}$$

$$n \rightarrow p + \pi^-$$
$$\pi^- \rightarrow e^- + \bar{\nu}$$
$$\overline{n \rightarrow p + e^- + \bar{\nu}}$$

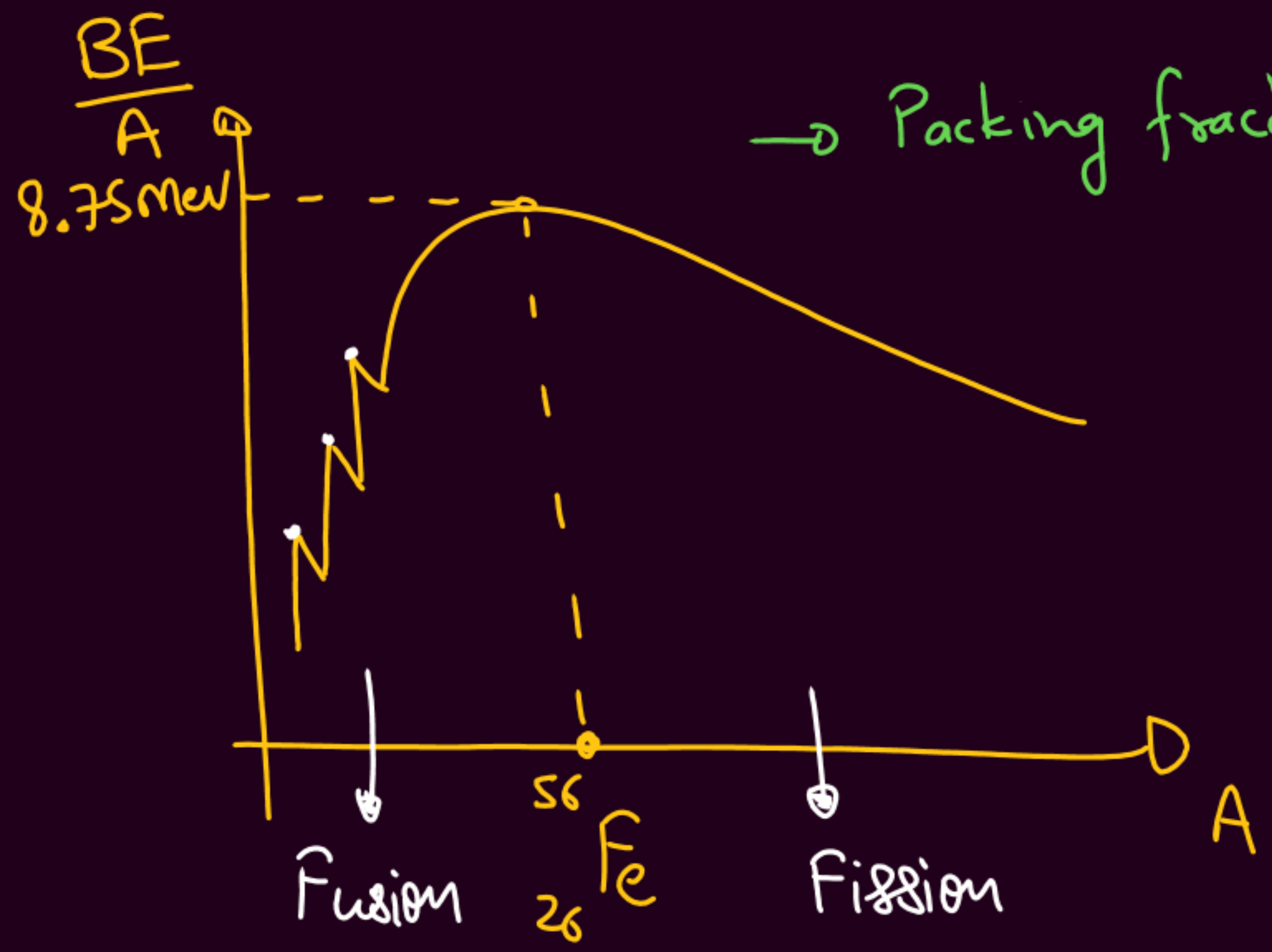
"Weak Nuclear Interaction"
↳ β - decay

Binding Energy

→ Mass Defect $\Delta m = (Z m_p + N m_n) - M$

→ $BE = \Delta m c^2$

→ Stability $\propto \left(\frac{BE}{A}\right)$ = BE per nucleon



→ Packing fraction $= \frac{\Delta m}{A}$

$1\,u = \frac{^{12}C\text{-atom}}{12}$

$1\,u \approx 1.67 \times 10^{-27}$ kg

$1\,u = 931.5\ MeV/c^2$

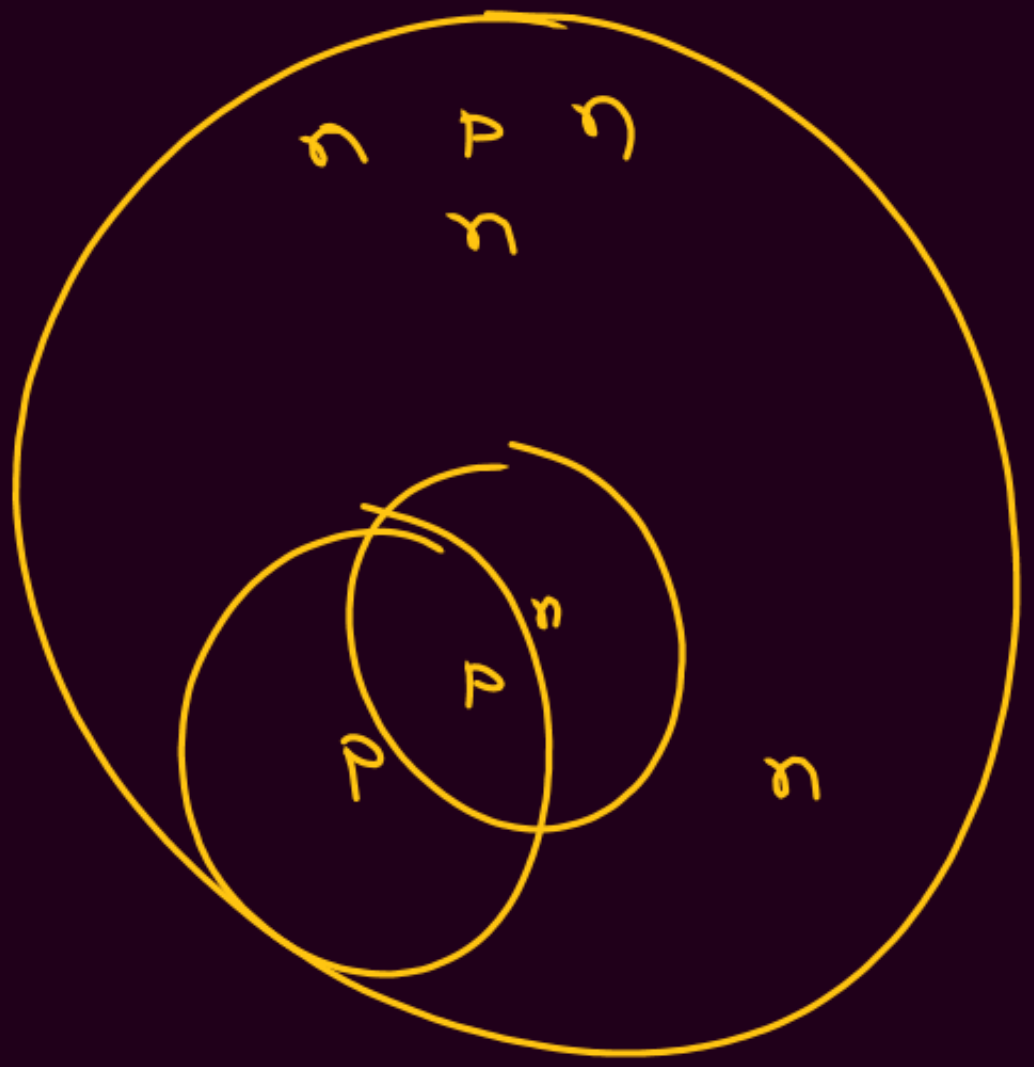
$m_e = 0.511\ MeV/c^2$

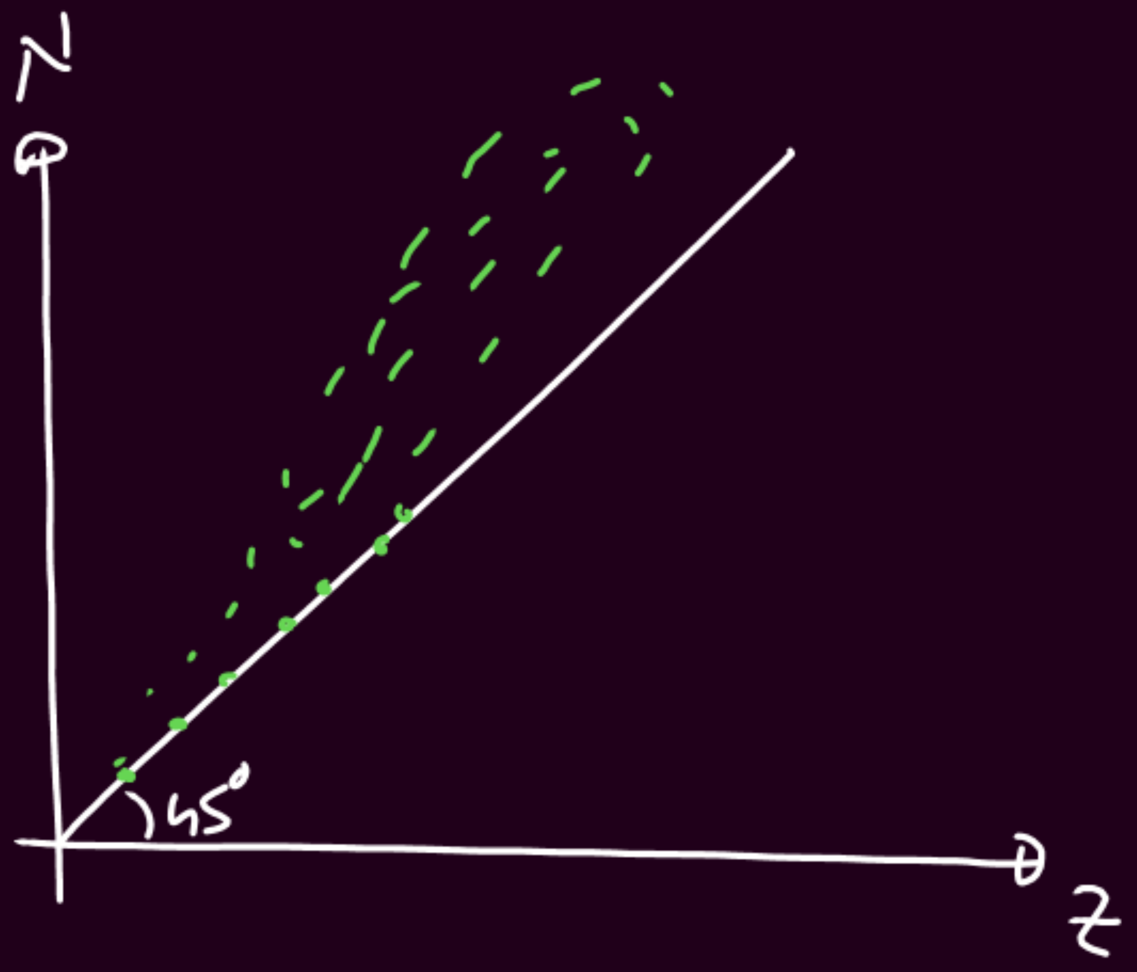
→ Smaller Nuclei $(N = Z)$

→ ${}^{40}_{20}Ca$

→ ${}^{209}_{83}Bi$

→ Heavier $(N > Z)$





Q. Mass defect in nuclear fission rxn is 0.05%. Then find $E = ?$ for 1 kg fuel.

$$E = mc^2$$

$$E = \left(1 \times \frac{0.05}{100}\right)(3 \times 10^8)^2$$

$$\boxed{E = 45 \times 10^{12}\ J}$$

Q. $BE = ?$ of ${}^{14}_{7}N$

given $m_H = 1.00783\ u$ (proton)

$m_n = 1.00867\ u$

$m_N = 14.00307\ u$

$$\Delta m = (7 m_H + 7 m_n) - m_N$$

$$= 0.11243\ u$$

$$BE = (0.11243)(931.5)\ MeV$$

Nuclear Reactions

$$A + B \longrightarrow C + D + \text{Energy}$$

[Q-value]

p n

$$A + B \longrightarrow C + D$$

15J 22J

Conserve

1. Charge
2. Mass No.
3. Linear Momentum
4. Angular —"—

$Q = \oplus$ feasible

$Q = \ominus$ Not feasible

$$Q = \left[M_{reac} - M_{Prod}\right]c^2 = \Delta m c^2$$

$$Q = \left[BE_{prod} - BE_{Reac}\right]$$

Q. $^{9}_{4}A + ^{14}_{6}B \longrightarrow ^{18}_{8}C + ^{5}_{2}D$

① charge $4 + 6 = 8 + Z$

② A $9 + 14 = 18 + A$

Q. $^{200}_{90}X \longrightarrow ^{184}_{85}Y + 4\alpha + 3\beta^-$

① $90 = Z + (4 \times 2) + 3(-1)$

② $200 = A + (4 \times 4) + 0$

Q. $^{200}_{90}X \longrightarrow ^{188}_{84}Y + 3\alpha$

① $90 = Z + (3 \times 2)$

② $200 = A + (3 \times 4)$

Q. $^{210}_{92}X \longrightarrow ^{190}_{90}Y + n_1\alpha + n_2\beta^-$

① $92 = 90 + 2n_1 - n_2$

② $210 = 190 + 4n_1$

$\boxed{n_1 = 5}$

$\boxed{n_2 = 8}$

Q. $^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{4}_{2}He$

BE per nucleon of $^{2}_{1}H = 1.5$ MeV

———— " ———————— $^{4}_{2}He = 6$ MeV

$Q = ?$

$$Q = (6 \times 4) - [(1.5 \times 2) + (1.5 \times 2)]$$

$$= \underline{\underline{18 \text{ MeV}}}$$

Q. $^{10}A + ^{12}B \longrightarrow ^{8}C + ^{14}D$

BE per Nucleon of $A = 1.5$ MeV

———— " ———————— $B = 2.5$ MeV

———— " ———————— $C = 2$ MeV

———— " ———————— $D = 3$ MeV

$$Q = [(14 \times 3) + (8 \times 2)] - [(12 \times 2.5) + (10 \times 1.5)]$$

$$\underline{\underline{Q = 13 \text{ MeV}}}$$

Nuclear Fission

Heavy Nucleus $(A > 230)$

$$A + n \longrightarrow B + C$$

→ Liquid drop Model

→ Avg. secondary neutrons → 2.5

→ Energy released per rxn → 200 MeV

→ 93% of Q KE & 7% as γ

→ $\Delta m = 0.1\%$

Fission of $^{235}_{92}U$

① $^{235}U + n \longrightarrow Ba + Kr + 3n + 200\ MeV$

② $^{235}U + \underbrace{n}_{\text{Thermal neutron}} \longrightarrow Xe + Sr + \underbrace{2n}_{\text{Secondary neutrons}} + 200\ MeV$

Nuclear Reactor

→ **Fuel**

Naturally → ^{235}U (0.7 %)
^{238}U (99.3 %)

Enriched → ^{235}U (3 %)

→ Moderator → To slow down 'n'

(Thermal neutron → slow moving)

D_2O

→ Control Rods → Absorb 'n'
→ Boron & Cadmium

→ Coolant → water at High Pressure

$$\text{Reproduction factor } (K) = \frac{\text{no. of } n \text{ produced}}{\text{no. of } n \text{ loss}}$$

$\boxed{K = 1}$ → Critical

Nuclear Weapon

$^{235}U + n \longrightarrow \longrightarrow \longrightarrow {}^{239}Pu$ (Best)

(Fast Breeder)

Nuclear Fusion

→ High Temp.

↳ Enough KE to overcome Electrostatic repulsion

→ High Pressure

↳ ↑ Probability of Collision

$$4\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2\beta_{+} + 2\nu + \underline{26\ MeV}$$

→ $\left(\begin{matrix}\text{Energy} \\ \text{per rxn}\end{matrix}\right)_{\text{fission}} > \left(\begin{matrix}\text{Energy} \\ \text{per rxn}\end{matrix}\right)_{\text{fusion}}$

200 MeV   26 MeV

→ Energy per nucleon per rxn → fusion ≃ 6.5 MeV

→ fission ≃ 0.85 MeV

Bomb

Atom

fission

Hydrogen

fission followed by fusion

Pair Anihilation

$$e^+ + e^- \longrightarrow \gamma + \gamma$$

Pair Production

$$\gamma \longrightarrow e^+ + e^-$$

$$E_{ph} \geq 1.02 \text{ MeV}$$

$$KE_{e^+} = KE_{e^-} = \frac{E_{ph} - 1.02}{2}$$

Decay

① α - Decay

$\boxed{\text{A changes}}$

② β - Decay $\rightarrow \beta_+$, β_-

③ γ - Decay $\rightarrow$ followed by α or β

$\frac{N}{Z} = \frac{12}{10}$

α	$\frac{10}{8}$	$\uparrow$
β_-	$\frac{11}{11}$	$\downarrow$
β_+	$\frac{13}{9}$	$\uparrow$

0.1	100	4000	7000		(Å)
γ	X	UV	V	R	IR

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

$$^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e + \bar{\nu} + Q$$

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

Q. $^{7}Li + p \longrightarrow 2\ ^{4}He$

BE per nucleon $^{7}Li = 5.6$ MeV

—— " —— $^{4}He = 7.06$ MeV

$$Q = BE_{prod} - BE_{Reac}$$

$$= 2(4 \times 7.06) - (7 \times 5.6)$$

$$= \underline{17.28 \text{ MeV}}$$

α - Emission

Parent A

$$v \longleftarrow (A-4) \quad \alpha \longrightarrow v_\alpha$$

Daughter

v = Recoil Speed

1. $(A-4)\,v = 4\,v_\alpha$

2. $$\frac{K_{A-4}}{K_\alpha} = \frac{4}{A-4}$$

3. $K_\alpha = \dfrac{A-4}{A}Q \qquad K_{A-4} = \dfrac{4}{A}Q$

$$X\,(a,\,b)\,Y$$

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