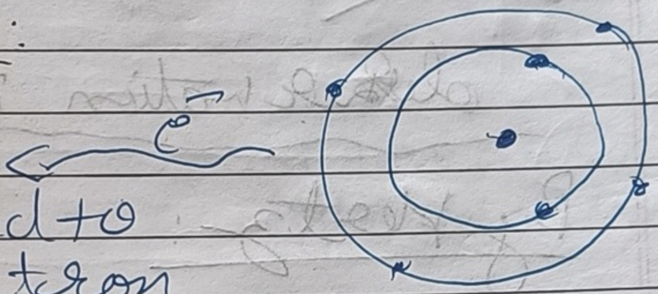
Modern Physics

Dual nature of EMW

Photo-electric effect

★ Electron emission:



Minimum Energy required to to make electron just come out of atom.

is Threshold energy or work function (ϕ_0)

$\phi_0 \rightarrow eV$ (unit)
($1 eV = 1.6 \times 10^{-19} J$)

ϕ_0 → depends on
1.) Properties of Metal
2.) Nature of Surface.
★ (Very sensitive to impurity)

★ Way of providing energy to atom.

(1). Thermeonic emmision → Heat

(2) Field emission: By applying Strong electric field to metal.

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(3) **Photoelectric emmision:** we illuminate metal surface with suitable frequency of light.

$h\nu$ ~ $\bar{e}$ (Photoelctrons)

observation in Photoelectric effect

a.) **By Hertz:**

b.) **By Lenard and Hallwach**

c.) **Einstien**

a) Hertz on discovering EMW observed that high voltage sparks across the detector loop were enhanced when emitter plate was illuminated by UV arc lamp. Light shining on metal surface somehow facilitated the escape of free, charged particles known as $\bar{e}$. When light fall on metal surface it $\bar{e}$ escape from metal.

b) Lenard observed when UV rays falls on on emitter plate of glass tube. Hallwach observed when -vely charged zinc plate became positively charged so he concluded that -vely charged particle is emitted and it was later discovered as electron.

(1) <u>Threshold frequency</u> :- The minimum value of frequency below which no $\bar{e}$'s were emitted in photoelectric effect.

$$\phi_0 = h\nu_0 = \frac{hc}{\lambda_0} \text{ (Threshold wavelength)}$$

(2) <u>Na, Li, K</u> → Sensitive to visible light for Photoelectric effect.

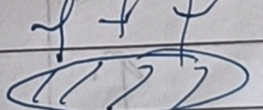
Zn, Mg → <u>not sensitive to visible light but sensitive to U.V rays</u>

ϕ_0 ↕ Energy meets
Instantly fill energy and give out electron in Modern Physics unlike of Classical Physics

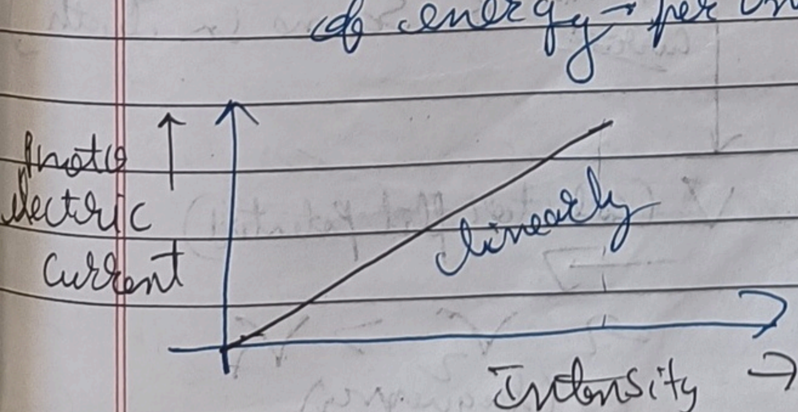
Experimental study of Photo electric effect

(1) Effect of Intensity of light :-

More Intensity means more packet of energy → per Unit time per Area Unit.

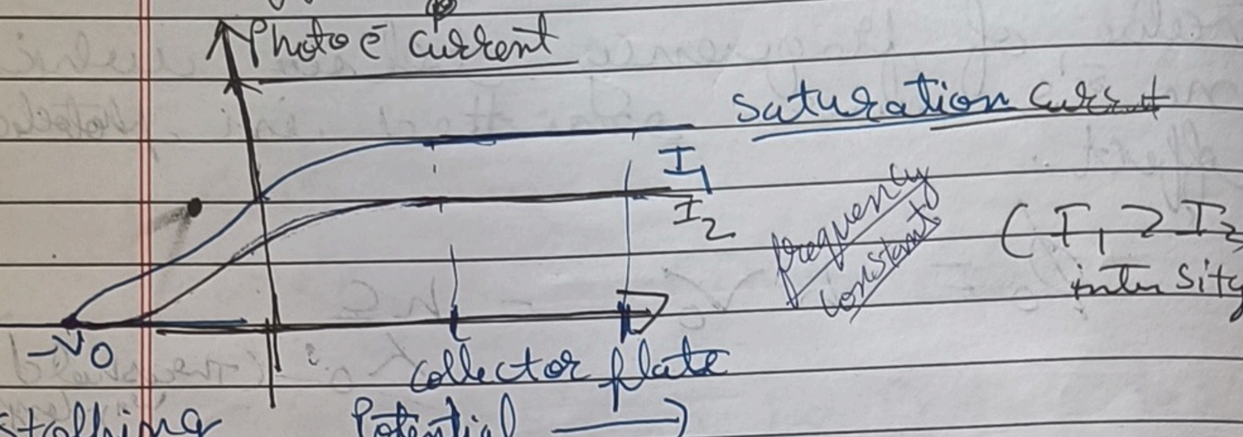


∴ no. of $\bar{e}$ ∝ Intensity



For High frequency $\nu > \nu_0$ or $\lambda < \lambda_0$

(2) Effect of Potential



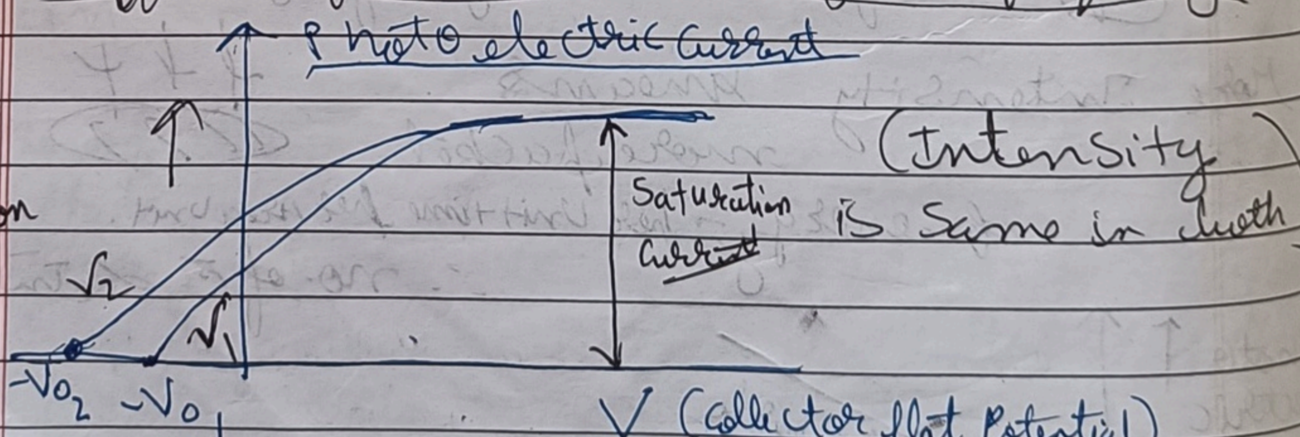
(Stopping Potential) or Cut off Potential

$$\boxed{KE_{max} = eV_0}$$

1.) For a given frequency of Incident light the stopping potential is independent of its intensity I.e.

2.) KE_{max} depends upon incident light source and emmitor plate Material.

(3) Effect of incident light frequency



as no. of electron emitted is equal if intensity is equal so current same.

$\Rightarrow V_{0_2} > V_{0_1}$ $\Rightarrow \nu_2 > \nu_1$ (frequency)

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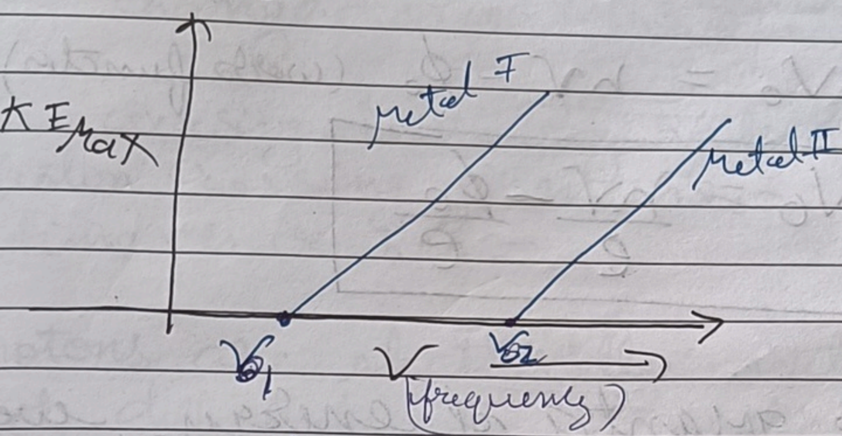
★ Stopping Potential (V_0)



(4) The photoelectron emission is an instantaneous process without any apparent time lag.

Einstein's Photoelectric equation

Einstein stated that photoelectric emission does not take place due continuous absorption of energy instead the Radiations are built up of discrete units called quanta of energy and energy of each quanta equal to $h\nu$

$$\text{Energy of quanta } (E) = h\nu$$

$h \rightarrow$ Planck's const.
$\rightarrow 6.626 \times 10^{-34}$ Js

$K.E_{max}$ = Total energy $- \phi_0$

★ $$K.E_{max} = h\nu - \phi_0$$

Since $KE_{max} = eV_0$

$$eV_0 = h\nu - \phi_0 \text{ (work function)}$$

☆
$$V_0 = \frac{h\nu}{e} - \frac{\phi_0}{e}$$

These quanta of energy were later named as photons [a particle by which light is made up]

Properties of Photon :-

1.) It travel with speed of light. Mass of photon is not defined. we simply state that rest mass of photon is zero

2.) Each photon has definate energy and definate momentum.

$$E_{(Photon)} = h\nu = \frac{hc}{\lambda}$$

$$P_{(Momentum)} = \frac{h}{\lambda} = \frac{E}{c}$$

3) A photon may collide or get absorbed or new photon may get emitted when it strikes the material. Hence total momentum and

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Energy is conserved but no. of photons may change during collision.

4.) On increasing Intensity of light no. of photon crossing given area in a given time increases.

5.) Photons are electrically neutral and are not deflected by Magnetic or electric field.

$$E = \frac{12375}{\lambda (\text{in } A^\circ)} \quad (eV)$$

De-Broglie Wavelength of matter wave

or Wave nature of matter :-

The wave particle nature of EMW led him to suggest that matter might also exhibit this duality. So he proposed a wavelength of matter

as $$\lambda = \frac{h}{P} \rightarrow \text{(momentum)}$$

$$\lambda = \frac{h}{mv}$$ (de Broglie wavelength)

As. $K.E = \frac{P^2}{2m}$

$$\lambda = \frac{h}{\sqrt{2m(K.E)}}$$

Also $K.E = qV$

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

For an $\bar{e}$ $q = e$, $m = m_e$

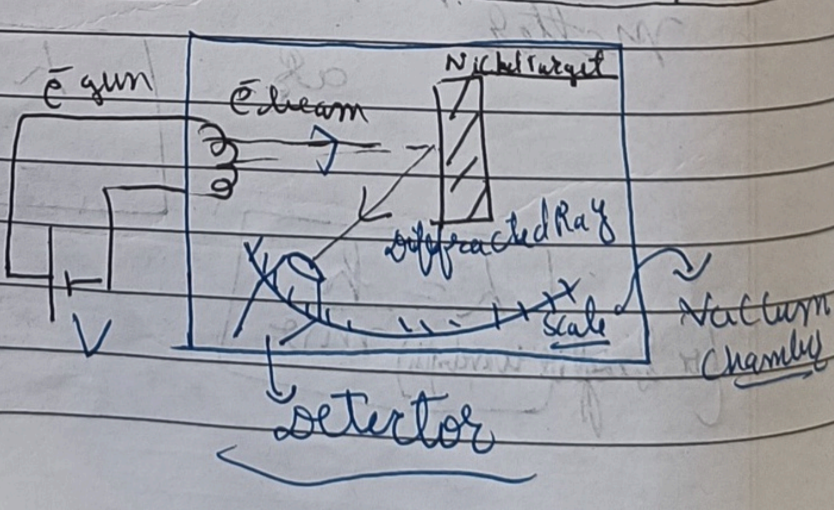
$$\lambda\,(\text{in } \mathring{A}) = \sqrt{\frac{150}{V}}$$

or $$\lambda\,(\text{in } \mathring{A}) = \sqrt{\frac{150}{K.E\,(\text{in eV})}}$$

$$\lambda\,(\text{in nm}) = \frac{1.227}{\sqrt{V}}$$

Davison and Germer Experiment

1.) When $\bar{e}$ beam strike nickle target, it diffracted the beam in all the directions.



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2.) Intensity was measured by an electron detector and it was observed that for $\theta = 50^\circ$ and applied voltage $= 54V$ the intensity was maximum.

3.) as a result we can say that at this point their was constructive interference of $\bar{e}$'s scattered from different layers of regularly placed atoms of target.

4.) since interference phenomenon was only confined to waves. Thus it proved the particles wave nature.

Q The energy of Photon is equal to the kinetic energy of proton, which is equal to E. then ratio λ_1/λ_2 is proportional to.

($\lambda_1, \lambda_2 \rightarrow$ de Broglie for proton and Ph)

$\frac{hc}{\lambda_1} = $

$E = \frac{h^2}{\lambda_1^2}$

$\lambda_1 = \frac{h}{\sqrt{2mE}}$ $\lambda_2 = \frac{h}{\sqrt{2mE}}$

$\frac{\lambda_1}{\lambda_2} = \frac{h}{\sqrt{2m}} \sqrt{\ } = \sqrt{\frac{m}{2}}$

$\Rightarrow E^0$

$\therefore$ a) E^0 b) $E^{1/2}$ c) $E^{-1/2}$

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$$\lambda_1 = \frac{h}{\sqrt{2mE}} \qquad \lambda_2 = \frac{h}{E}$$

$$\therefore \frac{\lambda_1}{\lambda_2} \propto E^{1/2}$$

a) E^0 ~~b) $E^{1/2}$~~ c) $E^{-1/2}$

Q — An alpha particle and a proton are accelerated from rest by $V = 100\,V$. After this de-Broglie wavelength are λ_α and λ_p resp. Find $\frac{\lambda_p}{\lambda_\alpha}$

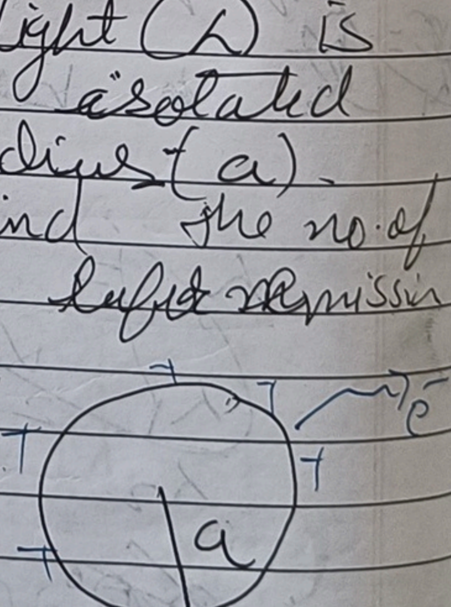
$$\lambda_\alpha = \frac{h}{\sqrt{2(4m)(2)V}}$$

$$\lambda_p = \frac{h}{\sqrt{2(m)(1)V}}$$

$$\boxed{\frac{\lambda_p}{\lambda_\alpha} = \sqrt{2}}$$

Q — A monochromatic light (λ) is incident on an isolated mettalic sphere of Radius (a). Given ($\lambda < \lambda_0$) Find the no. of photoelectron emitted before emission stops.

Potential of sphere will increase



Max value → V_{max}

$$eV_{max} = E_1 - \phi_0$$

$$V_{max} = \frac{hc}{e\lambda} - \frac{hc}{e\lambda_0}$$

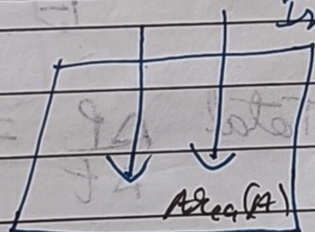
$$Q = CV = 4\pi \varepsilon_0 a V_{max}$$

$$n = \frac{Q}{e}$$

$$\boxed{n = \frac{4\pi \varepsilon_0 a}{e^2} hc \left[\frac{1}{\lambda} - \frac{1}{\lambda_0}\right]}$$

Force and pressure due to Radiations (photons)

$P = \frac{h}{\lambda}$
(Momentum)



Absorption coefficient = a
Reflection " = r

Such that $a + r = 1$

$n \rightarrow$ no. of photons striking per second

$\therefore$ $na \rightarrow$ no. of photons absorbed / sec
$nr \rightarrow$ no. of photons reflected / sec

Case I $a = 1$, $r = 0$ (full absorption)

$\therefore$ Total energy per unit time = Power (W) = $IA_\perp$ = IA

$$n = \frac{\text{Power}}{E} = \frac{IA\lambda}{hc}$$

$$\text{Total } \frac{\Delta P}{\Delta t} = \text{Force} = n\Delta P = \frac{IA\lambda}{hc} \times \frac{h}{\lambda}$$

~~Pressure~~ $= \frac{IA}{C} = \frac{W}{C}$ (Power)

$$\text{Pressure} = \frac{F_\perp}{A} = \frac{IA}{C(A)} = \frac{I}{C} = \frac{W}{AC}$$

$$\text{Pressure} = \frac{I}{C} = u \text{ (energy density)}$$

Case II $a = 0$, $r = 1$ (full Reflection)

The Energy / time = Power (W) $= IA\perp$

$$n = \frac{\text{Power}}{E} = \frac{IA\lambda}{hc}$$

$$\text{Total } \frac{\Delta P}{\Delta t} = \text{Force (F)} = n\Delta P = \frac{IA\lambda}{hc} \times \frac{2h}{\lambda}$$

$$= \frac{2IA}{C}$$

$$\text{Pressure} = \frac{F_\perp}{A} = \frac{2I}{C} = \frac{2W}{AC}$$

C = speed of light

Case III Let 'a', 'r' be the resp. coefficient.

I Energy / time = Power (W) $= IA\perp$
$= IA$

$$n = \frac{\text{Power}}{E} = \frac{IA\lambda}{hc}$$

$$n = \frac{Power}{E} = \frac{IA\lambda}{hc}$$

Total $\frac{\Delta P}{\Delta t}$ = Force = $n\Delta P = \frac{IA\lambda}{hc} \times \frac{h}{\lambda}$

~~Pressure~~ $= \frac{IA}{C} = \frac{W}{C}$ (Power)

Pressure $= \frac{F_t}{A} = \frac{IA}{C(A)} = \frac{I}{C} = \frac{W}{AC}$

Pressure $= \frac{I}{C} = u$ (energy density)

Case II $a = 0,\ r = 1$ (full Reflection)

Energy / time = Power (W) = $IA\lambda$

$$n = \frac{Power}{E} = \frac{IA\lambda}{hc}$$

Total $\frac{\Delta P}{\Delta t}$ = Force (F) $= n\Delta P = \frac{IA\lambda}{hc} \times \frac{2h}{\lambda}$

$$= \frac{2IA}{C}$$

Pressure $= \frac{F_t}{A} = \frac{2I}{C} = \frac{2W}{AC}$

C = speed of light

Case III let 'a', 'r' be the resp. coefficient.

Energy / time = Power (W) = $IA\lambda$ = IA

$$n = \frac{Power}{E} = \frac{IA\lambda}{hc}$$

$\frac{\text{Total } \Delta P}{\Delta t} = \text{Force } (F) = F_a + F_r$

$= n_a \Delta P_1 + n_r \Delta P_2$

$= n_a \frac{IA\lambda}{hc} \times \frac{h}{\lambda} + n_r \frac{IA\lambda}{hc} \frac{2h}{\lambda}$

$$\boxed{\text{Force } (F) = \frac{IAa}{c} + \frac{2rIA}{c}}$$

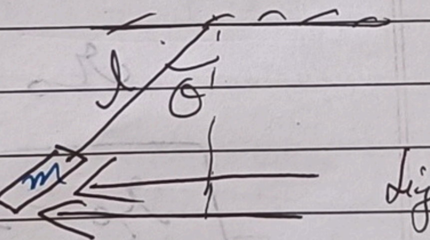
$$\boxed{\therefore \text{Pressure} = \frac{F}{A} = \frac{Ia}{c} + \frac{2rI}{c}}$$

$= \frac{I}{c}(2r + a)$

$$\boxed{\text{Pressure} = \frac{I}{c}(1+r)} \quad (\because a + r = 1)$$

$$\boxed{F_{net} = \frac{IA}{c}(1+r)}$$

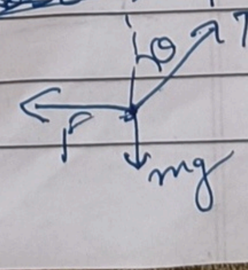
Q:- A small plane strip is suspended from a fixed support as shown. A continuous beam of light is incident on it (Monochromatic, W (Power)). The light is completely absorbed. Find:
a.) θ
b.) Time period for small oscillation.



A a.) Force = $\frac{W}{c\,mg}$

~~mg cosθ = T~~

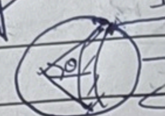
$T\cos\theta = mg$
$T\sin\theta = F$



$2\pi\sqrt{\frac{l}{g_{eff}}}$

$$g_{eff} = \sqrt{g^2 + \left(\frac{F}{m}\right)^2}$$

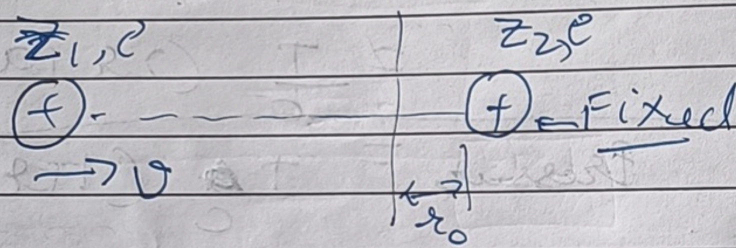
$$T = 2\pi\sqrt{\frac{l}{g}}$$

★ 

Parallel light Rays on sphere whether reflecting or absorbing → Force is $\frac{\pi r^2 I}{c}$

Bohr's Model and Physics of an atom

Determination of closest approach distance



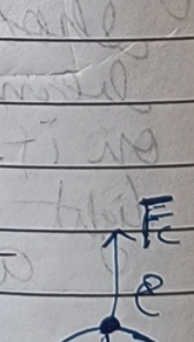
$$K.E_i = P.E_f$$

$$\frac{1}{2} \times m_e v^2 = \frac{K(Z_1 e)(Z_2 e)}{r_0}$$

$$r_0 = \frac{2KZ_1 Z_2 e^2}{m_e v^2}$$

$$\boxed{r_0 = \frac{KZ_1 Z_2 e^2}{K.E}}$$

Bohr's atomic Model :-



I st Postulate :-

$$F_a = F_c$$

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$$F_a = \frac{k(Ze)e}{r^2}$$ (r = Radius of orbit)

~~$F = \frac{mv^2}{}$~~

$$\left(F_a \propto \frac{1}{r^2}\right)$$

$$\boxed{\frac{mv^2}{r} = \frac{kZe^2}{r^2}} \rightarrow (1)$$

(Eqⁿ of Iˢᵗ Postulate)

IInd Postulate

$$L = \frac{nh}{2\pi}$$

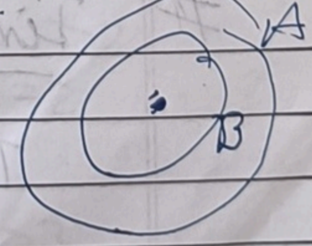
(angular momentum) (n = integer → Principle quantum no.)

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

$$\frac{h}{2\pi} = 1.05 \times 10^{-34}\ J/s$$

$(\hbar)$

IIIrd Postulate — Energy absorbed by $\bar{e}$



$$\Delta E = E_A - E_B$$

$$\Delta E = |E_A - E_B|$$

$$\boxed{\Delta E = |E_A - E_B| = \frac{hc}{\lambda}}$$

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☆ These postulate are applicable to Hydrogen atom and also the ions having just one electron.
(Hydrogen like He^+, Li^{++} etc)

$$r = \frac{\varepsilon_0 h^2 n^2}{\pi m Z e^2} \qquad v = \frac{Z e^2}{2 \varepsilon_0 h n}$$

For $Z = 1$ $n = 1$
$r \to r_0 = 0.53 Å$ and $v \to v_0 = 2.18 \times 10^6$ m/s

$$r = \frac{r_0 n^2}{Z} \qquad v = \frac{v_0 Z}{n}$$

$r \propto \frac{1}{m_e}$ $v \propto m_e^0$ (independent)

Energy of orbit

☆ $$K.E = -T.E = -\frac{1}{2} P.E$$

$$T.E = E = \frac{-m Z^2 e^4}{8 \varepsilon_0^2 h^2 n^2} = \frac{E_0 Z^2}{n^2}$$

$E_0 = -13.6 eV$

$E \propto m_e$

Timeperiod (τ)

$$T = \frac{1}{freq} = \frac{2\pi r}{v} = \frac{n^3 h^3}{4\pi^2 k^2 Z^2 e^4 m}$$

$T \propto \frac{1}{m_e}$

$T \propto \frac{n^3}{Z^2}$

Current In any orbit

$$I_n = \frac{e}{T} = \frac{4\pi^2 k^2 e^5 Z^2 m}{n^3 h^3}$$

$I \propto m_e$

Energy level in Hydrogen like atoms

$n=\infty$ ———— $E = 0$

$n=5$ ————

$n=4$ ————

$n=3$ ———— $E_3 = -1.51 Z^2$

$n=2$ ———— $E_2 = -3.4 Z^2$

$n=1$ ———— $E_1 = -13.6 Z^2$

$n = 1$ (ground state) (least E) $n > 1$ → Excited state

Spectral series of 'H' like atom

(1) Lyman ⇒ If e^- electron from any excited state of $n=1$ is called Lyman series.

n_i → Any Excited level

$n_f \to n=1$

(2) Balmer → $n_i \Rightarrow n > 2$

$n_f \Rightarrow n = 2$

(3) Paschen → $n_i = n > 3$

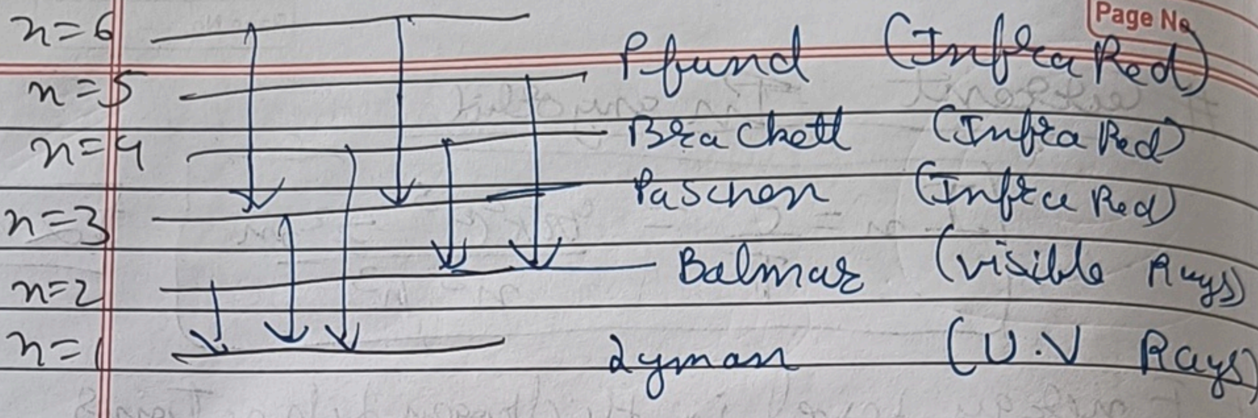
$n_f \to n = 3$

(4) Brackett : $n_i \to n > 4$

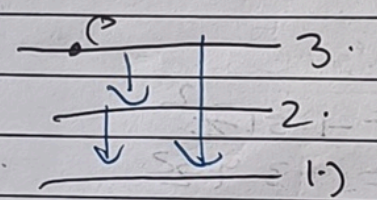
$n_f \to n = 4$

(5) Pfund : $n_i \to n > 5$

n_f $n = 5$



no. of Spectral Lines



e → 3 to 2 (1 Possibility)
e → 3 to 1 (2 Possibility)

∴ no. of spectral lines

$$= \frac{(n_2 - n_1)(n_2 - n_1 + 1)}{2}$$

$n_1 \Rightarrow$ Lower state
$n_2 \Rightarrow$ greater than n_1 $(n_2 > n_1)$

The state of atom with lowest energy is called Ground state. The state with higher energy are called its Excited state.

Excitation and Ionization of an atom

Ionization energy: The Minimum energy needed to ionise atom is called I.E.

Ionise means electron is not bound to nucleus. (free $\bar{e}$)

For Hydrogen atom in ground state I.E is $\boxed{13.6eV}$

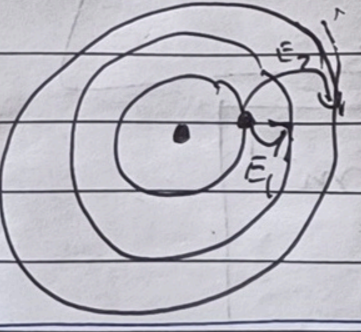
Binding energy: The energy Released when any two constituent element are brought together to form a system,

OR

Energy needed to seperate its constituents to a large distance.

$\therefore$ B.E for $\bar{e}$ in H^2 atom $= 13.6eV$

Excitation energy: Energy needed to take the atom from ground state to an excited state.



E_1 and E_2 both are Excitation energy

$E_1 = E_{(n=2)} - E_{(n=1)}$
$= 10.2eV$
1^{st} Excitation energy.

minimum Energy needed by neutron for inelastic collision is 20.4eV

or $\left[\frac{1}{2}mv^2 > 2\Delta E\right] \rightarrow$ (Energy released in transition)

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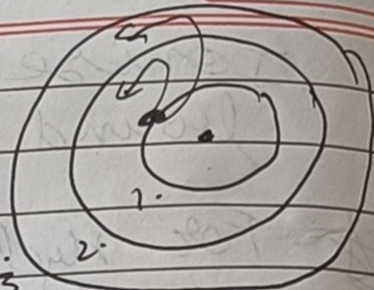

★ For an atom when a photon is supplied, an e^- absorbs it only if the photon energy is equal to the difference in the energies of the two energy levels involved in the transition.

★ If e^- has to jump from n_2 to n_1

$$[n_2 > n_1]$$

$$\Delta E = E_{n_2} - E_{n_1}$$

$$\frac{hc}{\lambda} = -13.6\, z^2 \left[\frac{1}{n_2^2} - \frac{1}{n_1^2}\right]$$

$$\Rightarrow \boxed{\frac{1}{\lambda} = -RZ^2 \left[\frac{1}{n_2^2} - \frac{1}{n_1^2}\right]}$$

$$\boxed{\frac{1}{\lambda} = -RZ^2 \left[\frac{1}{n_2^2} - \frac{1}{n_1^2}\right]}$$

$$R = \frac{13.6}{hc} = 1.1 \times 10^7 \ m^{-1}$$

(Rydberg constant)

★ $$\lambda (\text{in } \mathring{A}) = \frac{12375}{E_{n_2} - E_{n_1}}$$ (in eV)

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Limitation of Bohr's Model

It is only valid for hydrogen atom.

X-Ray

1.) Discovered by Roentgen

2.) Has wavelength λ ranging from 0.1 Å to 100 Å

3.) It is invisible to eye and has a speed equal to speed of light.

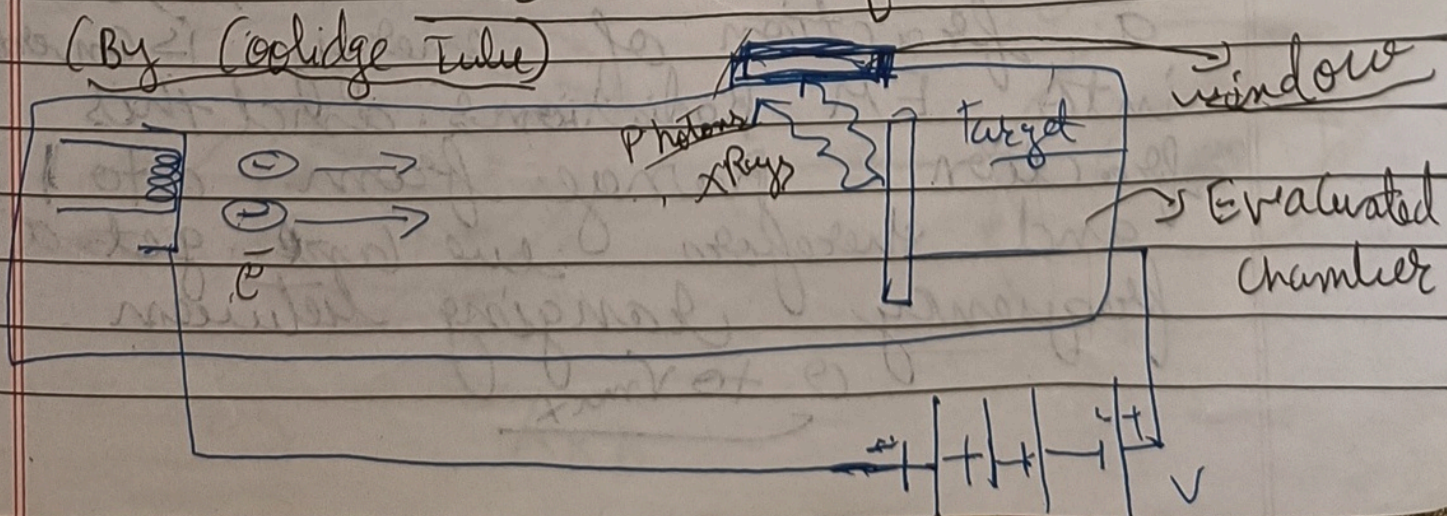
4.) It does not get deflected by Electric or Magnetic field.

5.) When passed through gases it produces ionisation effect

6.) Production of of X-Ray is also known as inverse photo-electric effect.

Production of X-Ray

(By Coolidge Tube)



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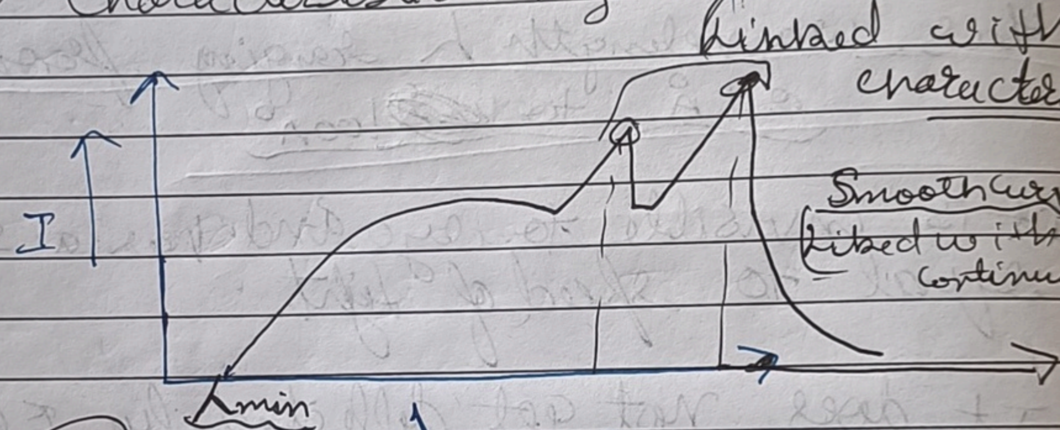
☆ 1) The Melting, specific heat Capacity and atomic no. of target should be high.

2 Types of X Ray

(i) Continuous X Ray
(ii) Characteristic X Ray

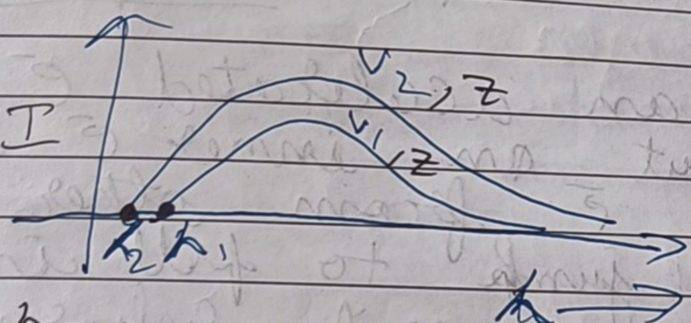


☆ There is λmin (minimum wavele below which no X-ray is emitted known as cutoff or threshold wavelength.

Continuous X-Ray

☆ When ē loses its Kinetic e in several Collision with a a fraction of energy is con into EM Radiations. and this fraction Range from 0 to and therefore we can get frequency ranging between 0 to ν_{max}

and λ vary from $\lambda_{min} \rightarrow \infty$.
* Thus a continuous spectrum is formed as shown —



* $\lambda_1, \lambda_2 \rightarrow$ corresponding λ_{min}.

* $V_1, V_2 \rightarrow$ Potential difference

$\lambda_{min} = \frac{12375}{V (in\ volts)}$ (in Å)

$V_2 > V_1$ as $V\uparrow$, $KE\uparrow$, $\lambda\downarrow$

So $V \propto \frac{1}{\lambda}$

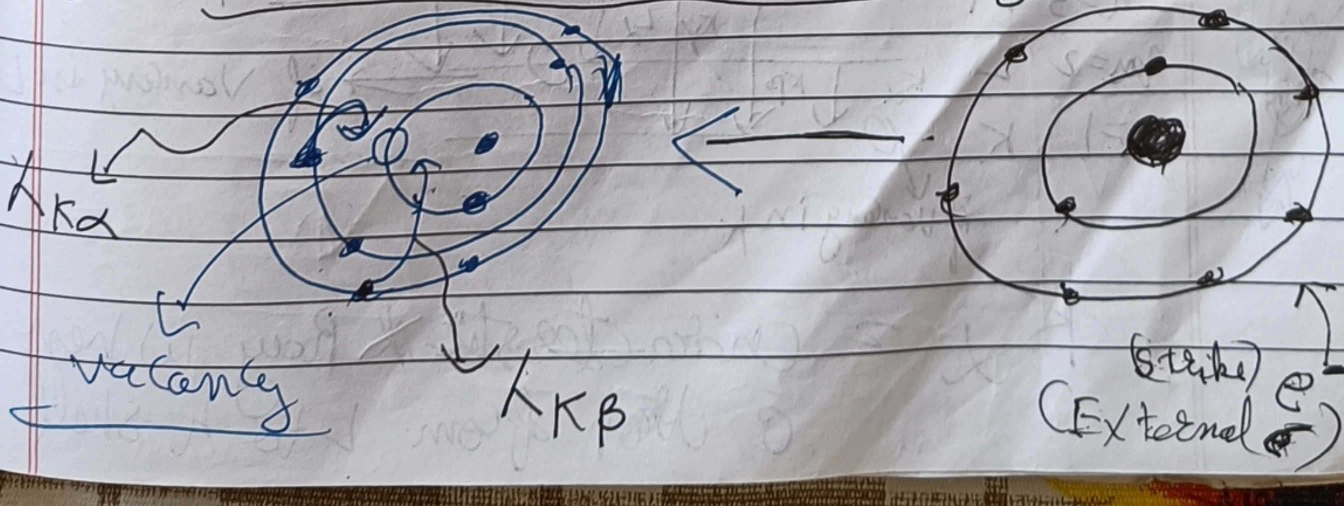
* λ_{min} is more for low Potential difference and decrease when we increase V

* ∴ (λ_{min}) depend on V (Potential) But not on element. So it is not the characterstic of element.

$\lambda_{min} = \frac{hc}{eV}$

(voltage across tube)

* Q. Characterstic X-Ray



$\lambda_{K\alpha}$

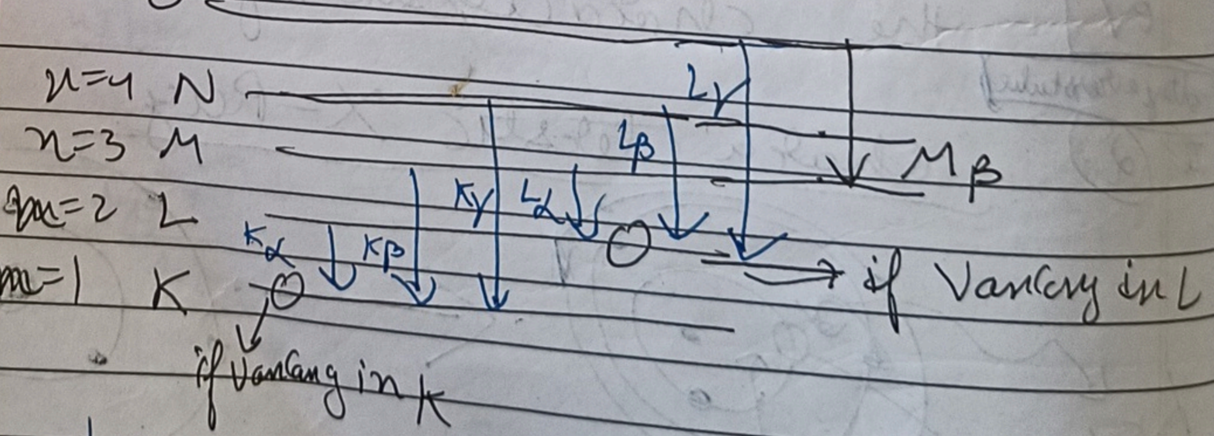
K → Shell to which $\bar{e}$ go
α → I^{st} probability

1.) If an accelerated $\bar{e}$ knock out an inner $\bar{e}$ then the $\bar{e}$ from other orbits will jump to fill in the vacancy, while releasing the Energy diff. as EM Radiations.

2.) These λ are characterstic of target material Hence named as Characterstic Spectra.

3.) These are observed as sharp peaks in I v/s λ graph

4.) The Photon emitted has the energy equal to difference in the energy between two levels.



K_α = Characterstic X Ray when $\bar{e}$ drop from

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K_β = characterstic X Ray when $\bar{e}$ drop from M to K shell

L_α = from M to L shell.

Energy variation

→ K_α vs K_β vs K_γ

Energy → $K_\gamma > K_\beta > K_\alpha$

ν → $K_\gamma > K_\beta > K_\alpha$

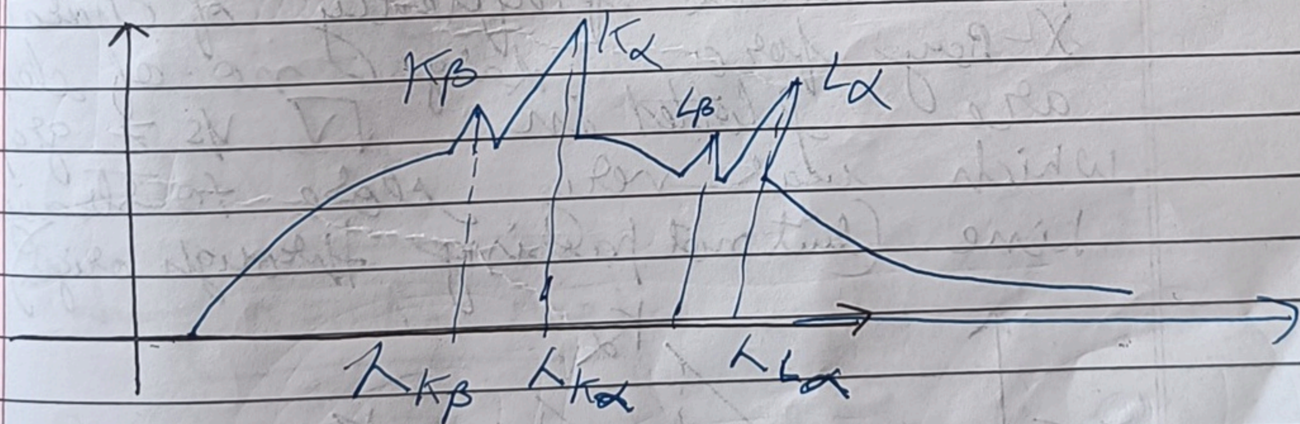
λ → $K_\gamma < K_\beta < K_\alpha$

→ K_α vs L_α vs M_α

E → $K_\alpha > L_\alpha > M_\alpha$

ν → $K_\alpha > L_\alpha > M_\alpha$

λ → $M_\alpha > L_\alpha > K_\alpha$



$$\lambda_{K_\alpha} = \frac{hc}{E_L - E_K}$$

$$\lambda_{L_\beta} = \frac{hc}{E_N - E_L}$$

★ E_K, E_L, E_M → are the energy levels related to the atom other than hydrogen like atom and they are characteristic property of that material

★ For diff. material these value will be diff.

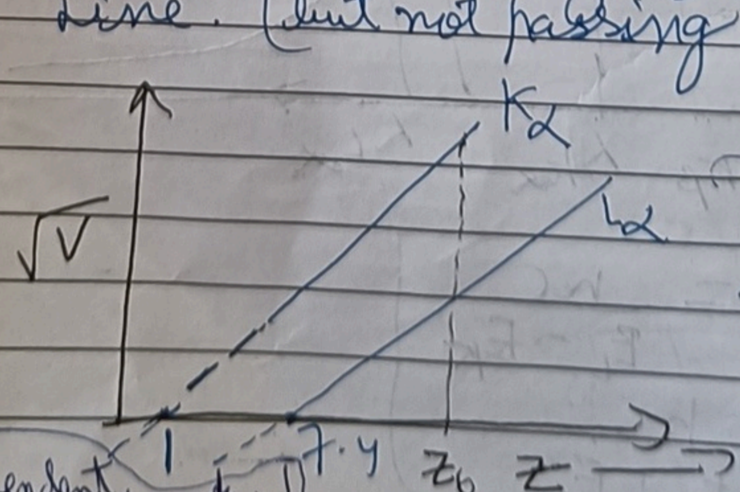
★ ∴ $|E_L - E_K|$ or $|E_M - E_K|$ it have definite value for a given material

★ X Rays of low wavelength (more Energy) are also known as hard X-Rays

★ X Rays of large wavelength (Less Energy) are called soft X-Rays.

Moseley's Law

The measured frequency of characteristic X-Ray for a large no. of elements are plotted in $\sqrt{\nu}$ v/s Z graph, which was very close to straight line. (but not passing through origin).



★ $$\sqrt{\nu} = a(Z - b)$$

ν → frequency of X-Ray

Z → Atomic no

a, b → Constant for particular X-Ray

★ [a, b → independent of material]