DUAL NATURE OF MATTER & RADIATION

Photon Theory

- Intensity (I) $= \frac{Power}{Area} = \frac{E}{tA}$

$=$ energy per unit area per unit time

Point source $I = \frac{P}{4\pi r^2} \Rightarrow I \propto \frac{1}{r^2}$

Line source $I = \frac{P}{2\pi r l} \longrightarrow I \propto \frac{1}{r}$

(1) no. of Photons

$E = n\,h\nu \Longrightarrow n = \frac{E}{h\nu} = \frac{E\lambda}{hC}$

(2) no. of Photons per unit time

$\frac{n}{t} = \frac{E}{th\nu} = \frac{P}{h\nu} = \frac{IA}{h\nu} = \frac{IA\lambda}{hc}$

(3) no. of Photons per area per unit time

$\frac{n}{At} = \frac{E}{tAh\nu} = \frac{P}{Ah\nu} = \frac{I}{h\nu} = \frac{I\lambda}{hc}$

- Power of incident radiation (P)

$P = \frac{nthc}{\lambda} \quad P \propto \left(\frac{n}{\lambda}\right)$

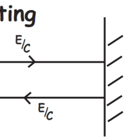
source1 $P_1 \rightarrow \lambda_1 \rightarrow n_1$

source1 $P_2 \rightarrow \lambda_2 \rightarrow n_2$

$\frac{P_1}{P_2} = \frac{n_1}{n_2} \times \frac{\lambda_2}{\lambda_1}$

Dual Nature of Radiation

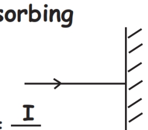
- Momentum of photon (p) $= \frac{E}{c} = \frac{h}{\lambda}$
- Force (F) $= \frac{\Delta p}{\Delta t}$
- Radiation Pressure $= \frac{F}{A}$
- For perfectly reflecting surface



$\Delta p = \frac{2E}{c} \quad F = \frac{2P}{c}$

Rad. Pressure $= \frac{2I}{C}$

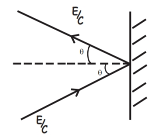
- For Perfectly Absorbing Surface



$\Delta p = \frac{E}{c} \quad F = \frac{P}{c}$

Rad. Pressure$(P_R) = \frac{I}{C}$

- Perfectly Reflecting at an angle



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

$F = \frac{2P}{C}\cos\theta$

Rad. Pressure $= \frac{2I}{C}\cos\theta$

PHOTOELECTRIC EFFECT

Energy of photon $E = h\nu$

- ν = Frequency of incident light in Hz $= \frac{c}{\lambda}$

Max. kinetic energy of emitted photoelectron

- $(K.E)_{max} = E - w = \frac{1}{2}mV_{max}^2$

Work function (w)

- Minimum energy required for photoelectric effect to occur

$w = h\nu_0 = h\frac{c}{\lambda_0} \quad h = 6.63\times10^{-34}$ Js

ν_0 = Threshold frequency in Hz

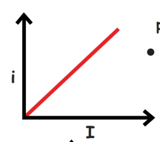
λ_0 = Threshold wavelength in m

- Work function only depends on nature of metal

Factors affecting photoelectric effect

- Intensity

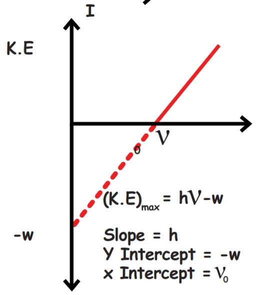
Intensity ↑, photoelectrons ↑, photocurrent ↑ (K.E Remains same)



photocurrent (i) ∝ Intensity (I)

- Frequency

Frequency ↑, Energy ↑, K.E ↑ (Work function Remains same)



$(K.E)_{max} = h\nu - w$

Slope = h

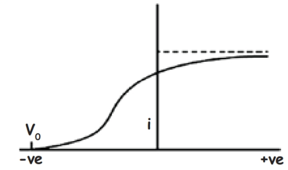
Y Intercept = -w

x Intercept = ν_0

- Anode potential

Opposes K.E of electron

Max Negative anode potential = Stopping potential (V_0) for which Photocurrent (i) = 0



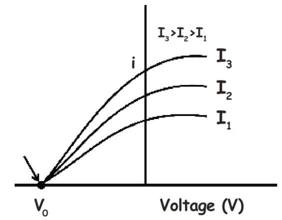
$(K.E)_{max} = eV_0 = \frac{1}{2}mV_{max}^2 = h(\nu - \nu_0) = h\left(\frac{c}{\lambda} - \frac{c}{\lambda_0}\right)$

Factors affecting stopping potential

- Intensity (I)

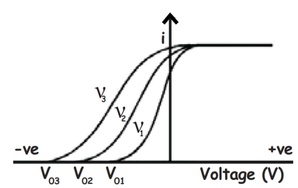
Intensity ↑, K.E Remains same

Stopping potential remains same



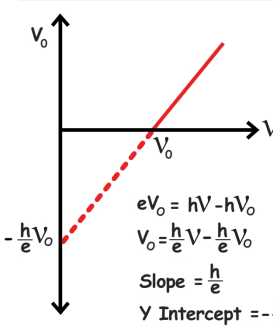
- Frequency

Frequency ↑, Energy ↑, K.E ↑, V_0 ↑



$\nu_3 > \nu_2 > \nu_1 \longrightarrow V_{03} > V_{02} > V_{01}$

Stopping potential V_0 vs frequency graph



$eV_0 = h\nu - h\nu_0$

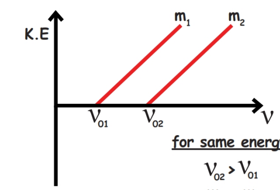
$V_0 = \frac{h}{e}\nu - \frac{h}{e}\nu_0$

Slope $= \frac{h}{e}$

Y Intercept $= -\frac{h}{e}\nu_0$

x Intercept $= \nu_0$

- Nature of material



for same energy E

$\nu_{02} > \nu_{01}$

$w_{02} > w_{01}$

$K.E_2 < K.E_1$

$V_{02} < V_{01}$

- Conceptual question

If green color have just sufficient energy for photoelectric effect

increasing order of λ

V	I	B	G	Y	O	R

E (at G); no photo electric effect (Y, O, R); sure photo electric effect (V, I, B)

E ↑ λ ↓ ν ↑

Useful conversions

- Wave Length (nm) ⟶ K.E (eV)

$K.E = \frac{1240}{\lambda}$ (eV)

- Wave Length (Å) ⟶ K.E (eV)

$K.E = \frac{12400}{\lambda}$ (eV)

- Two Identical photo cathode recieve light of frequencies f_1 & f_2. If velocity of photo elecrons are v_1 & v_2

then $v_1^2 - v_2^2 = \frac{2h}{m}[f_1 - f_2]$

Dual Nature of Matter

Wave nature of Matter

Debroglie waves

fast moving particles like electron with much smaller mass behaves like a wave ie., Circular stationary waves

$E = mc^2 = \frac{hc}{\lambda}$

$\lambda = \frac{h}{mc} \rightarrow \lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2m(K.E)}} = \frac{h}{\sqrt{3kmT}} = \frac{h}{\sqrt{2mqV}}$

K.E = qV (for charged particle)

V = accelerating potential in Volt

$K.E = \frac{3}{2}K_BT$ (thermal neutron)

K_B = Boltzmann's constant

T = Temperature in Kelvin

- Thermal Neutron

$\lambda = \frac{h}{\sqrt{3mk_BT}} = \frac{30.83}{\sqrt{T}}$ Å

- Electron $\lambda = \frac{12.27}{\sqrt{V}}$ Å
- Proton $\lambda = \frac{0.286}{\sqrt{V}}$ Å
- Deutron $(\lambda) = \frac{0.202}{\sqrt{V}}$ Å
- ∝-Particle $(\lambda) = \frac{0.101}{\sqrt{V}}$ Å

^1H (Proton) ⟶ 1 Proton ⟶ m,q

^2H (Deuteron) ⟶ 1 Proton + 1Neutron ⟶ 2m,q

^4_2He (∝-Particle) ⟶ 2 Proton+2 Neutron ⟶ 4m,2q

Relationship b/w wavelength of photon & that of electron

- Ratio of wavelength of photon to that of electron with same energy E

$\frac{\lambda_{photon}}{\lambda_e} = c\sqrt{\frac{2m}{E}} \qquad \lambda_{photon} \propto \lambda_e^2$

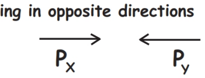
- Ratio of K.E of electron to that of photon with same wavelength

for Same $\frac{K.E_e}{K.E_{photon}} = \frac{V}{2C}$

- A particles formed due to completely inelastic collision of particle 'x' and 'y' having debroglie wave length λx and λy respectively.

If they are moving in opposite directions

$p = p_x - p_y$



then

$\frac{h}{\lambda} = \frac{h}{\lambda_x} - \frac{h}{\lambda_y} \qquad \lambda = \frac{\lambda_x\,\lambda_y}{\lambda_x - \lambda_y}$

- If they are moving at right angle to each other

$\Rightarrow p = \sqrt{p_x^2 + p_y^2} \longrightarrow \frac{h}{\lambda} = \sqrt{\frac{h^2}{\lambda_x^2} + \frac{h^2}{\lambda_y^2}}$

$\frac{1}{\lambda} = \sqrt{\frac{1}{\lambda_x^2} + \frac{1}{\lambda_y^2}}$