FREE NOTES · NCERT + JEE/NEET LEVEL

Dual Nature of Radiation & Matter

Electron emission, photoelectric effect ke experiments aur graphs, Einstein ki equation, photon, de Broglie wavelength aur Davisson-Germer experiment.

01 Electron emission
02 Photoelectric effect
03 Experiment ke results (graphs)
04 Wave theory kyun fail hui
05 Einstein's photoelectric equation
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01 Electron emission

Metal se free electron nikaalne ke liye kam se kam ek energy chahiye: **work function φ_0** (eV me). Ye metal pe depend karta (Cs sabse kam ≈ 2.1 eV, Pt zyada ≈ 5.6 eV).

Tareeka	Energy kahan se
Thermionic emission	Garmi (bulb ka filament)
Field emission	Bahut tez electric field (~10^8 V/m)
Photoelectric emission	Light (sahi frequency ki)

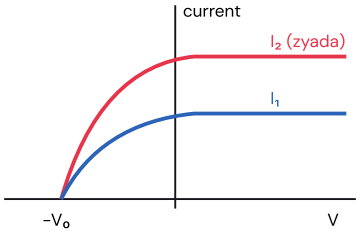
02 Photoelectric effect

Metal pe sahi frequency ki light padne pe electrons nikalte hain (Hertz, Hallwachs, Lenard ne dekha). Zinc pe UV, alkali metals (Cs, K) pe visible light bhi kaafi.

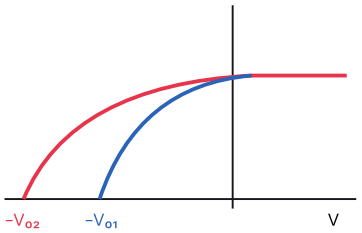
TERMS

- **Threshold frequency ν_0:** isse kam frequency pe koi electron nahi, chahe light kitni bhi tez.
- **Stopping potential V_0:** wo negative voltage jisse sabse tez electron bhi ruk jaaye: $eV_0 = K_{max}$.
- **Saturation current:** jab saare nikle electrons collect ho jaayein.

03 Experiment ke results (graphs)



Intensity badhao: saturation current badhe, V_o same



Frequency badhao ($\nu_2 > \nu_1$): V_o zyada, saturation same

Observation	Result
Photocurrent vs intensity	Current ∝ intensity (zyada photons, zyada electrons)
Stopping potential vs intensity	Koi asar nahi
K_{max} / V_o vs frequency	Seedhi line, ν_o ke upar badhti
Time lag	Nahi ($< 10^{-9}$ s), turant

04 Wave theory kyun fail hui

- Wave theory: tez light ⇒ zyada energy ⇒ K_{max} badhni chahiye. Asal me sirf current badhta.
- Wave theory: koi bhi frequency, thoda intezaar karo, energy jama hogi. Asal me ν_o se kam pe kabhi nahi.
- Wave theory: kamzor light me time lagna chahiye. Asal me turant.

Isliye Einstein ne kaha light **photons** (energy ke packets) me aati hai.

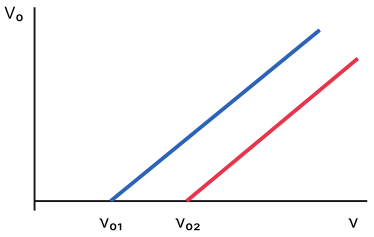
05 Einstein's photoelectric equation

$$K_{max} = h\nu - \varphi_0 = eV_0$$

$$\varphi_0 = h\nu_0 = hc/\lambda_0$$

$$V_0 = (h/e)\nu - \varphi_0/e$$

Ek photon ek electron ko poori energy deta. V_0–ν graph ki slope = h/e (har metal ke liye same). x-intercept = ν_0.



Do metals: lines parallel (slope h/e)

SHORTCUT

$$E\,(eV) = 1240 / \lambda\,(nm)$$

hc = 1240 eV·nm. Jaldi calculation ke liye.

06 Photon

Gun	Value
Energy	$E = h\nu = hc/\lambda$
Momentum	$p = h/\lambda = E/c$
Rest mass	0
Speed	c (vacuum me)
Charge	0 (field se nahi mudta)

Intensity badhane se photons ki **sankhya** badhti, har photon ki energy nahi. Takkar me photon ki sankhya badal sakti (ban/khatam ho sakte), par energy aur momentum conserved.

07 de Broglie wavelength

de Broglie: agar light (wave) particle jaisi behave karti, toh particles (electron) bhi wave jaisa behave karenge.

$$\lambda = h / p = h / (m\,v)$$

KE se: $\lambda = h/\sqrt{(2mK)}$

Charge q, voltage V se accelerate: $\lambda = h/\sqrt{(2mqV)}$

Electron ke liye: $\lambda = 1.227/\sqrt{V}$ nm

ROZ KI CHEEZON ME WAVE KYUN NAHI DIKHTI?

Cricket ball ka mass bahut zyada ⇒ $\lambda \approx 10^{-34}$ m, naapna impossible. Electron halka ⇒ λ atom ke size (~Å) jitna ⇒ crystal se diffraction dikhta.

Same KE: $\lambda \propto 1/\sqrt{m}$ (halka particle, lambi λ). Same V: $\lambda \propto 1/\sqrt{(mq)}$.

08 Davisson-Germer experiment

Nickel crystal pe 54 V se accelerated electrons daale. 50° pe intensity ka peak mila (diffraction) ⇒ electrons wave ki tarah behave karte hain.

Experiment: $\lambda \approx 0.165$ nm. de Broglie se: $\lambda = 1.227/\sqrt{54} \approx 0.167$ nm. Barabar ⇒ **matter waves prove.**

Isi idea pe **electron microscope**: electron ki λ light se bahut chhoti ⇒ bahut behtar resolution.

09 JEE Extra + Tricks

JEE LEVEL

- Photon: $E = hc/\lambda$; trick $E(eV) = 1240/\lambda(nm)$. Momentum $p = h/\lambda$.
- Einstein: $K_{max} = h\nu - \varphi = eV_o$; V_o vs ν ka slope = h/e (har metal ke liye same), intercept se threshold frequency.
- Intensity ↑ ⇒ photocurrent ↑ (K_{max} nahi); frequency ↑ ⇒ K_{max} ↑.
- de Broglie $\lambda = h/p = h/\sqrt{(2mK)} = h/\sqrt{(2mqV)}$; electron $\lambda = 12.27/\sqrt{V}$ Å.
- Same K pe $\lambda \propto 1/\sqrt{m}$ (electron ka λ proton se lamba).

10 Solved numericals ($h = 6.6 \times 10^{-34}$, $hc = 1240$ eV·nm)

Q1. 500 nm light ke photon ki energy?
E = 1240/500 = 2.48 eV ≈ 3.97×10^{-19} J. **Ans: 2.48 eV**

Q2. Metal ka φ_o = 2 eV, light 4 eV ki. K_{max} aur V_o?
K_{max} = 2 eV, V_o = 2 V. **Ans: 2 eV, 2 V**

Q3. φ_o = 2.48 eV. Threshold wavelength?
λ_o = 1240/2.48 = 500 nm. **Ans: 500 nm**

Q4. 100 V se accelerated electron ki λ?
λ = 1.227/10 = 0.1227 nm. **Ans: ≈ 0.123 nm**

Q5. Proton aur electron same KE pe. λ ka ratio (λ_p/λ_e)?
$\lambda \propto 1/\sqrt{m} \Rightarrow \sqrt{(m_e/m_p)} = \sqrt{(1/1836)} \approx 1/43$. **Ans: ≈ 1 : 43**

Q6. 1 mW ka laser (λ = 663 nm) har second kitne photons?
$E = hc/\lambda = 6.6 \times 10^{-34} \times 3 \times 10^{8}/6.63 \times 10^{-7} \approx 3 \times 10^{-19}$ J. $n = 10^{-3}/3 \times 10^{-19} \approx 3.3 \times 10^{15}$. **Ans: ≈ 3.3×10^{15} per s**

11 Common mistakes

- Intensity badhane se K_{max} badhti maan lena (sirf current badhta).
- eV aur J mix karna (1 eV = 1.6×10^{-19} J).
- de Broglie me v ki jagah KE ya V seedha daal dena.
- V_o–ν graph ki slope metal pe depend maan lena (h/e, sabke liye same).
- ν_o se kam frequency pe "thodi der me" emission maan lena.

12 Formula sheet

Photon	$E = h\nu = hc/\lambda,\ p = h/\lambda$
Shortcut	$E(\text{eV}) = 1240/\lambda(\text{nm})$
Einstein	$K_{max} = h\nu - \varphi_0 = eV_0$
Work function	$\varphi_0 = h\nu_0 = hc/\lambda_0$
de Broglie	$\lambda = h/mv = h/\sqrt{(2mK)} = h/\sqrt{(2mqV)}$
Electron	$\lambda = 1.227/\sqrt{V}$ nm
Photons per second	$n = P/(h\nu)$

13 Practice questions

1. Frequency 2 guna. K_{max} 2 guna hogi?
2. Electron ka accelerating voltage 4 guna. λ?
3. V_o–ν graph ki slope?
4. Photon ka momentum 3.3×10^{-27} kg·m/s. λ?

ANSWERS

1) Nahi, 2 guna se zyada ($2h\nu - \varphi_o$) · 2) Aadhi · 3) h/e · 4) λ = h/p = 200 nm

14 Quick revision: exam se pehle 5 minute

PHOTOELECTRIC

- $K_{max} = h\nu - \varphi_o = eV_o$.
- Intensity ⇒ current; frequency ⇒ K_{max}.
- $\nu < \nu_o$ ⇒ kuch nahi; time lag nahi.

PHOTON

- $E = 1240/\lambda(nm)$ eV.
- $p = h/\lambda$; rest mass 0.

DE BROGLIE

- $\lambda = h/p = h/\sqrt{(2mK)}$.
- Electron: $1.227/\sqrt{V}$ nm.
- Same K: $\lambda \propto 1/\sqrt{m}$.

PROOF

- Davisson-Germer: 54 V, 50°, Ni.
- Electron microscope.

Doubt hai? padhaiadda.netlify.app pe AI Doubt Solver se poocho, ya is chapter ka mock test do.