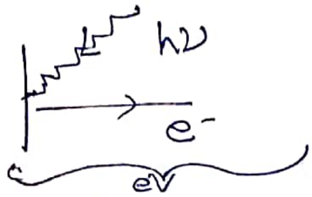
Photo-electric effect



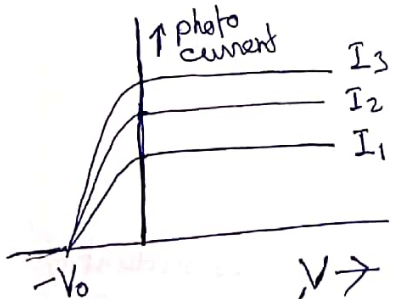
Work function → minimum energy, required to librate an ~~e~~ e^- from metal surface

$W = h\nu_0$ ↳ Threshold frequency

$N(h\nu - h\nu_0) = N\left(\frac{1}{2}mv^2\right) = eV$

N → no. of photon

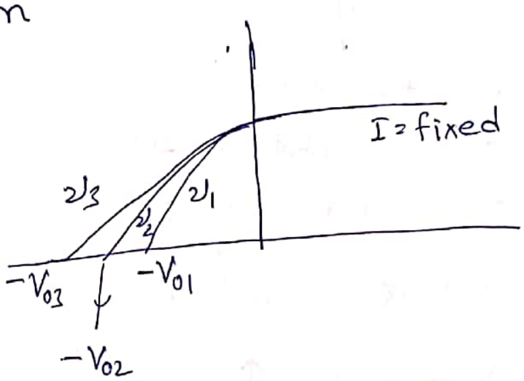
N → no. of electron



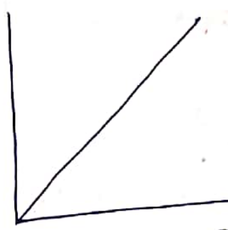
$-V_0$ → Stopping potential

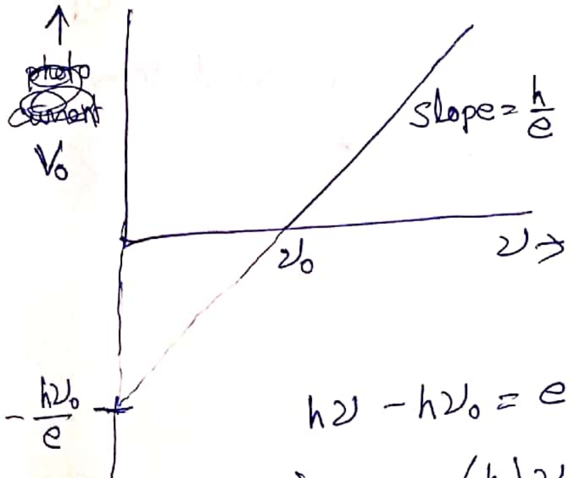
V → potential

$I_3 > I_2 > I_1$ → Intensity of light



$eV_0 = \frac{1}{2}mv_{max}^2$





$h\nu - h\nu_0 = eV_0$

$\Rightarrow V_0 = \left(\frac{h}{e}\right)\nu - \left(\frac{h\nu_0}{e}\right)$

$\left(\frac{h\nu_0}{e}\right)$ → Constant

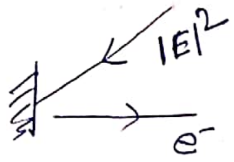
Scanned with CamScanner

Experimental facts

classical view

~~Failure~~ to explain

①



quantum view

Light → Energy = $h\nu$

Successful to explain

Work done = Power × time

$= \# |E|^2 \times \text{time} = W$ (work function) → But it is instantaneous process

need few week to create photo current, observed in experiment

② Intensity of light $= \# |E|^2 \uparrow$

$\Rightarrow$ Work done $\uparrow$

$\Rightarrow (\text{Work done} - W) = \frac{1}{2} m v^2 = K.E \uparrow$ → But K.E is independent of intensity of light

③ Why ν_0?

they fail to explain → When we consider

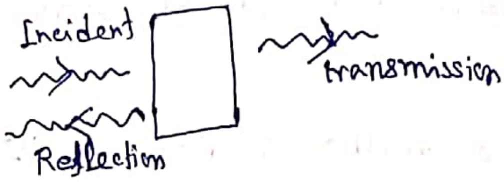
$\boxed{\text{Energy} = h \times \text{frequency}}$

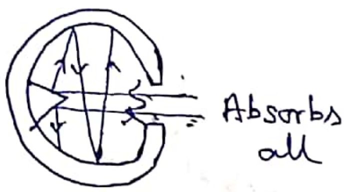
then we understand from Einstein relation.

Q.M. (1st year) PH-1011

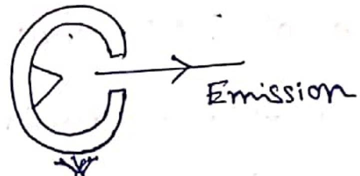
Black body radiation

Black body $\rightarrow$ Absorbs all incident (heat) radiation of all λ
but no transmission
no reflection



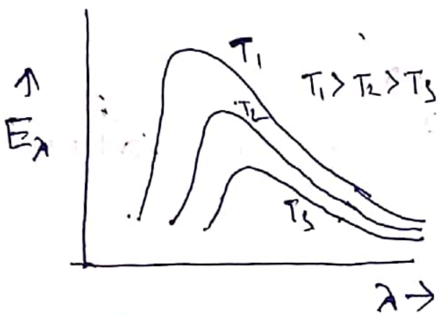


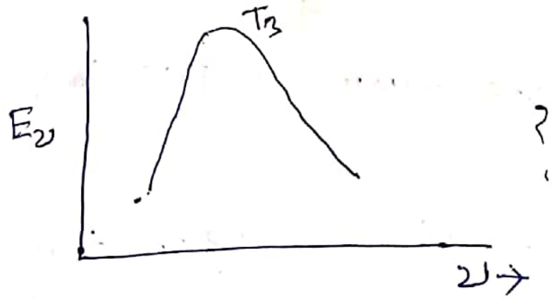
Black body



Heat (in uniform T)

Material $\rightarrow$ Lamb ~~to~~ black, Platinum black (>95% absorbtion)

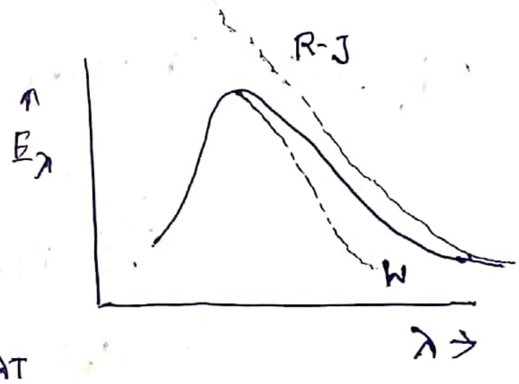




Emissibe power $\rightarrow$ Energy emitted / area / time / λ from the surface
(E_λ)

Wien's Radiation formulae

$$\boxed{E_\lambda d\lambda = \frac{A}{\lambda^5} e^{-B/\lambda T} d\lambda} \rightarrow \text{small } \lambda$$



$$\frac{dE_\lambda}{d\lambda} = A\left[\frac{-5}{\lambda^6} + \frac{1}{\lambda^5}\left(+\frac{B}{\lambda^2 T}\right)\right] e^{-B/\lambda T} = 0$$

$$\frac{5}{\lambda^6} = \frac{B}{\lambda^7 T} \quad \Rightarrow \lambda T = \frac{B}{5}$$

Wien's displacement law

$$\boxed{\lambda_{max} T = \text{Constant}}$$

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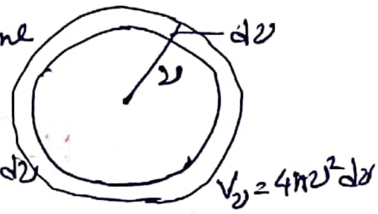
Rayleigh-Jeans law :-

$$\boxed{E_\lambda d\lambda = \frac{8\pi KT}{\lambda^4} d\lambda} \rightarrow \text{longer } \lambda$$

Assumptions :- (1) Standing waves in the cavity

(2) No. of oscillators (standing waves)/volume in range ν and $\nu + d\nu$ = $\frac{2 \times 4\pi\nu^2 d\nu}{c^3} = n_\nu d\nu$

Degrees of freedom

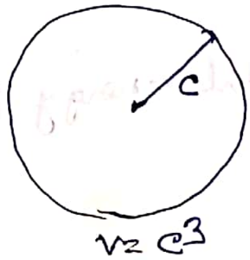


(3) Average energy of each oscillator

$$\bar{E} = 2 \times \underbrace{\frac{1}{2} KT}_{\text{Maxwell's law of equipartition energy}}$$

Degeneracy factor

$$\boxed{\begin{aligned} E &= \frac{3}{2} N_A KT \\ \frac{2}{3} E &= N_A KT \\ PV &= N_A KT \end{aligned}}$$



So $E_\nu d\nu = \bar{E}(n_\nu d\nu)$

$$= KT \frac{8\pi\nu^2 d\nu}{c^3} \qquad \nu = \frac{c}{\lambda}$$

$$d\nu = \left| -\frac{c}{\lambda^2} d\lambda \right|$$

$$E_\lambda d\lambda = KT \, 8\pi \frac{d\lambda}{\lambda^4}$$

$$\boxed{E_\lambda d\lambda = \frac{8\pi KT}{\lambda^4} d\lambda} \rightarrow \text{R-J}$$

Limitation $\rightarrow$ ultraviolet catastrophe

Stefan-Boltzmann's law :-

$$E_{total} = \int_\lambda E_\lambda d\lambda \propto T^4$$
$$= \sigma T^4$$

Planck's radiation formulae:

Additional assumption:- Energies are quantized / discrete

$0, \epsilon, 2\epsilon, 3\epsilon, \dots, r\epsilon, \dots$

Total no. of planck oscillator

$$N = N_0 + N_1 + N_2 + \dots + N_r + \dots \qquad N_r = N_0 e^{-E_r/KT} = N_0 e^{-r\epsilon/KT}$$

$$= N_0 + N_0 e^{-\epsilon/KT} + N_0 e^{-2\epsilon/KT} + \dots + N_0 e^{-r\epsilon/KT} + \dots$$

$$= N_0 \left[\frac{1}{1 - e^{-\epsilon/KT}} \right] \quad \text{as } x = e^{-\epsilon/KT} \ll 1$$

Total energy $E = E_0 + E_1 + E_2 + \dots + E_r + \dots$

$$= 0 + \epsilon N_1 + 2\epsilon N_2 + \dots + r\epsilon N_r + \dots$$

$$= N_0 \left[\epsilon e^{-\epsilon/KT} + 2\epsilon e^{-2\epsilon/KT} + \dots + r\epsilon e^{-r\epsilon/KT} + \dots \right]$$

$$= N_0 \epsilon e^{-\epsilon/KT} \left[1 + 2x + 3x^2 + \dots + r x^{r-1} + \dots \right]$$

$$\frac{d}{dx}\left(\frac{1}{1-x}\right) = \frac{d}{dx}\left(1 + x + x^2 + \dots + x^r + \dots\right)$$

$$\frac{1}{(1-x)^2} = \left(1 + 2x + 3x^2 + \dots + r x^{r-1} + \dots\right)$$

$$= \frac{N_0 \epsilon e^{-\epsilon/KT}}{(1 - e^{-\epsilon/KT})^2}$$

So average energy $\bar{\epsilon} = \frac{E}{N} = \frac{\epsilon e^{-\epsilon/KT}}{1 - e^{-\epsilon/KT}} = \frac{\epsilon}{e^{\epsilon/KT} - 1}$

Planck's also assume $\epsilon = h\nu \Rightarrow \bar{\epsilon} = \frac{h\nu}{e^{h\nu/KT} - 1}$

So $E_\nu d\nu = \left[\frac{8\pi\nu^2}{c^3} d\nu\right] \left[\frac{h\nu}{e^{h\nu/KT} - 1}\right] = (n_\nu d\nu)\bar{\epsilon}$

$$\boxed{E_\lambda d\lambda = \frac{8\pi hc}{\lambda^5} \frac{1}{e^{hc/\lambda KT} - 1} d\lambda}$$

Planck's law in limiting case

$$E_\lambda = \frac{8\pi hc}{\lambda^5} \frac{1}{e^{hc/\lambda KT} - 1}$$

When λ is small $\frac{hc}{\lambda KT} \to$ large $\Rightarrow \frac{1}{e^{hc/\lambda KT}-1} \approx e^{-hc/\lambda KT}$

So $E_\lambda = \frac{(8\pi ch)}{\lambda^5} e^{-hc/\lambda KT} \to \frac{A}{\lambda^5} e^{-B/\lambda T}$ $\boxed{\text{Wien's law}}$

When λ ~~$\to$~~ large, $\frac{hc}{\lambda KT} \to$ small

$$\Rightarrow \frac{1}{e^{hc/\lambda KT}-1} \approx \frac{1}{1 + \frac{hc}{\lambda KT} - 1} \approx \frac{\lambda KT}{hc}$$

So $E_\lambda = \frac{8\pi \cancel{hc}}{\lambda^5} \times \frac{\lambda KT}{\cancel{hc}} = \frac{8\pi KT}{\lambda^5}$ $\boxed{\text{Raley-Jeans law}}$

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1(xiii) No. of oscillation mode (Black body radiation)

$$n_\nu d\nu = \frac{2 \times 4\pi \nu^2 d\nu}{c^3} \Rightarrow n_\nu \propto \nu^2$$

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1(v) Emissive power of black body with T

(and Surroundings T_0) $E_{tot} = \int_\lambda E_\lambda d\lambda \propto \cancel{(T - T_0)^4}$?

$\propto T^4 - T_0^4$

$\propto (T^2 + T_0^2)(T_0^2 - T_0^2)$ if $T_0 \cancel{\to} 0$