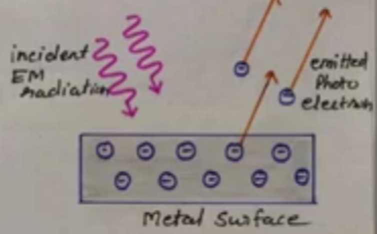
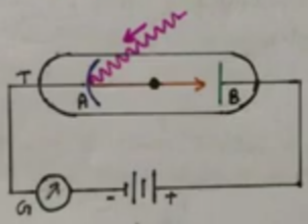
Photo-electric Effect

"When electromagnetic light are made to fall on any metal surface, free electrons from the metal surface begin to emit out from it. This pheno-menon is called the photoelectric effect and the electrons so emitted are called the photo-electrons."

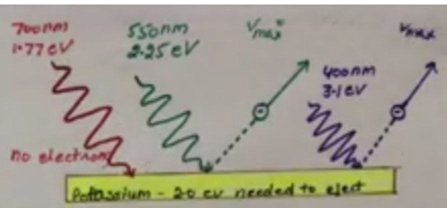


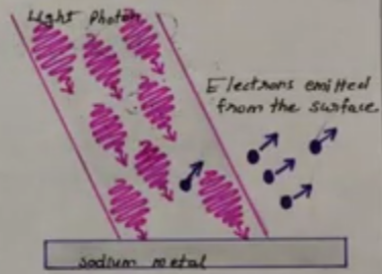


T – Evacuated glass tube
A – metal disc (zinc)
B – metallic grid detector
G – Galvanometer
incident light – UV / X-ray
current – Photoelectric

Experimental facts →

1. The photoelectric emission occurs only when the frq^{h} "ν" of the light incident on the metal surface is greather than a definite minimum value "ν_0". (ν_0 is called the thresh-old frq^{h} (देहली आवृत्ति) of the surface of metal.)





2. The maximum K.E. of the electron emitted, depends on the frequency of incident light. It does not depend on the intensity of incident light.
3. The number of electrons emitted, depends on the intensity of incident light it does not depend on its frq^{h}.
4. Electrons are emitted from the metal surface as the light falls on it without any time lag.

Reasons → Why Maxwell's E.M. wave theory Could not explain experimental facts

According to wave theory

1. If intensity increases → amplitude increases → energy increases → energy of free electron (Photoelectron) ↑

but it is against.

2. If intensity of incident light → Provide sufficient energy to bring out electrons of the metal

→ not depends on frequency but $\nu > \nu_0$ min freq^n

3. Energy of light wave distributed all surface

$\downarrow$

it will take time to emit electrons.

but there is no time leg betn emission of electron & light falling on the metal surface.

According to Einstein

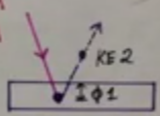
Light travels in form of small bundles or packets of energy with the speed of light. This bundle of light is called the photon.

Energy of each photon — $h\nu$ or hc/λ

Momentum — " — $\frac{h\nu}{c}$ or h/λ

frequency of light radiation — ν

wavelength — " — λ



Work function or threshold energy of a metal is the minimum energy which is required to bring a free electron from interior of the metal to its surface. "ϕ"

① Part → Now if ν_0 — threshold freq^n

λ_0 — " — wavelength

∴ work func^n $\boxed{\phi = h\nu_0 = hc/\lambda_0}$ — ①

② Part → remaining part of energy is used up in providing K.E. to the free electron to emit it out. If "m" — mass of electron & v — velocity

$$\boxed{E_k = \frac{1}{2}mv^2} \text{ — ②}$$

From law of conservation of energy

The energy imparted by the photon = max K.E of the emitted electron + workfuc^n of the metal

$$\boxed{h\nu = E_k + \phi} \quad \text{--- (3)}$$

Thus max. K.E. of the electron emitted $\rightarrow E_k = h\nu - \phi$

if $h\nu = \phi$ then $E_k = 0$ — In this cond^n frq^n of incident light is called threshold frq^n

means $\nu = \nu_0$ then $E_k = 0$

so from eq^n (3) $0 = h\nu_0 - \phi$

or $\boxed{\phi = h\nu_0}$ — (4)

Using eq^n (4) & (3)

$$\boxed{E_k = h\nu - h\nu_0 = \frac{hc}{\lambda} - \frac{hc}{\lambda_0}} \quad \text{--- (5)}$$

This eq^n is called the Einstein's Photo electric eq^n.

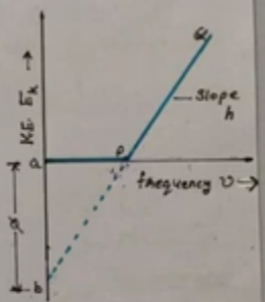
Explanation of exp. facts from the photoelectric equation

1. Frequency of incident light 'ν' increased max. KE of Electron increases ($\because$ work fun^n ϕ of a metal surface is cons.). E_k does not depend on the intensity of light

2. on decreasing ν, E_K of Photoelectron emitted decrease. and when $\nu \longrightarrow \nu_0$, then "$v$" velocity of Photoelectron $= 0$
$\therefore$ KE $= 0$, This freq^n ν_0 is called threshold freq^n

here if $\nu < \nu_0$ then $E_K = (-)$ve, but K.E can never negative hence emission of Photoelectron will not be Possible.

3. number of photoelectron (Photoelectric current) depend on the number of Photons striking the metal surface, means intensity of light.

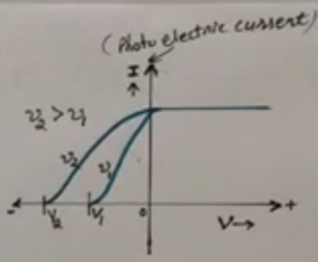


from graph we conclude that.

1. The slope of the straight line gives the value of 'h'.
2. length of intercept of straight line $ab = \phi$
3. On Changing the I (intensity), the graph is unaffected.
4. at Point 'P' freq^n shows threshold freq^n of metal surface.
5. For different metals, different parallel straight lines are obtained. (slope of each line h remains cons. and line for low ϕ will be towards left.)

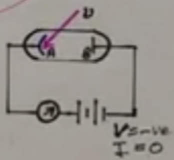
Experimental verification of Photoelectric eqn →

The negative potential of the anode of a photoelectric tube for which Photoelectric current stops or becomes zero is called stoping potential.



K.E of Photoelectron emitted is

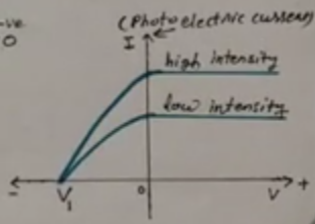
$$\frac{1}{2} m v^2 = eV = h\nu - h\nu_0$$



Experimentally, it is found that

1. $\nu \uparrow \rightarrow V \uparrow \rightarrow K.E \uparrow$
   but I (Photoelectric current) = cons

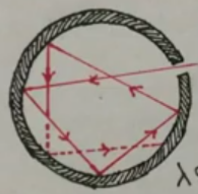
2. intensity of incident light $\uparrow \rightarrow$ no effect on V
   but Value of max Photo elctric current increases.



Black Body Radiation कृष्णिका पिण्ड विकिरण

A black body → "A body which absorbs completely the entire radiations incident on its surface whatever may be their wavelength and reflects none of the light incident on it."

Ideal black body →



A spherical isothermal cavity blackened inside & completely closed except a narrow aperture

$\lambda \rightarrow E_\lambda$ & u_λ

λ & $\lambda + d\lambda \rightarrow E_\lambda d\lambda$ & $u_\lambda d\lambda$

When radiant energy emitted out per second / unit area of the body then it is called emissivity (उत्सर्जकता) of the body. "E_λ"

The radiant energy contained per unit volume of the body is called its energy density ऊर्जा घनत्व : "u_λ".

1. At each temp. $\rightarrow$ $\lambda = 0 \rightarrow E_\lambda = 0$

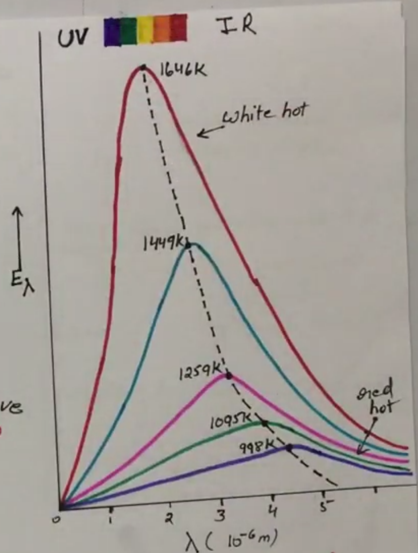
$\lambda \uparrow \rightarrow E_\lambda \uparrow$

$\lambda_m \rightarrow E_\lambda$ (max)

$\lambda \uparrow$ beyond $\lambda_m \longrightarrow E_\lambda \downarrow$

$\lambda \rightarrow \infty \rightarrow E_\lambda = 0$

$E_\lambda - \lambda$ curve is continuous at each temp. & radient energy cont. distributed in all λ ie $0 \rightarrow \infty$



2. At each temp., the area enclosed by the curve with λ- axis represents "total energy" emitted by black body.

Total energy emitted $\propto T^4$

3. $E_\lambda \propto T^5$

4. temp of the body $\uparrow \rightarrow \lambda_m \downarrow$ (Peak shifted towards shorter wavelength).

5. $\lambda_m \propto \frac{1}{T}$ or $\lambda_m T = b$ (cons)

$\therefore b = 2.88 \times 10^{-3}$ metre $\times$ kelvin $\longrightarrow$ Wein's cons.

Explanation of black body radiation curve

1. Stefan's law → $\boxed{E \propto T^4 \text{ or } E = \sigma T^4}$

   ($\sigma = 5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$)
   Stefan's cons.

   ($\because$ E – emissivity total)
   (T – absolute temp.)

2. Wien's law → (a) $\boxed{\lambda \propto \frac{1}{T}}$ or $\lambda T =$ cons.

   (b) $\boxed{E_\lambda \propto T^5}$

This law could explain ↓
Shorter wavelength range ($0 - \lambda_m$) of the curve at any temp.

in this range $e^{-c_2/\lambda T}$ is more effective compared to $1/\lambda^5$.

$\therefore$ (Value of E_λ ↑ with λ ↑)

emissivity of radiation emitted in range λ & $\lambda + d\lambda$

$$\boxed{E_\lambda d\lambda = \frac{A}{\lambda^5} f(\lambda T) d\lambda}$$

(here $f(\lambda T)$ – unknown, A – cons.)

according to Wein → $f(\lambda T)$ = exponential

$$\boxed{E_\lambda d\lambda = \frac{c_1}{\lambda^5} e^{-c_2/\lambda T} d\lambda}$$

3. Rayleigh- Jean's law →

Energy density $u_\lambda d\lambda$ (range λ & $\lambda+d\lambda$) = no. of modes of vibrations in Unit Volume (range λ & $\lambda+d\lambda$)

X

mean energy per mode of vibrations.

according to Rayleigh Jean's law

$$u_\lambda d\lambda = \left(\frac{8\pi}{\lambda^4} d\lambda\right) \times kT$$

(mean energy per mode vibration at T is kT)

or

$$\boxed{u_\lambda d\lambda = \frac{8\pi kT}{\lambda^4} d\lambda}$$

This law could explain only heigher wavelength [$\lambda\uparrow \rightarrow E_\lambda\downarrow$]

4 Planck's law

$E \propto \nu$ or $E = h\nu$ & $p = \frac{h\nu}{c}$ *

average energy corresponding to each mode of vibration

$$\bar{\varepsilon} = \frac{h\nu}{e^{h\nu/kT}-1} = \frac{hc/\lambda}{e^{h\nu/\lambda kT}-1}$$

according to Planck's $u_\lambda d\lambda = \frac{8\pi hc\, d\lambda}{\lambda^5 (e^{hc/\lambda kT}-1)}$ & $u_\nu d\nu = \frac{8\pi h\nu^3 d\nu}{c^3 (e^{h\nu/kT}-1)}$

WAVE PARTICLE DUALITY

Particle
- Mass
- Velocity
- Momentum
- Energy

Wave
- Frequency
- Wavelength
- Wave velocity (Phase
- Amplitude
- Intensity

Radiation (light)

Wave

[Visible / IR / UV / X-ray]
(λ / freq^n)

↓ shows

[Interference / Diffraction
Polarization]

↓ when

[Two waves at the same
Position at the same time]

↓ conclusion

[The radiations behaves
like wave]

Particle

[Photon (quanta)]
($E = h\nu$, $P = h\nu/c$)

↓ shows

[Black body Radiation
Photo Electric Effect
Compton Effect]

↓ when

[The radient energy
in its interaction
with matter in the
form of Photon]

↓ conclusion

[The radiations
behaves like Particle]

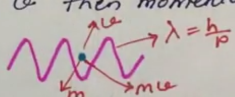
Wave Particle Duality
तरंग कण द्वैतता

On the basis of dual nature of light in 1924 Louis de-Broglie suggested that the dual nature is not only of light, but "each moving material particle has the dual nature"
(गतिशील द्रव्य कण)

He assumed "a wave to be associated with each moving material Particle which is called the matter wave, and wavelength of this matter wave is given as $\lambda = \frac{h}{p}$."

Now if mass of the particle is 'm' & velocity is v then momentum

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



- mass is greater → wavelength is small → not show Int. / Diff.
- mass is smaller → —"— is big → show Int. / Diff

Value of λ not depend on charged or uncharged (neutral) particle.

Wave & Particle nature is complementary of each other examples

(1) $m = 10\ gm$, $v = 100\ m/s$ (bullet)

$$\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}\ Js}{(10 \times 10^{-3}\ kg)\ (100\ m/s)} = 6.6 \times 10^{-34}\ m$$

here λ is very small (Particle nature) (not shows Interference Diffraction)

(2) $m = 9.1 \times 10^{-3}\ kg$, $v = 10^{6}\ m/s$ (Particle is very small – electron)

$$\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}\ Js}{(9.1 \times 10^{-31}\ kg)\ (10^{6}\ m/s)} = 7.2 \times 10^{-10}\ m$$

here wavelength is the order of X-ray's wavelength (wave nature) (shows Interference & Diffraction)

—x—