QUANTUM PHYSICS

Photon :-

→ Can be counted/integral multiple

Def. Discrete packet or quantum of energy of electromagnetic radiations identified by $E = hf$ is photon.

Energy of a photon :-

$$E \propto f$$

$$E = hf$$

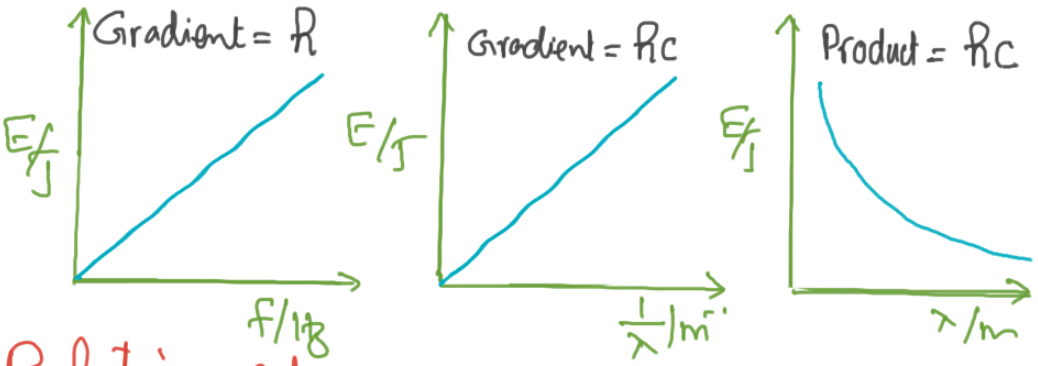
where 'h' is the constant of proportionality and is called Planck's constant. Its value in S.I. is 6.63×10^{-34} Js.

Also, speed of e.m. waves,

$$c = f\lambda \Rightarrow f = \frac{c}{\lambda}$$

Therefore, $E = \frac{hc}{\lambda} \Rightarrow E = \frac{\text{Constant}}{\lambda}$

$$E \propto \frac{1}{\lambda}$$



Relative order: E/J or f/s⁻¹

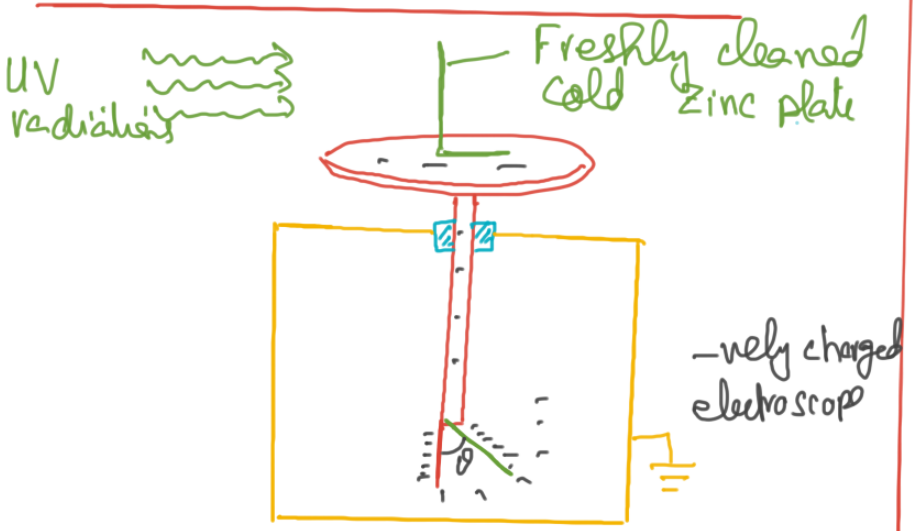
Gamma rays	X-Rays	ultra violet	Visible light	Infra-Red	Micro wave	Radio waves

λ/m →

PHOTO-ELECTRIC EFFECT:-

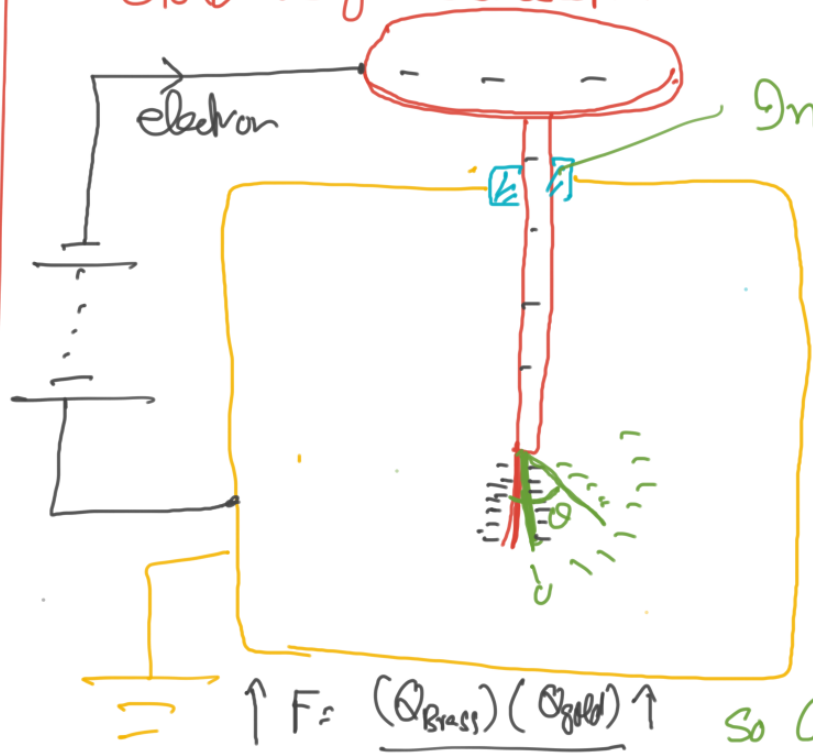
Statement: The emission of electrons from the surface of cold metal when electromagnetic radiations of sufficient frequency are incident on it.

Exp: To study electrons are emitted in photo-emission:-



Rough column

How -ve charge is provided to Gold leaf electroscope.



$\uparrow F = \frac{(Q_{Brass})(Q_{Gold})}{r^2} \uparrow$

So Gold Leaf is repelled and move to a greater angle because of Coulomb's force.

observational analysis :-

S.No.	Exposure of UV radiation	Change in deflecting Angle	Photo-emission
1	OFF	Constant 24°	No
2	ON	decreases to 18°	Yes
3	OFF	Remain Constant at 18°	No
4	ON	Further decreases to 7°	Yes

Deflecting angle decreases only when Zinc plate is exposed to Ultra-violet photons.

Reason: Photons remove electrons from Zinc plate leaving behind +ve charge on it. These +ve charges are neutralised by -ve charges of Brass strip and Gold leaf which therefore decreases the strength of similar (-ve) charges on them. Hence Coulomb's repulsive force decreases and so is the deflecting angle

Note: No significant change of deflecting angle is observed if same experiment is repeated with a +vly charged electroscope.

Result: Only electrons are emitted in photoelectric effect and are known as photoelectrons.

CHARACTERISTICS OF PHOTO-ELECTRIC EFFECT :-

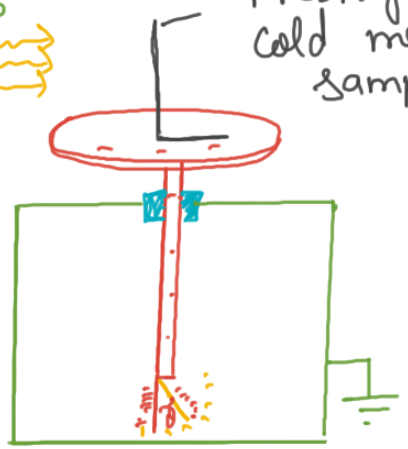
(1) Photo-emission depends upon threshold frequency :-

Def. The minimum frequency of incident photons required to release electrons from the surface of metal.

Symbol :- f_0

Experiment:

e.m. radiations



Observational Analysis

S.No.	Metallic sample	e.m. radiations	Deflecting angle	Photo-emission
1	Zinc	Radio wave, Microwave, Visible light	No change	No Photo-emission
2	Zinc	UV	decrease	occur
3	Zinc	x-rays	"	"
4	Zinc	γ-rays	"	"
5	Caesium	Radio wave, Micro wave	No change	No photoemission
6.	Caesium	Visible	decrease	occur
7.	Caesium	UV, x-rays, γ-rays	decrease	occur

Result: Threshold frequency of Zinc is greater than threshold frequency of Caesium ie $(f_0)_{Zn} > (f_0)_{Cs}$

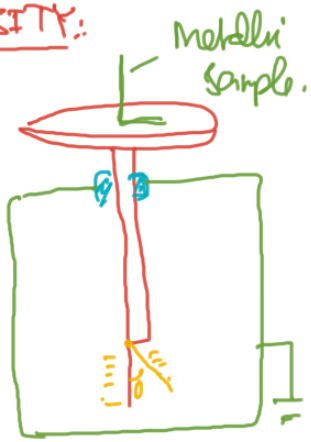
Dependance: Threshold frequency depends upon nature of material because more energy is required to remove electrons from an atom if it is strongly bound to it.

(2) PHOTOEMISSION IS AN INSTANTANEOUS PROCESS:-

Electrons emit instantaneously if a metal is exposed to incident photons having frequency greater than threshold level of metal. i.e. there is no time delay between incidenting photons and emission of photo-electrons. This also defines the particle nature of e.m. radiations.

(3) PHOTO-EMISSION DEPENDS UPON THRESHOLD FREQUENCY AND IS INDEPENDENT OF INTENSITY:

S.No	Metal	Frequency	Power of source	Deflecting angle
1	Zinc	Radio wave, microwave, visible	Increase	No change
2	Zinc	UV	Constant	Decrease
3	Zinc	UV	Increases	Greater Decrease
4	Zinc	X-rays	Constant	Decrease
5	Zinc	X-rays	Increase	Greater Decrease



The increase in Power rating of source signify that no. of photons emitted from

that source is increased without changing the frequency of single photon.

Result: No photo-emission occur if the frequency of source/em radiation is less than the threshold frequency of metal, what so ever the intensity (no. of photons incident per unit time per unit perpendicular area) of source is.

(4) **Einstein's equation of photo-electric effect**:

By principle of conservation of energy.

Energy of a Photon = Minimum energy required to remove electrons from a metal surface + Kinetic energy of photo-electrons

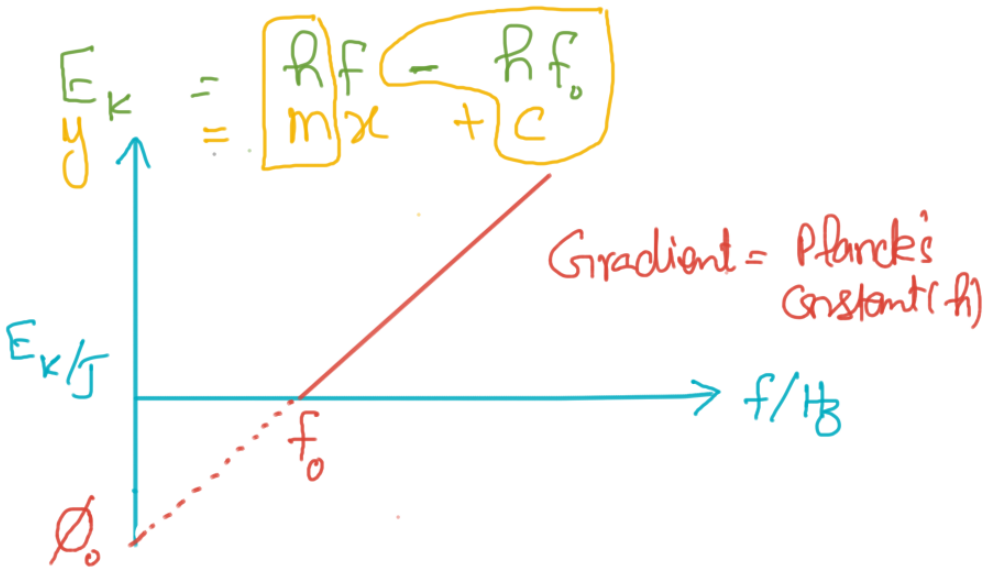
$$E = \text{Work function} + E_K$$

$$E = \phi_0 + E_K$$

$$hf = hf_0 + E_K$$

$$E_K = hf - hf_0$$

$$y = mx + c$$



Gradient = Planck's Constant
= $h = 6.63 \times 10^{-34}$ Js

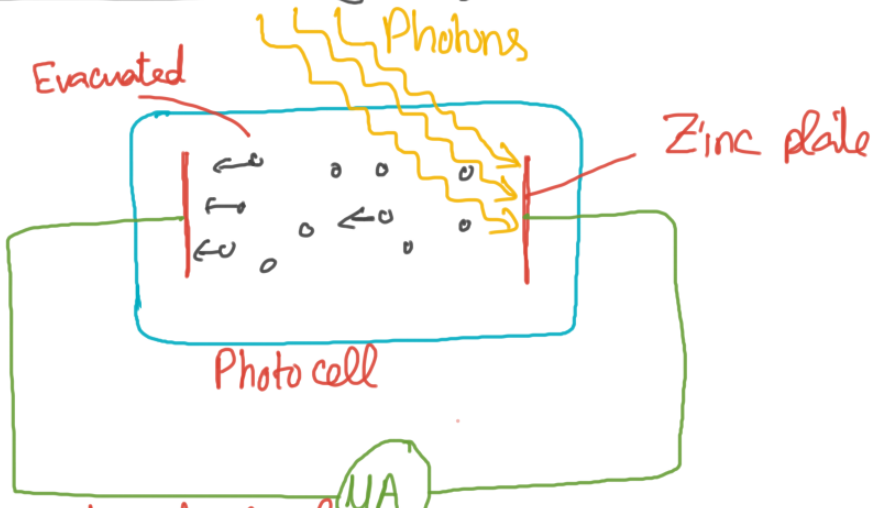
X-intercept = Threshold frequency (f_o)

Y-intercept = Work function (ϕ_o)

Kinetic energy of photons is independent upon intensity and dependent upon frequency.

(5) Photo-electric current depends upon intensity of photons:-

Exp.



Observational Analysis

S.No	Photons	Power rating of Source	I/UA	Reason
1	UV	Constant	detect	Kinetic energy of Photo electrons
2	UV	↑	↑	(no. of photons) ↑
3	UV	↑↑	↑↑	(no. of photons) ↑↑
4	X-Rays	Constant	detect	E_K of photoelectrons
5	X-Rays	↑	↑	(E_K and n) ↑

$$\text{Intensity} = \frac{\text{Total energy}}{\text{time} \times \text{Perp. Area}}$$

$$\text{Intensity} = \frac{(\text{no. of photons})(\text{Energy of a photon})}{(\text{time})(\text{Area})}$$

$$I = \frac{nE}{tA}$$

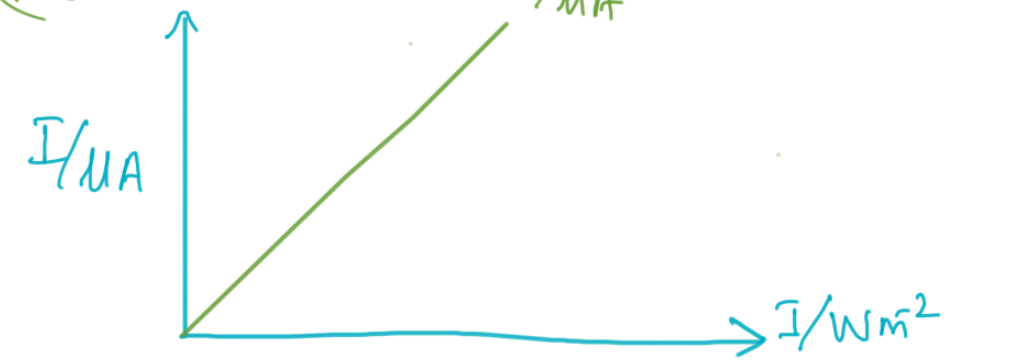
(Intensity) ↑ if

(i) n ↑ ie (no. of photons) ↑ by increasing the power rating of source.

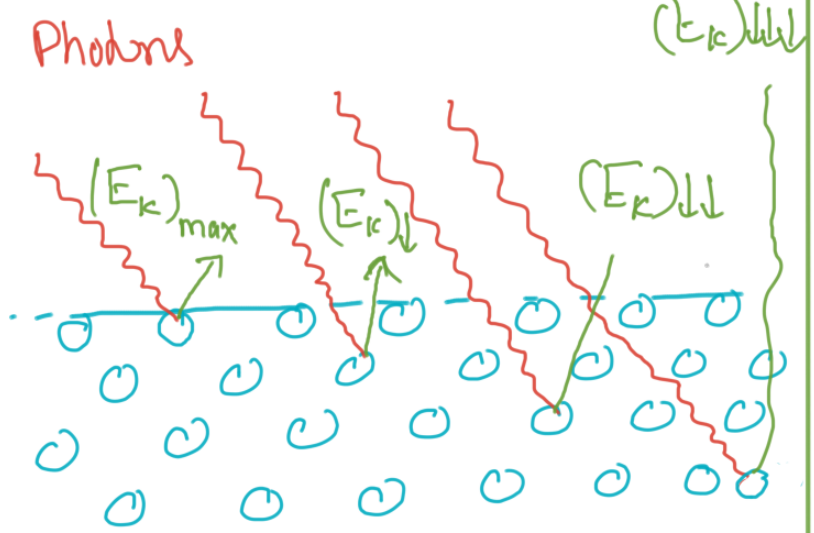
(ii) E ↑ ie energy of a photon is increased by increasing its frequency ($E = hf$) e.g replace the e.m wave source with one having greater frequency

Result: Photoelectric current increases directly by increasing the intensity of source.

(Photoelectric current)/μA ∝ (Intensity/Wm⁻²)



(6) Experiment to determine maximum Kinetic energy of Photoelectrons:-



Electrons emitted from a metal have a range of Kinetic energy. Maximum Kinetic energy corresponds to electrons which are emitted from the surface. other electrons have lesser energy depending upon the depth from where they are emitted out.

To determine maximum Kinetic energy of photoelectrons, apply a reverse potential across the photocell and detect the variation in photoelectric current.