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Dual Nature of Radiation & Matter

* **Electron Emission :-**

The process of ejection of electron from metal surface by applying external energy is called electron emission.

Types of Emission :-
(on the basis of energy source).

(1) **Thermionic emission** — The process of electron ejection from metal surface by heating is called thermionic ejection.

↳ The emitted electron are called thermions or thermal electron.

(2) **Photoelectric emission** — The process of ejection of e- from the metal surface by falling light on it.

↳ Emitted electrons are called photoelectron.

(3) **Field emission** — The process of ejection of e- from the metal surface by applying electric field.

(4) **Secondary emission** — The ejection of electrons from a solid that is bombarded by a beam of charged particles.

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↳ The bombarding electrons are called primary, and emitted electrons are secondary electrons.

Work Function :-

Minimum energy required by an electron to escape from metal surface.

↳ It is denoted by ϕ_0.
↳ Its unit is ev.
↳ $1ev = 1.6 \times 10^{-19} J$.

Note:- It depends upon the nature of metal. It varies from one metal to another.

for example : Na = 2.75 ev
Pt = 5.65 ev

* Photoelectric effect :-

Photoelectric effect — The phenomenon of converting light energy into electric energy is called photoelectric effect.

↳ The current produced by photoeffect is called photocurrent.

* Hertz's observations :-

Hertz's observations are key to understanding the photoelectric effect. Heinrich Hertz, a

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physicist, conducted experiments in the late 19th century that revealed how ultraviolet light could cause electrons to be emitted from a metal surface.

Hertz observed that when ultraviolet light struck a metal electrode, it emitted electrons, but this only happened if the light's frequency was above a certain threshold. He found that:

(i) The number of emitted electrons increased with the intensity of the light.

(ii) The energy of the emitted electrons depended on the frequency of the light, not its intensity.

These observations were crucial in showing that light must have enough energy to free electrons from the metal surface, leading to the development of the concept of photons.

Hertz's work laid the foundation for the quantum theory of light and helped in understanding the dual nature of radiation.

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* Hallwachs' and Lenard's observations :-

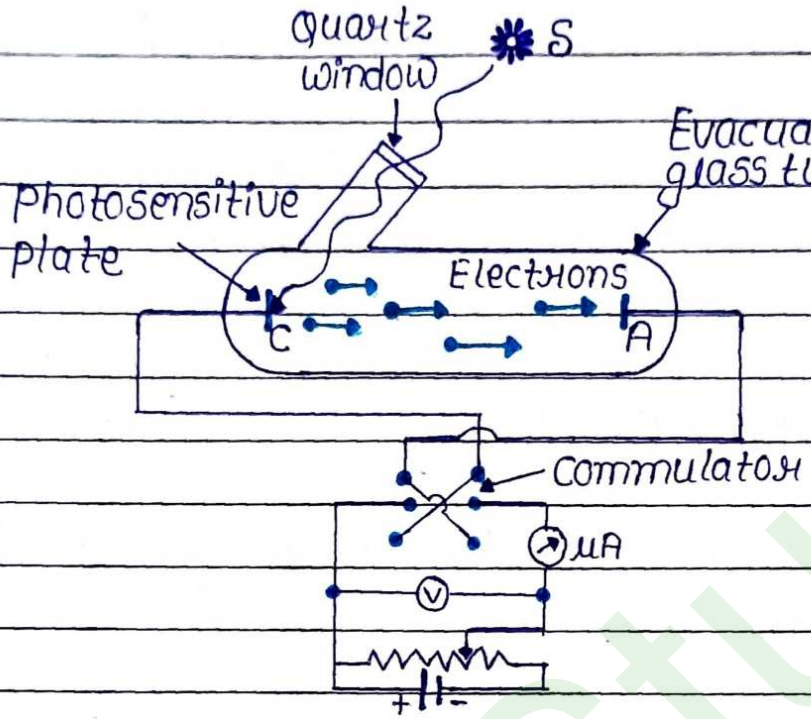
Hallwachs' Observation :

In the late 19th century. Wilhelm Hallwachs dicovered that when ultraviolet light (or any light of sufficient frequency) is directed at a metal surface, it causes the metal to emit electrons. This was the first evidence that light can cause electrons to be ejected from a metal.

Lenard's Observation :

Following Hallwachs, philipp Lenard conducted experiments that confirmed Hallwachs' findings. Lenard observed that the emitted electrons (photoelectrons) had a range of energies and their number increased with the intensity of the incident light. He also found that the kinetic energy of these electrons depended on the frequency of the light, not its intensity.

* Experimental study of photoelectric effect :-



1) Setup :- A metal plate is exposed to light in a vacuum. The plate is connected to an electric circuit that measures the current of ejected electrons.

2) Observation :- When light with a certain frequency hits the metal, electrons are emitted. The amount of current depends on the intensity of the light, while the frequency of light determines whether electrons are ejected at all.

This experiment supports the idea that light behaves as particles, providing evidence for the dual nature of radiation and matter.

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Law of Photoelectric emission :-

1) The photoelectric current is directly proportion to intensity of incident light.

2) Saturation current is found to be proportional to intensity of its incident radiation.

3) The stopping potential is independent of intensities.

4) The value of saturation current is independent of frequency.

5) The stopping potential increases in negative for higher frequency.

6) Stopping potential of photoelectrons increases linearly with frequency after minimum out of frequency.

7) There exist a certain minimum frequency of incident radiation below which no emission take place. This frequency is called threshold frequency.

8) It is a spontaneous process. i.e., there is no time lag.

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Einstein Photoelectric Equation :-

When a photon of energy $h\nu$ fall on a metal surface, the energy of the photon is absorbed by the electrons is used in following two ways —

(i) A part of energy is used to overcome the surface barrier and e^- come out of the metal surface. This part of energy is called work function (ϕ_0).
It is expressed as $\boxed{\phi_0 = h\nu_0}$.

(ii) The remaining part of energy is used in giving a velocity to the photoelectron. This is equal to the maximum kinetic energy.

$$h\nu = \phi_0 + \frac{1}{2}mv^2$$
$$h\nu = h\nu_0 + \frac{1}{2}mv^2$$
$$h\nu - h\nu_0 = \frac{1}{2}mv^2$$
$$h(\nu - \nu_0) = \frac{1}{2}mv^2$$

$$\because K.E_{max} = h(\nu - \nu_0)$$

↳ This equation is called Einstein's photoelectric equation.

Case 1. If $\nu < \nu_0$
In this case no emission will take place.

Case II. If : $\upsilon = \upsilon_0$

In this case emission will take place but the ejected electron will have no kinetic energy.

Case III. If $\upsilon > \upsilon_0$

In this case ejection will take place and ejected e⁻ will have kinetic energy.

* Important Graphs related to photoelectric effect and its experiment :-

Effect of intensity of light on photocurrent :

Higher Intensity :-

If the light's intensity is increased, more photons hit the metal surface. This causes more electrons to be ejected, which increases the photocurrent.

Lower Intensity :-

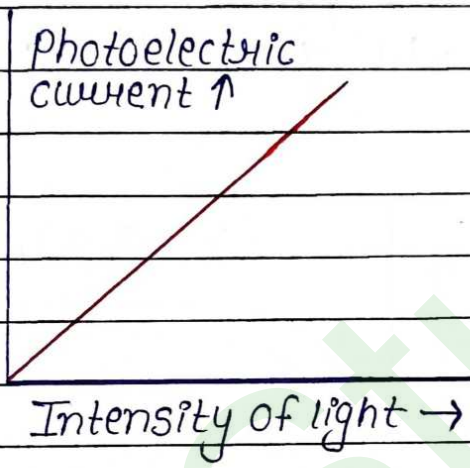
If the light's intensity is decreased, fewer photons hit the metal. This means fewer electrons are ejected, so the photocurrent is lower.

Formula :-

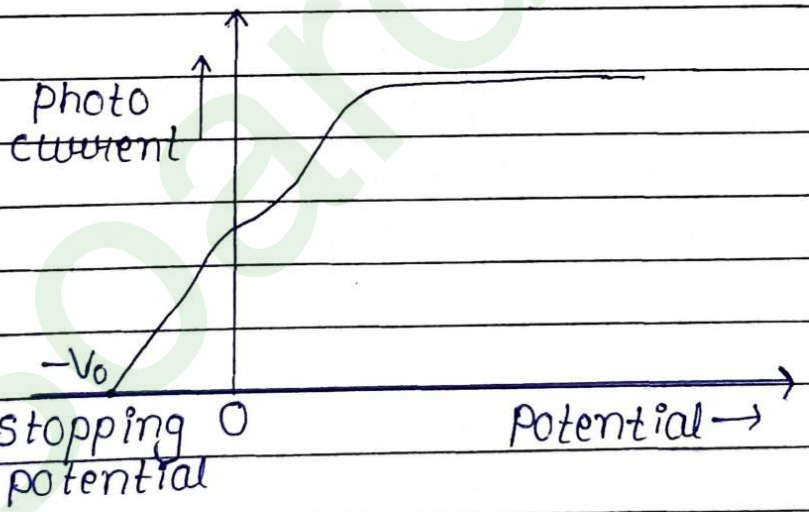
The photocurrent (I) is directly proportional to the light intensity (I_0):

$I \propto I_0$

In short, more intense light produces a higher photocurrent because it ejects more electrons from the metal surface.



Effect of potential of plate 'A' with respect to plate C :-



As shown in graph, if we make the collector plate more positive it will attract more number of electrons. Therefore the photo current will increase, but it will increase up to a certain point called saturation

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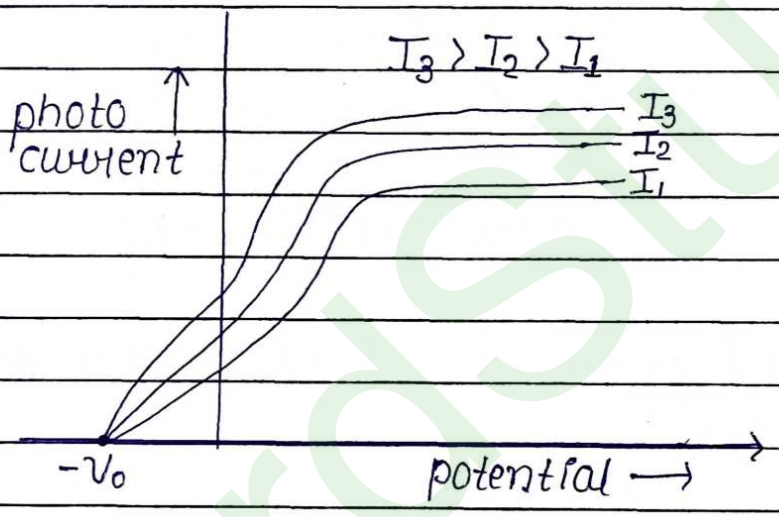
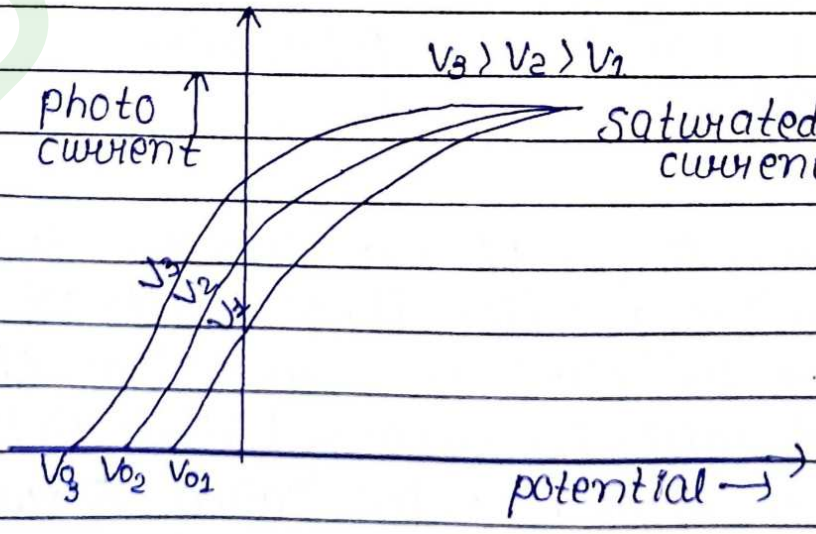
point. After that photocurrent will become stable and saturate.

If we reverse the battery i.e. Now the plate 'A' is at -ve potential. Therefore at certain potential the photocurrent will become zero and -ve potential called stopping potential.



This is the graph between current and potential when frequency of incident radiations are same but intensities are different.



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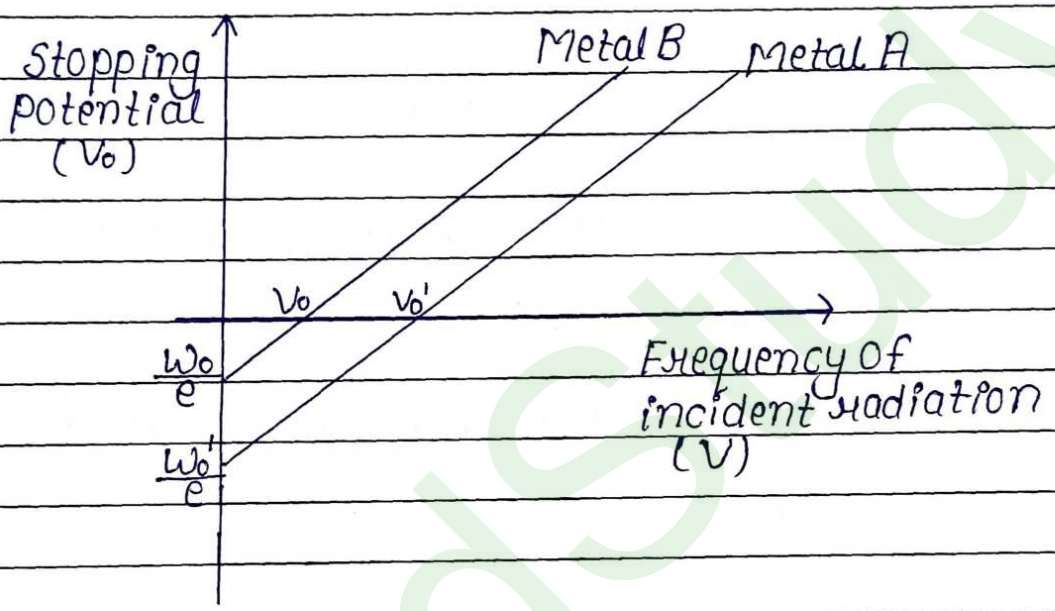
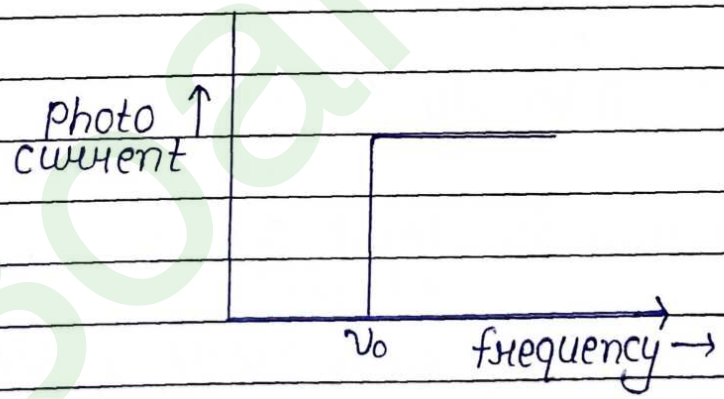
This graph between current and potential, when intensity is same but frequency of incident radiations are different.

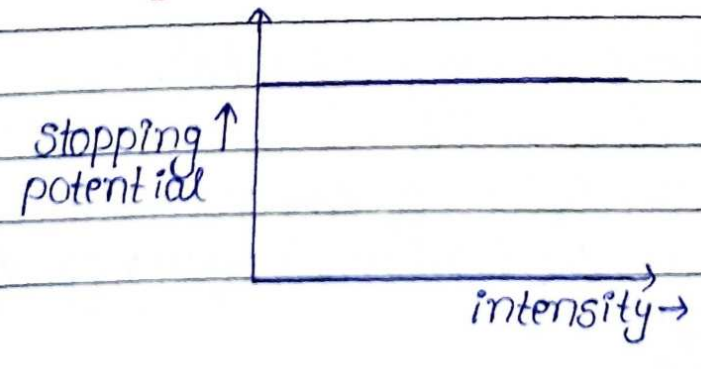
Stopping potential and frequency graph –



Current and frequency graph :–



Stopping Potential and Intensity graph –



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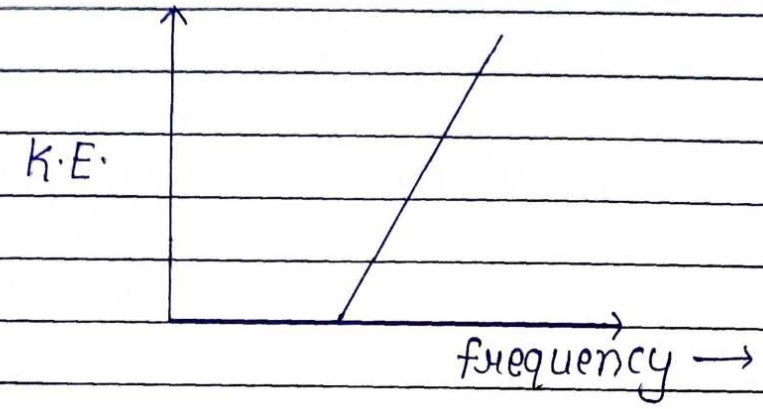
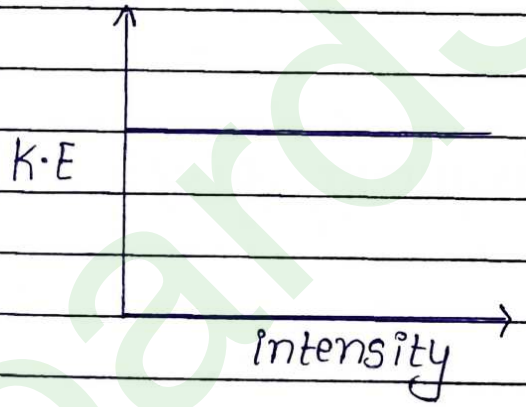
Kinetic Energy and frequency graph –



Note:- You can trace this graph to get the work function of metal.

Kinetic Energy and Intensity graph –



* Particle Nature of light :-

1) In interaction of radiation with matter radiation behave as if it is made of particle like photon.

2) Each photon have energy, $\varepsilon = h\nu$.

3) Irrespective of intensity of radiation, all the photons of particular frequency have same energy.

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4) By increasing the intensity of radiation of given frequency there is only increase in number of photon but their energy will remain same.

5) All the photons travel with the speed of light in space.

6) The velocity of photon in different medium is different.

7) The rest mass of photon is zero and its moving mass can be given as -

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

8) Photons are not deflected by eletric and magnetic field i.e. why photons are electrically neutral.

↳ **Failure of wave theory of light to explain photoelectric effect:-**

1) According to wave theory of light, the energy carried by light is measured in terms of intensity but actually it is measured in terms of frequency.

2) According to this theory, the photoelectric emission is possible from the metal surface on all the frequencies but this was wrong because their exist a minimum frequency called threshold frequency below which no emission will take place.

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* Wave Nature of Matter :-

De Broglie Hypothesis —

According to this, a moving material particle sometime acts as a wave and sometime as a particle.
A wave associated with moving particle which controls the particles in every aspect. This wave is know as de broglie wave or matter wave.

According to Einstein —

$$E = mc^2 \quad —①$$

According to plank's —

$$E = h\nu \quad — ②$$

from ① and ② —

$$h\nu = mc^2$$

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

$$\lambda = \frac{h}{mc}$$

$\because \lambda = \frac{c}{\nu}$

$\nu = \frac{c}{\lambda}$

For a ~~moving~~ body moving with velocity v.

$$\lambda = \frac{h}{mv} \quad \text{or} \quad \lambda = \frac{h}{p}$$

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Physical quantity	Symbol	Dimensions	Unit	Remarks
Planck's constant	h	$[ML^2T^{-1}]$	Js	$E = hv$
Stopping potential	V_0	$[ML^2T^{-3}A^{-1}]$	V	$eV_0 = K_{max}$
Work function	ϕ_0	$[ML^2T^{-2}]$	J; eV	$K_{max} = E - \phi_0$
Threshold frequency	v_0	$[T^{-1}]$	Hz	$v_0 = \phi_0 / h$
de Broglie wavelength	λ	$[L]$	m	$\lambda = h/p$