DUAL NATURE OF RADIATION AND MATTER

(CHAPTER-11)

ELECTRON EMISSION :-

- The process of emission of electron from a metal surface is called electron emission.

* In metal large number of free electrons are present which can move everywhere in a metal. But these electron cannot leave the surface of the metal.

WORK FUNCTION (ϕ_0):-

The minimum energy required by an electron to escape from the metal surface is called work function of the metal.

- It is measured in eV.

$$1\,eV = 1.602 \times 10^{-19}\,J$$

- It depends on the properties of the metal and nature of its surface.

The mininum energy required for the electron emission from the metal surface can be supplied to the free electrons by any one of the following physical processes:-

(1) THERMIONIC EMISSION:-

- The process of emission of an electron when a metal is heated is known as thermionic emission.
- The free electrons in the metal absorb the heat energy and can overcome the surface barrier. As a result, the free electrons are emitted from the metal surface.
- The electrons emitted are known as Thermions because they are emitted due to thermal energy.

(2) FIELD EMISSION:-

- The process of emission of free electrons when a strong electric field of the order $10^8\,V/m$ is applied across the metal surface is known as field emission.
- It is also known as cold cathode emission.

(3) PHOTO-ELECTRIC EMISSION :-

- The process of emission of electrons when light of suitable frequency is incident on a metal surface is known as photo electric emission.
- When light of suitable frequency illuminates a metal surface, electrons are emitted from the metal surface.
- The electrons emitted are known as photoelectrons.

PHOTOELECTRIC EFFECT :-

- The emissions of electrons from the surface of the metals due to the incidence of light of suitable frequency is called photoelectric effect.
- The ejected electrons are called as photoelectrons and the current constituted is called photocurrent.

(1) HERTZ'S OBSERVATION :-

Hertz observed that when ultraviolet rays are incident on negative plate of electric discharge tube then conduction takes place easily in the tube.

(2) HALLWACHS' AND LENARD'S OBSERVATIONS :-

Hallwach observation :-

Hallwach observed that if negatively charged Zn plate is illuminated by U.V light, its negative charge decreases and it becomes neutral and after some time it gains positive charge. It means, in the effect of light, some negative charged particles are emitted from the metal.

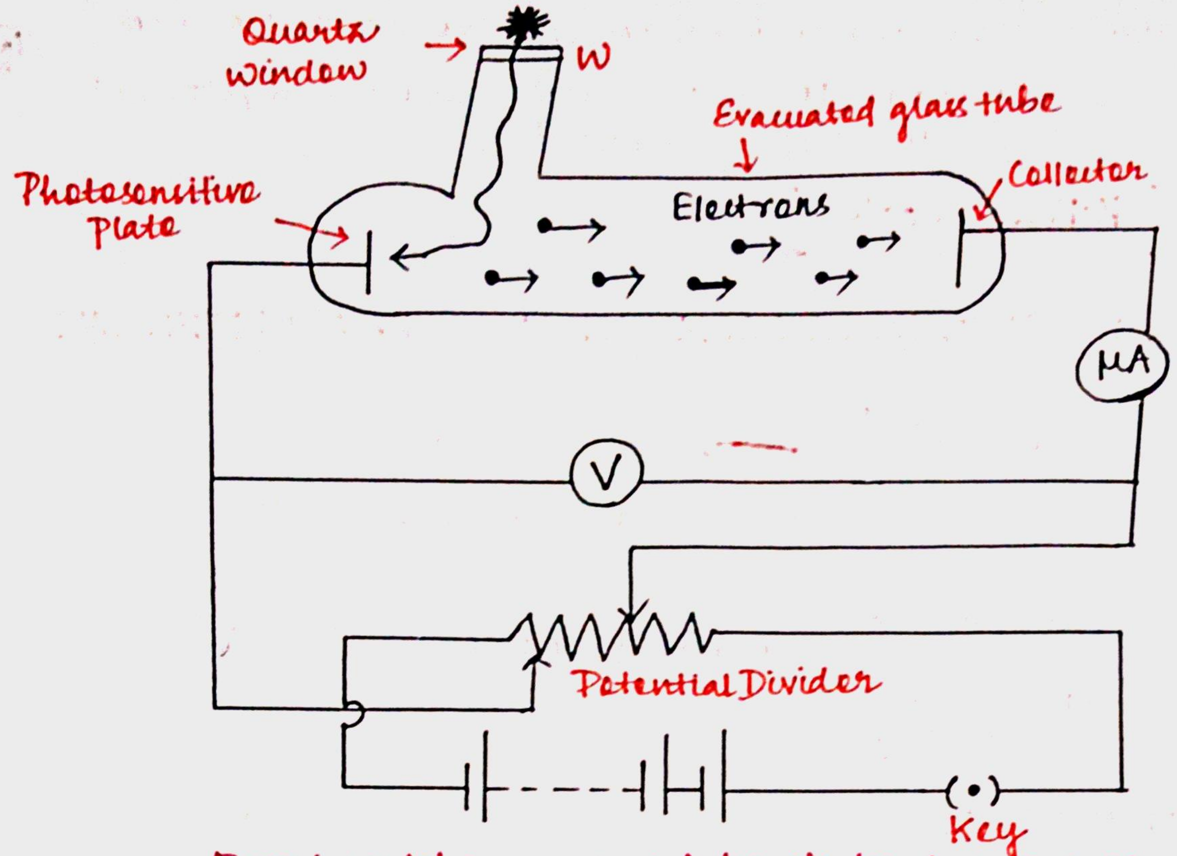
Lenard observation :-

He told that when U.V rays are incident on cathode, electrons are ejected. These electrons are attracted by anode and circuit is completed due to flow of electrons and ~~current~~ (current) flows. When U.V rays are incident on anode, electrons are ejected but current does not flow.

For the photoelectric effect the light of short wavelength (or high frequency) is more effective than the light of long wavelength (low frequency).

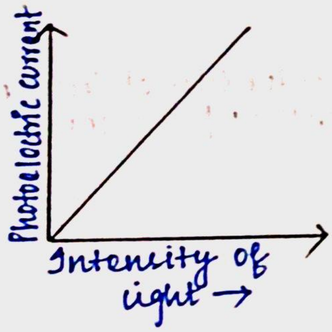
EXPERIMENTAL STUDY OF PHOTOELECTRIC CURRENT :-

When light of frequency ν and intensity I falls on the cathode, electrons are emitted from it. The electrons are collected by the anode and a current flows in the circuit. This current is called photoelectric current. This experiment is used to study the variation of photoelectric current with different factors like intensity, frequency and the potential difference betn the anode & cathode.



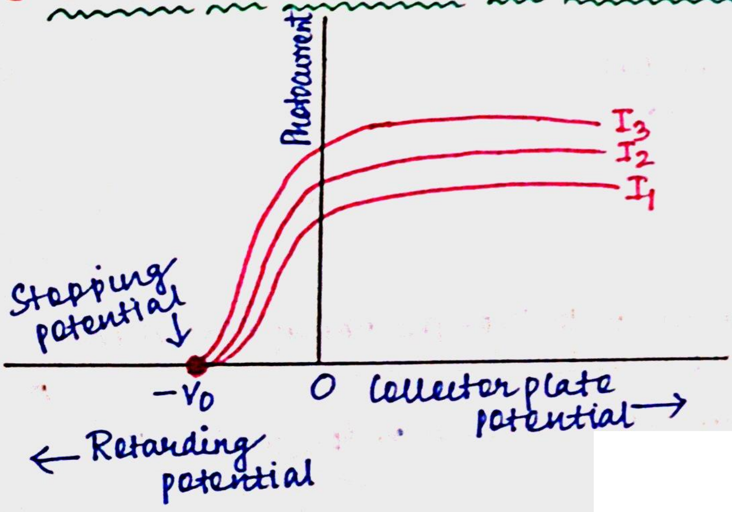
Experimental arrangement for study of photoelectric effect.

(a) EFFECT OF INTENSITY OF LIGHT ON PHOTOCURRENT:-



- The photocurrent is directly proportional to the number of photoelectrons emitted per second.
- This implies that no. of photoelectrons emitted per second is directly proportional to the intensity of incident radiation.

(b) EFFECT OF POTENTIAL ON PHOTOELECTRIC CURRENT:-



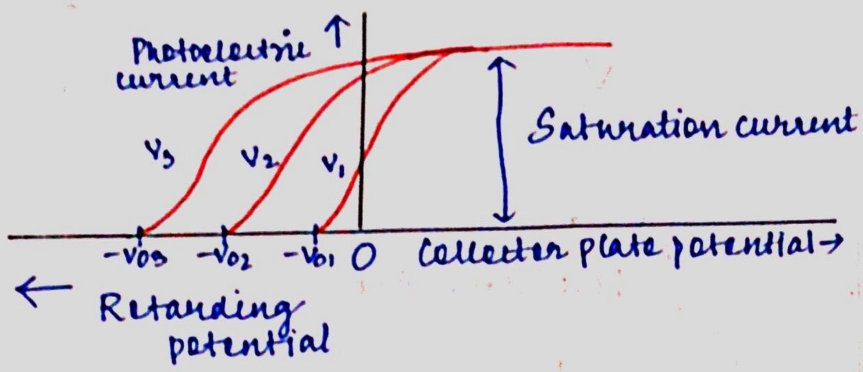
Zero potential- When anode is at zero potential, the photocurrent is not zero.

Positive potential- When anode is at +ve potential, it attracts the ejected $e^{\ominus}$. When it is made more +ve, gradually photocurrent increases and becomes constant called as Saturation current.

Negative potential :- When anode is made −ve, the ejected e^- are repelled, so photocurrent decreases. For a particular value of −ve potential, photocurrent is zero, which is called stopping potential.

$$K.E_{max} = eV_0$$

(c) EFFECT OF FREQUENCY OF INCIDENT RADIATION ON STOPPING POTENTIAL :-

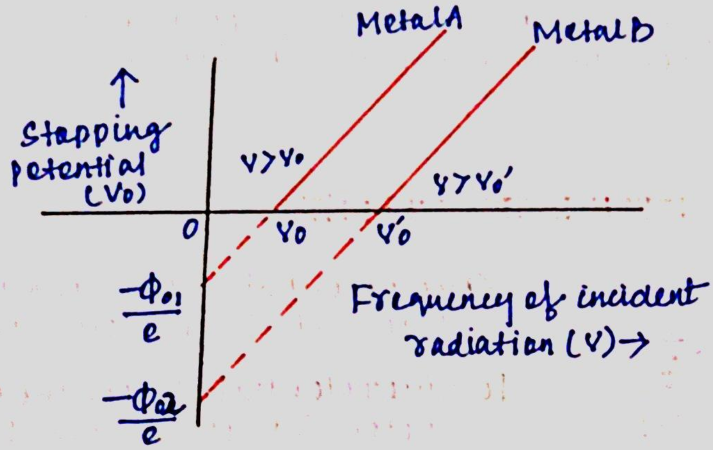


From the graph, we observe that :-

(i) The value of stopping potential is different for radiation of different frequencies but same value of saturation current (for given intensity).

(ii) Greater the frequency of incident radiation, greater is the max K.E of photoelectrons, consequently greater retarding potential or stopping potential is required to stop them completely.

(iii) The value of the saturation current depends on the intensity of incident radiation but is independent of frequency of the incident radiation.



The graph shows that :-

(i) The stopping potential V_0 varies linearly with the frequency of incident radiation for a given photosensitive material.

(ii) There exists a certain minimum cut-off frequency ν_0 for which the stopping potential is zero.

THRESHOLD FREQUENCY (ν_0):- For a given metal surface, there exists certain or minimum frequency below which no photoelectric emission takes place.

LAWS OF PHOTOELECTRIC EFFECT:-

(1) It is an instantaneous process.

(2) For a given metal, there exists a certain/minimum frequency of incident radiation below which no photoelectric emission take place. This frequency is called threshold frequency.

(3) The photoelectric current is directly proportional to intensity of incident radiation but is independent of frequency of light.

(4) The maximum K.E of ejected e^- depends on the frequency of incident radiation and is independent of its intensity.

EINSTEIN'S PHOTOELECTRIC EQUATION:-

Einstein explained photoelectric emission basing on planck's quantum theory. According to Einstein, when light is incident on a metal, each photon interacts with one e^- and transfer its energy. It is utilized in 2 purposes:-

① To just eject the e^- from metal surface which is called work function ($\phi_0 = h\nu_0$)

② rest energy becomes K.E of e^-.

If ν is the frequency of incident light then,

$$h\nu = \phi_0 + K.E$$

$$h\nu = h\nu_0 + \frac{1}{2}mv^2_{max}$$

$$\Rightarrow K_{max} = h\nu - h\nu_0 = h(\nu - \nu_0) = h\nu - \phi_0$$

$$\boxed{K_{max} = h\nu - \phi_0}$$

WAVE NATURE OF MATTER:-

The wave associated with moving material particle is called matter wave or de-Broglie wave whose wavelength is called de-Broglie wavelength which is given by:-

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

According to planck's quantum theory, the energy of the photon is given by :-

$$E = h\nu = \frac{hc}{\lambda} \quad \text{——} \text{(I)}$$

According to Einstein's theory, the energy of photon is given by

$$E = mc^2 \quad \text{——} \text{(II)}$$

From (I) & (II), we get,

$$\lambda = \frac{h}{mc} = \frac{h}{p}$$, p = mc is momentum of a photon.

According to de-broglie hypothesis, the wavelength of wave associated with moving material particle becomes.

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

DE-BROGLIE WAVELENGTH OF AN ELECTRON:-

$$\lambda = \frac{12.27}{\sqrt{V}} \, A^{\circ}$$

or $$\lambda = \frac{1.227}{\sqrt{V}} \, nm$$

DAVISSON AND GERMER EXPERIMENT:-

PURPOSE:- To prove wave nature of electron.