# 1. DUAL NATURE OF RADIATION AND MATTER

## DIFFERENT TYPES OF EMISSION:

1. **Thermionic emission:** When a cathode is heated indirectly or directly and if there is emission of radiation is called thermionic emission
2. **Photoelectric emission:** When light of suitable frequency is made to fall on a metal surface and if there is emission of photoelectrons then it is called photoelectric emission
3. **Field emission:** When a metal plate is subjected to strong electric field $(10^8\ eV)$ and if there is emission of electron then it is called field emission.
4. **Secondary emission:** When a fast moving electrons collide with an atom and if there is emission of electron then it is called secondary emission.

**DEFINE WORK FUNCTION:** It is the minimum energy of incident light on a metal, which is required to emit a photoelectron without imparting any KE $[W_0\ or\ \varphi_0\ ]\ W_0 = h\ \nu\ _0$.

Work function depends on a )properties of the metal b) the nature of its surface.

The work function for $pt$ is high $5.65e\ V$ and cesium has lowest value of $2.14eV$

**Threshold frequency $(\nu_0)$:** It is the minimum frequency of incident light above which there is emission of a photo electron from the metal surface without imparting any $KE$ to the electron.

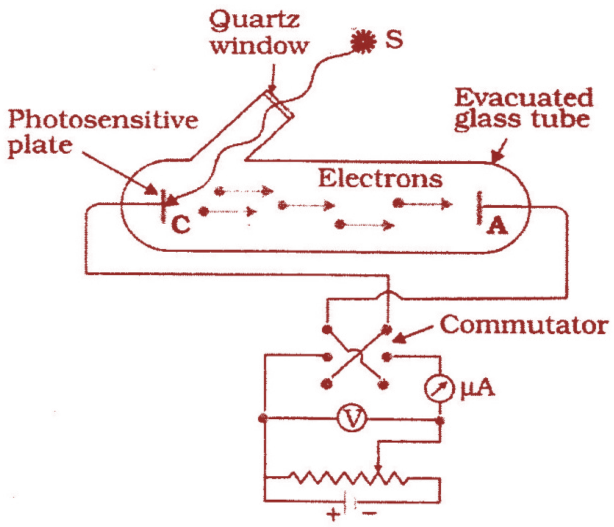
**Threshold wavelength $(\lambda_0)$:** It is maximum wavelength of incident light incident on a metal surface below which there is an emission of photoelectron. $W_0 = h\ \ c/\lambda_0$

**One electron volt $[eV]$:** Is the energy acquired by an electron when it has been accelerated by a pd of 1 volt. $1\ eV = 1.6 * 10^{-19}\ J$

**PHOTOELECTRIC EFFECT:** It is the phenomenon of the emission of photoelectrons from the metal surface when light of suitable frequency is falling on a metal surface.

**The photoelectric effect involves conversion of light energy into electrical energy.** The metal like zinc, cadmium and Mg will respond to $UV$ light only. Some alkali metal such as sodium, potassium, cesium and rubidium are sensitive to even visible light.

## EXPERIMENTAL STUDY OF PHOTOELECTRIC EFFECT:-




It consists of evacuated glass or quartz tube have photo sensitive plate $C$ and another plate $A$. A monochromatic light of suitable frequency falls on the metal plate $C$. The photo electrons are emitted form the plate $C$, which reaches the plate $A$ when positive potential is applied to plate $A$ with respect to $C$. A photo electric current is flowing which is measured by $\mu$ Ammeter.

## HERTZ' S OBSERVATIONS:

He discovered the phenomenon of photo electric emission during his $EMW$ experiments. High voltage sparks across the detector loop were enhanced when the emitter plate was illuminated by $UV$ light from arc lamp. Light shining on the metal surface, some electron near the surface abosorb enough energy from the Incident radiation to overcome attraction of the positive ions in the metal surface. After gaining sufficient energy escape from the surface of the metal into the surrounding space.

## HALLWACHS AND LEONARD'S OBSERVATION:

He observed that when UV light was allowed to fall on the emitter plate on a evacuated glass tube enclosing two electrodes, current flows in the circuit. As soon as the UV radiations were stopped, the current flow also stopped. These observations indicate that when UV radiations fall on the emitter plate C, electrons are ejected from it, which are attracted towards the positive collector plate A by the electric field. The electron flows through the evacuated glass tube, resulting current flow. They

studied about the variation of PE current with collector potential and intensity of light.
Hallwachs connected a negatively charged zinc plate to an electroscope and observed that the zinc plate was lost its charge when it was illuminated by UV light. Further a charged zinc plate became positively charged and it was irradiated by UV light positive charge on a positively charged zinc plate was found to be further enhanced when it was illuminated by UV light. From these observations he concluded that the negatively charge particle were emitted from the zinc plate under the action of UV light.
Hallwachs and Leonard's also observed that when UV light fell on the emitted plate no electrons were emitted at all when the frequency of incident light was smaller than certain minimum value called the threshold frequency. This minimum frequency depends on the nature of the material of the emitter plate.
Certain metal like zinc, cadmium, Mg etc responded only to UV light having short wavelength to cause electron emission from the surface. However some alkali metals metals such as Li, Na, K caesium, Rubidium were sensitive even to visible light. All the photosensitive substances emit the electrons when they are illuminated by light.
[Alkali metal havelowworkfunction]

## EFFECT OF POTENTIAL ON PHOTOELECTRIC CURRENT:

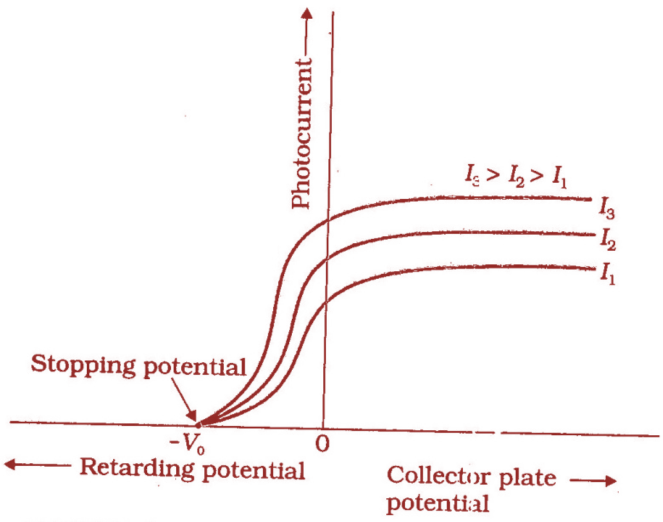
Keeping intensity of light and frequency of light constant, the plate A is maintained some positive potential with respect to C. Some current flows in the external circuit. When the potential is increased then the number of photo electrons reaching the plate A increases. This will continue until a stage reaches when the photo electric current attains saturation i.e. for the increase of the potential of A the photoelectric current does not increase. This maximum current is called saturation current i.e. all the photoelectrons emitted reach the plate A.

When the plate A is given negative potential with respect to C, the photo electric current decreases because some fast moving electrons only can reach the plate A. When the negative potential increases, Photo electric current decreases because few electrons can reach the plate A since electrons are repelled by plate A. At particular potential all electrons stops in reaching the plate A, i.e. Photo electric current becomes zero. This potential is called stopping potential $V_0$.

**Stopping potential** is the minimum retarding potential given to plate A with respect to plate C such that even the fast moving electrons are stopped in reaching the plate A i.e. Photo electric current becomes zero.

$$eV_0 = 1/2mv^2{}_{max}$$

If the intensity of the incident light increases, the number of photon in the radiation increases, the number of photoelectrons emitted increases so the saturation current increases. But the stopping potential does not change.
Stopping potential independent of the intensity of light.

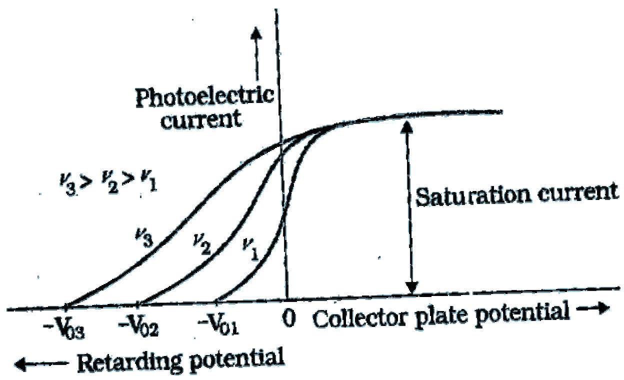



## INFERENCE:

a) If the intensity of the incident light increases, the saturation current increases since number of electrons emitted is proportional to intensity of light.

## EFFECT OF FREQUENCY OF LIGHT ON PHOTOELECTRIC EFFECT:

In this, the intensity is kept constant, for various frequencies, the variation of Photo electric current with voltage is studied. For particular frequency, as the applied plate A voltage is increased, the Photo electric current also increases until saturation current is attained. We obtain the retarding potential by applying retarding potential.




If the frequencies of incident radiation increases $\nu_1 < \nu_2 < \nu_3$, the $KE$ max of photo electrons increases so the stopping potential increases. $V_{01} < V_{02} < V_{03}$. But the saturation current remains the same i.e. saturation current is independent of frequency. The graph shows that

a) The stopping potential $V_0$ varies linearly with the frequency of incident radiation for a given photo sensitive metal.
b) There exits a certain minimum cut off frequency $\nu_0$ for which stopping

potential is zero.

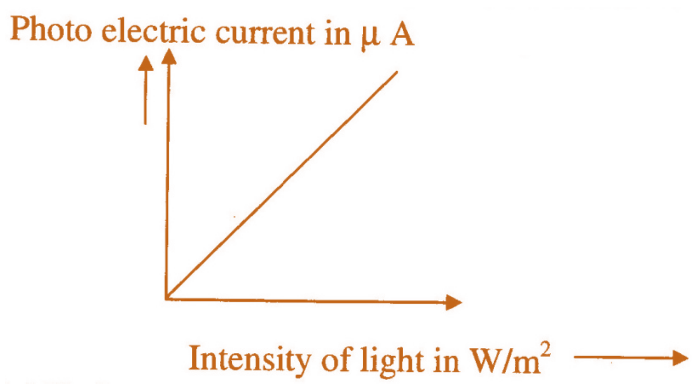
The observation produces two important results:

1) The KE max of the photoelectron varies linearly with the frequency of the incident radiation but is independent of its intensity.
2) For a frequency $\nu$ of incident radiation lower than the cut off frequency $\nu_0$, no Photoelectric emission is possible even if the intensity is large enough.

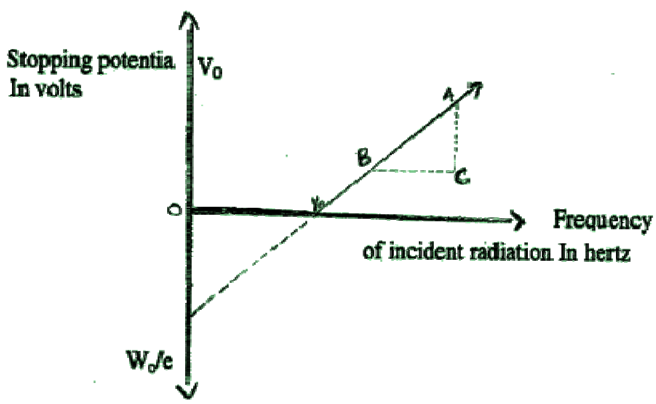
## EFFECT OF INTENSITY ON PHOTOELECTRIC EFFECT:

Keeping frequency constant $(\nu > \nu_0)$, if the intensity of the incident light increases, number of photon in the radiation increases, more electrons are emitted from the plate C and are attracted by the plate A, when the positive potential is given to the plate A. As the intensity increases, saturated (photoelectric) current increases. If the positive potential kept constant and if the intensity increases, the Photoelectric current is found to increase linearly.

But the stopping potential remains the same. It is independent of intensity.




**Draw Stopping potential $V_S$ frequency graph and how will you find the Planck's constant form the graph**.



According Einstein's Photoelectric Equation

$hv_1 - hv_0 = 1/2mv^2{}_{max} = eV_{02} \rightarrow (1)$

$hv_2 - hv_0 = 1/2mv^2{}_{max} = eV_{01} \rightarrow (2)$

Equ $(2)-(1)$

$h(\upsilon_2 - \upsilon_1) = e(V_{02} - V_{02})$

$h\,\Delta\,v = e\,\Delta\,V_0\,;\ h = e * \Delta\ V_0/\Delta\,v$

$i.e. h = e *$ Slope of the graph where slope $= AC/BC$

The intercept of the line in X axis given the threshold frequency and the intercept of the line in Y axis gives work function is volt. $(W_0/e)$. The $V_0\ V_S\ v$ graph is independent of the nature of the material.

The successful explanation of PE effect using hypothesis of light quanta and the experimental values of h and $W_0$, in agreement with values obtained from the other experiments led to the acceptance of Einstein's picture of PE effect.

## STATE LAWS OF PHOTOELECTRIC EMISSION

1) For a given photoelectric metal, there exit certain minimum cut off frequency above Which there is emission of photoelectrons and below which there is no emission of photoelectrons whatever may be the intensity of light. It is called threshold frequency
2) Above vo as the frequency increases, stopping potential also increase. But is independent of intensity
3) For a given photo sensitive material and constant frequency of incident light, as the Intensity of incident light increases, saturation photo electric current also increases linearly, where as stopping potential is independent of intensity of light.
4) Photoelectric effect is an instantaneous process without any apparent time $leg(10^{-9}s)$, even when the incident radiation is made exceedingly dim.

## STATE EINSTEIN'S PHOTOELECTRIC EQUATION:

Photoelectric emission was explained successfully by Plank's quantum theory. According to this theory, light radiation consists of tiny pockets of energy called quanta or photon, which travels with the speed of light. The energy is $E = h\ \ v$ where h is Plank's constant and V is the frequency of the incident light.

He assumed that one photon of suitably high – energy releases only one electron from the metal surface. One electrons absorbs one photon completely, in which a) part of the energy is used to liberating the electron from the metal surface which equal to work function b) the rest of the energy is converted into KE of the electrons.

If v is the frequency of the incident light and $W_0$ is the work function of the metal and the velocity of the photoelectron v then

E-$W_0 = kE_{max}$; $E$ is the energy of the incident radiation and $\mathrm{KE_{max}}$ is the maximum KE of the emitted photoelectron.

$h\,v - h\,v_{\,0} = {}^1\!/_2\ m\ \ V^2{}_{max}$ where h is the Planck's constant.

$h\,v - h\,v_{\,0} = {}^1\!/_2\,mV^2{}_{max} = e\,V_0$ is the stopping potential.

This is the Einstein's photoelectric equation.

$hc\left(1/\lambda - 1/\lambda_0\right) = {}^{1}/_{2}\ m\, V^2{}_{max} = e\, V_0$

## Explanation of the laws of the photoelectric emission on the basis of Einstein's photoelectric equation

$h(V - V_0) = {}^{1}/_{2}\, mV^2{}_{max} = e\, V_0$

1) If the frequency of the incident radiation is greater than the threshold frequency of the metal, then there is emission of photoelectron. If $v < v_{0,}$ the KE becomes negative, which is not possible.
2) If the frequency of the incident radiation increases $(v > v_0)$, the KE max of the Photoelectron increases and the corresponding stopping potential also increases.
3) If the intensity of the incident radiation increases, the number of photoelectrons increases, photo electric current increases but KE of the photoelectrons does not get affected and hence stopping potential.
4) Absorption of energy of photon by the electron, which involves transfer of energy from at once without any time lag. Due to this, photoelectric emission takes place without any time lag.

## Failure Of Wave Theory Of Light to explain The Photoelectric Effect

Wave theory explains successfully the phenomenon interference, diffraction and polarization but could not explain photoelectric effect. According to this theory, light is a electro magnetic wave consisting of electric and magnetic fields with continuous distribution of energy over the region of space over which the wave is extended.

a) According to the wave picture of photoelectric emission, the free electrons at the surface of metal absorbs radiation and the amplitudes of EMW and energy density increases. If the intensity of the incident radiation increases, the absorption of energy increases. I.e. the maximum KE of the electrons increases. If the intensity of incident radiation increases the KE of photoelectrons increases and hence gets released from the metal surface irrespective of the frequency of the incident radiation. So threshold frequency does not exist. But experimentally we found that if the frequency of incident radiation is lesser than the frequency of the threshold frequency then what ever may be intensity of light there is no emission of photoelectrons.
b) In wave theory, the absorption of energy by electron takes place continuously over the entire wave front of the radiation. Since large number of electrons shares the available energy, each electron absorbs less amount of energy only. To get the required amount of energy, for the electron, to get emitted from the metal surface, the metal surface should be exposed for the longer time. So the time taken for the ejection of electrons, after gaining enough energy to overcome work function, is very large. But experimentally we found that time lag between the incident radiation and the emission of electrons is about $10^{-9}$ sec. Thus wave picture fails to explain the photoelectric effect.

**PHOTON:** Photons are the packets of energy or energy particles, which are emitted by the source of radiation. They travel in a straight line.

Main features of photons:

1) According to Planck's quantum theory, a source of radiation emits energy in the form of photons, which travels in the straight line. In interaction of radiation with matter, radiation behaves as if it is made up of particles called photons.
2) Energy of photon is $E = h\nu$ and $P = h/\lambda$ where $\nu$ is the frequency of incident radiation whatever the intensity may be. If the intensity increases, the number of photons increases,
3) All the photons emitted from the source will travel with the same speed in the same medium.
4) The energy of the radiation does not change when it travels into the second medium.
5) There is change in velocity of photon when the photon travels from one medium into another medium due to change in wavelength.
6) $m_0 = m\sqrt{[1-(V^2/C^2)]}$ If $v = c$ for photon, $m_0 = 0$, so the photon can not exist at rest.
   Photon has zero rest mass.
7) Photons are electrically neutral and it has momentum $P = h/\lambda$ and $E/c$ and energy $E = h\nu$. In a photon – particle collision, the total energy and total momentum are conserved. However, the number of photons may not be conserved in a collision. The photon may be absorbed or a new photon may be created.
8) If the intensity of incident light increases, number of photons increases, number of photo electron emitted increases saturated photo electric current increases.
9) If frequency of incident light increases, energy of each photon increases, KE max increases, stopping potential increases.

## DUAL NATURE OF RADIATION:

The phenomenon of interference, diffraction and polarization of light could be explained by radiation of the wave nature and photoelectric effect and Compton effect are explained by the radiation of particle. So radiation has dual nature.

## Photoelectric cell

It is a device which converts light energy into electrical energy. It is also called an electric eye. Photoelectric cells are of three types, namely

Photo emissive cell, photovoltaic cell, photoconductive cell

## Photo emissive cell (also called photo tube)

It consists of an evacuated glass or quartz tube. Inside the tube, there is a semi-cylindrical photo-sensitive metal plate C and a wire loop A which serve as cathode and anode respectively. The tube is provided with insulating base on which metallic pins are connected to these pins and through these pins, photocell is fitted into a socket and is connected to the external circuit having a battery (B), and micro ammeter ($\mu A$), and a load resistance R in the circuit.

## WORKING:

When light of suitable frequency is allowed to fall on the cathode, photoelectrons are emitted. These are attracted by anode, which is kept at positive potential w.r.t cathode. So a current starts flowing in the circuit. Due to it, micro-ammeter shows a deflection. The photoelectric current is very small, so it is to be amplified first before it is used for some useful purpose. When the light is cut off, no photoelectrons are ejected from the cathode and hence there is no current in the external circuit.

## APPLICATIONS OF PHOTO ELECTRIC CELLS:

1) Photoelectric cells are used in television camera for telecasting scenes and in photography.
2) Photocells are used for the reproduction of sound recorded on films along with pictures in the movie theatre.
3) Photocells are used in counting devices, which records every interception on the light beam caused by a person passing across the beam provided they come one by one. Invisible light is continuously made to fall on the photocell installed at the doorway. A person entering the door interrupts the beam falling on the photocell. The abrupt change in photocurrent is used to start an electric bell ringing.
4) Photocells are also used in burglar alarm and fire alarms. A number of photocells are installed at suitable places in a building. In the event of breaking of fire, light radiation fall upon the photocell. This complete the electric circuit through an electric bell or a siren which starts operating as a warning signal.
5) Photocells are also used to measure the temperature of stars and to study the spectrum of heavenly bodies.
6) They are used to switch on and off the street lighting system at dusk and dawn, without any manual attention.
7) They are used in photometry to compare the illuminating powers of two sources.
8) They are used in industries for locating minor flaws or holes in metallic sheets.
9) They are used as photoelectric sorters to sort out the materials of different shades.
10) They are used to determine the opacity of solids and liquids.
11) They are used to control the temperature and chemical reactions.
12) They are used for the determination of Planck's constant.

## DE BROGLIE DUALISTIC HYPOTHESIS

## DUAL NATURE OF MATTER.

Since radiation has dual nature i.e. it possesses properties of both wave and particle and universe is composed of radiation and matter, therefore de Broglie concluded that the matter must also possess dual nature, since nature loves symmetry.

## De-Broglie hypothesis

According to de-Broglie a moving material particle sometimes acts as a wave and sometimes acts as a particle or a wave is associated with moving material particle, which controls the particle in every respect. **The wave associated with moving particle is called matter wave or de-broglie wave whose wavelength called de-broglie wavelength, is given by**

$\boldsymbol{\lambda = h/mv}$

where $m$ and $v$ are the mass and velocity of the particle and $h$ is a Planck's constant.

### Derivation of de-broglie wavelength

According to Planck's quantum theory, the energy of photon of a radiation of frequency $\upsilon$ and wavelength $\lambda$ is

$E = h\upsilon \rightarrow (1)$ Where $h$ is a Planck's constant. If photon is considered to be a particle of mass $m$, the energy associated with it, according to Einstein mass energy relation, is given by $E = mc^2 \rightarrow (2)$

From (1) and (2) we get, $h\upsilon = mc^2$ or $hc/\lambda = mC^2$; $\lambda = h/mC$

Since each photon moves with the same velocity $c$, therefore momentum of photon,

$\lambda = h/p = h/mv$………(4)

This is **de-broglie wave equation** for material particle

From de-broglie hypothesis, we conclude the following

(i) $v = 0$, $\lambda$ =infinity, and if $v$ =infinity then $\lambda = 0$

It means the waves are associated with the material particles only if they are in motion. The material particle may be charged or uncharged but when it is in motion; the waves are associated, which are independent of charge. It means de-broglie waves cannot be electro-magnetic in nature because electro-magnetic waves are produced by motion of charged particles.

Since the position of wave cannot be located exactly, therefore, the wave nature of material particle introduces the problem of particle location. It means the wavelength of a wave associated with moving particle defines a region of uncertainty, within which the whereabouts of particle are unknown.

## De-Broglie Wavelength Of An Electron:

Consider an electron of mass $m$ and charge $e$. Let $v$ be the velocity of the electron where accelerated from rest through a $pd$ of $V$ volt, then

Gain in KE of electron $= 1/2\ mv^2$; WD on the electron $= eV$

$1/2\ mv^2 = eV$; $v = \sqrt{(2eV/m)}$

If $\lambda$ is the wavelength associated with the electron, then $\lambda = h/mv = h/\sqrt{(2meV)}$;

$\lambda$ =[6.63*$10^{-34}$/$\sqrt{}$(2*9.1*$10^{-31}$*1.6*$10^{-19}$*V)]= 12.27 $A^{\circ}/\sqrt{V}$

## DAVISSION GERMER EXPERIMENT

Experimental demonstration of wave nature of electron.
Davisson and Germer have established the wave nature of slow moving electrons [particle] experimentally.
[The graphs show that there is a sharp bump when accelerating voltage is 54V and latitude angle $\phi = 50^{\circ}$.
The appearance of bump in a particular direction is due to constructive interference of electrons scattered from different layers of regularly spaced atoms of the crystal. This establishes wave nature of electron.]
This proves the existence of de Broglie waves for the electrons in motion.