Chapter 11

DUAL NATURE OF MATTER AND RADIATION

Introdcution

Light exhibit dual nature - wave nature and particle nature. In Phenomena like Interference, diffrection etc wave nature is exhibited. In photo electric effect, compton effect etc particle nature is observed. Thus light exhibit wave - particle duality.

Matter can also exhibit dual nature. Moving particle like electrons, protons etc can exhibit wave properties.

- **What is Photoelectric effect? Explain the laws of Photoelectric effect.**

Photoelectric effect was discovered by Hertz in 1887. When light of suitable frequency is incident on certain metals free electrons are emitted from the metal. This process is called photoelectric effect. Generated electrons are called photoelectrons and current due to this is called photoelectric current.

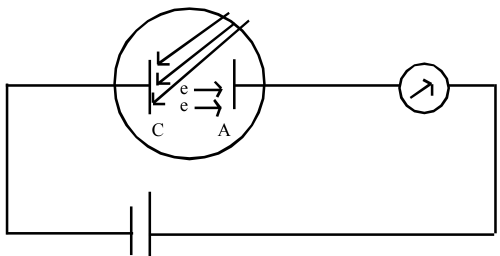
Ordinary metal shows this effect when UV rays falls on them. But alkali metals like Potassium, Sodium etc exhibit this effect even with visible light.

Laws of Photo electric emission

1. For a given metal there is a minimum frequency called threshold frequency for incident radiation, below which there is photo electric emission, however high the intensity is
2. For a given metal, the photoelectric current directly proportional to intensity of incident radiation provided frequency is higher then threshold frequency
3. The KE of the photoelectrons depends on the frequency of the incident radiation.
4. Photoelectric emission is an instantaneous process. ie there is no time lag between incident radiation and emission of photoelectron.
5. KE of photo electrons almost independent of intensity.

- What is saturation current?
- What is stopping potential? Does it change with intensity of light.

Maintain the anode A at some accelerating potential and cathode C is illuminated with light of intensity I_1. When the accelerating potential increases the phot electric current also increases and become maximum.



This maximum value of photoelectric current is called saturation current for that intensity. This saturation current increases with increase in intensity.

Now apply retarding (-ve) potential to anode A with respect to C. When this retarding potential increases, the photo current decreases and becomes zero at a particuler retarding potential (V_o).

The minimum retarding potential given to anode for which photoelectric current become zero is called stopping potential (V_o). Stopping potential is the same for all intensities. It doesnot depend on intensity of light. $KE_{max} = eV_o$ (Max KE if phot electrons)

- **Einstein's Photo electric Equation**

Einstien gave explanation to photo electric effect based on quantum theory of light. The emission of electron is as a result of interaction of single photon with an eletron, in which the photon is completely absorbed by the electron.

To remove an electron from the metal, a certain minimum energy called work function (ϕ) is required.

$\therefore$ By law of conservation of energy

Energy of incident photon= Work function + KE of emitted electron

ie. $h\nu = \phi + \frac{1}{2} mv^2$ .... (1)

$\frac{1}{2} mv^2 = h\nu - \phi$

When $\nu = \nu_0$, $KE = \frac{1}{2} mv^2 = O$

$O = h\nu_0 - \phi$

ie. $\phi = h\nu_0$

$\therefore$ eqn (1) becomes

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

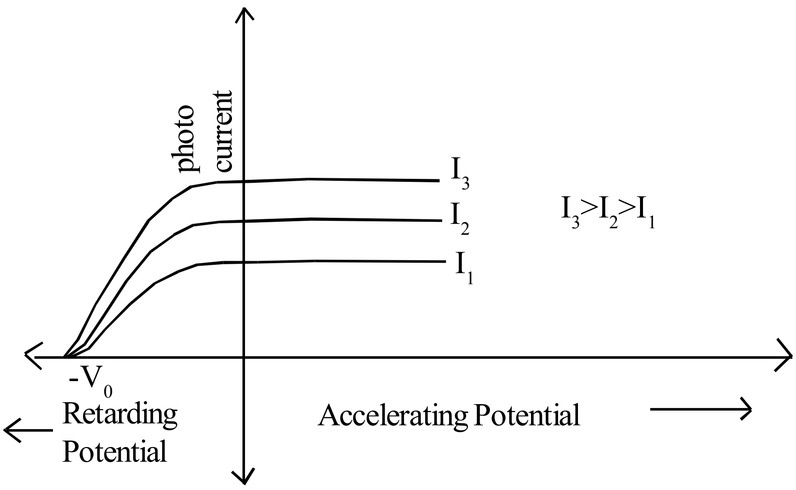
or $\frac{1}{2} mv^2 = h(\nu - \nu_0)$

This is Einstein's Photo electric equation. Says (1) Kinetic Energy of Photo electrons depends on frequency (ν) (2) $\nu < \nu_0$ Photo electric emission is impossible.

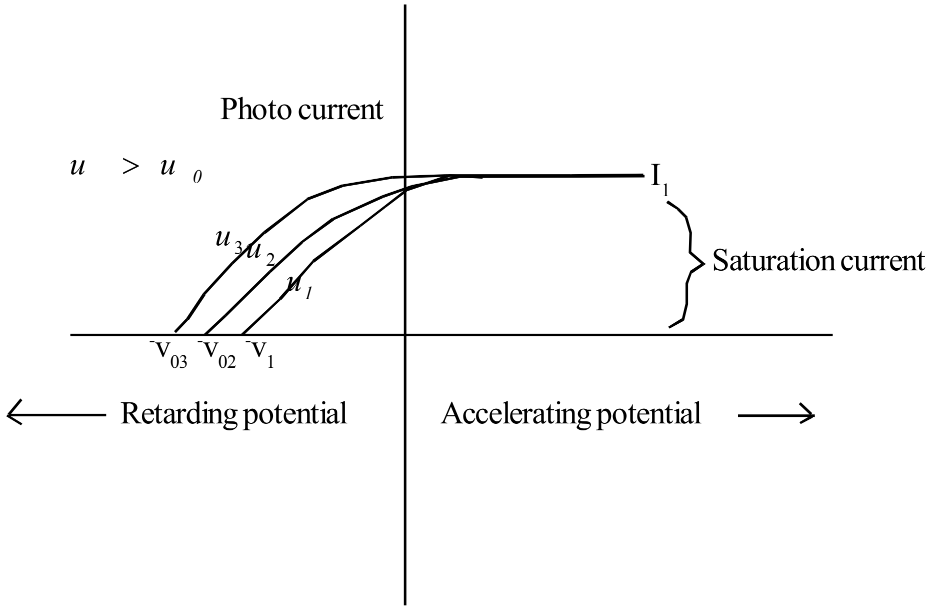
Note : $\nu = \frac{c}{1_0}$ $\upsilon_0 = \frac{c}{1_o}$

$$\therefore \frac{1}{2} mv^2 = h\left(\frac{c}{\lambda} - \frac{c}{\lambda}\right)$$

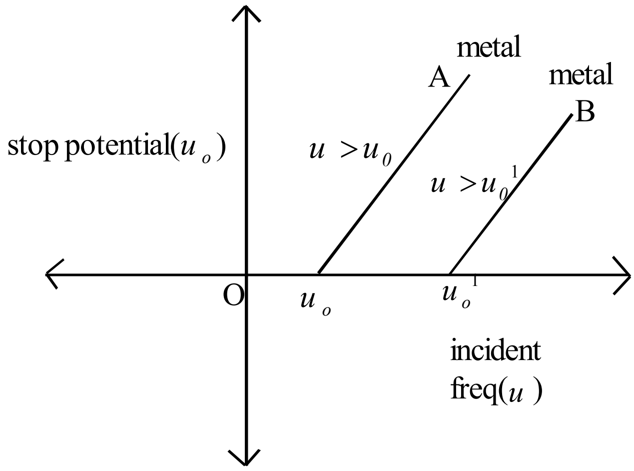
$\frac{1}{2} mv^2 = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right)$, Photo Electric Emission (PEE) in terms of wavelength.



- What is the effect of frequency of incident radiation on stopping potential?
  For a particular intensity of light, the stopping potential is more negative for higher frequency of incident radiation



Below is the graph showing the variation of stopping potential with freqency of incident radiation.



Note :

If V_0 is the stopping potential

$\frac{1}{2}mv^2 = eV_o$

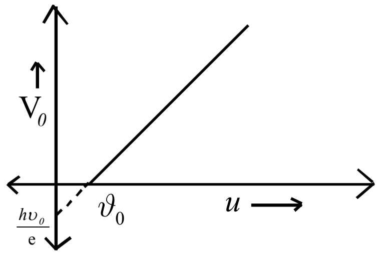
$\therefore$ Einstein's Photo electric eqn

$eV_o = h(\upsilon - \upsilon_0)$

or $V_0 = \frac{h\upsilon}{e} - \frac{h\upsilon_o}{e}$

Comparing with y = mx+c

Slope of frequency (υ) - Stopping potential V_0 graph is,



$m = \frac{h}{e}$, Slope x e = h, Planks constant.

y intercept $c = \frac{-h\upsilon_0}{e}$

- What will be the max. KE of photo electrons emitted from magnesium ($\phi = 3.7eV$) when uv of $\lambda = 1.5 \times 10^{15}$ the is incident.

  $hu = 6.6 \times 10^{-34} \times 1.5 \times 10^{15} = 9.9 \times 10^{-19}$ J

  $\phi = 3.7$ eV $= 3.7 \times 1.6 \times 10^{-19}$

  $\therefore \frac{1}{2} mV^2_m = 9.9 \times 10^{-19} - 3.7 \times 1.6 \times 10^{-19} = 3.98 \times 10^{-19}$ J

  $= 2.5$ eV

Evaluation

- Monochrometic radiation of wave length 640.2nm from Neon lamp irradiates a phot sensitive material made of cesium on tungsten. The stopping voltage is measured to be 0.54V. The source is replaced by source of 427.2nm irradiating the same photo cell. What is the new stopping potential.

Wave Nature of matter - Matter Waves

In 1924 Louis de Brolglie proposed that moving particle of matter shows wave - like property under suitable condition. This wave associated with moving particle is called matter wave.

De Brolglie wave length :

The wave length associated with a particle of mass 'm' moving with a speed v is given by

$\lambda = \frac{h}{p} = \frac{h}{mv}$ Where h is planks constant.

This wave length is called de Brolglie wave length associated with matter wave.

- De Broglie wave length of electron

  Consider on electron of mass 'm' accelerated from rest through a pd of V volts. The KE of electron, K= eV

  but K $= \frac{1}{2}mv^2 = \frac{P^2}{2m}$

  $\therefore P = \sqrt{2mk} = \sqrt{2meV}$

  $\therefore$ De Brolglie wave length of electron

  $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}}$

  Substituting h, e, n, m

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

- Define work funciton of a metal

  The minimum energy required to liberate an electron from the surface of the metal.

  $w = h\upsilon_o$ where $h = 6.63 \times 10^{-34}$ JS. υ_o - Threshold freqency - Frequenty of the incident radiation for which electron emission just starts.

- What is the unit of work function - Electron Volt (eV)

- What are the methods used for supplying work function.

Thermonic emission	Electric field emisson,	Photo electric emission
(Supplying Heat energry)	(Supplying electric field)	(Incidenting Light)

- Work function of A is 1.92 eV and B is 5eV which of them is photo emission for a radiation wavelength 3300⁰A.

  Note :\ $\upsilon_o < \upsilon$ - the metal is photo emissive

$$\upsilon = 9 \times 10^{14} g$$

$$\upsilon = \frac{c}{\lambda} = \frac{3\times10^{8}}{3300\times10^{-10}} = 9\times10^{14}\ \text{Hz}$$

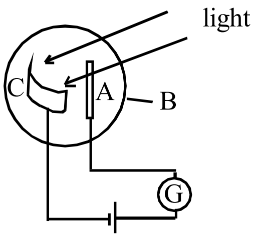
$$\upsilon_o(A) = \frac{w}{h} = \frac{1.92\times1.6\times10^{-19}\ J}{6.63\times10^{-34}} = 5\times10^{14}\ \text{Hz},\ \text{Photo emissive}$$

$$\upsilon_o(B) = \frac{w}{h} = \frac{5\times1.6\times10^{-19}\ J}{6.63\times10^{-34}} = 12\times10^{14}\ \text{Hz},\ \text{not photo emissive}$$

- Condition for Photo electric emission - $\upsilon > \upsilon_0$ or $\lambda < \lambda_0$
- Alkali metals are suitable for Photo electric emmission

  Work function of alkali metal is small.
- Which photon is more energetic Red or Violet - Justify.

  Violet since KE $\propto \upsilon$, υ of violet is greater than that of Red.
- Explain Photo electric Cell : Device which converts change in intensity of lgiht into corresponding change in electric current.



B - Evaluated Glass bulb

C - Emitter - A metallic plated coated with photo sensitive material (sodium oxide)

A - Anode (Nickel Rod)

- Photo electric cell is called "Electric Eye" - It responds to the light falling on it, like eye.

- Uses of photo electric cell.

  1) Used to measure intensity of light (Measures rate of flow of Photons)
  2) Automatic switching of street light.
  3) Conversion of solar energy into electrical energy (Solar cell)

- Explain matter waves or de-Broglie waves.

  Waves associated with material particles. Eg.: Electron, Proton, Neutron.

- Express the relation for de-broglie wave length.

  Consider a photon of mass m moving with the velocity c

  Energy of photon, $E = mc^2 = h\upsilon$ where υ - frequency photon.

  $$m = \frac{h\upsilon}{c^2}$$

  Momentum of photon $P = mc = \frac{h\upsilon}{c} = \frac{h}{\lambda}$

  de-Broglie wavelength of photon $\lambda = \frac{h}{p}$

  In general, the de-Broglie wavelength associated with a material particle of mass m moving with velocity. $\lambda = \frac{h}{p} = \frac{h}{m\upsilon}$ - It connects momentum (P) and wave length λ

- De-Broglie waves are always associated with a moving particle. If v=0 then de-Broglie wave length $\lambda = \alpha$, infinity.

- Write the application of wave nature of matter

  Electron microscope having high resolving power designed by Ernest Ruska.

- Why de-Broglie waves associated with a moving train is not visible.

  Since . $\lambda = \frac{h}{m\upsilon}$, $\therefore \lambda \propto \frac{1}{m}$

  Mass (m) of the train is large λ is very small.

Davison and Germer Experiment

Davison and Germer in 1927 succeeded in measuring De Brolglie wave length associated with an eletron. A beem of electrons emitted from a heated filement F is accelerated by applying p.d V between the filement and cylinder. The beem is now narrowed by passing it through two slits s_1 & s_2 and strikes the target T of Nickel crystal. The electrons are scattered in all direction by the target.

The intensits of scattered electron beem in a given direction is measured by an electron detector which is connected to a galvanometer. The current in the galvanometer is a measure of intensity of diffracted electron beem. The observations are repeated for various accelerating potential and angle of scattering. The intensity of diffracted beem is maximum at 54V for angle $\phi = 50^0$

From electron diffraction measurement wave length of matter wave was found to be 0.165nm.

λ of electron using eqn is $\lambda = \frac{1.227}{\sqrt{V}} nm$

$$= \frac{1.227}{\sqrt{54}} = 0.167 nm$$

Thus there is an excellent agreement between theoretical and experimentally observed value. Thus Davison and Germer expt. confirms the wave nature of electron and de Brolglie relation.