DUAL NATURE OF MATTER AND RADIATION

WAVE NATURE OF LIGHT ⇒ Wave nature of light was established by Maxwell's equation of electromagnetism and Hertz experiment on generation and detection of electromagnetic wave.

ELECTRON EMISSION

FREE ELECTRON ⇒ In metals, the electrons in the outer shells of the atom are loosely bound. They move out freely throughout the lattice of positive ions.

* These free electrons are held inside the metal surface by attractive force of ions.

* These electrons can only come out of the metal surface only if they are provided some energy.

WORK Function ⇒ It is the minimum energy required to pull out electron from a metal surface.

* Work function depends upon nature of metal.

* Work function (ϕ_0) of Cs is minimum (2.14ev) where as for platinum (Pt) it is highest and having value of 5.65ev.

One electron Volt [ev] = It is energy gained by one electron when it is accelerated through one volt.

So $1ev = 1.6 \times 10^{-19} J$

To convert electron-volt into joule we will multiply by 1.6×10^{-19}

for example $10ev = 10 \times 1.6 \times 10^{-19} J$

Following Are the Method For Emission Of Electron

(I) **THERMIONIC EMISSION** ⇒ By suitable heating sufficient thermal energy can be imparted to free electrons so that they can leave metal surface.

(II) **FIELD EMISSION** ⇒ By applying high Voltage electric field to a metal electron can be pulled out from them.

(III) **Photo ELECTRIC EMISSION** ⇒ When light of suitable frequency illuminates a metal surface, electrons are emitted from the metal surface.

PHOTOELECTRIC EFFECT

The process of emission of electron from the metal surface when a radiation of suitable frequency strike the metal surface is known as photo electric effect.

HERTZ'S OBSERVATION ⇒ The phenomenon of photoelectric emission was discovered by Hertz during his electromagnetic wave experiment.

In his experimental investigation of the production of electromagnetic wave by means of spark across the detector loop were enhanced when the emitter plate was illuminated by ultraviolet light from an arc lamp.

LENARD'S OBSERVATION ⇒

LENARD observed that when ultraviolet radiation were allowed to fall on emitter plate of evacuated glass tube enclosing two electrodes current flows.

A soon as ultraviolet radiation were stopped the current flow also stopped.

Hallwach's Observation ⇒

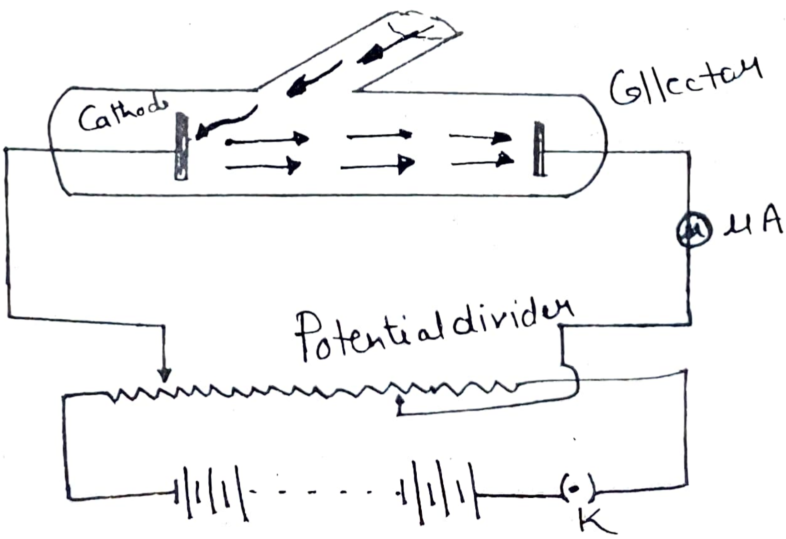
He connected a negatively Charged zinc plate to an electroscope. Observed that zinc plate lost it charge when illuminated by UV light and uncharged plate becomes positively charge.

He also observed that no electrons were emitted when the frequency of light was less than that a minimum frequency known as Threshold frequency.

EXPERIMENTAL STUDY OF PHOTOELECTRIC EFFECT

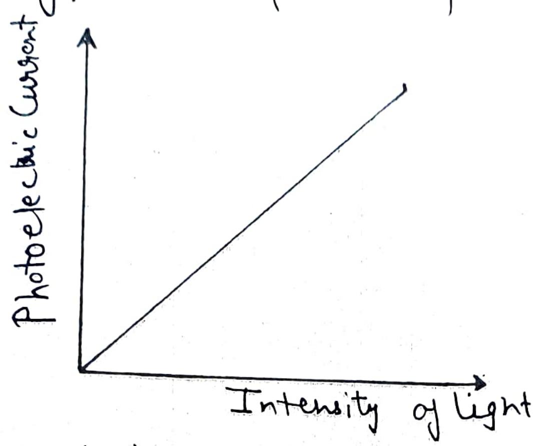
An extensive study of photoelectric effect was made by Lenard and R.A Millikan

For experimental study of various factor affecting photoelectric effect he has used the following apparatus



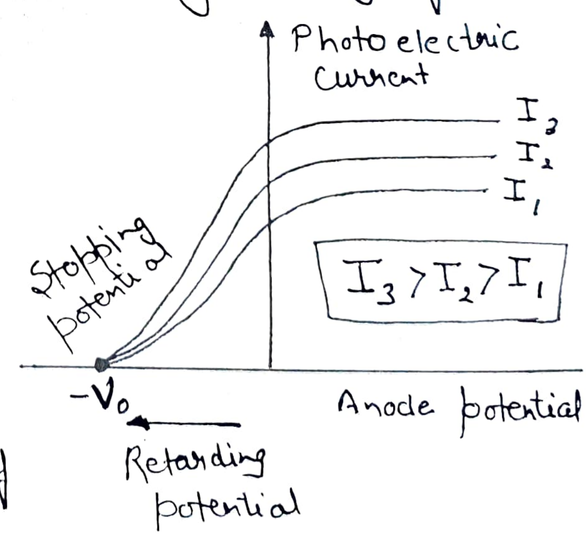
1 Effect Of Intensity of light on photoelectric Current

The number of photoelectrons emitted per second is directly proportional to the intensity of light incident on metal surface provided that frequency of radiation is greater than threshold frequency and potential difference b/w two plate is kept constant.



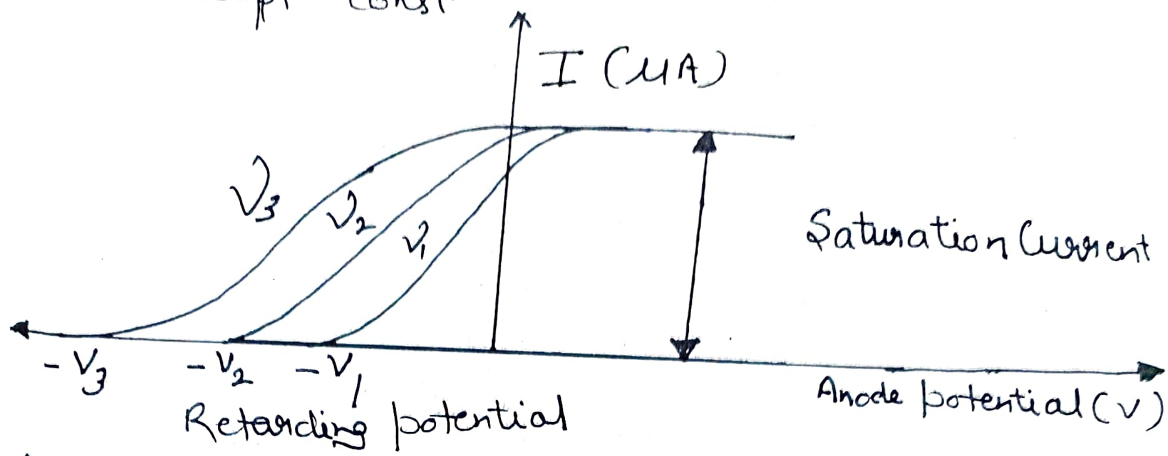
2 Effect of potential on photoelectric Current.

If we keep Intensity of light and frequency of incident radiation is kept fixed then it is found that that photoelectric current increases with positive potential or accelerating potential till a stage known as saturation stage after that even with increase in the value of accelerating potential value of photo current remain same



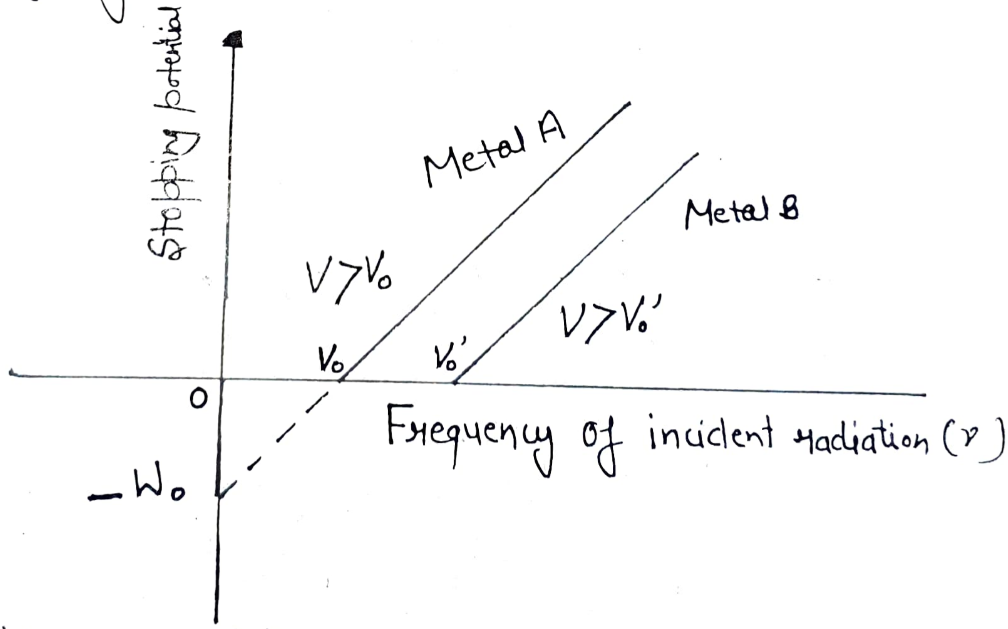
(3) Effect of frequency of incident radiation on photocurrent

There is no impact of frequency of incident radiation on photoelectric current when frequency of incident radiation is greater than the threshold frequency provided that intensity of radiation and accelerating potential is kept const.



(4) **Effect of frequency of incident radiation on stopping potential.**

Experimentally it was seen that stopping potential becomes more and more negative with increase in the frequency of incident radiation



Stopping Potential ⇒ The value of the retarding potential at which the photoelectric current becomes zero is called cut off or stopping potential.

Laws Of Photoelectric Emission

(1) For a given photosensitive material and frequency of incident radiation (above threshold frequency), the photoelectric current is directly proportional to the intensity of light.

(2) For a given photosensitive material there exist a certain minimum cut-off frequency below which no photoelectrons are emitted, howsoever high is the intensity of incident radiation.

(3) Above the threshold frequency, the stopping ~~pote~~ potential is directly proportional to the frequency of incident radiation, but is idependent of its intensity.

(4) The photoelectric emission is an instantaneous process.

Failure Of Classical wave theory to explain ~~wave theory~~ photoelectric effect

No matter what the frequency of incident radiation is, a light wave of sufficient intensity (over a sufficient time) should be able to impart enough energy required to eject the electrons from the metal surface.

But we have seen that electrons are not ejected below threshold frequency. So wave theory was failed to explain photoelectric effect.

Planck Quantum theory ⇒

According to Planck quantum theory light radiation travels in the form of discrete photons.

The energy of each photon is $h\nu$ where h is Planck's constant and ν is frequency of light

$$\boxed{E = h\nu}$$

Properties Of photon ⇒

1. All photons emitted by any source travel through free space with the speed of light $c = 3 \times 10^{8} ms^{-1}$.

2. The energy of photon depends upon frequency of photon.

$$E = h\nu$$

3. Frequency of photon does not change when it travels from one medium to another medium.

(4) Mass of photon moving with velocity V is given by

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

where m_o = rest mass of photon
C = speed of light.

Rest mass of photon is always taken as zero

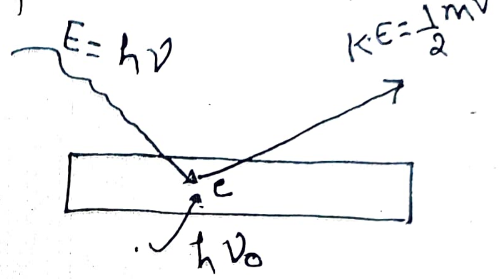
(5) Photons are electrically neutral

Einstein's Theory Of Photoelectric Effect

Einstein used Planck quantum theory to explain the photo electric effect.

According to Einstein the radiation striking the metal surface supplies energy to the metal surface is used for two purposes.

(i) First for providing the threshold energy so that electrons can eject from metal surface. ($h\nu_0$)



(ii) To provide kinetic energy to ejected electrons. ($\frac{1}{2}mv^2$)

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

$h\nu$ → Energy of incident radiation

$h\nu_0$ → Threshold Energy

$\frac{1}{2}mv^2$ → Kinetic energy of ejected electron

$$h\nu = h\nu_0 + K.E$$

$$K.E = h\nu - h\nu_0$$

Case - I if $\nu < \nu_0$

K.E = $-ve$

No electrons will be ejected

Case II if $\nu = \nu_0$

K.E = 0

electrons will be ejected with zero K.E

Case - III $\nu > \nu_0$

K.E = $+ve$

electrons will be ejected with K.E.

Imp

Kinetic energy of electron = Work done to stop electron

$\frac{1}{2} m v^2 = e V_0$ { where V_0 = stopping potential

Variation Of Kinetic energy with frequency :→

$\frac{1}{2} m v^2 = h(\nu - \nu_0)$

K.E = $h(\nu - \nu_0)$

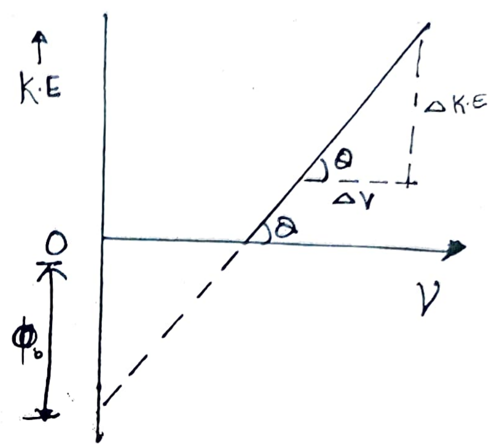
K.E = $h\nu - h\nu_0$

On comparing above equation with equation of straight line

$y = mx + c$

{ m = h = slope }

intercept OC = ϕ_0



Dual Nature Of Matter

In 1924 the French ~~physicist~~ physicist de-Broglie put forward that material particle in motion should display wave like properties.

For the above consideration he has given two reason

(i) Einstein's mass energy equivalence i.e $E = mc^2$

(ii) Nature loves symmetry → Since radiation has dual nature matter must also ~~possess~~ possess dual nature.

de-Broglie's Wave Equation ⇒

Considering photon as EM wave of frequency ν its energy will be given by

$$E = h\nu \quad \text{--- (1)}$$

Considering photon as particle of mass m energy associated with is given by

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

from equation (1) and (2)

$$h\nu = mc^2$$

$$\frac{hc}{\lambda} = mc^2 \qquad \{ c = \nu\lambda$$

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

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

$$p = \sqrt{2mK.E}$$

$$\lambda = \frac{h}{\sqrt{2mK.E}}$$

$$K.E = eV_0$$

$$\lambda = \frac{h}{\sqrt{2meV_0}}$$

Conclusion

(i) if $v = 0$

$\lambda = \infty$ [This can not be visualised]

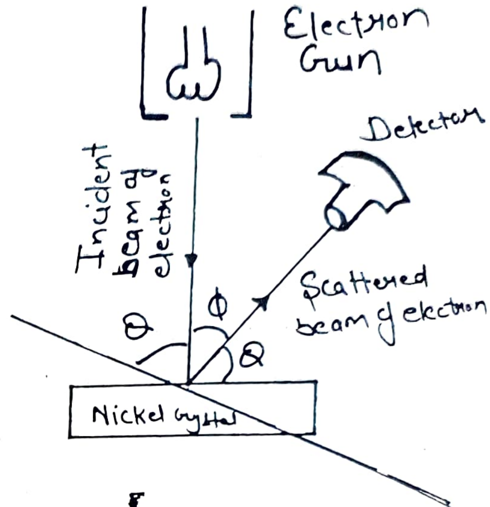
(ii) λ does not depend upon charge.

(iii) They are not electromagnetic in nature.

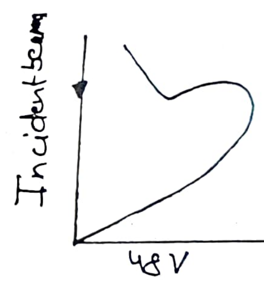
Darisson And Germer Experiment ⇒

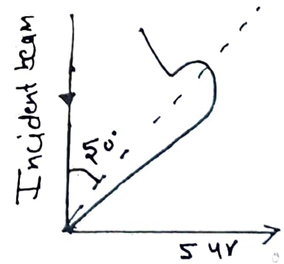
Darission and Germer performed an experiment to study the wave nature of electron.

* The beam of electron is made to fall on the nickel crystal as shown in the fig.
* The scattered beam of electron is recieved by the detector which can be positioned at any angle by rotating it about point the point of incidence.

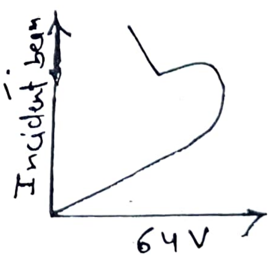


Observation ⇒ According to classical physics the intensity of scattered beam of electrons at all the scattering angles will be same but when the graph b/w the intensity of scattered beam of electrons at different angles of scattering at different accelerating voltages were plotted by Darission and Germer they found that intensity is not same.





They found that when the incident beam of electrons accelerated through a potential of 54 V and was made to incident on Ni crystal the intensity was max at 50°



By de Bragg's law $2d\sin\theta = n\lambda$

$n = 1 \quad d = 0.914 A°$

$\lambda = 1.65 Å$

By De-Broglie's hypothesis

$$\lambda = \frac{h}{\sqrt{2mK.E}} = \frac{12.3}{\sqrt{V}} = \frac{12.3}{\sqrt{54}} = 1.66 \text{ A}$$

In both way we got same wave length so it proves existence of de-Broglies wave.