Chapter 11 : Dual nature of matter and radiation.

Work function: Minimum energy required by an electron to be emitted from a metal surface is called as work function.
It is expressed in "eV" ($1 eV = 1.6 \times 10^{-19} J$)

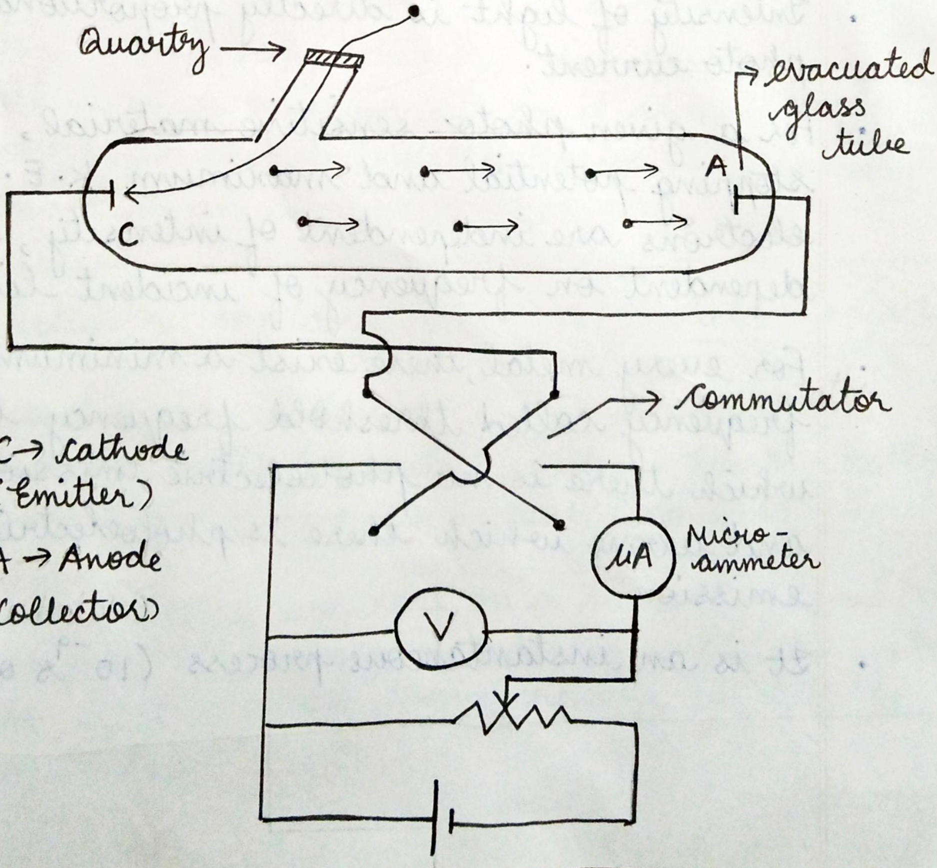
3 methods of electron emission:

a) Thermionic emission - by heating the metal surface, electrons are emitted.

b) Field emission - by applying a high electric field across the metal surface, electrons are emitted.

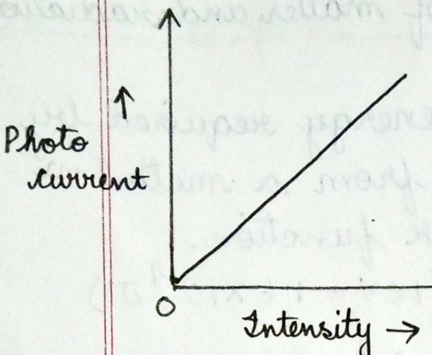
c) Photoelectric emission - when light of suitable frequency is incident on a metal surface, electrons are emitted from the metal surface

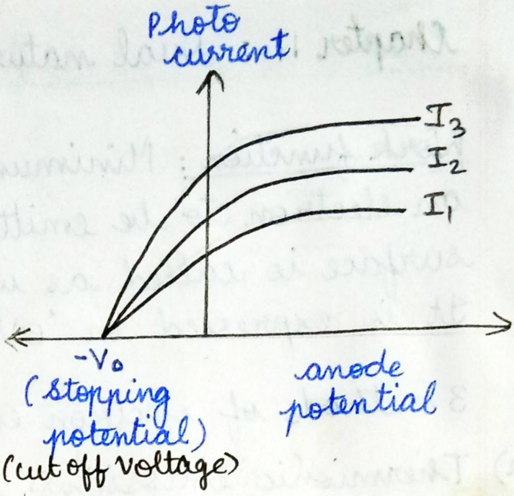
Hallwach's and Lenard's expt.

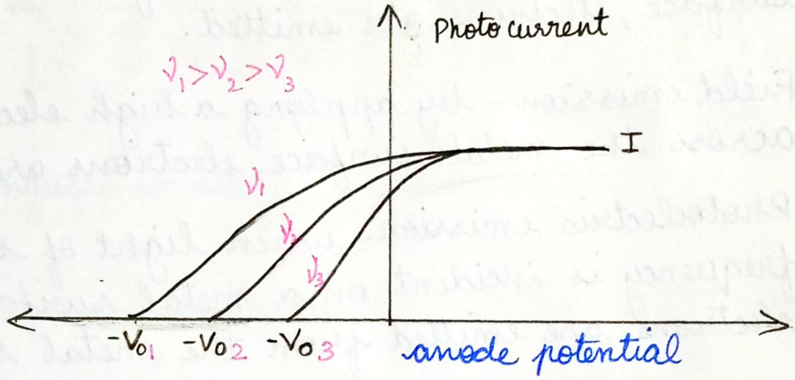


C → Cathode (Emitter)

A → Anode (Collector)







Laws of photoelectric emission:

- Intensity of light is directly proportional to photo current.
- For a given photo-sensitive material, stopping potential and maximum K.E. of electrons are independent of intensity, but dependent on frequency of incident light.
- For every metal, there exist a minimum frequency called threshold frequency below which there is no photoelectric emission and above which there is photoelectric emission.
- It is an instantaneous process (10^{-9} s or less)

Stopping potential: The negative potential given to the anode so that photo current reduces to zero.

At V_0 (stopping potential): $KE_{max} = eV_0$.

Why wave theory could not explain photo-electric effect? (Pg - 393, sec. 11.5, 2, 3 para).

- Greater the intensity of radiation, greater is the amplitude of electric and magnetic field. Hence as intensity ↑ ses, energy absorbed by each electron should also increase. Therefore max. KE. of e^- must be dependent on intensity.
- Whatever may be the frequency of radiation, if the beam is sufficiently intense, it should be able to impart enough energy to the electrons to be emitted from the metal surface. So threshold frequency should not exist.
- As the no. of free electrons in a metal is very large, the energy absorbed per electron per unit time is very small. So it should take hours for the electron to be emitted. Hence it cannot be an instant process.

Einstein's explanation of photoelectric effect.

According to Einstein, light consists of discrete units / quanta / photon. Each photon has energy $E = h\nu$ (h = plank's const.)

When light is incident on a metal surface, each photon undergoes elastic collision with each electron and transfers the energy to the electron.

Part of the energy is utilised by the electron to come out of the metal surface, and the rest of the energy appears as its kinetic energy.

Hence $KE_{max} = h\nu - \phi_0$.

This is called Einstein's photoelectric equation.

a) As there is no intensity term in the equation, maximum KE of e^- and stopping potential are dependent on frequency, but independent of intensity.

b) $KE_{max} > 0$.

$h\nu - \phi_0 > 0$.

$h\nu > \phi_0$.

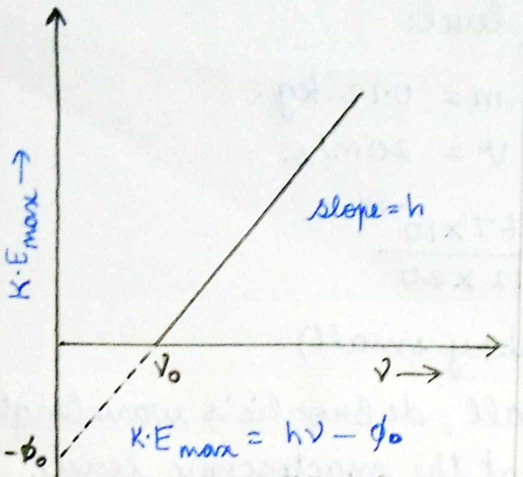
$h\nu > h\nu_0$

$\nu > \nu_0$. ; ν_0 = threshold frequency.

Hence threshold frequency exists.

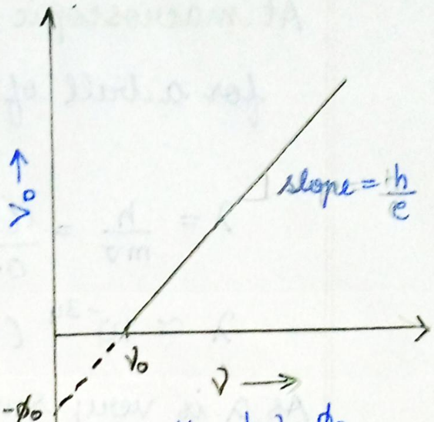
c) Intensity is proportional to no. of photons incident per unit area per unit time. So if intensity increases, no. of photons incident on the metal surface will increase and so more no. of collisions and hence more e^-s will come out of the metal. Hence photocurrent $\propto$ Intensity.

d) As it is basically elastic collision between photon and electron, it is an instantaneous process.



$K \cdot E_{max} = h\nu - \phi_0$

$y = mx + c$



$eV_0 = h\nu - \phi_0$

$\therefore V_0 = \frac{h}{e}\nu - \frac{\phi_0}{e}$

$y = mx + c$

Characteristic properties of a photon:

1) Each photon has energy $E = h\nu$ and momentum $p = \frac{h\nu}{c}$

2) They are neutral, they can't be deflected by electric and magnetic field.

3) During photon–electron collision, total energy and total momentum are conserved as it is. (elastic collision)

Debroglie's hypothesis:

- According to de Broglie, every moving material particle has a wave nature associated with it.
- The de Broglie wavelength of a moving material particle is given as: $\lambda = \frac{h}{p} = \frac{h}{mv}$

For a photon, $p = \frac{h\nu}{c}$; $\frac{h}{p} = \frac{c}{\nu}$.

Hence wavelength of a photon is equal to the wavelength of the electromagnetic radiation of which photon is a part.

At macroscopic level:

for a ball of $m = 0.12$ kg.
$v = 20$ m/s.

$$\lambda = \frac{h}{mv} = \frac{6.67 \times 10^{-34}}{0.12 \times 20}$$

$\lambda \simeq 10^{-34}$ (very small).

As λ is very small, de Broglie's wavelength is insignificant at the macroscopic level.

At microscopic level:

For an e^- accelerated by potential diff. V,

KE of $e^- = eV$.

$$\frac{m}{m} \times \frac{1}{2} mv^2 = eV.$$

$$\frac{m^2 v^2}{2m} = eV$$

$$\frac{p^2}{2m} = eV \quad ; \quad p = \sqrt{2meV}.$$

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}} = \frac{h}{\sqrt{2m\,KE}}.$$

$h = 6.67 \times 10^{-34}$
$m = 9.11 \times 10^{-31}$ kg
$e = 1.6 \times 10^{-19}$ C.

$$\lambda = \frac{1.227}{\sqrt{V}} \text{ n.m}$$ (let V = 120 volts)

$\lambda = 0.112 \times 10^{-9}$ m – significant

As the value is large, de Broglie's wavelength becomes significant at macroscopic level.