Chapter-17
Electrons & Photons

Photons :

The photon is a particle that has energy and momentum but it doesn't have mass and electric charge.

Properties of photon:

* The velocity of photon is different in different medium due to change of its wavelength.
* It travels with the speed of light in the straight line in a vacuum.
* It is not reflected by both electric and magnetic field.
* Each photon has energy $(= hf)$ and momentum equal to $\frac{hf}{c} \left(= \frac{h}{\lambda}\right)$.

Photoelectric effect:

When light or electromagnetic radiation such as x-rays, uv-rays falls on a metal surface it emits electron. This phenomena of emission of electron from metallic surface when radiation of suitable frequency falls on it is called photoelectric effect. These electron are photoelectron.

Impt Important terms:

1. Threshold frequency (f_0):

The minimum frequency of incident radiation at which the photoelectric emission will occur is called threshold frequency. Different metal have different threshold frequency.

2. Threshold wavelength (λ_0):

The wavelength crossponding to threshold frequency is known as threshold wavelength.

We have,

$$\lambda_0 = \frac{c}{f_0}$$

where c = speed of light in vacuum
f_0 = threshold frequency

Since threshold frequency is minimum frequency so that threshold wavelength is maximum wavelength.

3. Work function (ϕ):

The minimum amount of energy required to take a free electron out of metal surface is known as work function. It's value depends upon the nature of metal.

If f_0 be the threshold frequency of incident radiation for given metal then work function is given by,

$$\phi = hf_0 \quad (h = \text{Plank's constant})$$

Quantum theory of radiation : $E=hf$

According to this theory, the energy associated with each photon of frequency 'f' is given by,

$$E=hf$$

(where 'h' is plank's constant)

V.imp: Einstein's photo electric equations

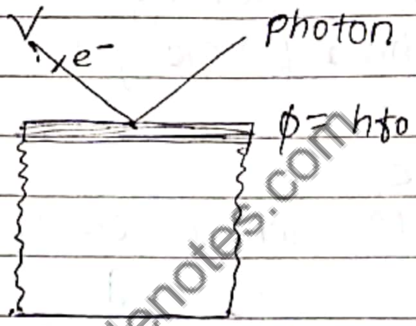


fig: photoelectric effect

When photon of energy 'hf' is incident on a metal surface then a part of energy is used to eject an electron from the surface and rest of energy is used to accelerate the photoelectron as shown in figure above.

If 'm' be the mass and 'v' be the velocity of emitted photoelectron then K.E of emitted photoelectron is given by,

$$K.E = \frac{1}{2}mv^2$$

But, energy of incident photons = work function + K.E of emitted electron

$$hf = hf_0 + \frac{1}{2}mv_{max}^2$$

Frenz

$$h(f - f_0) = \frac{1}{2} m V_{max}^2 \quad \text{--- (I)}$$

Equation (I) is Einstein's photo electric equation

Also,

$$f = \frac{c}{\lambda}$$

$$\& \; f_0 = \frac{c}{\lambda_0}$$

then eqn (I) become

$$h\left(\frac{c}{\lambda} - \frac{c}{\lambda_0}\right) = \frac{1}{2} m V_{max}^2$$

$$hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right) = \frac{1}{2} m V_{max}^2$$

$$(K.E)_{max} = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right) \quad \text{--- (II)}$$

This equation shows that kinetic energy of photoelectron varies with wavelength of incident radiation.

Experimental study of photoelectric effect:

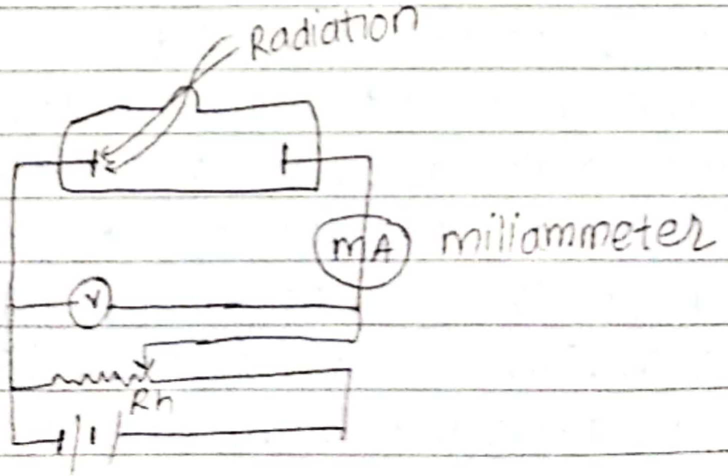


fig: Experimental arrangement for the study of photoelectric effect

The experimental arrangment consist of evacuated glass tube with two electrodes cathod 'c' and anode 'a' as shown in figure above. A constant potential difference is applied between cathode and anode with help of battery. Photoelectric current is measured by miliammeter and potential difference is measured by voltmeter.

When a suitable frequency of radiation falls on cathode electrons are emitted and they are accelerated towards anode If it is kept at up positive potential with respect to cathode Due to flow of electron current is flow in the circuit which is called photoelectric current.

When potential of anode is varied then photoelectric current also varied. It is found that the photoelectric increase with the increase in positive potential on the anode and it becomes maximum when all the emitted electrons from cathod reaches at anode. This current is called saturation current. There is not further increase of photoelectric current with increase in positive potential at anode.

When negative potential is applied to anode with respect to cathode then photoelectric current decreases and finally becomes zero at certain value of ~~-ve~~ negative potential. The value of negative potential at which photoelectric current becomes zero is called stopping potential / cut off potential (V_0). In this case workdone by stopping potential is equal to the maximum kinetic energy of the photoelectrons emitted.

$$\therefore eV_0 = \frac{1}{2} m V_{max}^2$$

The effect of potential on photoelectric current is shown in graph below:

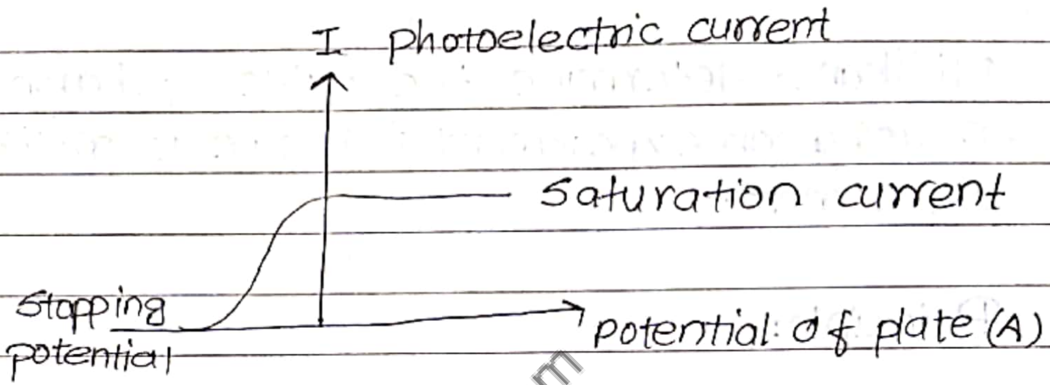


Fig: effect of potential on photoelectric current

Electron:

The sub atomic particle with negative charge about $1.6 \times 10^{-19}C$ and having mass $9.1 \times 10^{-31}kg$ is known as electron.

Millikan's oil drop experiment

Millikan's determine the value of charge of an electron using an experiment is known as Millikan's oil drop experiment.

Principle:

Millikan's oil drop experiment is based on stokes law of viscocity. This law state that, " When sphere of radius (r) falling through a viscus medium of coefficient of viscocity (η) under the action of many forces. It attains steady velocity is called terminal velocity and force on sphere's."

$$f = 6\pi\eta r v$$

Construction:

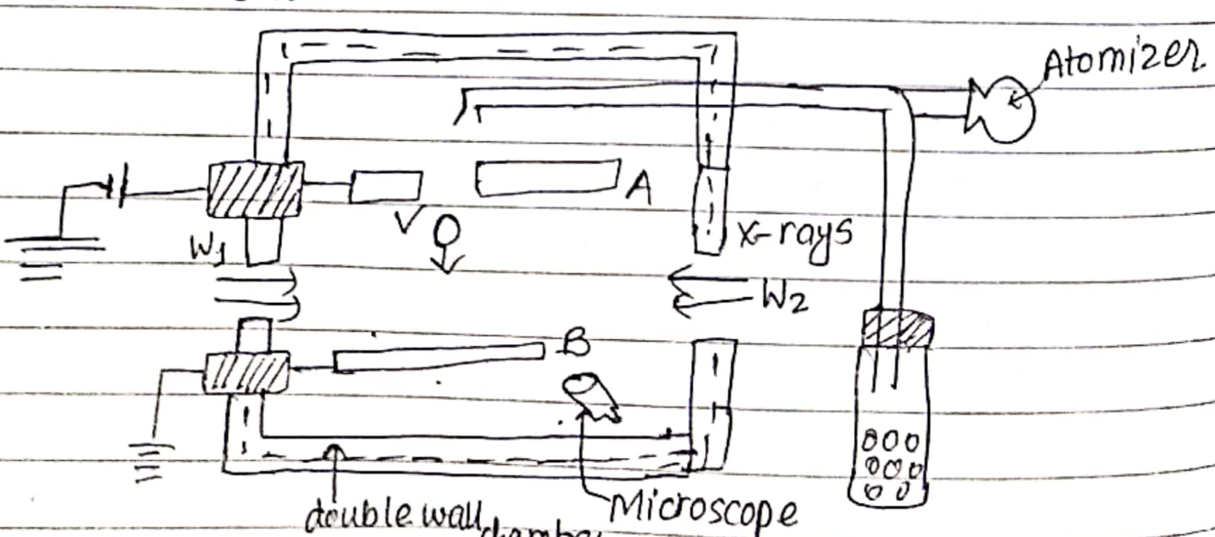
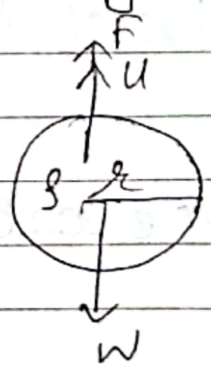


Fig: Experimental arrangment of Millikan's oil drop experiment

The experimental arrangement of this experiment consist of double walled chamber having two windows W_1 and W_2 as shown in figure above. The window (W_1) is used to pass light in order to illuminate (shine). The oil drop and window 'W_2' is used to pass x-ray in order to ionized oil drop. Inside the double walled chamber, there are two metal plate A and B where plate 'A' have hole at it's centre. The upper plate 'A' is connected to a high tension battery while the lower plate is connected with ground. Lock oil (a non-volitile liquid) can be sprayed into the hole at upper plate 'A' with the help of atomizer. The microscope is provided with a crosswire and micrometer scale. So that the motion of the oil drop can be observed and measured.

(i) Motion of oil drop under gravity :

When electric field is not applied, the oil drop falls under gravity with increasing velocity. When the viscus force act on oil drop, then its velocity becomes constant called terminal velocity.



where, r = radius of oil drop
ρ = density of oil drop
σ = density of air
v_1 = terminal velocity

Frenz

Now,

volume of oil drop $(V) = \frac{4}{3}\pi r^3$

Weight of oil drop (W_1) = mass of oil drop × g

$$\therefore mg = V \cdot \rho \cdot g$$
$$= \frac{4}{3}\pi r^3 \rho g$$

Again,

Upthrust due to air (U) = wt. of air displaced by the oil drop

$$= \frac{4}{3}\pi r^3 \sigma g$$

Also,

Viscus force $(F) = 6\pi\eta r V_1$

When oil drop moving with constant velocity,

$$F + U = W$$

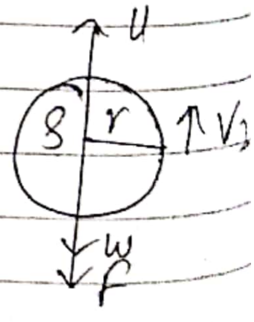
$$6\pi\eta r V_1 + \frac{4}{3}\pi r^3 \sigma g = \frac{4}{3}\pi r^3 \rho g$$

$$6\pi\eta r V_1 = \frac{4}{3}\pi r^3 (\rho - \sigma) g \quad \text{— (A)}$$

$$r = \sqrt{\frac{9\eta V_1}{2(\rho-\sigma)g}} \quad \text{— (1)}$$

eqn (1) measure the radius of oil drop.

(II) Motion of oil drop under electric field



When strong field is applied between two plates, the negatively charged oil drops moves in upward direction and soon attains a terminal velocity (v_2) in upward direction.

Also let 'ε' be electric field intensity and 'q' be the charge, then electric force on oil drop in upward direction be

$$F_e = qε$$

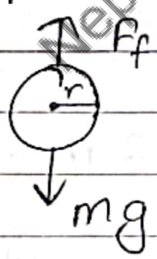
& viscus force in downward direction is

$$F = 6\pi \eta r v_2$$

when the oil drop attains terminal velocity v_2 then,

$$F_e + U = W + F$$

(iii) When oil drop is at rest or stationary



$$F_e = W$$

$$qε = mg$$

$$qε = V\rho g$$

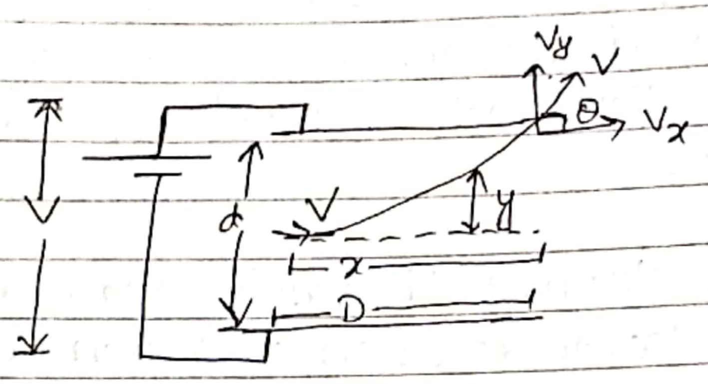
$$= \frac{4}{3}\pi r^3 \rho g$$

Also

$$q = ne$$

$$ε = \frac{V}{d} \quad \text{where } V = P.D$$

Deflection of the electron inside the electric field



Let us consider an electron of charge 'e' is inside the electric field of strength 'E' as shown in figure. Then force experienced by an electron inside the electric field.

$$F = eE$$

Thus acceleration produced on this electron is,

$$a = \frac{F}{m}$$

$$a = \frac{eE}{m} \quad \text{—(I)}$$

where m = mass of electron

If 'y' is the deflection in vertical direction in time 't' then,

$$y = u_y t + \frac{1}{2} at^2$$

$$y = \frac{1}{2} at^2$$

$$y = \frac{1}{2} e \frac{E}{m} t^2 \quad \text{—(II)} \quad \text{using eqn (I)}$$

If 'x' be the horizontal distance in time 't'

$$x = u_x t$$

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Page No.

$$x = vt$$
$$t = \frac{x}{v} \quad \text{— (III)}$$

Using eqn (III) in (II)

$$y = \frac{1}{2} e \frac{E}{m} \left(\frac{x}{v}\right)^2 \quad \text{— (IV)}$$

If 'v' be the potential difference between two plates of separation 'd' then electric field is given by

$$E = \frac{V}{d}$$

then eqn (IV) becomes.

$$y = \frac{1}{2} e \frac{V}{md} \left(\frac{x}{v}\right)^2 \quad \text{— (A)}$$

$$y = \frac{1}{2}\left(e \frac{V}{md\vartheta^2}\right) x^2$$

where V = potential difference
ϑ = velocity

$$y = kx^2 \quad \text{— (V)}$$

where $k = \frac{1}{2} e \frac{V}{md\vartheta^2}$

Equation (V) represent the equation of parabola. Hence the path of an electron inside the electric field is parabolic in nature.

When the electron just pass the plate,

$$x = D$$

then eqn (A) becomes

$$y = \frac{1}{2}\left(\frac{eV}{md}\right)\left(\frac{D}{v}\right)^2$$

Let θ be the angle at which the beam emerged out from the field. Then,

$$\tan\theta = \frac{v_y}{v_x}$$

where, $v_y = at$

$v_x = v$

Motion of electron in magnetic field

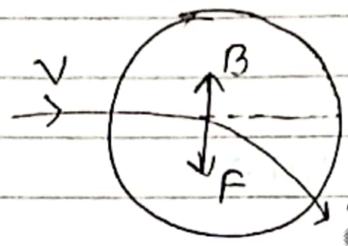

fig: Motion of electrons in magnetic field

Let us consider a beam of electron moving with velocity 'v' horizontally enters inside uniform magnetic field 'B' perpendicular to direction of 'v'. When it enters inside the magnetic field, a lorentz force act on a electron beam which is given by,

$$\vec{F_L} = e(\vec{v} \times \vec{B})$$

$$= evB \sin 90° \hat{n}$$

$F_L = evB \rightarrow (1)$ (magnitude only)

This force is perpendicular to both B and v. Due to this electron deflected into a circular path as shown in figure above.

Suppose 'm' be the mass of electron and 'r' be the radius of circular path inside the magnetic field.

Then the lorentz force provide the necessary centripetal force.

i.e lorentz force = centripetal force

$$BeV = \frac{mv^2}{r}$$

$$r = \frac{mv}{Be} \quad \text{— (ii)}$$

This relation gives the radius of circular path.

Also,

$$Be = \frac{mv}{r}$$

$$Be = \frac{m\omega r}{r} \quad \because V = \omega r$$

$$\omega = \frac{Be}{m} \quad \text{— (iii)}$$

So, frequency of electron inside the magnetic field is given by,

$$f = \frac{\omega}{2\pi} \quad (\because \omega = 2\pi f)$$

$$f = \frac{Be}{2\pi m} \quad \text{— (iv)}$$

&,

time period of electron inside magnetic field is,

$$T = \frac{1}{f}$$

$$T = \frac{2\pi m}{Be}$$

Note:

$$eE = BeV = \frac{mv^2}{r}$$

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

Impt

J.J Thomson experiment :

J.J thomson discuss an experiment to determine the specific charge of electron $\left(\frac{e}{m_e}\right)$ which is known as J.J Thomson experiment.

Principle:-

When a beam of electron is subjected to uniform electric field and magnetic field acting perpendicular to each other in such a way that deflection produce by other is cancelled by deflection produced by another. Then path of beam of electron remains undeflected.

Construction:

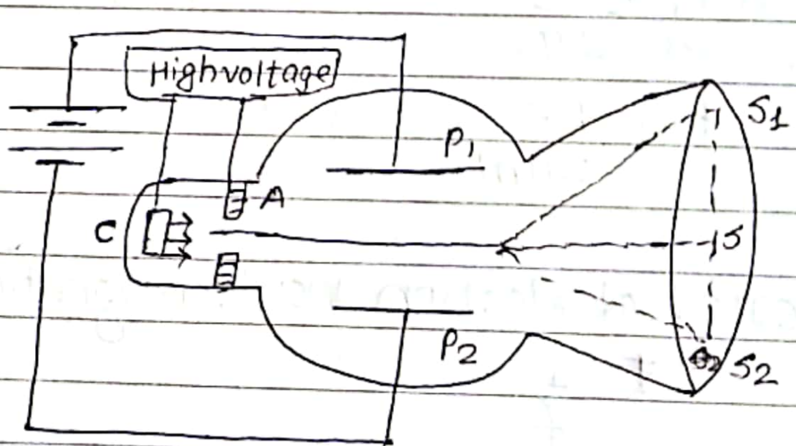

Fig: Experimental arrangment of J J Thomson experiment

Experimental arrangement of J J Thomson consist of cathode (C) and anode (A) which are enclosed in a evacuated discharge tube. When high voltage is applied between cathode and anode, a fine beam of electrons emits from cathode and through the hole of anode they pass between two parallel plates P_1 & P_2.

When electric field is applied between two plates P_1 & P_2 then electron beams deflected upward and appears at position s_1. And when magnetic field is applied the electron beam deflected downward and appears at position 's_2'. But when both electric & magnetic field is applied then electron beams remains undeflected and appears at position 'S'.

Theory:

When a potential difference (V_0) is applied between cathode and anode, the beam of electron is highly accelerated and gain a velocity 'v' whose kinetic energy is given by,

$$eV_0 = \frac{1}{2} m v^2$$

$$\frac{e}{m} = \frac{1}{2} \frac{v^2}{V_0} \quad \text{--- (1)}$$

When both magnetic and electric field are applied perpendicular to each other such that the beam of electron does not bend. Then the magnetic force and electric force are equal.

i.e. electric force = magnetic force

$$eE = BeV$$

$$V = \frac{E}{B} \quad \text{—(II)}$$

using eqn (II) in eqn (I)

$$\frac{e}{m_e} = \frac{1}{2} \frac{E^2}{B^2 V_0}$$

$$= \frac{E^2}{2B^2 V_0} \quad \text{—(III)}$$

If V be the potential difference ~~two~~ between two plates and 'd' be separation between them.

Then electric field $(E) = \frac{V}{d}$ —(IV)

using eqn (IV) in (III)

$$\frac{e}{m_e} = \frac{V^2}{2B^2 d^2 V_0}$$

By knowing the value of V, B, d & V_0 we can find the value of $\frac{e}{m_e}$ or specific charge.

By using this experiment, J.J thomson calculate the value of specific charge,

$$\frac{e}{m} = 1.77 \times 10^{11} \text{ C/kg}$$

Cathode Rays:

The glow is due to flourescence of glass produced by the invisible rays coming from the cathode called cathode rays.

Properties of Cathode Rays:

1. They travels in the straight lines perpendicular to the surface of the cathode.
2. They exert mechanical pressure.
3. Cathode rays produce flourescence.
4. They affect photographic plate.
5. They ionize the gas through which they pass.
6. They can produce chemical changes.
7. They can penetrate a thin sheet of matter.