Unit - 3

Electron

J.J thomson experiment to determine the specific charge of electron (e/m).

Specific charge of electron:- It is defined as the ratio of charge of electron to it's mass.

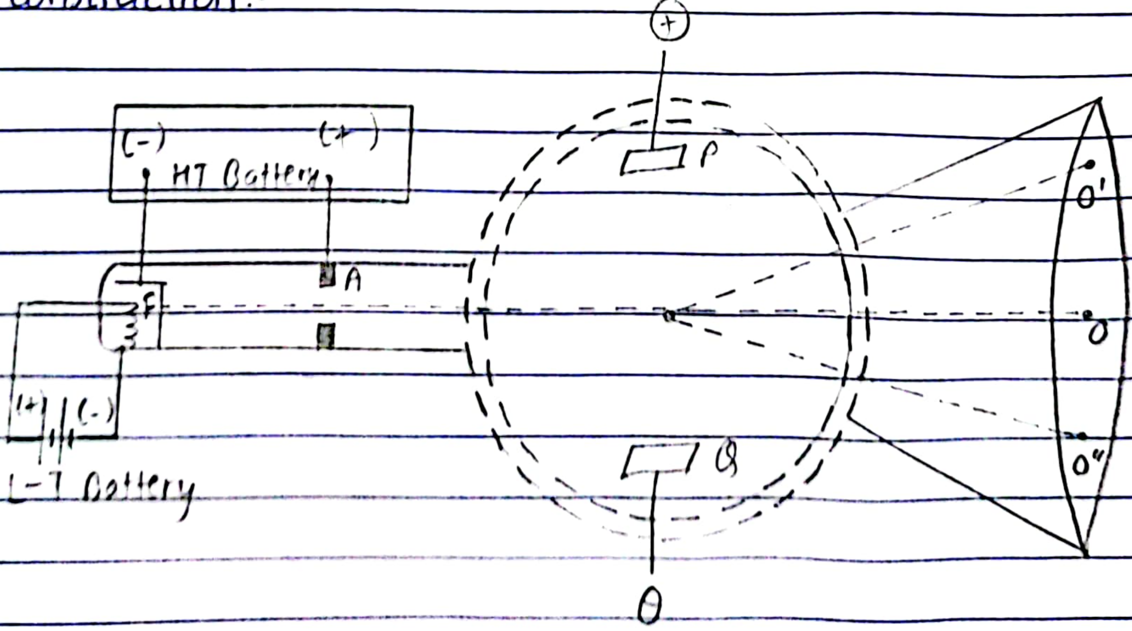
Principle:- It is based on the principle of cross field i.e. when the beam of electron is subjected to the cross field, than the deflection produced by electric field is cancelled by deflection produced due to magnetic field.
Thus, at crossfield

Force due to electric field = Force due to magnetic field

$$eE = Bev$$

$$\text{or} \quad v = \frac{E}{B} \quad ----- (i)$$

Construction:-



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The experimental diagram for Thomson experiment is shown in the figure. It consist of hard glass tube inside which a filament is kept which is heated with the help of low tension (L.T) battery as a result electrons are emitted. The emitted electron gets accelerated towards anode and reaches to the crossfield where the two parallel plates P, Q produces electric field and the circular coil produces magnetic field.

Theory:- When no any field is applied, then the beam of electron passes through the crossfield without any deviation and strike at ~~it~~ 'O' point of the screen. If both fields are applied then also electron passes through crossfield without any deviation and strikes at same point of screen. If only electric field is applied then the beam of electron after passing through the crossfield gets deflected in upward direction and strikes at 'O'' point of screen. But if only magnetic field is applied then the beam of electron gets deflected in downward direction and strikes at 'O''' point of screen.

If 'm' be the mass of electron and 'e' be it's charge, then the K.E ~~eon~~ gained by electron is given by

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

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or $\frac{e}{m} = \frac{1}{2}\frac{v^2}{V}$

or $\frac{e}{m} = \frac{1}{2}\frac{E^2}{B^2V}$ $\quad \left[\because v = \frac{E}{B}\right]$

$$\boxed{\therefore \frac{e}{m} = \frac{1}{2}\frac{E^2}{B^2V}}$$

On knowing the value of quantities on R.H.S we can calculate the value of specific charge of electron.

Proton – 1.672×10^{-27} kg
Neutron – 1.675×10^{-27}
Electron – 9.1×10^{-31} kg

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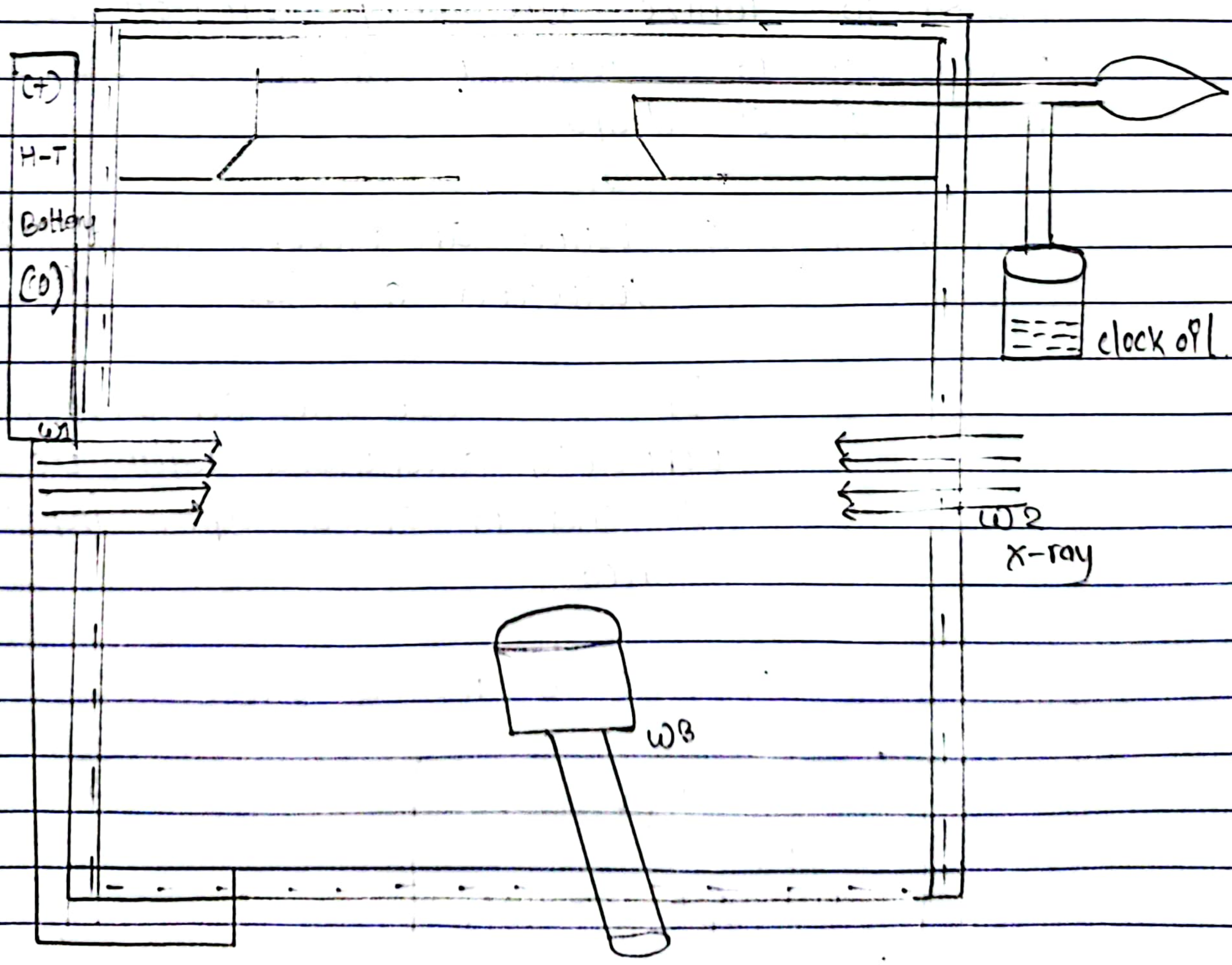
Milkan's oil drop experiment

Principle:- It is based on the principle of ~~et~~ Stoke's law. According to Stoke's law when a sphere of radius 'r' falls through a viscous medium having coefficient of viscocity 'η' is acted upon by many forces and attains a uniform velocity called terminal velocity. Then the net force acting on it is given by:

$$\boxed{F_{net} = 6\pi\eta r v_t}$$

Construction:



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The experimental diagram for Milken's oil drop experiment is shown in the figure. It consist of double walled chamber inside which two parallel plates are kept which is 1.5cm apart. The upper plate is connected to the positive terminal of H-T battery while the lower plate is connected to the -ve terminal of the battery. At upper plate a small hole is made through which the oil drop enters between the plates whenever atomizer is ~~provided~~ ~~wi~~ compressed. The double walled chamber is provided with three windows. Through W_1 light rays are passed which illuminates the oil drops, through W_2 x-rays are passed to ionize the drop, through W_3 a microscope is attached in order to observe the motion of oil drops.

Step-I

Working Theory:- When an electric field is switched off.

In this case the oil drop moves vertically downward with velocity v_1 and is acted upon by two forces

i) Due to it's weight $= mg$

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

$$\left[\begin{array}{c} \because \rho = m/v \\ m = \rho v \\ \text{Vol. sphere} = \frac{4}{3}\pi r^3 \end{array}\right]$$

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2) Due to upthrust in air $(U) = V\sigma g$

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

The net force acting on the oil drop is given by

$$F_{net} = mg - U$$

or $6\pi\eta r v_1 = \rho \times \frac{4}{3}\pi r^3 \times g - \frac{4}{3}\pi r^3 \times \sigma \times g$

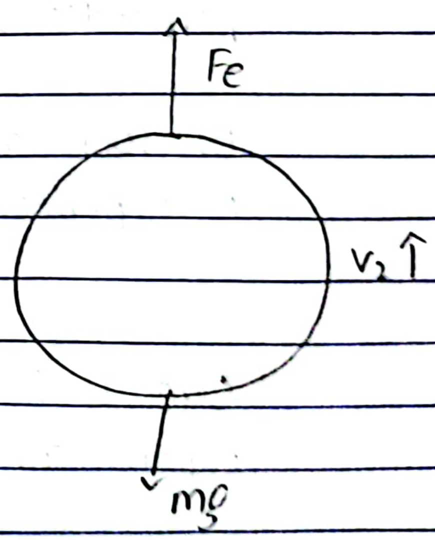
or $6\pi\eta r v_1 = \frac{4}{3}\pi r^2 (\rho - \sigma) g$

or $9\eta v_1 = 2r^2(\rho - \sigma) g$

or $r = \sqrt{\frac{9\eta v_1}{2(\rho - \sigma) g}}$

Case: II (When electric field is switched on)

In this case the oil drop moves vertically upward with velocity 'v_2' and is acted by 3 forces.



1) Due to it's weight $= mg$
2) Due to upthrust $U = V\sigma g$
3) Due to electric field $f_e = qE$

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The net force acting on the oil drop is given by

$$f_{net} = f_e + U - mg$$

or $6\pi\eta r v_2 = qE - (mg - U)$

or $6\pi\eta r v_2 = qE - 6\pi\eta r v_1$

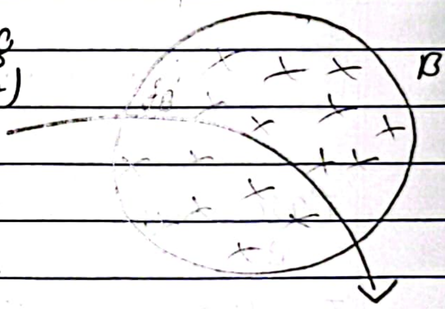
or $6\pi\eta r (v_2 + v_1) = qE$

or $q = \dfrac{6\pi\eta (v_2 + v_1)}{E} \sqrt{\dfrac{9\eta v_1}{2(\rho - \sigma) g}}$

On knowing the values of quantities on RHS. We can calculate the value of charge in oil drop.

Motion of electron in magnetic field

Consider a beam of electron having mass 'm' moving with velocity (v) that enters into magnetic line region of uniform magnetic field perpendicularly as shown in figure.



As soon as electron enters into uniform magnetic field it experiences a force which is given by:

$$f_B = BeV \quad \text{——} (i)$$

Due to this force electron moves in a circular path and experiences centripetal force. Which is given by

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

But $f_B = f_c$

or $Bev = \dfrac{mv^2}{r}$

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$$\text{or } \boxed{r = \frac{mv}{Be}}$$ → which is the required expression for radious path.

again, $r = \frac{m\omega r}{Be}$

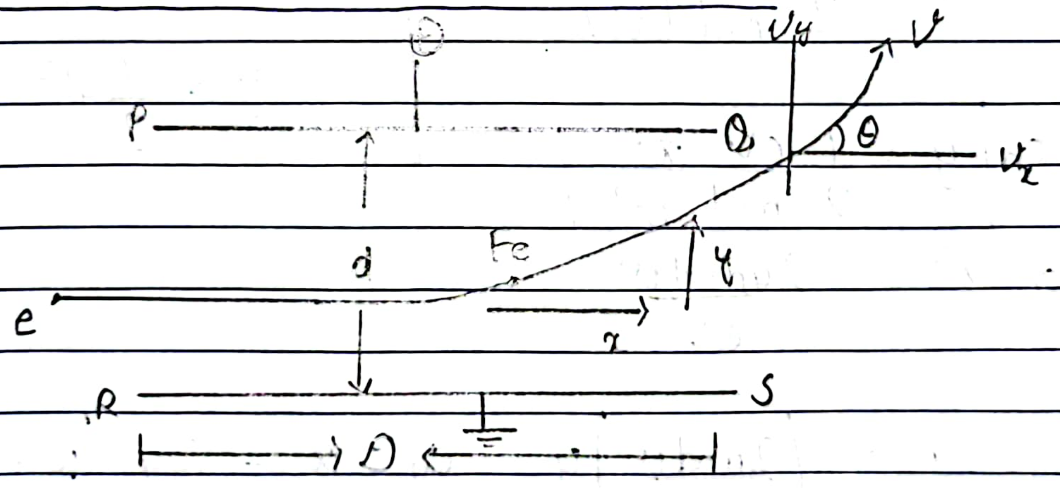
or $Be = \frac{m \times 2\pi}{T}$ or $\boxed{T = \frac{2\pi m}{Be}}$ ——— (iii)

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

or $\boxed{f = \frac{Be}{2\pi m}}$ ——— (v)

From eqⁿ (iii) and (iv) it is clear that both frequency and time period are independent of velocity of electron.

- Motion of electron in electric field



Consider a beam of electron having mass 'm' moving horizontally with velocity (v) and enters the ~~electric~~ region of electric field set up by two parallel plates PQ and RS as shown in figure.
As soon as electron enters in the region of electric field it experiences a force due to electric field which is given by

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$$F_e = eE \text{ ——— (i)}$$

Also,

The upward acceleration experienced by electron is given by

$$\boxed{E = \frac{V}{d}} \qquad ma = eE$$

$$a = \frac{eE}{m} = \frac{eV}{md}$$

Suppose electron travels horizontally 'x' distance and vertically 'y' distance. Then,

$$\text{(ii) ——— } x = v \times t \qquad \boxed{\because v = \frac{d}{t} \rightarrow x}$$

Also,

$$y = \frac{1}{2}\frac{eV}{md}\left(\frac{x}{v}\right)^2 \qquad \left[\because S = ut + \frac{1}{2}at^2 \quad y = \frac{1}{2}at^2\right]$$

$$\text{or } \boxed{y = \frac{1}{2}\frac{eV}{md}\frac{x^2}{v^2}}$$

$$\text{or } x^2 = \frac{2ymdv^2}{eV}$$

$$\text{or } x^2 = \left(\frac{2mdv^2}{eV}\right)y \quad \text{or } x^2 = 4ay \left(\text{where } 4a = \frac{2mdv^2}{eV}\right)$$

$$x^2 = 4ay \text{ ——— (iii)}$$

From eq^n (iii)

It is clear that the motion of eletron in electric field is parabolic in nature.

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Vertical velocity (v_y)

For vertical velocity $(v_y) = at$

$$\text{or } v_y = \left(\frac{eV}{md}\right)\left(\frac{D}{v}\right)$$

Resultant velocity (v)

The resultant velocity can be calculated by using formula

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{v^2 + v_y^2}$$

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

Deflection (θ)

It is calculated by using formula

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

$$\text{or } \theta = \tan^{-1}\left(\frac{v_y}{v_x}\right)$$

$$\theta = \tan^{-1}\left(\frac{eVD}{mdv^2}\right)$$

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Q. What are the importance of Milkan's oil drop experiment?

⇒ Following are the importance of Milkan's oil drop experiment:-

1) The electron have smallest charge.
2) It proves quantization of charge
   i.e, $q = ne$ where, $n = 1, 2, 3 \ldots\ldots$
3) From Milkan's oil drop experiment the mass of electron can be determined as

$$\left(\frac{e}{e/m}\right) = \frac{1.6 \times 10^{-19}}{1.75 \times 10^{11}}$$

$$= 9.1 \times 10^{-31} \text{ kg}$$

Q. Beam of proton and electron have same initial K.E enters normally in electric field region. Which one will deflect more and why?

⇒ Since,

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

And,

$$y \propto \frac{1}{m}$$

As deflection is inversely proportional to mass of a particle. So, electron being smaller in mass than proton will deflect more when enters in electric field.

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Q. An electron and proton moves with same speed in a uniform magnetic field of equal magnitude. Compare the radii of their circular path.

⇒ Since,

$$r = \frac{mv}{Be} \qquad \text{And,} \quad r \propto m$$

Radius of path is directly proportional to mass of a particle so, proton being greater in mass than electron will have greater radius thakn that of ~~p~~ electron.

Q. Why is a magnetic field used to deflect electron beam but not electric field in a T.V picture tube?

⇒ As small magnetic field can produce large deflection so, magnetic field is used to deflect electron beam but not electric field ~~in a~~ ~~Tv~~ ~~picture~~ which requires high voltage or long length of tube.

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Formula

1) Radius of path or orbit $(r) = \frac{mv}{Be}$

2) Radius of oil drop $(r) = \sqrt{\frac{9\eta v}{2(\rho - \sigma)g}}$

3) Force due to electric field $(F_e) = qE$

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

5) Force due to magnetic field $(F_B) = BeV$

6) Vertical deflection $(y) = \frac{1}{2}\left(\frac{eV}{md}\right)\left(\frac{L}{v}\right)^2$

7) acceleration $(a) = \frac{eV}{md}$

8) When beam of electron passes without deflection

$$v = \frac{E}{B}$$

9) For equilibrium, stationary, just suspended case

$$qE = mg \text{ ----- (i)}$$

$$\frac{qV}{d} = mg \text{ ------ (ii)}$$

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$$\frac{qV}{d} = \frac{4}{3}\pi r^3 \times \rho \times g \text{ ------ (iii)}$$

$$\frac{\eta eV}{d} = mg \text{ ------ (iv)}$$

Where, $m = 9.1 \times 10^{-31}$ kg
B = magnetic field
v = velocity of electron
$e = 1.6 \times 10^{-19}$ C
η = coefficient of viscosity
ρ = density of oil drop
σ = density of medium
g = acceleration due to gravity
E = electric field
V = Potential difference
d = separation of plates

10) Resultant velocity when electron emerges out of two parallel plates.

$$v = \sqrt{v^2 + \left(\frac{eVL}{mdv}\right)^2}$$

11) Charge in oil drop

$$q = \frac{6\pi\eta}{E}(v_1 + v_2)\sqrt{\frac{9\eta v_1}{2(\rho-\sigma)g}}$$

12) $v = \sqrt{\frac{2eV}{m}}$ or $\sqrt{\frac{2\,KE}{m}}$