As

S.T

Electron ($_{-1}e^0$)

- Charge: -1.6×10^{-19} C [1909 Robert millikan]
- S.P charge ($\frac{e}{m}$): 1.75×10^{11} C/kg [1897 JJ Thomson]
- Mass: 9.1×10^{-31} kg OR 5.48×10^{-4} amu OR 0.511 MeV
- Spin: $\pm\frac{1}{2}$

Millikan oil drop experiment

- This experiment was performed to find the value of charge of the e^-. This exp is based on the principle of Stokes' law of viscocity. Here a drop of oil is moving freely on the viscous medium (air).
This experiment is based on the measurement of terminal velocity of the oil drop.

(a) Under the effect of gravity alone.
(b) Under the combined effect of electric field & gravity

= This exp arrangement of this experiment is shown in the fig below:

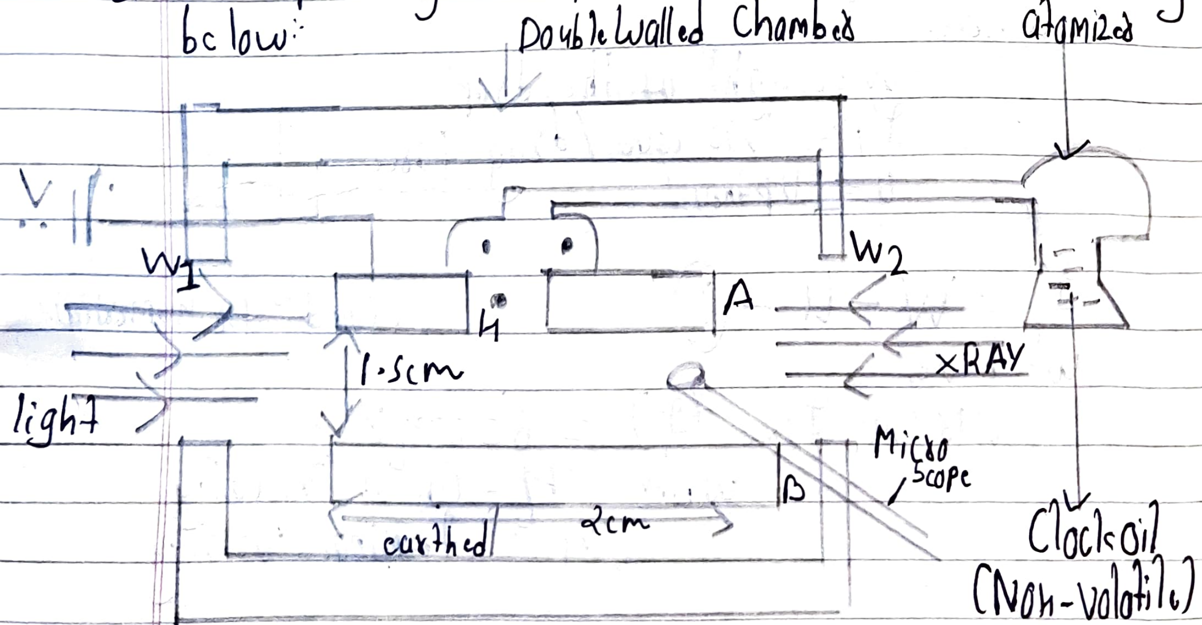

Fig: Millikan's oil drop experiment setup

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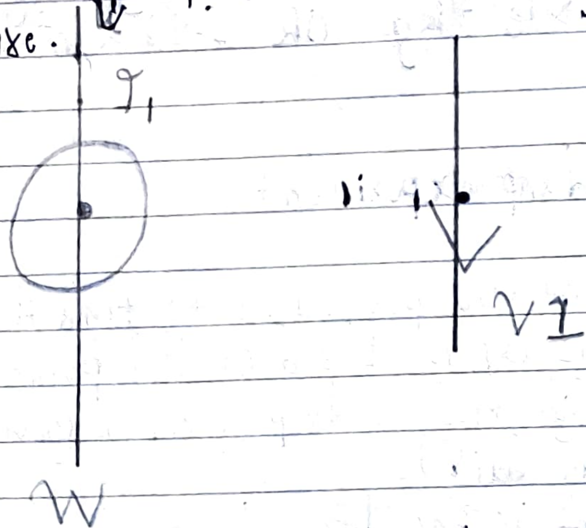
(a) Motion of the drop under the effect of gravity alone (In the absence of electric field).

Let the drop of radius 'r' is falling downward as shown in figure.



As we know, the velocity of the drop goes on ~~there~~ increasing, a time will come at which the drop starts to move with constant velocity (terminal velocity). At this condition net downward force is equal to the net upward force i.e.

$$W = F_1 + U$$

where,

W = weight of the drop
F_1 = Viscous / drag force
U = Upthrust

$$F_1 = W - U \quad \text{—(i)}$$ (condn for numerical)

we have,

Viscous Force $(F_1) = 6\pi\eta r v_1$

where η = Coe of viscosity
v_1 = terminal velocity

weight of the drop

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

ρ = density

Upthrust = wt of air displaced by the drop.

$$\frac{4}{3}\pi r^3 \sigma g \quad (\sigma = \text{density of air})$$

Plugging the value of F_1, U & W in (i) we get

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

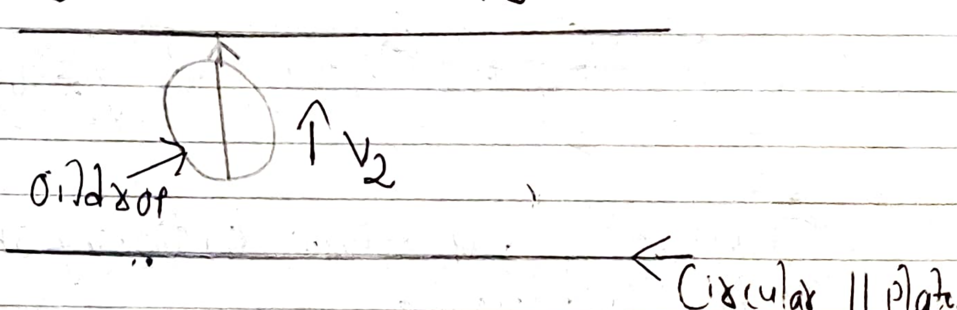
$$6\pi\eta r v_1 = \frac{4}{3}\pi r^3 g(\rho - \sigma)$$

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

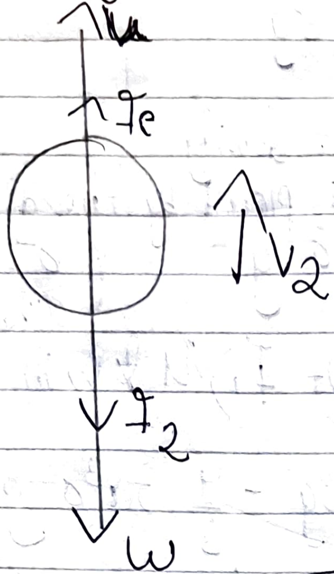
Case-II

Under the combined effect of motion of drop with ~~ef~~ effect of electric field & gravity.

-> As electric field is applied to the plate (circular plate) the drop starts to move vertically upwards towards +ve plate with velocity 'v_2' as shown in fig:



-> As the drop gains terminal velocity (Both forces eq) kept down



U = Upthrust
Fe = Electrostatic force
F_2 = Viscious force
W = mg

$F_e + U = W + F_2$ [For numerical]

$F_e = W - U + F_2$

$F_e = F_1 + F_2$ $[W - U = F_1]$

$QE = 6\pi\eta r v_1 + 6\pi\eta r v_2$

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

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

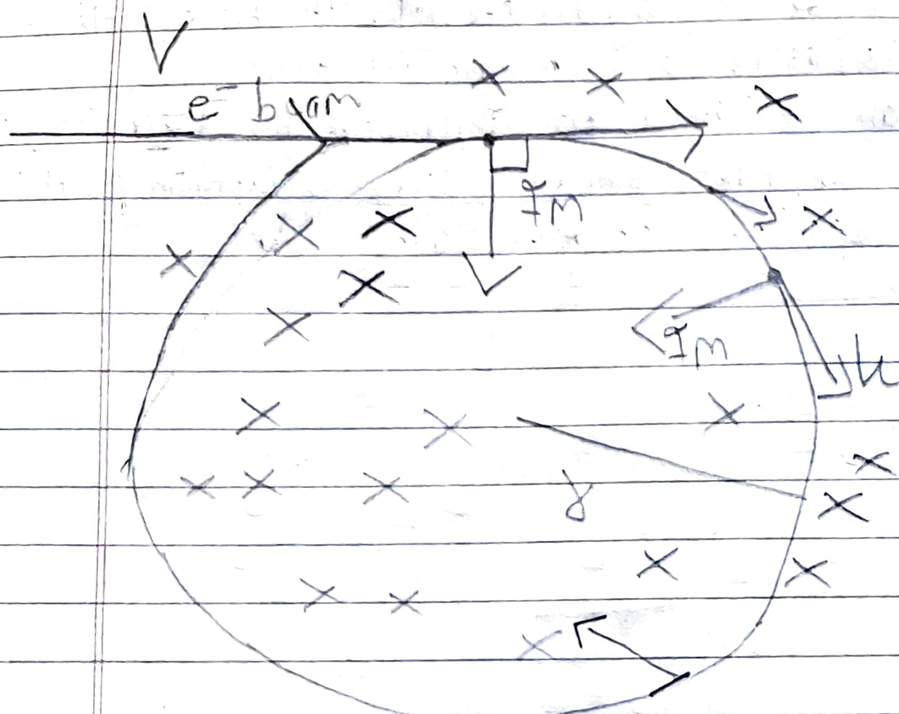
It determine value of charge of e^-

Case I
If the drop falls downward on the application of electric field then,

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

Case II - If drop remains stationary on application of electric field then,
$QE = mg$

II Motion of an electron beam in a magnetic field.



Consider an electron beam is moving in +x direction with uniform velocity V. The beam enters a uniform magnetic field of intensity B acting in $\perp^r$ direction to the direction of motion of the beam so, the magnitude of magnetic force acting on the beam is given by

$$\vec{F_m} = q(\vec{V} \times \vec{B}) \quad (\theta\ VB \sin\theta \ldots)$$

$$F_m = Bev \quad \text{--- (i)}$$

where e is the charge of an e^-

The direction of force is along -ve y-direction (determined by flemming's left hand rule). which is $\perp^r$ to its motion & hence the velocity of beam remains same. The e- beam moves in a circular path having radius r as the magnetic force is always $\perp^r$ to its motion & hence the magnetic force provides the necessary centripetal force to the beam to move in a circular path given by:

$$F_c = \frac{mv^2}{r} \quad \text{(ii)}$$

Where m is the mass of an e⁻.

From (i) & (ii)

$$F_m = F_c$$

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

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

Eqn three gives the radius of circular path.

Let T be the time period of an electron beam covering a distance equal to its circumference & given by

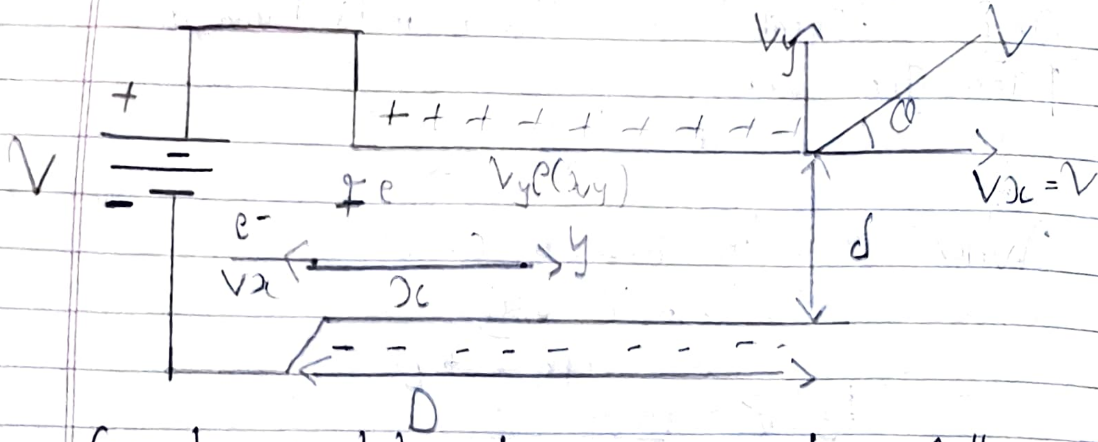
$$T = \frac{d}{v} = \frac{2\pi r}{v} = \frac{2\pi mv}{vBe} = \boxed{\frac{2\pi m}{Be}} \quad \text{(iv)}$$

&

frequency,

$$f = \frac{1}{T} = \frac{Be}{2\pi m} \quad \text{(v)}$$

Motion of an electron in an electric field.



Consider an electron beam is moving horizontally with uniform velocity V_x. This beam enters a constant electric field provided by two parallel plates of length D & are kept at a small distance 'd' apart. The electron beam describes different path from its midway towards +ve plate as shown in fig. The upper plate is connected to the +ve terminal of a high tension battery & the lower plate to the -ve terminal. If V be the potential diff then electric field intensity created in between charged plates is given by

$$E = \frac{V}{d} \quad \text{— (i)}$$

If 'e' be the charge of an electron then the electrostatic force experienced by it is given by

$$F = eE = \frac{eV}{d} \quad \text{— (ii)}$$

$$F = ma$$

If 'm' is the mass of an electron then from Newton's 2nd law, we have

$$a = \frac{F}{m} = \frac{eE}{m} = \frac{eV}{md} \quad \text{— (iii)}$$

Since, the motion of beam is unaffected in horizontal direction.

$$V_x = \frac{x}{t}$$

$$t = \frac{x}{V_x} \quad \text{— (iv)}$$

Since, the electron beam is accelerated in vertical direction. So using eqn of motion, we have

$$y = u_y t + \frac{1}{2} a t^2 = \frac{1}{2} \frac{eV}{md} \left(\frac{x}{V_x}\right)^2$$

$$y = \left(\frac{eV}{2mdV_x^2}\right) x^2 \quad \text{— (V)}$$

Since eqn (V) represents a parabola so the path or trajectory of an electron beam in an electric field is parabolic in nature.

$V = u_y + at$ Let θ be the angle of electron beam emerging from the plate with the horizontal then

$$u_y = u_y + at$$

$$V_y = \frac{eV}{md} \cdot \frac{D}{V_x} \qquad \left\{ V_x = \frac{D}{t} \right\}$$

$$\tan\theta = \frac{V_y}{V_x} \quad \theta = \tan^{-1}\left(\frac{eVD}{mdV_x^2}\right)$$

Determination of specific charge of an e^- by JJ Thompson's method:

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

An exp setup to determine the specific charge of an electron by J J Thompson's method as shown in fig.

It consist of a cathode plate connected with a low tension battery to eject out electrons from its surface & an anode plate A connected to the +ve terminal of a high tension battery to acc^{n} these e⁻ towards anode plate there is a narrow opening at the centre of anode plate through which the e⁻ beam passes & strikes the screen placed ⊥^{r} to the direction of motion of e⁻ beam at point S.

Two horizontal parallel plates are kept parallel to the motion of e⁻ beam such that when an electric field (E) is applied the beam deflects upward towards +ve plate & finally strikes the screen at point S, the electrostatic force is given by

$$F_e = qE \quad \text{(i)}$$

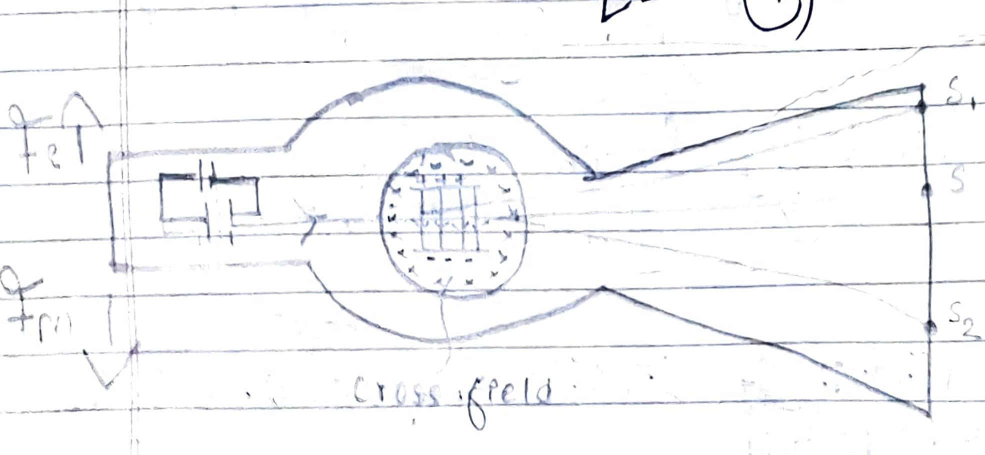


Fig: Evacuated glass tube

When ~~targeted~~ magnetic field of intensity B is applied, the beam deflects downwards & strikes the point S_2 & deflection is in the same plane as that of by electric field. The magnetic force acted upon ~~electric field~~ magnetic field is

$$F_m = BeV \quad \text{—— (ii)}$$

By adjusting the magnitude of these two fields (E & B) in such a way that the beam remains undeflected as before striking at point S. Here, the two fields electric & magnetic acting ⊥r to each other are called cross fields & from eqn (i) & (ii) we can write,

$$F_e = F_m$$

$$eE = BeV$$

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

The electron beam is accelerated initially, by potential diff V the work done on an electron is,

$$W = eV \quad \text{—— (iv)}$$

The change in kinetic energy of an electron inside potential diff V is given by,

$$\Delta K.E = \frac{1}{2}mv^2 \quad \text{—— (v)}$$

where m & v are mass of an electron & final velocity of an electron.

From work-energy theorem, we have

$$W = \Delta K.E.$$

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

$$v = \sqrt{\frac{2eV}{m}} \quad \text{—— (vi)}$$

From (iii) & (vi), we have

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$$\frac{E}{B} = \sqrt{\frac{2eV}{m}}$$

$$\frac{E^2}{B^2} = \frac{2eV}{m}$$

$$\left[\frac{e}{m} = \frac{E^2}{2VB^2}\right] \quad \text{— (vii)}$$

If deflecting potential diff is V' & d be the distance between two parallel plates then from eqn (vii)

$$\frac{e}{m} = \frac{V'^2}{2d^2VB^2} \quad \text{— (viii)}$$

Thomson calculated the specific charge of one e-k found to be 1.76×10^{11} C/kg.