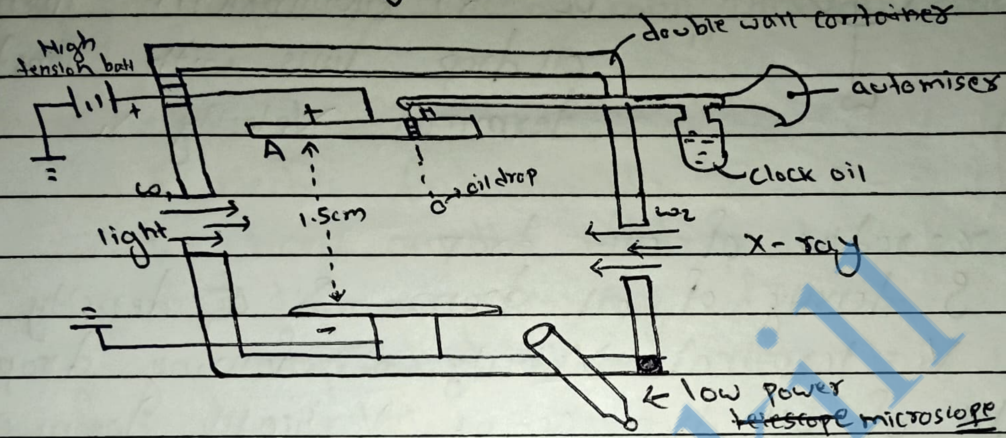
Millikan's oil drop experiment.

Principle:- It is based on the measurement of terminal Velocity of the charge particle on the influence of gravity and electric field.



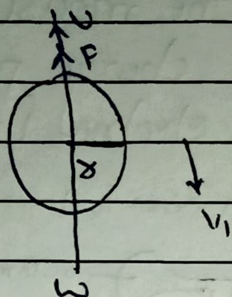
Construction:- It consist of 2 circular metal plates A & B having diameter of 20 cm & are seperate at 1.5 cm distance one plate is connected to +ve terminal of high tension battery & another is grounded. It is placed inside the double wall contai

- one hole is placed at the center of plate A, from where the fine drops of clock oil is sprayed with the help of atomiser.
- These drops gets charge by the friction during their passage through the tube
- for illumination light rays are passed from window (ω_1)
- from win (ω_2), X-rays are passed to ionize the oil drop in case if it doesnot get charge from automiser
- A low power microscope is used to measure the terminal velocity of oil drop.

air = viscus fluid in this case,

1. Motion of oil drop under the infulence of gravity. alone

air



under the infulence of gravity only, at first the oil drop will be in equilibrium then the oil drop falls with constant terminal velocity v_1

let, r = radius of oil drop

ρ = density of oil drop & σ = density of air.

v_1 = terminal velocity of falling drop.

- weight of oil drop acting vertically downward,

$$W = mg = \underbrace{V}_{\text{volume}}\rho g = \frac{4}{3}\pi r^3 \rho g$$

- upthrust on oil drop acting vertically downward

U = wt of equal volume of air displaced

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

- viscus force on oil drop (vertically upward)

$F = 6\pi \eta r v_1$ (from Stoke's law)

where η = coefficient of viscocity of air.

on equilibrium,

$$W = F + U$$

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

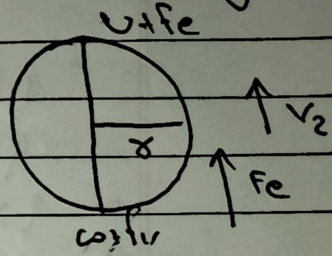
$$\frac{4}{3}\pi r^3 g(\rho - \sigma) = 6\pi\eta r v$$

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

from this eqn, radius of oil drop is calculated

2) Motion of oil drop under the infulence of gravity & elec

when strong electric field is applied bet^n the plates, the coulamb (C) force fe will move the charged oil drop in upward direction with constant terminal velocity.



Here, let,

E = electric field strength

q = charge on the oil drop

V_2 : terminal velocity of oil in upward direction.

So, force due to electric field

$$F_e = qE = \frac{qV}{d} \quad \left[\because E = \frac{V}{d}\right]$$

on equilibrium

Total upward force = total downward force

$$F_e + U = W + F_v$$

or, $$qE + \frac{4}{3}\pi r^3 \sigma g = \frac{4}{3}\pi r^3 \rho g + 6\pi\eta r V_2$$

or, $$q \cdot \frac{V}{d} = 6\pi\eta r V_2 + 6\pi\eta r V_1 \quad [\text{From } (i)]$$

$$q \times \frac{V}{d} = 6\pi\eta r\,(V_1 + V_2)$$

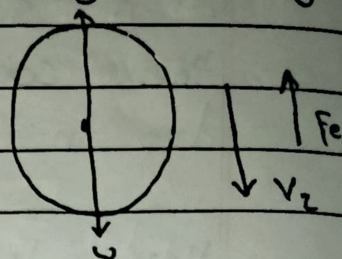
$$\therefore q = 6\pi\eta r(V_1 + V_2) \cdot \frac{d}{V}$$

$$\therefore q = 6\pi\eta(V_1 + V_2)\frac{d}{V}\sqrt{\frac{9\eta V_1}{2(\rho-\sigma)g}}$$

This eq^n gives charge oil which is found to be integral multiple of elementary charge of an electron.

Special case:

① when oil drop is moving downward with constant terminal velocity, even though applying electric field.



In this case;

$$U + F' + F_e = W$$

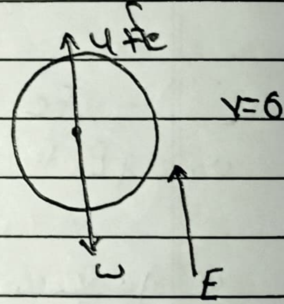
$$qE + U + F' - W = 0$$

$$qE = -F' - F_e + W$$

or $q \times \frac{V}{d} = \frac{4}{3}\pi r^3(\rho - \sigma)g - 6\pi\eta r V_2$

or, $q = \frac{6\pi\eta(V_1 - V_2)d}{V}\sqrt{\frac{9\eta V_1}{2(\rho-\sigma)g}}$

⑪ when oil drop is in rest



Here, Viscous force = 0

$$U + F_e = W$$

or, $qE = \frac{4}{3}\pi r^3(\rho - \sigma)g$

or, $q \cdot \frac{V}{d} = \frac{4}{3}\pi r^3(\rho - \sigma)g$

or, $q = \frac{4}{3}\pi r^3(\rho - \sigma)g \cdot \frac{d}{V}$

Importance of Millikan's experiment,

① This experiment proves that charge of an electron is minimum charge of the charged body.

⑪ This experiment proves the quantization of charge
$q = ne$

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(11) By combining the values of Millikan's experiment & Thompson's experiment the mass of electron is determined.

$e = 1.607 \times 10^{-19} C$ (∵ By millikan's experiment)

$e/m = 1.76 \times 10^{11}$ c/kg [∵ By Thomson's experiment]

$\therefore m = e/(e \div m) = 1.607 \times 10^{-19} / 1.76 \times 10^{11}$

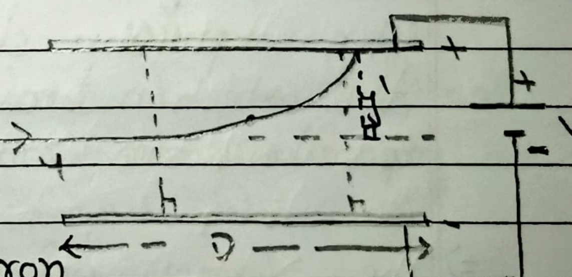
$m = 9.1 \times 10^{-31}$ kg.

Motion of electron in uniform electric field.

Consider the cathode ray (beam of electrons) is moving in between the two parallel metal plates are connected with positive & negative terminal of the battery source of p.d 'V'

The electric field produce betn plates

$E = \frac{V}{d}$ ∴ $V = Ed$,



Intially, the electrons is moving with the Velocity u, before entering inside the electric field. As soon as it enters inside the plates, the electron is attracted by positive plate, because of electro static attraction, So the force due to electric field deviate the path of electron beam.

But in horizontal motion there is no any affective force, So horizontal velocity is constant.

Electron beam:- Cathode ray

if D = Seperation of plate

At any time instant t, the electron descri[illegible] x distance in horizontal direction & y distance in vertical axis.

$$\therefore x = ut \qquad \text{then, } t = \frac{x}{u} \quad \text{--- (i)}$$

$$y = \cancel{ut}^{\,0} + \frac{1}{2}at^2$$

$$\text{or, } y = \frac{1}{2}at^2$$

Here, intially $u_y = 0$

$$y = \frac{1}{2} \times \frac{F_e}{m} \times t^2 \qquad \left[\therefore F = m \times a \quad \text{or, } a = \frac{F_e}{m}\right]$$

$$y = \frac{1}{2} \times \frac{E e}{m} \times t^2 \qquad \left[F = E \times q \quad \text{or, } \frac{V}{d} \times q\right.$$

$$y = \frac{1}{2} \times \left(\frac{V}{d}\frac{e}{m}\right) \times t^2 \qquad \text{from (i)}$$

$$y = \frac{1}{2} \times \frac{eV}{md} \times \frac{x^2}{u^2}$$

$$y = \left(\frac{1}{2} \times \frac{eV}{mdu^2}\right) x^2 \quad \text{--- (ii)}$$

that express $y = Kx^2$ where $K = \frac{1}{2} \times \frac{eV}{mdu^2}$

The expression shows the path of the electron beam in the electric field parabolic in nature.

⇒ The vertical deflection of electron beam after emerging out of the plate. is given by.

$$y' = \left(\frac{eV}{2mdu^2}\right) x'^2$$

After emerging out from the plate, the electron beams moves in the new constant velocity v, deflect at angle θ with horizontal

horizontal component of v, $v_x = u$

Vertical component of v, $v_y = \cancel{v_y}^{\,0} + at$

$v_y = at$

Here, t is time taken by beam at which it is inside the plate.

$t = D/u$

then, $v_y = \frac{F_e}{m} \times \frac{D}{u} = \frac{eV}{md} \cdot \frac{D}{u}$

$\therefore$ Velocity v is given by,

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

$= \sqrt{u^2 + \left(\frac{eVD}{mdu}\right)^2}$ — (v)

& the direction is given by

$\tan\theta = \frac{v_y}{v_x} = \frac{eVD}{mdu} \times \frac{1}{u}$

$\therefore \theta = \tan^{-1}\left(\frac{eVD}{mdu^2}\right)$ — (vi)

eqn (v) & (vi) gives magnitud & direction of final velocity of electron beam after emerging out from parallel out from parallel plates.

Motion of electron beam in uniform magnetic field.

Note:

• dot - moving outward to plane

x cross - moving upward to plane

Lorentz force

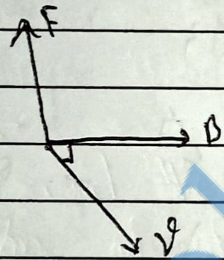
$F = Bev$

when not perpendicular

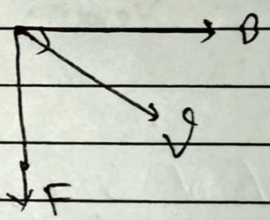
$F = Bev \sin\theta$

Fleming's left hand rule,

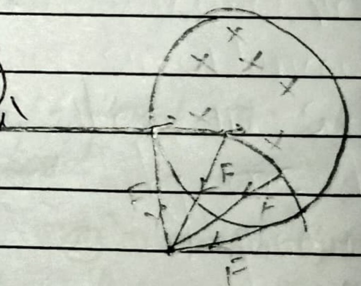
for +ve,



for -ve



Consider the electron beam moving with velocity 'v' in the horizontal direction, which enters into the uniform magnetic field of strength 'B' directed perp^n to the direction of motion.



As, it enters inside the magnetic field it expirences the lorentz force given by

$$F = Bev \quad --(1)$$

which is perpendicular to both $\vec{B}$ & $\vec{v}$ whose dirr is given by fleming's left hand rule. i.e in downward dirn as in figure.

This force unaltered the velocity of electron, but it deflects path.

Everytime, when the electron beam changes, its path, it continues to be perp^n to magnetic field B & as magnetic field is constant. So the force acted on an electron also remains same & directed perp^n to the new direction of velocity v. So, throughout the motion, inside the magnetic field, force: F, will be directed towards the fixed point. so, that the motion of electron takes a circlar path.

For the electron beam to be in circlar path. the necessary centripetal force must be provided by this lorentz force,

$\therefore F = BeV = \frac{mv^2}{r}$ — (ii) wher, m = mass of e^-
r = radius of the circlar path

$r = \frac{mv}{Be}$ — (iii)

$r = \frac{P}{Be} = \frac{\text{momentum}}{Be}$, $Be = \frac{mv}{r}$

$Be = m\omega$

$\omega = Be/m$ -- iv

This eq^n gives the angular velocity of the circlar path of electron beam.

Again we know that, $\omega = 2\pi f$, $f = \frac{\omega}{2\pi}$

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

From eq^n (v) & (vi), the frequency or time period of the circlar path motion of electron beam is independent of the velocity electron beam,

Thomson's experiment to determine specific charge (e/m) of the electron.

Specific charge (e/m) :- It is the ratio of the charge to the mass of an electron.

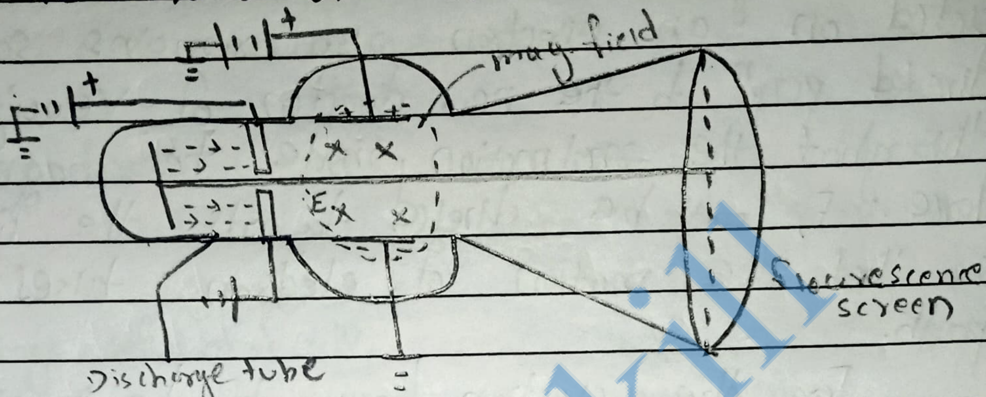


fig: experimental arrangement for thomson's $\frac{e}{m}$ exprt

Principle:-
Thomson used the principle of cross field to determine the e/m of of the electron. when a beam of electrons is subjected to uniform electric field A uniform magnetic field acting simultaneously and ~~per~~ perpendicular to each other in such a way that the deflection produced by one field is exactly cancelled by the deflection produced by the other, the beam of electron passes through field undeviatedly.

In such case

$v = \frac{E}{B}$, E = electric field,
B = magnetic field,

It consists of the cylinder discharge tube having cathode & anode connected with P.d of 10kV, so that the cathode ray energy emerges out from cathode to anod fine beam of cathode ray passes through the small hole on anode which travels with velocity v, horizontally when electron accelerates from cathode to anode

P.E of electron in cathode = K.E of electron beam

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

$$\text{or, } \frac{e}{m} = \frac{v^2}{2V} \quad \text{--- (i)}$$

now, the electron beam is subjected to the cross field of uniform electrical & magnetic field held perpendicular to each other so, that they deflect the beam in opposite direction.

If both fields are absent, then the beam travel horizontally & undeflected to strike on flourescent screen at centre spot S.

If only electric field is applied, then the beam is deflected upward to strike on screen at spot S
i.e force due to electric field on electron,

$$F_e = eE \quad \text{--- (ii)}$$

if only magnetic field is applied, then beam is deflected downward to strike on screen at spot S_2
i.e force due to magnetic field on electron

$$F_m = BeV$$

now both the field are applied & adjusted in a such a way that the force due to electric field is equal & opposite to that due to magnetic field, so that the beam is undeflected & strike on the screen on the screen at centre spot S again, In this case,

$$F_e = F_m$$

$$eE = BeV$$

$$V = E/B \quad \text{---(iv)}$$

putting (v) in eq^n (1) we get,

$$\frac{e}{m} = \frac{E^2}{2VB^2}$$

Again for electric field,

let V' = p.d applied bet^n the two parallel plates

d = distance betn plates.

Electric field = $E = \frac{V'}{d}$

By,

Putting this value in eq^n (V), we get.

$$\frac{e}{m} = \frac{V'^2}{2Vd^2B^2}$$

By knowing values in R.H.S. the Specific charge of an electron is determined.