Ex-6

Experiment

Objective: Determining the value of specific charge e/m of an electron by Thomson Method

$e v B = \frac{m v^2}{r}$

$\frac{e}{m} = \frac{v}{Br}$

Items Required

1. Deflection Magnetometer
2. Two Bar Magnets
3. CRT
4. Stand Arrangement

$e v B = eE$

$v =$

Theory

In this method cathode ray tube is used in which cathode emits electrons, anode accelerate them, passes through a small hole, to another anode which concentrate them into a fine beam. Then passes through between two parallel plates, which can deflect the beam in a vertical plane by an electric field E applied between both the plates. The beam of electron can also be deflected in same plane applying a magnetic field B perpendicular to the plane of plates. This narrowed collimated beam of accelerated electrons than strikes the fluorescent screen to produce a glowing spot. Three terms arise as,

1. If an electric field E applied by a potential difference of V volts between plates the electrons experience a force F in a direction perpendicular to the direction of motion of the beam.

$$F_e = E\,e \qquad \ldots 1$$

2. If B be the uniform magnetic field applied in the region P-P in a horizontal direction perpendicular to the direction of electrons beam, the force experienced by electrons is,

$$F_{mag} = B\,e\,v \qquad \ldots 2$$

Where e is the electron charge, v is the velocity of electron and F_{mag} is the magnetic force.

This force F_{mag} acts perpendicular to the direction of B as well as in the original direction of electron motion (in accordance to Fleming's left thumb rule). The speed of electrons remains unchanged, but its path becomes circular providing the amount of centripetal force.

$$F_{mag} = B\,ev = \frac{mv^2}{r} \qquad \ldots 3$$

Where m is the mass of an electron and r is the radius of circular path.

$$\text{Thus } \frac{e}{m} = \frac{v}{Br} \qquad \ldots 4$$

$F_m =$

3. If an electric field E applied to deflect the beam in OO' direction, than a magnetic field B is applied to bring beam back to O. It means that the force of electrostatic field is equal and opposite to applied magnetic field, so $F_e = F_{mag}$, and two forces nulled each other to bring beam back to original position.

Thus $$Ee = B\,e\,v$$ ... 5

Or $$v = \frac{E}{B}$$ 6

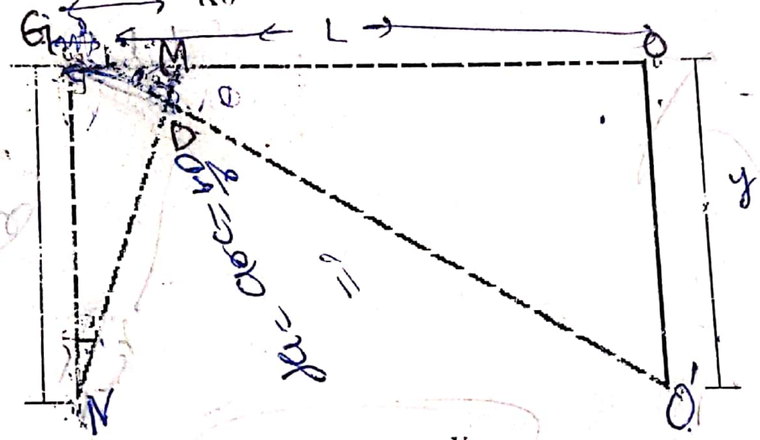
Substituting values of v from 6 into 4

$$e/m = E/B^2r \qquad ....7$$

Radius 'r':

According to the figure below, the original electron beam is preceding straight path G, M, O and impressed upon screen at a point O. In the presence of magnetic field, the beam travels along a circular arc G, D whose radius is r. beyond point D, the beam leave magnetic field and proceeds straight in direction along with the tangent K, DO' (drawn on the circular arc at point D). Drawing GN normal to GKO and MDN normal to KDO'. Let these normal meet at point N. Then GN = ND = r = the radius of circular arc. Let GND = OK 0' = θ

Then in angle KOO'...... $\tan\theta = \frac{00'}{K0}$ and the angle θ is small enough,



$$\theta = \tan\theta = \frac{y}{L}$$

Where L is distance of the screen from mid point of magnetic field region (generally mid point of electric field too).

$$\text{Again } \theta = \tan\theta = \frac{\text{arc GD}}{r} = \frac{GM}{r}$$ since GD is nearly equal to GM.

$$\text{Or } \theta = \frac{l}{r}$$

Where l is the length of the region of magnetic field equals to electric field too. By comparing both values of θ.

$$\frac{l}{r} = \frac{y}{L}, \text{ so } r = \frac{lL}{y} \qquad ...8$$

Substituting values of r into ...7,

$$\frac{e}{m} = \frac{Ey}{B^2 l\, L} \qquad ..9$$

If a potential difference of V volts is applied between the plates P-P, and d is the gap between both plates than, the electric field is given by, E = V / d

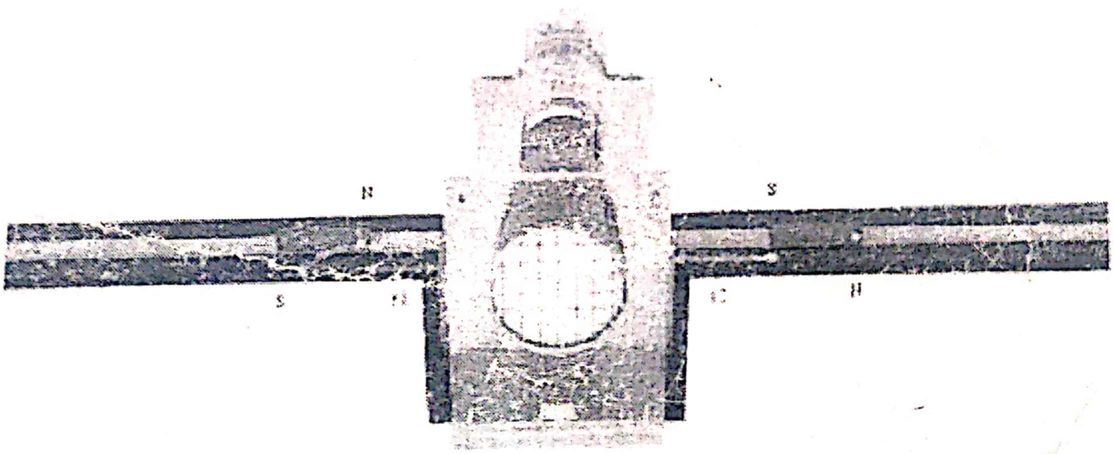
Therefore, $$\frac{e}{m} = \frac{Vy}{B^2 lLd} \qquad \text{...... 10}$$

Where y = distance between spot positions displayed on the screen of CRT in centimeters. l is the length of the deflection plates. L is the distance between screen and plates, d is the distance between plates, V is applied DC voltages across plates and B is magnetic field strength determined by B = H tan θ where H is the Horizontal component of earth's magnetic field at that place.

Procedure:

Note: While performing experiments keep other electronics equipment away from the e/m setup.

1. Using compass needle, find and note **North-South** and **East-West** directions. Place CRT in between stand in such a way that its screen is faced towards North and both arms of stand to East – West direction.
2. Adjust the **Intensity** and **Focus** potentiometer in its mid position.
3. Connect the CRT to octal socket of instrument (socket provided upon the panel). Care should be taken while inserting CRT plug.
4. Keep instrument to south direction far from CRT.
5. Select **Polarity** selector switch at '**0**' position.
6. Set the Deflection Voltage potentiometer at anti clockwise direction.
7. Switch on the Power Supply and wait for some times (3-5 minutes) to warm up the CRT. A bright spot appears on the screen.
8. Adjust intensity and focus controls to obtain sharp spot.
9. Bring the spot at the middle position of the CRT by the help of X-plate deflection voltage pot given to back side of the instrument.
10. Set polarity selector to '+' position, adjust **Deflection Voltage** to deflect the spot 1cm away towards upward. Note the deflection voltage from the meter as **V1** and spot deflection as **y**.
11. Now place the bar magnets (on the stand arm) to both sides of CRT such that their opposite pole faces each other.



Adjust position of magnets to get spot back downward to original position.

12. Note the distances of bar magnet (poles facing the screen) as r_1 and r_2 from the scale.
13. Now remove magnets from the arms of stand.
14. Select '–' **position** from polarity switch. Apply DC voltage to deflect the spot 1 cm away in downward direction. Note deflection voltage from display as **V2** and deflection as y.
15. Place bar magnets again and adjust the position of magnets to bring spot back to original position. Note the distance of the magnets (poles facing the screen) as r_1' and r_2'.
16. Remove CRT and magnets. Place Magnetometer arrangement in between stand such that its centre lies on the center of the stand arm.

    Note: Position of stand should not be disturbed.
17. Rotate Magnetometer and adjust the needle to read 0° - 0°.
18. Now place magnets at a distance equal to r_1 & r_2 as previous polarity adjusted. The pointer deflects along the scale. Note the deflections as θ_1 and θ_2.
19. Repeat similar procedure placing magnets at r_1' and r_2' distances. Note the deflection of compass needle as θ_3 and θ_4.
20. Now we know that magnetic field

$$B = H \tan \theta$$

Where

$$\theta = \frac{\theta 1 + \theta 2 + \theta 3 + \theta 4}{4}$$

$$H = \sim 0.37 \times 10^{-4}\ \text{Tesla}$$

21. Calculate e / m using following formula

$$\frac{e}{m} = \frac{Vy}{B^2 lLd}$$

Where

Distance between plates **d** = 1.4 cm

Length of plates ***l*** = 3.23 cm

Distance between screen and plates ***L*** = 14.5 cm

Deflection Voltage **V = (V1+V2)/2**

Deflection in cm **y** = 1cm

22. Take more readings by repeating experiment and deflecting spot to other distances.
23. Calculate the % error as

$$= \frac{\text{Standard value} - \text{calculated value}}{\text{Standard value}} \times 100$$

Precautions and sources of error:

- The cathode ray tube should be handled carefully. There should not be any magnetic substance nearby the place of experiment.
- Axis of magnets and axis of tube should lie perpendicular to each other in same horizontal plane. To correct it loose the neck clamp of CRT and rotate CRT so the spot deflects right up/down with deflection voltage.
- When magnets are place upon the arms. It is better to move stand slightly back & forth to obtain maximum magnetic field at deflecting plates. It should be done before bringing spot back to original position.
- Rotate magnet (s) on there axis if spot does not come back to its original position.
- When direction of spot is reversed the direction of magnets should also be reversed.

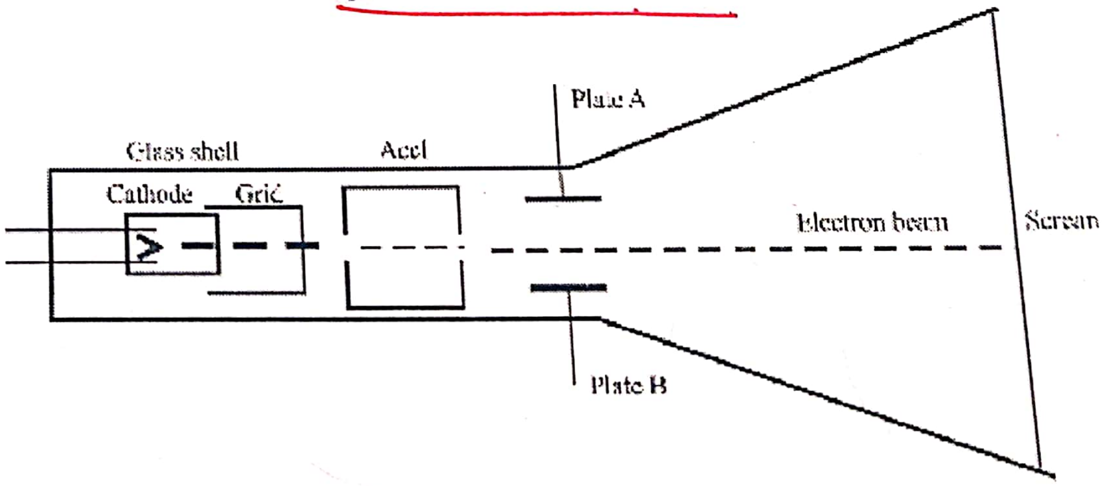
  The magnets should move tight to the scale in closest possible distances.
- The electric field between plates cannot be uniform due to shorter distance between them.
- The given constants are generally taken from data; there may be slight variations to produce error.

Specification of given CRT:

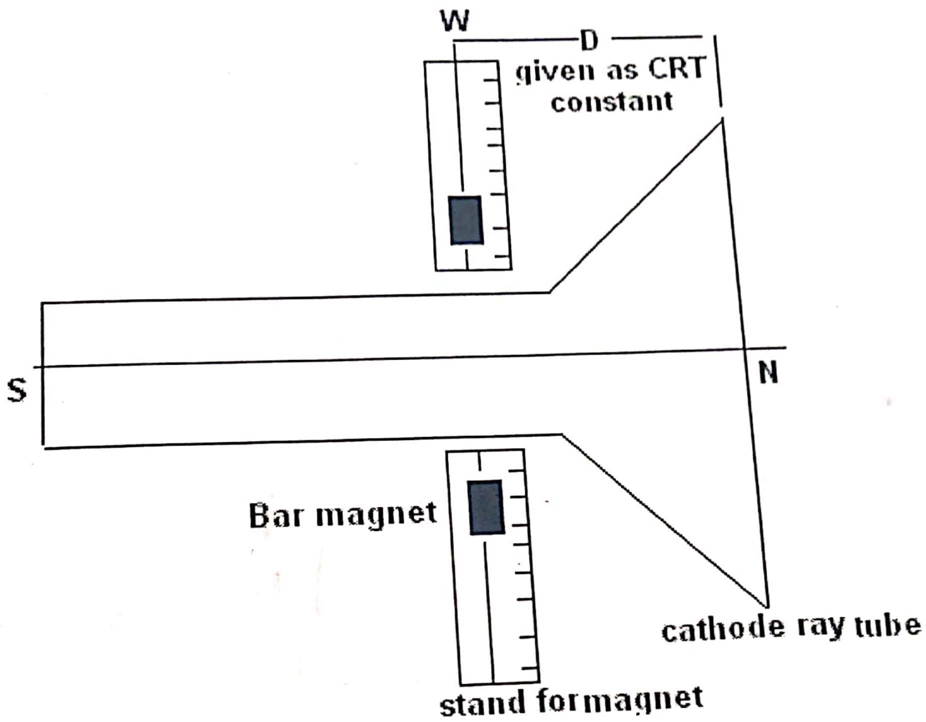
- Distance between plates, : $d = 1.4$ cm
- Length of plates : $l = 3.23$cm
- Distance between screen and plates (edge) : $L = 14.5$ cm

Standard Value of e/m:

$$e/m = 1.75888\times10^{11} \text{ C/Kg}$$



Cathode ray tube used in Thomson method



Way to place cathode ray tube

Nvis 6103

Sample Reading

Experiment

Objective : Determining the value of specific charge e/m of an electron by Thomson Method.

Formula Used :

$$\frac{e}{m} = \frac{Vy}{B^2 lLd}$$

Standard values :

- H = ~0.37x10-4 Tesla
- Distance between plates, d = 1.4 cm = 1.4×10^{-2} m
- Length of plates, l = 3.23 cm = 3.23×10^{-2} m
- Distance between screen and plates, L = 14.5 cm = 14.5×10^{-2} m
- V = deflection voltage
- Deflection of spot, y = 1cm = 1×10^{-2} m

V? 40₂

Calculated value :
V = 14.8 Volt
$\theta 1 = 72^0$
$\theta 2 = 73^0$
$\theta 3 = 75^0$
$\theta 4 = 76^0$

Formula used for calculation :-

Formula for calculation Value of magnetic field

$$B = H \tan \theta$$

$$\theta = \frac{\theta 1 + \theta 2 + \theta 3 + \theta 4}{4}$$

Putting the values of θ in above formula,

we have

$$\theta = \frac{72+73+75+76}{4}$$

It gives, $\theta = 74^0$

Now putting value of θ for calculating B

$B = 0.37 \times 10^{-4} \times \tan(74^0)$

$= 0.37 \times 3.487 \times 10^{-4}$

$= 1.2903 \times 10^{-4}$ Tesla

Formula for calculating e/m ratio

$$\frac{e}{m} = \frac{Vy}{B^2 ILd}$$

Substituting all the above values to determine the e/m ratio

$$\frac{e}{m} = \frac{14.8 \times 1 \times 10^{-2}}{(1.2903 \times 10^{-4})^2 \times 3.23 \times 10^{-2} \times 1.4 \times 10^{-2} \times 14.5 \times 10^{-2}}$$

On solving the above equation we have

e/m = 1.35×10^{11} C/Kg

Calculation of % Error

$$\frac{(\text{Standard value} - \text{calculated value}) \times 100}{\text{Standard value}}$$

$$\% \text{ Error} = \frac{1.75 - 1.35}{1.75} \times 100$$

% Error = 22.8 %