## AIM:

Determination of the specific charge of the electron (e/m) from the path of an electron beam by Thomson Method.

## APPARATUS USED:

The set up contains the following parts:

1. Narrow electron beam tube

2. Pair of Helmholtz coils of radii 0.14m each (No. of turns in each coil = 160, current limit 1.8A)

3. Power supply (0 – 250V)

## FORMULA USED:

$$\frac{e}{m} = \frac{2V}{B^2 r^2} = \frac{8V}{B^2 d^2}$$

where *d* is diameter of the circular path. This result assumes that the magnetic field *B* is uniform. This in the apparatus is produced by a pair of Helmholtz coils (separated by a distance equal to their radius). If *n* is number of turns in a coil and *a* its radius, then the magnetic field *B*, midway between the coils is given by

$$B = 2 \times \frac{\mu_0 I n}{2(5/4)^{\frac{3}{2}} a} = 2 \times \left[ \frac{2\pi I n}{(5/4)^{\frac{3}{2}} a} \times 10^{-7} \right] tesla$$

Substituting all the constants and experimental set up data (mentioned in theory part) the final formula is:

$$\frac{e}{m} = \left(7.576 \times 10^6\right) \times \frac{V(volt)}{I^2 (amp^2) d^2 (m^2)} coul/kg$$

## INTRODUCTION

This arrangement for measuring *e/m*, the charge to mass ratio of the electron is based on Thomson's method. The *e/m*-tube is bulb-like and contains a filament, a cathode, a grid, a pair of deflection plates and an anode. The filament heats the cathode which emits electrons. The electrons are accelerated through a known potential applied between the cathode and the anode. The grid and the anode have a hole through which electrons can pass. The tube is filled with helium at a very low pressure. Some of the electrons are emitted by the cathode collide with helium atoms which get excited and radiate visible light. The electron beam thus leaves a visible track in the tube and all manipulations on it can be seen. The tube is placed between a pair of fixed Helmholtz coils which produce a uniform and known magnetic field. The socket of the tube can be rotated so that the electron beam is at right angles to the magnetic field. The beam is deflected in a circular path of radius *r* depending on the accelerating potential *V*, the magnetic field *B* and the charge to mass ratio *e/m.* This circular path is visible and the diameter *d* can be measured and *e/m* obtained from the relation

$$\frac{e}{m} = \frac{8V}{B^2 d^2}$$

The deflecting plates play no role in the *e/m* experiment. They are interesting for a visual observation of how the electron beam gets deflected then a potential difference is applied between the deflecting plates.

This set-up can also be used to study various features of Lorentz force $\vec{F} = e(\vec{E} + \vec{v} * \vec{B})$ by observing the electron beam deflection for different directions of the magnetic field and different orientation of the *e/m*-tube.

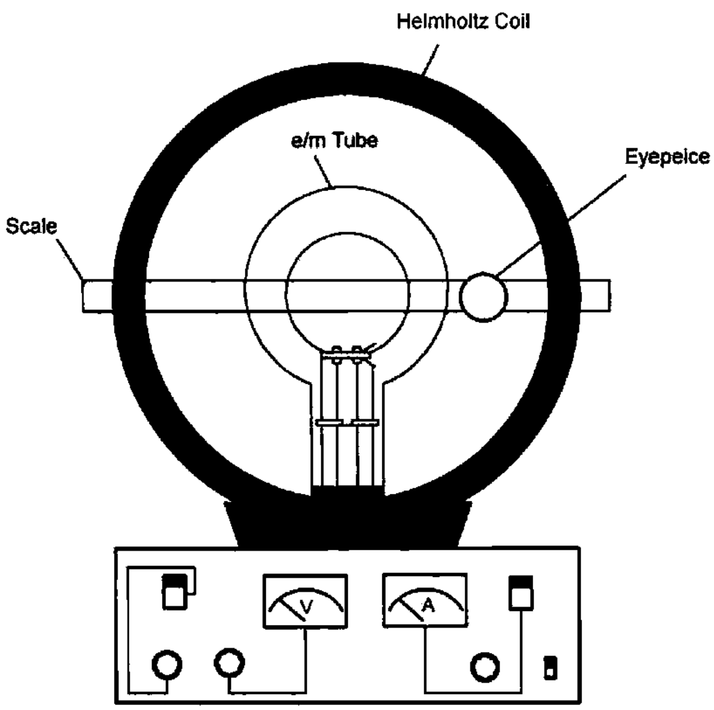



**Fig. 1: e/m Experiment, EMX-01**

## THEORY

### Relation connecting *e/m* to accelerating potential *V*, magnetic field *B* and radius *r* of the circular path

When the electrons are accelerated through the potential *V*, they gain kinetic energy equal to their charge times the accelerating potential. Therefore $eV = \frac{mv^2}{2}$. The final (non-relativistic) velocity of the electrons is therefore

$$v = \left(\frac{2eV}{m}\right)^{1/2} \qquad (1)$$

When these electrons pass through a region having a magnetic field *B*, they are acted upon by a force, called the Lorentz force, given by $e\vec{v} * \vec{B}$. If the electrons are initially moving along *x*-axis and the magnetic field is along *z*-axis, the electrons describe a circular path in the *XY*-plane with the centripetal force balancing the Lorentz force,

$$evB = \frac{mv^2}{r} \qquad (2)$$

or $$v = \frac{eBr}{m}$$

Eliminating *v* between Eqs. (1) and (2), we get

$$\frac{eBr}{m} = \left(\frac{2eV}{m}\right)^{1/2}$$

or $$\frac{e}{m} = \frac{2V}{B^2 r^2} = \frac{8V}{B^2 d^2} \qquad (3)$$

where *d* is diameter of the circular path. This result assumes that the magnetic field *B* is uniform. This in the apparatus is produced by a pair of Helmholtz coils (separated by a distance equal to their radius). If *n* is number of turns in a coil and *a* its radius, then the magnetic field *B*, midway between the coils is given by

$$B = 2\times\frac{\mu_0 In}{2(5/4)^{\frac{3}{2}}a} = 2\times\left[\frac{2\pi In}{(5/4)^{\frac{3}{2}}a}\times 10^{-7}\right] tesla$$

when a current of *I* amp is flowing in the coils. $\mu_0$ is permeability of free space and is given by $\mu_0 = 4\pi\times 10^{-7}\, N/A^2$. This field is uniform in the region where the electrons move. Putting the value of B in Eq. (3), we get

$$\frac{e}{m}=\left[\frac{125a^2}{128\pi^2n^2}\times10^{14}\right]\frac{V}{I^2d^2} \qquad (4)$$

The coils in this apparatus have 160 turns each and their radii are 0.14 m. using these values

$$\frac{e}{m}=\left(7.576\times10^6\right)\times\frac{V(volt)}{I^2(amp^2)d^2(m^2)}coul/kg \qquad (5)$$

## DESCRIPTION OF THE APPARATUS

The central part of set-up is the e/m-tube. This is energized by

(i) Filament current supply,
(ii) Deflection plates voltage supply,
(iii) Continuously variable accelerating voltage supply to the anode.

The tube is mounted on a rotatable socket and is placed between a pair of Helmholtz coils. The tube can be rotated about a vertical axis, varying the orientation of the electron beam with respect to the Helmholtz coils. This allows magnetic deflection of the beam to be demonstrated. Circular, helical or undeflected paths can be seen. The direction of the current to the Helmholtz coils can be changed. The magnetizing current *I* and the accelerating voltage *V* are respectively measured by an ammeter and a voltmeter mounted on the front of the panel. For the measurement of *e/m,* the socket of the tube is rotated so that the electron beam path at right angles to the magnetic field. The beam is deflected in a circular path. The diameter of the electron beam path is measured by a detachable scale mounted in front of the bulb of the tube. This scale has a slider with a hollow tube (fitted with cross wires at its both ends) to fix the lines of sight while making the measurements of the beam path diameter. Base of the unit contains the power supply that provides all the required potentials and the current to the Helmholtz coils. The entire apparatus is contained in a wooden case for convenient storage.

## SPCIFICATIONS

| | |
|---|---|
| Helmholtz coils of radii | 14 cm |
| Number of turns | 160 on each coil |
| Accelerating Voltage | 0 -250V |
| Deflection plates voltage | 50V – 250V |
| Operating Voltage | 220V AC/ 50Hz |

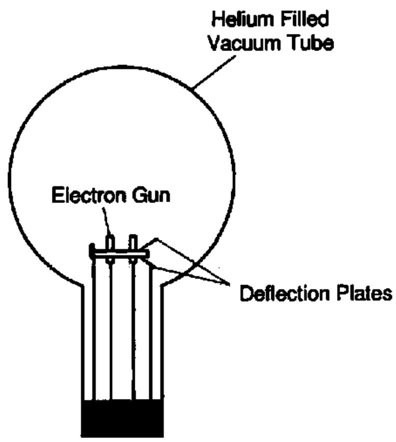



**Fig 2: e/m Tube**

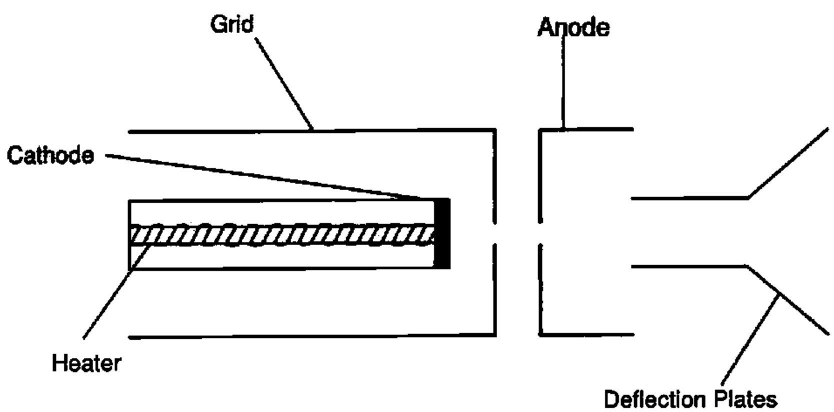


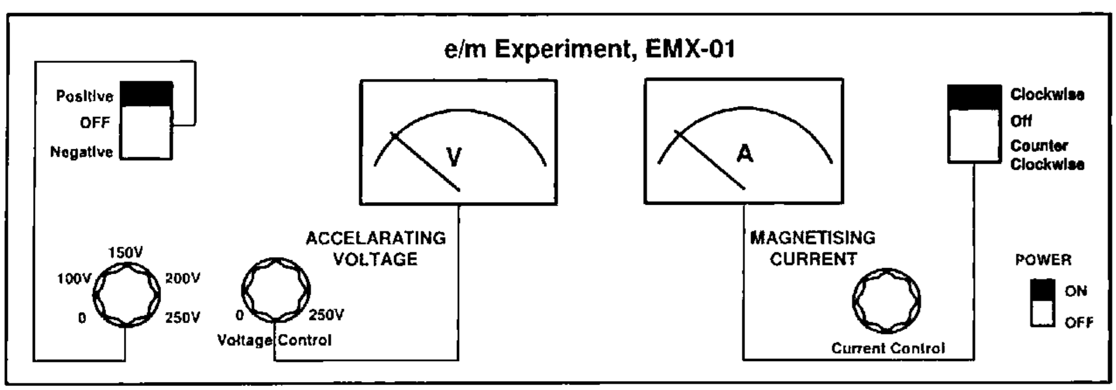

**Fig. 3: Electron Gun**

## PROCEDURE

1. Before the power is switched to 'ON', makes sure all the control knobs are at their minimum position.
2. Turn the power switch to 'ON'. The indicator lamp will glow.
3. Wait a little for the cathode to heat up.
4. Turn the accelerator voltage adjust knob clockwise to increase the voltage. Rectilinear electron beam emerging from the cathode will be visible. Adjust the accelerator voltage at about 200 volt.
5. It should be clear that the electrons themselves in the beam are not visible. What is observed is the glow of the helium gas in the tube when the electrons collide with the atoms of the

gas. We actually see the glow of gas atoms which have been excited by collisions with electrons.

6. Rotate the e/m- tube so that the electron beam is parallel to the plane of the Helmholtz coils. Do not take it out of its socket.
7. Earth's magnetic field interferes with the measurements. However this magnetic field is weak compared to the field generated by the Helmholtz coils and we could ignore its effect as a first approximation.
8. Slowly turn the current adjust knob clockwise to increase the current for the Helmholtz coils. The electron beam will get curved. Increased the current will increase the curvature of the beam.
9. In case the electron beam does not make a complete (closed) circle and the circular path is skewed, rotate the socket of the tube until the path is closed circle. This happens when the tube pointer is set at about $90^0$.
10. Measure the diameter of the electron beam. This measurement has been facilitated by fixing a hollow tube (fitted with cross wires at its both ends) on the slider of the scale. This tube fixes the line of sight during measurements.
11. Note the ammeter reading for the current to the Helmholtz coils and the voltmeter reading for the accelerating voltage.
12. Decrease the accelerating voltage by a small amount (20 volt, say) and measure the diameter of the electron beam path.
13. Carry on the observations. The voltmeter reading should not be increased beyond 250 volt. A value lower than 80 volt is also not advisable. Similarly the current to the Helmholtz coils should not be more than 2 amp.
14. Do not leave the beam ON for long periods of time.




**Control Panel**

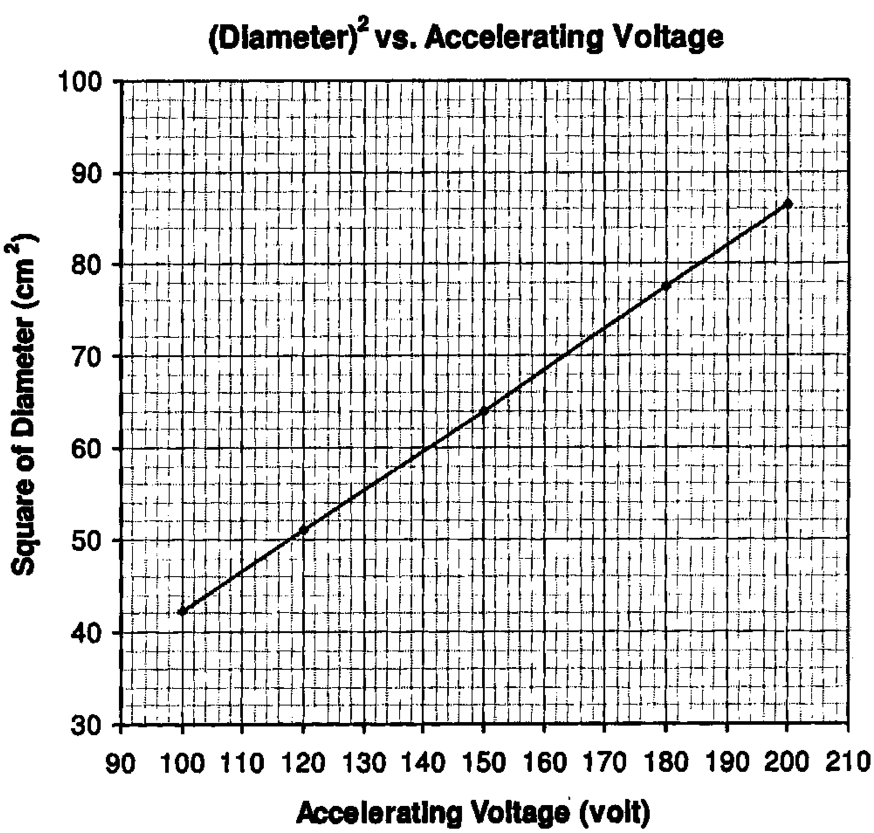
## OBSERVATIONS

Measurements of accelerating voltage V, magnetizing current I and diameter *d* of the electron beam path.

| Accelerating Voltage (Volt) | Current to the Helmholtz coils (amp) | Diameter of the Beam path (m) | $(\text{Diameter})^2$ $(m^2)$ | $\frac{V}{I^2 d^2}$ |
|---|---|---|---|---|
| 200 | 1 | | | |
| 180 | 1 | | | |
| 150 | 1 | | | |
| 120 | 1 | | | |
| 100 | 1 | | | |
| | | | Mean value of $\frac{V}{I^2 d^2} =$ | |

For a given value of the current $I$ , draw a graph between $V$ and $d^2$. It should be a straight line.

**Graph 1**



## RESULT

1. The value of *e/m* may be obtained from the relation given above in Eq (5) for your set of observations.
2. Plot graph 1 which is a straight line find its slope and calculate (e/m) as follows:

$$\frac{e}{m} = \left(7.576 \times 10^{6}\right) \times \frac{1}{Slope} Coul / Kg$$

(Note that current $I$ is 1.0 Amperes)

3. Standard value of e/m is **1.77 X $10^{11}$ coul/kg**.

## SOURCES OF ERROR

The main source of error in this experiment is the velocity of the electrons. There is a hole in the anode to allow the electrons to pass through it. This makes the velocity of the electrons non uniform and slightly less than theoretical value. Further the collisions of the electrons with the helium gas in the tube decrease their velocity a little bit. The effect of these errors can be minimized by measuring the outside radius of the electron beam path and by not using low values of the accelerating voltage.

Other source of error is in the measurement of the diameter of the electron beam.