Experiment Number 5
Specific charge (e/m) by Thomson's method

AIM - To determine the value of specific charge (e/m) of an electron by Thomson's method.

APPARATUS – Filament current supply, Deflection plates voltage supply, Continuously variable accelerating voltage supply to the anode, Helmholtz coils, Scale, Eyepiece, e/m tube, Electron Gun (Grid, Cathode, Anode, Heater, Deflection Plates), Helium gas.

FORMULA USED -

The specific charge of an electron is given by

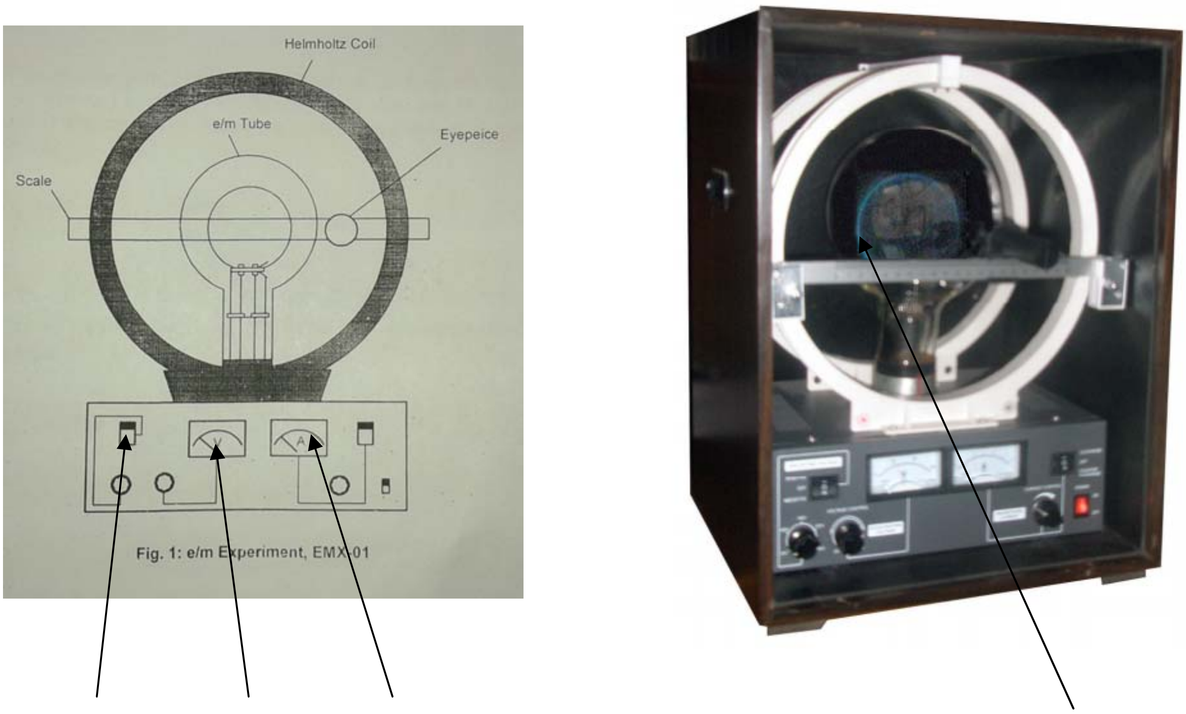
$$\frac{e}{m} = \frac{V(volt) \times 7.576 \times 10^{6}}{I^{2}(amp^{2})d^{2}(m^{2})} Coulomb / Kg \qquad (1)$$

where,

V = Accelerating Voltage applied in volt. between cathode and anode
d = Diameter of beam path in meter
I = Magnetizing current in ampere

<u>Points to remember:</u>

Helmholtz coils of radii (a)	14 cm = 0.14 m
Number of turns (n)	160 on each coil
Accelerating Voltage	0 – 250V (The voltmeter reading should not be increased beyond 250 volt. Value lower than 100 volt. is also not advisable.)
Deflection plates voltage	50V – 250V
Operating Voltage	220V AC/ 50Hz
Operating Current	1 amp. - 2 amp.



Deflection plate Voltage supply | Accelerating Voltage | Filament Current | Visible Light

Fig. 1 (a) and (b) e/m Experimental set-up

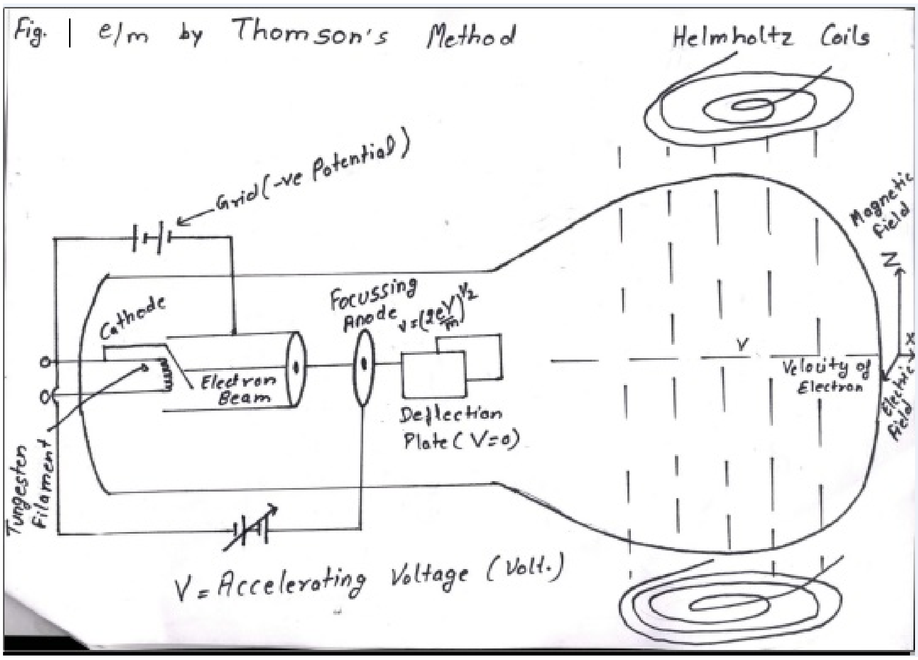
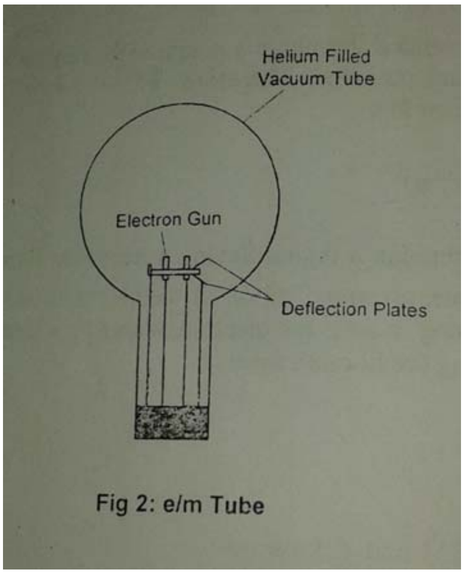


Fig. 2 Experimental set-up for determination of e/m




Visible Light

Fig. 3 (a) and (b) e/m Tube

THEORY

An arrangement for measuring e/m, the charge to mass ratio of the electron is a very simple (as shown in Fig. 1). It 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 (as shown in Fig. 2). The filament heats the cathode and the anode. The grid and the anode have no role through which electron can pass. The tube is filled with helium at a very low pressure. Some of the electrons emitted by the cathode collide with helium atoms which (helium atoms) get excited and radiate visible light. So, the path of electron beam is visible in the tube (as shown in Fig. 3). 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

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

This set-up can also be used to study the electron beam deflection for different directions of the magnetic field by varying the orientation of the e/m-tube.

The deflecting plates plays no role in the experiment. They are interesting for a visual observation of how electron beam gets deflected when a potential difference is applied between the deflecting plates.

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 un-deflected paths can be seen. The direction of the current 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. 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 line 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.

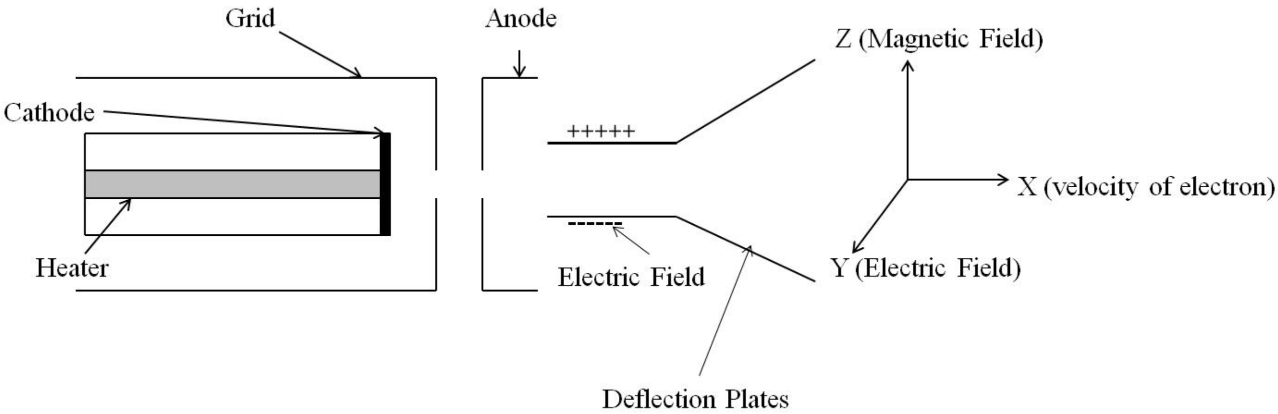


Fig. 4 Electron Gun

When the electrons are accelerated through the potential *V* (Fig.4), they gain kinetic energy equal to their charge times the accelerating potential. Therefore eV = $mv^2/2$. The final (non-relativistic) velocity of the electrons is therefore,

$$v = (2eV/m)^{1/2} . \tag{2}$$

When these electrons pass through a region having a magnetic field B, they are acted upon by a force, called Lorentz force, given by $e\,(\vec{v} \times \vec{B})$. 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,

$$evB = mv^2 / r;$$
$$v = eBr / m. \tag{3}$$

Eliminating *v* in Equations (2) and (3) we obtain

$$eBr / m = (2eV / m)^{1/2}$$
$$e/m = 2V / B^2r^2 = 8V / B^2d^2, \tag{4}$$

where d (d=2r) is diameter of the circular path. This results assumes that the magnetic field *B* is uniform. Magnetic field (*B*) 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, *I* is current and *a* its radius, then the magnetic field *B*, midway between the coils is given by

$$B = \frac{\mu_\circ a^2 In}{2(a^2 + x^2)^{3/2}}$$

The distance between the coils is equal to radius of Helmholtz coils, $a = L$ and therefore at the centre of Helmholtz coil, $x = L/2$. Putting values and solving above equation we get

$$B = 2 \times \frac{\mu_\circ In}{2(5/4)^{3/2} a} = 2 \times \left(\frac{2\pi In}{(5/4)^{3/2} a} \times 10^{-7} \right) \text{Tesla.}$$

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

$$\frac{e}{m} = \left(\frac{125a^2}{128\pi^2 n^2} \times 10^{14} \right) \frac{V}{I^2 d^2}. \qquad (5)$$

The coils in this apparatus have 160 turns (*n*) each and their radii are 0.14 m (*a*). Using these values we get

$$\frac{e}{m} = \frac{V(volt) \times 7.576 \times 10^6}{I^2 (amp^2) d^2 (m^2)} coulomb / Kg$$

PROCEDURE -

1. Before the power is switched to 'ON', make 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 helium gas in the tube when the electron collide with the atoms of gas. Actually see the glow of gas atoms which were excited by collisions with electrons.
6. Rotate the e/m-tube so that electrons beam is parallel to the plane of 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 this can be ignored. 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. Increasing 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 a closed circle. This happens when the tube pointer is set at about 90º.
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. Adjust current at 1 ampere.
13. Decrease the accelerating voltage by a small amount (20 volt) and measure the diameter of the electron beam path. Show in eyepiece at one end of circle say d_1 (note the position) and then at other end of circle say d_2 (note the position). Take the difference ($d = d_1 - d_2$), which is the diameter of visible circle.
14. Decrease voltage from 200 volt. to 100 volt. and take five readings as shown in table. The voltmeter reading should not be increased beyond 250 volt. Value lower than 100 volt is also not advisable. Current to the Helmholtz coils should not be more than 2 amp.
15. Take 3 sets of data at different value of current (for 1 ampere, 1.5 ampere and 2 ampere).

OBSERVATION -

TABLE - 1 (Set-1 for current = 1 ampere)

Accelerating Voltage (volt)	Current to the Helmholtz coils (amp)	Distance d_1 (m)	Distance d_2 (m)	Diameter of the beam path $d = d_2 - d_1$ (m)	$(\text{Diameter}=d)^2$ (m^2)	V/I^2d^2 ($V/amp^2\, m^2$)
200						
180						
150						
120						
100						

Mean value of V/I^2d^2 =

Take two more sets (set-2 and set-3) of data at different value of current (for 1.5 ampere and 2 ampere).

CALCULATIONS - Calculate the value of e/m using equation (1).

$$\frac{e}{m} = \frac{V(volt) \times 7.576 \times 10^6}{I^2 (amp^2) d^2 (m^2)} Coulomb / Kg$$

Plot graph between square of diameter (d^2) and Accelerating voltage (V). By using slope of the graph, calculate the value of e/m.

MAXIMUM PROBABLE ERROR –

$$\frac{e}{m} = \frac{V(volt) \times 7.576 \times 10^{6}}{I^{2}(amp^{2})d^{2}(m^{2})} coulomb / Kg$$

$$\ln(\frac{e}{m}) = \ln(\frac{V(volt) \times 7.576 \times 10^{6}}{I^{2}(amp^{2})d^{2}(m^{2})})$$

$$\ln(\frac{e}{m}) = \ln(\frac{V}{I^{2}d^{2}})$$

$$\ln(\frac{e}{m}) = \ln(V) + 2\ln(I) + 2\ln(d)$$

$$\frac{\Delta(e/m)}{(e/m)} \times 100\% = \left(\frac{\Delta V}{V} + \frac{2\Delta I}{I} + \frac{2\Delta d}{d}\right) \times 100\%$$

RESULT - The calculated value of e/m by Thomson's method is _________________.

PRECAUTIONS -

1. The voltmeter reading should not be increased beyond 250 volt. Value lower than 100 volt is also not advisable.
2. Current to the Helmholtz coils should not be more than 2 amp. Value lower than 1 amp. is also not advisable.
3. Do not leave the beam ON for long periods of time.

SOURCES OF ERROR -

1. The main source of error is the velocity of the electrons. There is a hole in the anode to allow the electrons to pass through it, which makes the velocity of the electrons non-uniform and slightly less than the theoretical value.
2. The collision of the electron with the helium gas in the tube decrease the velocity of electrons a little bit.
3. Measurement of the diameter of electron beam causes error.

REFERENCES -

1. Arthur Beiser Concepts of Modern Physics
2. K.K.Dubey and B.N.Dutta, Practical physics, Kalyani publishers, New delhi.
3. Halliday and Resnick, Fundamentals of Physics. New York: John Wiley and Son’s Inc. 1970.
4. Basic Concepts in Physics.

http://www.sestechno.com/pro1/2b1.htm

http://web.lemoyne.edu/~giunta/jthomson.html

Viva Questions

1) Who was the first scientist to measured the charge to mass ratio (e/m) for electron?
2) Which type of gas is filled in e/m- bulb-like- tube?
3) What is centripetal force?
4) Derive the formula $\frac{e}{m} = \frac{V(volt)\times 7.576\times 10^{6}}{I^{2}(amp^{2})d^{2}(m^{2})} coulomb/Kg$?
5) How does a charged particle move in crossed uniform electric and magnetic fields?
6) Explain Lorentz relation?
7) Define the terms fluorescence and luminescence?
8) Explain the effect of the Earth's magnetic field in the measurements?
9) Does the value of *e/m* depend on the nature of the gas used in the cathode tube?
10) What is the CGS and SI units of e/m?
11) What is the standard value of e/m in SI unit?