Specific charge (e/m) of electron

Objective:

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

Theory:

J. J. Thomson first determined the specific charge (charge to mass ratio e/m) of the electron in 1887. In his experiment, J. J. Thomson had found a charged particle that had a specific charge two thousand times that of the hydrogen ion, the lightest particle known at that time. Once the charge on the particles was measured he could conclude with certainty that these particles were two thousand times lighter than hydrogen. This explained how these particles could pass between atoms and make their way out of thin sheets of gold. Measurement of the specific charge of cathode rays for different metals made him conclude that the particles that constituted cathode rays form a part of all the atoms in the universe. For his work J. J. Thomson received the Nobel Prize in Physics in 1906, "*in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases*".
The direct measurement of mass of the electron is difficult by experiments. It is easier to determine the specific charge of the electron e/m from which the mass m can be calculated if the elementary charge **e** is known.

Charged particle in a magnetic field accelerated by a potential

An electron moving at velocity **v** perpendicularly to a homogenous magnetic field **B**, is subject to the Lorentz force **F**:

$$\vec{F} = e\left(\vec{V} \times \vec{B}\right) \qquad (1)$$

which is perpendicular to the velocity and to the magnetic field. The electron takes a circular orbit with its axis parallel to the direction of magnetic field. The Lorentz force is balanced by the centripetal force which forces the electron into an orbit r (see Fig. 1). Hence

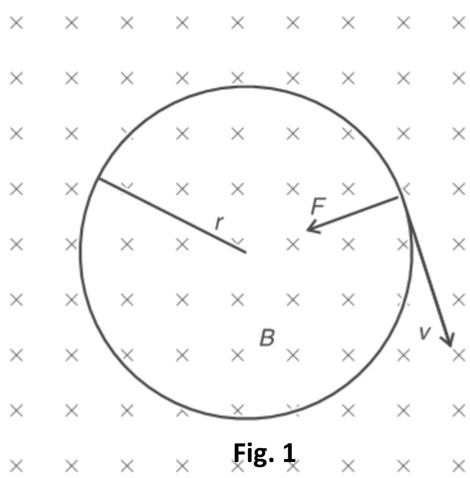


Fig. 1

$$F = m_e . \frac{v^2}{r} \qquad (2)$$

where m_e is the mass of electron. Thus, the specific charge of electron (e/m_e) is given by

$$\frac{e}{m_e} = \frac{v}{\vec{r} \cdot \vec{B}} \qquad (3)$$

B. Electrons accelerated by a potential U

In the experiment, the electrons are accelerated in a beam tube by applying a potential U. The resulting kinetic energy is given by

$$e.U = \frac{1}{2} m_e v^2 \qquad (4)$$

Combining equation (3) and (4), the specific charge of the electron thus is

$$\frac{e}{m_e} = \frac{2U}{(\vec{r} \cdot \vec{B})^2} \qquad (5)$$

C. The magnetic field generated in a pair of Helmholtz coils

The magnetic field generated by a pair of Helmholtz coils is twice the field generated by a single coil. If R is the radius of each coil and I is the current flowing through each of them having N turns, then the magnetic field due to both the coils at a distance x = R/2 is given as

$$B = \mu_0 N I \frac{R^2}{(R^2+x^2)^{3/2}} = \left(\frac{4}{5}\right)^{\frac{3}{2}} \frac{\mu_0 I N}{R} = kI \qquad (6)$$

where $k = \left(\frac{4}{5}\right)^{\frac{3}{2}} \frac{\mu_0 N}{R}$ and $\mu_0 = 1.2566 \times 10^{-6} N/A^2$.

Thus from Eqs 5 and 6, the final expression for e/m is given as

$$\frac{\boldsymbol{e}}{\boldsymbol{m_e}} = \frac{\boldsymbol{2 \cdot U}}{(\boldsymbol{r \cdot k \cdot I})^2} \qquad (7)$$

Experimental set up:

The set up contains the following parts see Fig.2:

1. Narrow electron beam tube of diameter 0.16m, filled with hydrogen gas at pressure 1Pa
2. Pair of Helmholtz coils of radii 0.15m each (No. of turns in each coil = 130, current limit 2A)
3. Holder for the entire assembly
4. Measuring device for beam diameter

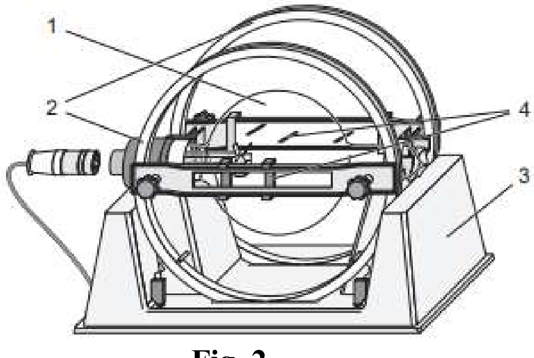


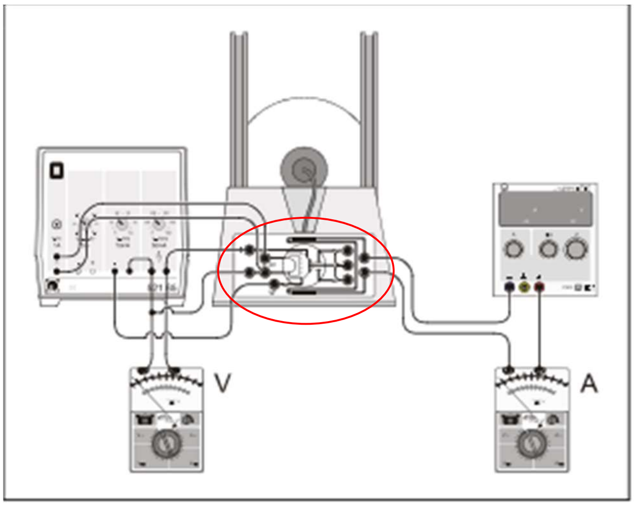
Fig. 2

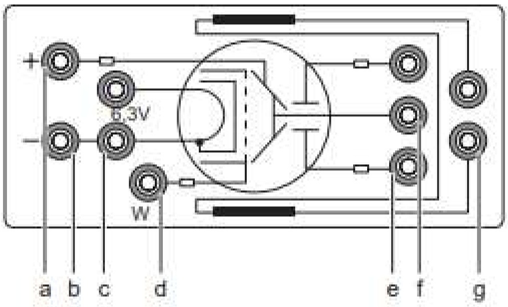
In addition to the above set up two power supplies are connected to it:

(a) DC power supply for electron beam system (0 – 300V): Heating voltage: 6.3 V Heating current: approx. 0.7-0.8 A Anode voltage: 150-300 V DC Wehnelt voltage: ±20 V Plate voltage: 0-300 V DC

(b) DC power supply for Helmohltz coils (0-3A, 20V)

Figures 3 and 4 below show the complete experimental set up.





(a)Anode (b) Cathode (c) Heating filament (d) Wehnelt cylinder (e) Deflection plates (f) Anode, for symmetrical adjustment of the deflection voltage (g) Helmholtz coils

Fig. 3: Complete schematics of the set up with electrical connections to DC power supplies and multimeters. A blow up of red marked area gives details of connection sockets.

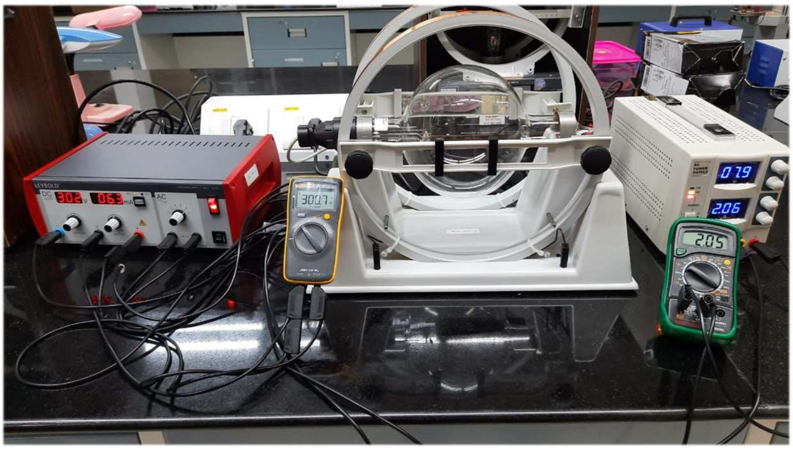


Fig. 4(a): Actual experimental set up

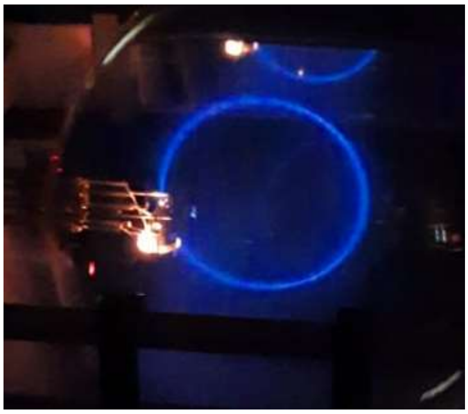


Fig. 4(b): Circular trajectory of electron beam observed in dark

Procedure:

1. Before starting, make sure that both the power supplies are turned off and all rotary potentiometers are at the left-most position. Check out the precautions provided at the end of the manual.
2. Connect the 6.3V input end of the fine beam tube to the 6.3V output of the tube power supply. Short-circuit the positive pole of the 50V output of the tube power supply with the negative pole of the 500V outlet and connect with the socket "-" of the fine beam tube (cathode). Connect the socket "+" of the fine beam tube (anode) with the positive pole of the 500V output. Connect the socket W (Wehnelt-cylinder) with the negative pole of the 50V output.
3. Connect a multimeter across the 500V output to measure the acceleration potential U Short the deflection plates of the fine beam tube to the anode. Connect another multimeter to the DC power supply (0-3A, 20V) in series with the Helmholtz coils to measure coil current and hence the magnetic field.
4. Ensure that your connections are right before switching on the power supplies.
5. Switch on the power supply for the electron beam system and set the voltage at U= 300V. Thermionic emission starts after warming up for a few minutes.
6. If needed, optimize focussing of the electron beam by varying the voltage at the Wehnelt-cylinder from 0-10 V until it leads to a narrow, well defined beam with clear edge definition.
7. Switch on the DC power supply of the Helmholtz coils and look for current I, at which the electron beam is deflected into a closed orbit. If the electron beam after leaving the anode is deflected to the wrong (left) side, then disconnect both power supplies. Exchange the connections at the DC power supply for the coils in order to change the polarization of the magnetic field.
8. If the electrons do not move on a closed orbit but on a helical curve line, do the following in presence of the technician/TA. Loosen the mounting bolts of both holding brackets. Carefully rotate the fine beam tube around its longitudinal axis, until the electron beam runs on a closed circular orbit. Fasten the mounting bolts.
9. Now to start the measurement, fix the acceleration potential U at 300V (say). Vary the coil current I and measure the diameter (2r) of the circular trajectory of the electron each time. To measure diameter move the left slide of the measuring device so that its inner edge, mirror image and escape aperture of the electron beam lie on one line of

sight. Slide the inside edge of the right slide, align it with its mirror image such that the electron beam runs tangentially along it.

10. Now, keeping the coil current I constant (say 2A) reduce the acceleration potential U from 300V to 200 V in steps of 10 V, measure the diameter of the electron beam for each value of U.

Observations:

Table 1: U = 300V

Sl#	I	2r	r

Table 2: I = 2A

Sl#	U	2r	r

Graph:

Plot appropriate graphs for each observation table above and determine e/m_e.

Results:

Conclusions:

Reference:

Supplier manual

Precautions:

1. Do not exceed the coil current in beyond 3A.
2. The fine beam tube requires dangerous contact voltages up to 300 V for accelerating the electrons. Other voltages that are connected with this dangerous contact voltage also present a contact hazard. Dangerous contact voltages are thus present at the connection panel of the holder and at the Helmholtz coils when the fine beam tube is in operation.
3. Connect the connection panel only via safety connecting leads.
4. Always be sure to switch off all power supplies before connecting and altering the experiment setup.
5. Do not switch on the power supplies until you have finished assembling the circuit.
6. Do not touch the experiment setup, particularly the Helmholtz coils, during operation.
7. Danger of implosions: The fine beam tube is a evacuated glass vessel with thin walls. Do not subject the fine beam tube to mechanical stresses. Operate the fine beam tube only in the holder.