# MEASUREMENT OF e/m OF THE ELECTRON

## Purpose

1. To study the effect of electric and magnetic fields on charged particles.

2. To measure the charge to mass ratio of an electron.

## Theory

When an electron moves in a magnetic field $B$ whose direction is perpendicular to the velocity $v$ of the electron, it is acted on by a Lorentz force $F$ perpendicular to $B$ and $v$ with a magnitude given by:

$$F = e\,v\,B \qquad (1)$$

where $e$ is magnitude of the charge of the electron. This force causes the particle to move in a circle in the plane perpendicular to the field.

Applying Newton's 2nd law for the circular motion of electron gives

$$e\,v\,B = m\frac{v^2}{r} \qquad (2)$$

where r is the radius of the circle and $m$ is the mass of the electron.

If the electron has been accelerated from rest through a potential difference $V$, then the kinetic energy acquired is equal to the loss of potential energy.

$$\frac{1}{2}mv^2 = eV \qquad (3)$$

Combining equations (2) and (3) gives

$$\frac{e}{m} = \frac{2V}{B^2 r^2} \qquad (4)$$

Thus, when the accelerating voltage $V$ (in volts), the magnetic field $B$ (in Tesla), and the radius of the circular path $r$ (in meter) are known, the value of the $e/m$ can be computed and is given in units of Coulomb/kg by equation (4).

## Apparatus

The Cathode ray tube used in this experiment is a special one in which the path of a beam of electrons can be observed directly. The tube is filled with helium gas at a low pressure. Electrons emitted by the heated cathode are accelerated by the potential difference applied between the cathode and anode cylinder. Some of the electrons come out in a narrow beam through a circular hole in the center of the cylinder. This emission is then focused into a narrow beam by the grid of the tube. When electrons of sufficient high kinetic energy leaving the cathode collide with helium atoms a fraction of the atoms will be ionized. Upon combination of these ions with stray electrons, the helium-arc spectrum is emitted and the characteristic green color of the undispersed visible light is observed.

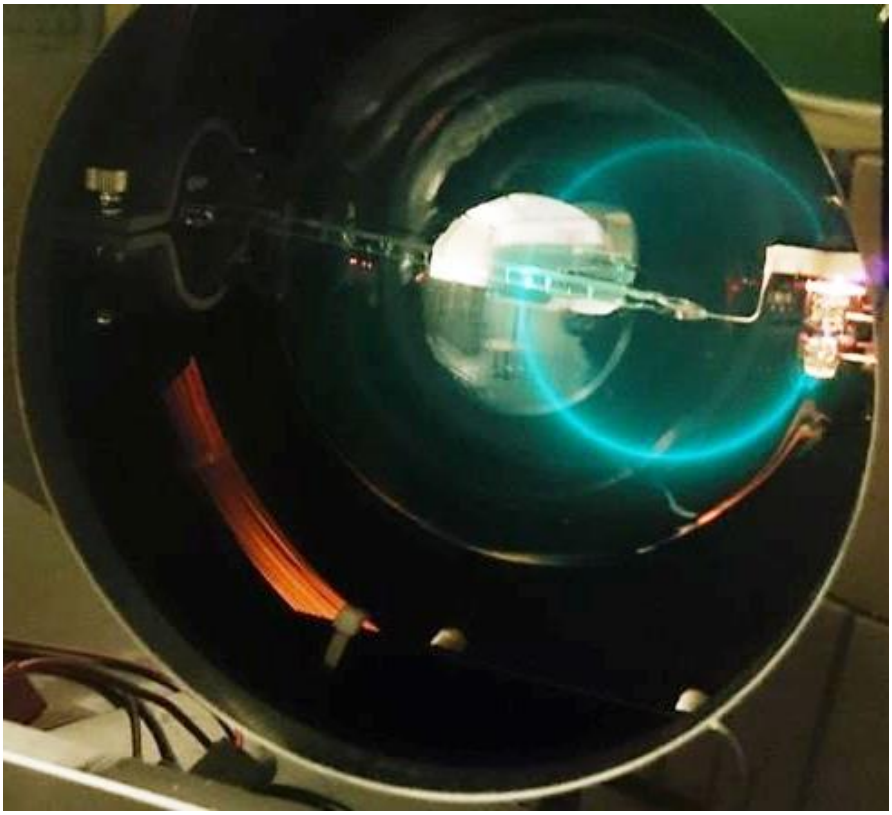


**Figure 1**

A homogenous magnetic field is produced in the region of the cathode ray tube by a current through two circular coils (see Figure 1). Whenever a charged particle, such as an electron in the present experiment, is emitted, the force F given by equation (1) acts on the particle and will deflect it. The particle, therefore, moves under the influence of this force which has a constant magnitude but whose direction is always at right angle to the velocity of the particle. The orbit of the particle is, therefore, a circle.

**Calculation of the magnetic field**

The magnetic field produced at the position of the electron beam by a current *I* flowing through the coils must be calculated. For the equipment used in this experiment, there are two circular coils with N turns on each, the coils being connected to contribute equally to the field at the center. This arrangement is known as a pair of Helmholtz Coils and has the advantage that the field is uniform in the region near the center. For this particular geometry and constructional details of the apparatus, the relationship between *B* and *I* is given by:

$$B = \frac{0.716\,\mu_0 N I}{R} \qquad (5)$$

where $\mu_o$ is the permeability constant which is equal to $4\pi \times 10^{-7}$ T.m/A, $N$ = 130 turns and $R$ is the radius of the coils = 14.5 cm.

## Procedure

1. Use a magnetic compass to determine the North-South direction at the location of the laboratory. Then set the equipment so that the plane of the Helmholtz Coils lies in the plane of the earth's magnetic field. **Why is this step important? Explain.**

2. The circuit has already been connected for you. The power supplies to the filament, coil, and anode are contained in one pack. Note the following, however:




**Figure 2**

(i) The black knob on the left controls the anode voltage, and the display above this knob reads the accelerating voltage $V$ (0−500 volts).

(ii) The black knob on the right controls the current through the Helmholtz coils, and the display above this knob reads the current $I$.

(iii) The diameter of the beam $2r$ is measured by allowing the beam to fall on one of the phosphor coated cross bars, which allows the direct measurement of the diameter, as shown in Figure 3.

(iv) **The CR Tube power supply uses high voltage (500 V) and is capable of delivering high current (350 mA), which can be dangerous**.

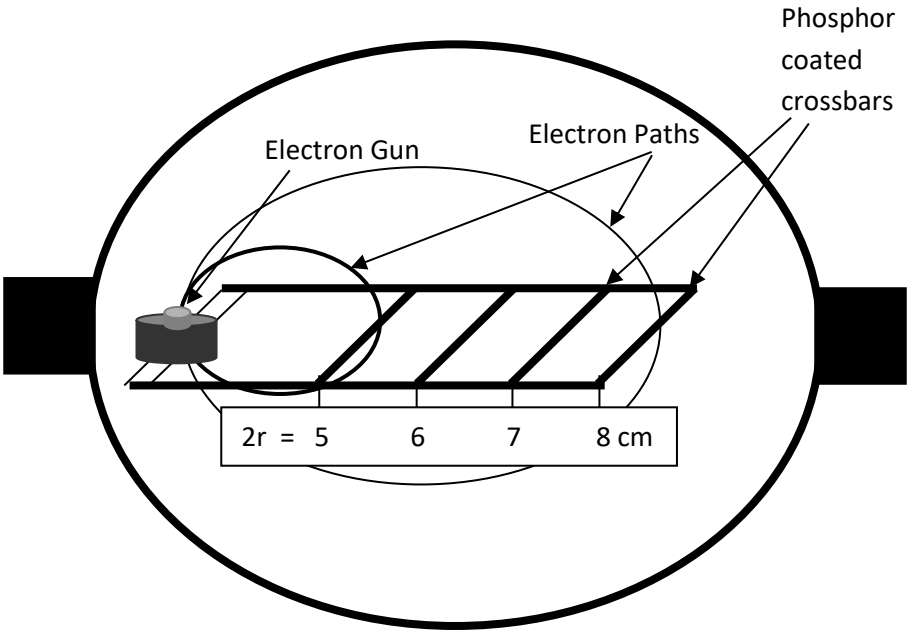



**Figure 3**

3. Switch on the power supply. This will automatically turn on the filament current. Allow one or two minutes for the filament to heat up.

4. Turn the anode voltage knob to apply about 150 volts to the anode. This is the accelerating voltage $V$. A fine greenish-colored beam will now be observed.

5. Switch on the current to the coils. Adjust the current and observe how the beam bends over and eventually circles back on itself. It may be necessary to rotate the whole tube to achieve this condition.

6. Set the current at some value about 1.8 A. Adjust the anode voltage to give an accelerating voltage *V* between 150 and 250 volts so that the beam falls on the phosphor-coated crossbars. Before taking your measurements, however, make sure that with the current value chosen you will be able to bend the beam to fall on the 5 cm cross bar. If not, then increase the coil current slightly and decrease the anode voltage until the beam is observed to fall on the cross bar. Keep this value of current I constant in the rest of the experiment. **Record the diameter of the orbit (5 cm) and the accelerating voltage *V* in Table 1. Assume 5% error in the ammeter and voltmeter readings. Record the current as well.**

***I* =** ***Δ I* =**

7. Adjust the anode voltage to get the circles of diameters 6, 7, 8, 9, 10 and 11 cm and record the corresponding values of V in Table 1. Complete Column 3 as well.

8. After finishing your measurements in step 7, turn the current through the coils to zero, reverse the current leads and increase the current. Observe that the beam is deflected in the opposite direction. **Why does the beam deflect in the opposite direction?**

**Table 1**

| **2r (cm)** | **V** | **ΔV** | **$r^2$** | **$\Delta(r^2)$** | **e/m** | **Δ(e/m)** |
|---|---|---|---|---|---|---|
| 5.0 | | | | | | |
| 6.0 | | | | | | |
| 7.0 | | | | | | |
| 8.0 | | | | | | |
| 9.0 | | | | | | |
| 10.0 | | | | | | |
| 11.0 | | | | | | |

## Data analysis

1. Use equation (5) to calculate the magnetic field *B*.

***B* =**

Write the expression for $\frac{\Delta B}{B}$ =

Therefore, ***ΔB* =**

2. Estimate the uncertainty in r to be the thickness of the crossbar.

***Δ(r)*** **=**

Write the expression for $\frac{\Delta(r^2)}{r^2}$ =

Therefore, ***Δ(r²)*** **=**

Complete Columns 4 and 5 in Table 1.

3. Use equation (4) to calculate the ratio e/m.

Write the expression for $\frac{\Delta(e/m)}{e/\mathrm{m}}$ =

Therefore, ***Δ(e/m)*** **=**

Complete Columns 6 and 7 in Table 1.

4. Calculate the average value of e/m.

***e/m*** **=** ±

5. The accepted value of e/m is $1.7\times10^{11}$ C/kg. Calculate the percent difference between the experimental and accepted values of e/m.

Is the percent difference smaller or larger than your percent error in measuring e/m?

6. What are the sources of error in this experiment?