

**Purpose:**

Determine the ratio of charge to mass ( $e/m$ ) for an electron, by deflecting the motion of an electron using a magnetic field.

**Structure:**

Please refer to Figure 1, which shows the structure of the device.

1. A uniform magnetic field is produced in the center of a Helmholtz coil. A Helmholtz coil consists of two circular coils mounted parallel to each other, and along a common axis. The coils are electrically connected in series. If a voltage is applied to the Helmholtz coil an electrical current will flow in the same direction in both coils. The B-field from each coil will be oriented the same direction and a uniform magnetic field is created between the coils.
2. The discharge tube used for measuring  $e/m$  is placed within the uniform magnetic field created by the Helmholtz coils. The discharge tube contains an electron gun and is filled with low-pressure Helium. The electron beam emitted by the electron gun excites the low pressure Helium and appears as a luminous circular trace.
3. Terminals for external power supplies are located on the front panel of the  $e/m$  device, as well as a knob for adjusting the current through the Helmholtz coils.

(Coil rating)

Number of turns per coil: 130

Radius (internal):  $R = 0.150\text{m}$

(Rating of discharge tube)

Heater: 6.3V, 0.4A

Maximum operating voltage/current: Plate voltage: 500V (plate current: 10mA)

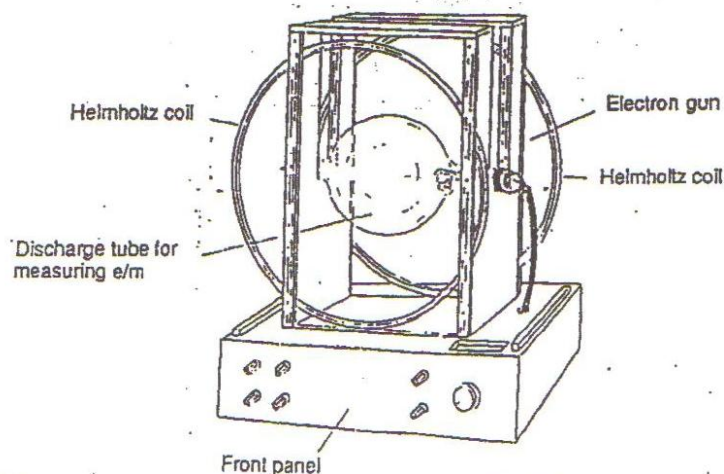


Figure 1

**Features:**

The discharge tube incorporates the following special features:

- 1) Helium gas sealed within the tube produces light when excited by the electron beam.
- 2) The discharge tube incorporates a built-in scale for measuring diameter of the path traced by the electron beam. The graduations and numerals of the scale are illuminated by light produced when electrons collide with the low pressure Helium.

**Principle of operation:****1. Acceleration of electrons (electron gun):**

Figure 2 illustrates the electron gun used to accelerate electrons by means of an applied electromagnetic field.

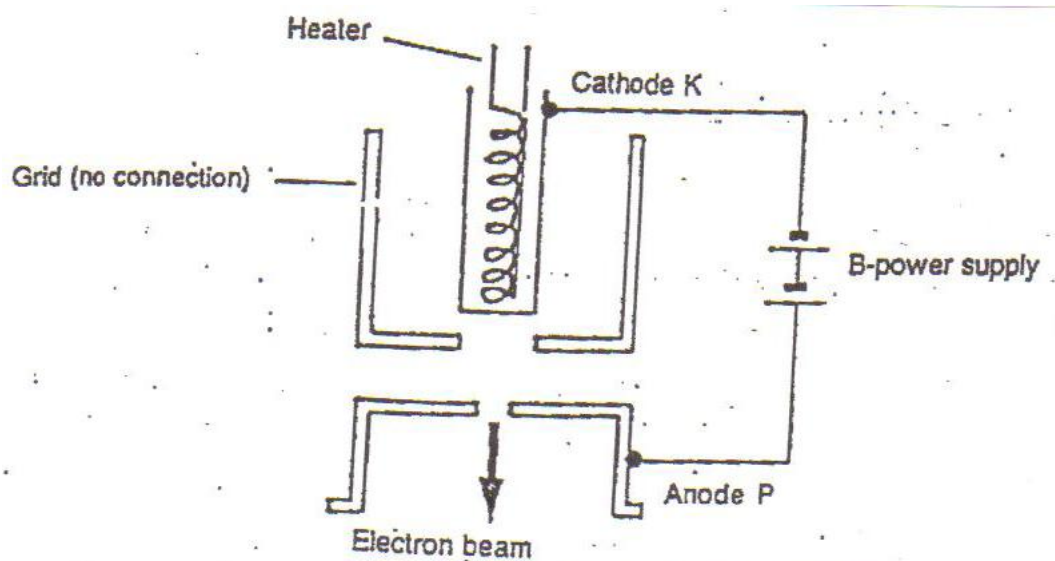


Figure 2: Electron Gun

The Cathode K (Figure 2) is heated, releasing thermal electrons, whose motion is accelerated by the electric potential (V) applied between anode P and Cathode K. The velocity ( $v$ ) of an electron accelerated by the electric potential (V) applied at the anode, can be calculated using the Law of the Conservation of Energy, as follows (ignoring the initial velocity of the electron as it is discharged from the cathode):

$$\frac{1}{2}mv^2 = eV$$

$$i) \quad v = \sqrt{\frac{2eV}{m}}$$

Where  $m$  (kg) is the mass of electron and  $e$  [C] is the elementary electrical charge of the electron.

## **2. Electron's Motion in a Magnetic Field:**

Electrons that travel with a velocity ( $v$ ), perpendicular to a uniform magnetic field ( $B$ ), experience the Lorentz Force ( $F = e v B$ ). The Lorentz Force causes the electrons to move in a circular path in the plane perpendicular to the magnetic field. Given a magnetic field with magnetic flux density  $B$  ( $b/m^2$ ), the following formulas are obtained, where ( $v$ ) is the velocity of circular motion, ( $r$ ) is the radius of the circular motion. The Lorentz Force is the centripetal force that constrains the electrons to move along a circular path:

$$evB = \frac{mv^2}{r}$$

$$ii) \quad eB = \frac{mv}{r}$$

With the formulas i) and ii) given above, the charge to mass ratio ( $e/m$ ) of the electron can be expressed as:

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

### 3. Helmholtz Coils:

Two circular coils of equal radius are mounted, in parallel and along a common axis. When an electrical current is applied to both coils, so that the current is in the same direction for each coil, a uniform magnetic field is formed between the coils. According to Bio-Savart's Law, the intensity  $H$  (A/m) of the magnetic field between the two coils of radius ( $r$ ), carrying a current  $I$  (A), is given by the following formula:

$$H = \frac{8}{5\sqrt{5}} \frac{I}{R} = 0.7155 \times \frac{I}{R} [A/M]$$

$$B = 0.7155 \times \frac{4\pi}{10^7} \frac{NI}{R}$$

When there are  $N$  turns of wire in each coil, the intensity of the magnetic field is multiplied  $N$  times. Given that the permeability of vacuum is  $4\pi/10^7$ . The intra-coil magnetic flux density is given as:

$$B = 8.99 \times 10^{-7} \frac{NI}{R} \left[ \frac{Wb}{m^2} \right]$$

The coils in this apparatus are constructed with 130 turns of wire with a radius of 0.150m; the formula given above can be applied to determine  $B$  between the coils:

$$B = (7.79 \times 10^{-4}) I \left[ \frac{Wb}{m^2} \right]$$

## **Experimental Procedures:**

### **1. Preparation:**

#### (1) Configuration

- (1) Power supply (0-500V) suitable for vacuum tubes
- (2) Power supply (6.3 volt, AC or DC)
- (3) Regulated DC power supply unit, (0-15V)
- (4) DC voltmeter (measure 0-500V)
- (5) DC ammeter, (measure up to 2A).
- (6) Magnetic needle

#### (2) Connecting the power supply system:

- (1) Connect a 6.3V power supply to the power terminal of the heater on the main body of the unit (either AC or DC can be used).
- (2) Connect the 0 - 500V DC "B-power supply" to the "B-power" terminal of the main unit (see figure 3.).  
(Red terminal "P" is +, black terminal "K" is -)  
Note: The power supply requirements for both (1) and (2) can be met by a power supply unit suitable for vacuum tubes.
- (3) Connect the DC (0-15V) power supply to the coil, power supply terminals on the main unit.  
(Red terminal "P" is +, black terminal "K" is -)

Note: A regulated DC power supply (0 - 15V) should be used for this purpose. When using this type of power supply, turn the knob of the coil power terminal fully counter clockwise. When using storage batteries (6 - 12V), turn the knob of the coil power supply terminal fully counterclockwise and set the resistance to maximum.

## 2. Observation and experimentation:

### Circular motion of electron beam

- (1) Set the voltage of the “B-power supply” as well as the coil power supply to the minimum. Turn on the filament power (the 6.3 V unit).
- (2) When the cathode glows red, gradually raise the voltage of the “B-power supply” as you observe the discharge tube. An glowing electron beam will gradually appear at just under 200V.
- (3) Gradually increase the voltage of the coil-power supply. (When a storage battery is used; turn the adjustment knob for the coil current clockwise .

Increasing the voltage in the coils will raise the intensity of the magnetic field, until the electron beam is bent into a circular pattern. When the path of the beam becomes circular, use a magnetic needle to check the polarity at the magnetic field formed between the Helmholtz coils. This will make it possible to confirm the relation of the magnetic field with the direction of Lorentz force.

Note: If the electron gun is not pointed perpendicular to the magnetic field, the electron beam will trace a spiral path rather than a circular one. In this case, loosen the mounting screw of the discharge tube and rotate the position of the tube until the electron beam traces a circular path.

### (2) Spiral motion (just for fun)

Loosen the mounting screw of the discharge tube and slightly rotate the position of the tube. The electron beam should assume a spiral shape. The shape of the spiral can be changed by varying the intensity of the coil current, the voltage level of the B-power supply, or the position of the discharge tube.

### (3) Affect of bringing a magnet near the discharge tube

The magnetic field of a magnet brought near the discharge tube will complicate the path of the electron beam.

**Caution:** If the B-voltage is raised too high, the discharge tube will be damaged ! Be careful when raising the B-voltage, do not raise the applied voltage above 500V!

### 3. Measurement:

#### Setting up e/m device and power supplies

1. Use a voltmeter and ammeter, which are not connected to the power supply system and which meet the required level of accuracy. Some of the power supplies come with integrated volt and ammeters.
2. In order to minimize the influence of the earth's magnetic field, use a magnetic needle to locate magnetic north and align the e/m device so that the faces of the Helmholtz coils are parallel to the needle. This will reduce the influence of geomagnetism on the magnetic field between the coils.
3. Connect the power supply, voltmeter, and ammeter to the appropriate terminals of the main unit, as shown in Figure 3.

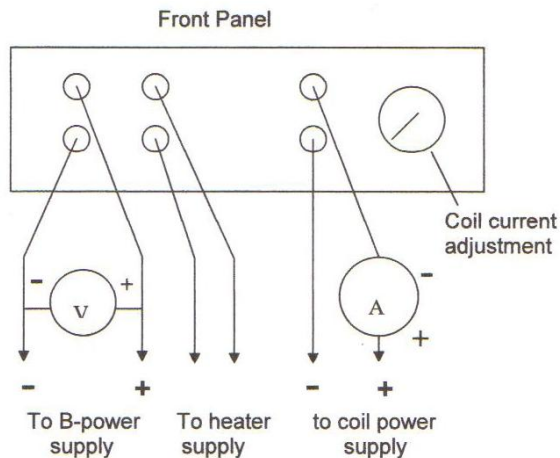


Figure 3: Wiring

Note: The influence of geomagnetism or other sources of magnetic fields can be observed by the deflection of the circular path of the electron beam, while the main unit is rotated. The magnitude of this deflection is greater when a small current is flowing through the coils.

Set up the device as in Fig. 1 thru 3 to produce a circular motion and calculate  $e/m$  by measuring the voltage ( $V$ ) applied to the B-power supply, current ( $I$ ) flowing through the coils, and diameter ( $2r$ ) of the circular path traced by the electron beam.

Example of measurement:

With B-voltage set to 300V, adjust the coil current to produce a circular path of 100mm in diameter. When these values and the measured value of the current (1.48A) are applied in the following formula, we find.

$$[V = 300V, I = 1.48A, r = 0.0500m]$$

$$\frac{e}{m} = \frac{2V}{r^2 B^2} = \frac{2V}{r^2 (I \times 7.79 \times 10^{-4})^2}$$

$$\frac{e}{m} = \frac{2V}{(0.05 \times 7.79 \times 10^{-4} \times 1.48)^2} = 1.81 \times 10^{11} \left[ \frac{C}{kg} \right]$$

$$[\text{Reference}] e/m = 1.7588 \times 10^{11} [C/kg]$$

### **Report:**

1. For a constant current ( $I$ ), plot a graph of the voltage  $V$  as a function of  $r^2$ . Obtain the slope of this curve.
2. For a constant voltage ( $V$ ), plot a graph of  $I^2$  as a function of  $(1/r)^2$ . Obtain the slope of this curve.
3. Determine the value of the ratio  $e/m$  from each of the curves that you plotted.
4. Compare the average of the values of  $e/m$  obtained with the accepted value.



**Data:**

**Constant I**

**(I= )**

V	r	$r^2$

**Constant V**

**(V= )**

$I^2$	r	$1/r^2$

**Note:** All units must be MKS.