The Islamia University of Bahawalpur

DEPARTMENT OF PHYSICS

Physics Lab-V (Phy-01505/Phy-21105) and VI (Phy-01604/Phy-21205)

Charge to Mass Ratio (e/m)

Experiment: To determine the charge to mass ratio (e/m) of an electron by using the fine-beam tube.

Theory:

If a narrow beam of electrons moving with constant speed v be projected into a magnetic field (directed, say, into the plane of paper), a constant force **F** acts normally on each electron and makes the beam move in a circular path of radius r, as shown in **Fig. 1**. The force **F** provides the necessary centripetal force and is given by,

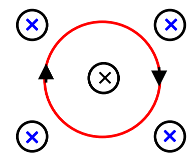

Fig. 1 Field B directed into the plane of paper

Magnetic Force, $F = Bev$ - - - (1)

Centripetal force, $F = \frac{mv^2}{r}$ - - - (2)

Where v, m, and e are, respectively, the velocity, mass and the charge of the electron; $\boldsymbol{B}$ is the magnetic field and r, the radius of the circular path shown in **Fig. 1**. Equating (1) and (2) we get

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

Or $$e/m = v/(Br) \quad - - - (3)$$

Now in this experiment the electron beam is obtained by heating a cathode (electrically) and accelerating the electrons given off by it through a potential difference of V volts applied between the cathode and an anode containing a small orifice through which the electron beam issues out. (The beam is made visible by the presence of a gas in a tube at low pressure. Gas atoms are excited by the colliding electrons and emit light enabling us to see the path of the beam.) The kinetic energy gained by the electrons in falling through the potential V is given by,

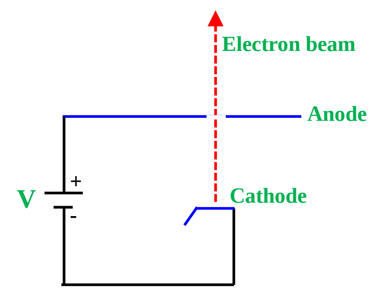

Fig. 2 Thermionic emission (Schematic)

$$eV = \frac{1}{2}mv2 \quad - - - (4)$$

Assuming, of course, that electrons come out of the cathode with zero velocity (actually the velocity distribution is Maxwellian, see any text on Physical Electronics). From equation (4) we have,

$$v^2 = \frac{2eV}{m}$$

or $$v = \sqrt{\frac{2eV}{m}} \quad - - - (5)$$

Substituting the value of v from (5) into (3), we get

$$\frac{e}{m} = \frac{\sqrt{\frac{2eV}{m}}}{Br} \quad \text{or} \quad \frac{e^2}{m^2} = \frac{2\left(\frac{e}{m}\right).V}{B^2 r^2}$$

or $$\frac{e}{m} = \frac{2V}{B^2 r^2} \qquad \text{- - - (6)}$$

Which is the relation that we intend to use to calculate e/m.

Experimental details:

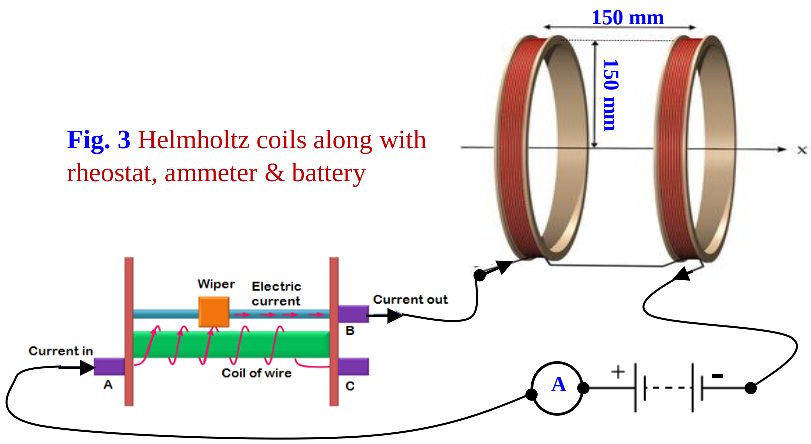

Fig. 3 Helmholtz coils along with rheostat, ammeter & battery

In this experiment there are only **three** quantities that have to be measured, namely, V, **B** and r. The magnetic field **B** is produced by a pair of Helmholtz Coils, each standing in a vertical plane. The coils have equal number of turns (130 turns each) and the separation between them is equal to the radius (150 mm.) of each coil. The pair of coil is mounted on a base board and the fine-beam tube with diameter approx. 175mm (shown in **Fig. 3**) is placed between the two coils. (The arrangement of having two coils with spacing equal to their radii gives rise to uniform magnetic field in the region between the coils, where the path of the electron beam is made to lie.)

Current (I) from a battery is passed through the coils (connected in series) and can be controlled by a rheostat and measured by an ammeter. The maximum allowed current is 2 amperes.

The voltage (V) and the current (I) should be so adjusted that the path of the beam becomes a circle. This will be possible only when the magnetic field is set exactly perpendicular to the initial direction of the beam *i.e.* as it comes out of the anode. The wiring connections are not difficult to learn and you should consult the instructor for this purpose. A complete schematic diagram is given in **Fig. 4**.

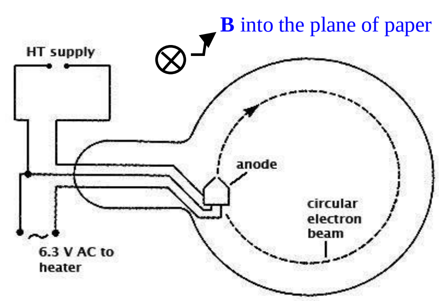

Fig. 4 Fine beam tube

Lastly, the radius of the circular path of the electron beam should be measured with a vernier (travelling) microscope both in the vertical and the horizontal directions and several readings taken, at each value of the voltage V and current I.

Use at least 5 different values of the current I at each setting of the voltage V and each time take several readings of the diameter (2r) in both directions. The voltage V should then be changed somewhat and the above process repeated. If five different values of the voltage (V) are taken then you will have 25 (5×5) sets of readings. Thus e/m can be calculated 25 times and then its mean value and the standard error of the mean should be computed.

The magnetic field B can be calculated using the formula,

$$B = \mu_\circ \left(\frac{4}{5}\right)^{3/2} \frac{n.I}{R} \, , \frac{Vs}{m^2} \qquad \text{- - - (7)}$$

Where $$\mu_\circ = 1.26 \times 10^{-6} \, \frac{Vs}{Am} \qquad \text{- - - (8)}$$

The mean and its standard error:

Let x_1, x_2 ,- - -, x_n be a set of n observations of the variable x(e/m in our case), then the mean value of x is simply,

$$\bar{x} = \frac{x_1+x_2+x_3+x_4+\cdots+x_n}{n} \qquad \text{- - - (i)}$$

The standard deviation of the above set of observations is

$$\sigma = \sqrt{\frac{(x_i - \bar{x})^2}{n}} \qquad \text{--- (ii)}$$

The standard error of the mean is then

$$S.E\,(\bar{x}) = \sigma/\sqrt{n} \qquad \text{--- (iii)}$$

You should also plot a graph between v and r^2 (keeping I constant) and see that it is linear as shown in **Fig. 5**.

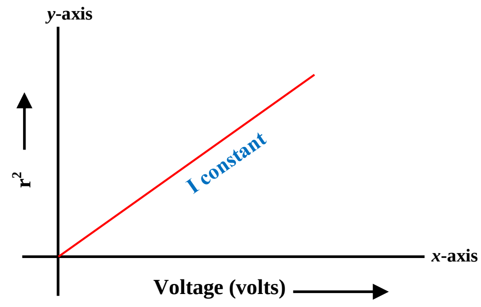

Fig. 5 Graph between V and r^2.

Procedure:

1. Increase the anode voltage until you begin to see the beam issuing vertically out of the anode. Now switch on the current supply to the Helmholtz coils and adjust the current until the path of the beam becomes circular. The circle should have a sufficiently large diameter to minimize measurement error, (Remember that as r is squared, 5% error in r will give rise to 10% error in the results.)
2. Now measure the diameter of the circular path of the beam in the horizontal & vertical directions by means of vernier microscope. Take several readings in each direction. As the beam has finite thickness the cross–wire of the microscope should be focused on the centre of the beam when taking readings.
3. Now change V slightly keeping magnetic field constant until the diameter of the circle changes noticeably, and repeat above measurements. In this way take readings at least 5 different values of voltage. Then change the current slightly and repeat the above observations at different values of the voltage V.

Precautions:

(a) The magnetic field should be set exactly perpendicular to the electron beam.
(b) The high voltage supply should not be switched on until all the connections have been checked by the instructor.
(c) The meter should be set on their appropriate ranges before wiring them in the circuit.

Observations/Calculations:

1. Keeping current constant.

Current = 1 A			Current = 1.2 A			Current = 1.4 A		
Voltage (V)	D (cm)	R (cm)	Voltage (V)	D (cm)	R (cm)	Voltage (V)	D (cm)	R (cm)
200			200			200		
220			220			220		
240			240			240		
260			260			260		
280			280			280		
300			300			300		

2. Keeping voltage constant.

V = 200 V			V = 240 V			V = 280 V		
I (A)	D (cm)	R (cm)	I (A)	D (cm)	R (cm)	I (A)	D (cm)	R (cm)
1.0			1.0			1.0		
1.1			1.1			1.1		
1.2			1.2			1.2		
1.3			1.3			1.3		
1.4			1.4			1.4		

3. Draw graphs between Current & radius and also between Voltage & radius.
4. Perform calculations for each data set by using the following equations:

$$B = \left(\frac{4}{5}\right)^{3/2} \frac{\mu_o n I}{R}$$

And

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

5. Get average values and calculate error.

Relevant Physics:

1) Helmholtz Coils

A **Helmholtz coil** is a device for producing a region of nearly uniform **magnetic field**, named after the German physicist Hermann von Helmholtz. It consists of two solenoid electromagnets on the same axis. Besides creating magnetic fields, Helmholtz coils are also used in scientific apparatus to cancel external magnetic fields, such as the Earth's magnetic field.

A Helmholtz pair consists of two identical circular magnetic coils (**solenoids**) that are placed symmetrically along a common axis, one on each side of the experimental area, and separated by a distance h equal to the radius R of the coil. Each coil carries an equal **electric current** in the same direction.

If the radius is R, the number of turns in each coil is n and the current through the coils is I, then the magnetic field B at the midpoint between the coils will be given by

$$B = \left(\frac{4}{5}\right)^{3/2} \frac{\mu_o n I}{R}$$

where μ_o is the permeability of free space ($4\pi \times 10^{-7} T.m\,A^{-1}$).

2) Lorentz Force

In **physics** (particularly in **electromagnetism**) the **Lorentz force** is the combination of electric and magnetic **force** on a **point charge** due to electromagnetic fields. A particle of charge q moving with velocity **v** in the presence of an electric field **E** and a magnetic field **B** experiences a force

$$\boldsymbol{F} = electric\ force + magnetic\ force = q\boldsymbol{E} + q(\boldsymbol{v} \times \boldsymbol{B}) = q[\boldsymbol{E} + (\boldsymbol{v} \times \boldsymbol{B})]$$

3) Thermionic Emission

Thermionic emission is the thermally induced flow of charge carriers from a surface or over a potential-energy barrier. This occurs because the thermal energy given to the carrier overcomes the **work function** of the material. The charge carriers can be electrons or ions, and in older literature are sometimes referred to as "thermions". After emission, a charge that is equal in magnitude and opposite in sign to the total charge emitted is initially left behind in the emitting region. But if the emitter is connected to a battery, the charge left behind is neutralized by charge supplied by the battery as the emitted charge carriers move away from the emitter, and finally the emitter will be in the same state as it was before emission.

The classical example of thermionic emission is the emission of electrons from a hot cathode into a vacuum (also known as **thermal electron emission** or the **Edison effect**) in a **vacuum tube**. The hot cathode can be a metal filament, a coated metal filament, or a separate structure of metal or carbides or borides of transition metals. Vacuum emission from metals tends to become significant only for temperatures over 1,000 K (730 °C; 1,340 °F).

4) Excitation, in **physics**, the addition of a discrete amount of energy (called **excitation** energy) to a system—such as an atomic nucleus, an atom, or a molecule—that results in its alteration, ordinarily from the condition of lowest energy (ground state) to one of higher energy (excited state).

5) Electron excitation is the transfer of a bound electron to a more energetic, but still bound state. This can be done by photo-excitation (PE), where the electron absorbs a photon and gains all its energy or by electrical excitation (EE), where the electron receives energy from another, energetic electron.

6) De-excitation When the electron falls back to its ground state it releases a photon. The energy of the released photon exactly matches the difference in the electron energy states and the energy of the initially absorbed electron. This process is called **de-excitation**.

7) Electric Current An **electric current** is a flow of **electric charge**. In electric circuits this charge is often carried by moving electrons in a wire. It can also be carried by ions in an **electrolyte**, or by both ions and electrons such as in an ionised gas (plasma).

The **SI** unit for measuring an electric current is the **ampere**, which is the flow of electric charge across a surface at the rate of one **coulomb** per second. Electric current is measured using a device called an **ammeter**.

Electric currents cause **Joule heating**, which creates light in incandescent light bulbs. They also create magnetic fields, which are used in motors, inductors and generators.

The particles that carry the charge in an electric current are called charge carriers. In metals, one or more electrons from each atom are loosely bound to the atom, and can move freely about within the metal. These conduction electrons are the charge carriers in metal conductors.

The conventional symbol for current is *I*, which originates from the French phrase *intensité de courant*, meaning *current intensity*. Current intensity is often referred to simply as *current*. The *I* symbol was used by **André-Marie Ampère**, after whom the unit of electric current is named, in formulating the eponymous **Ampère's force law**, which he discovered in 1820.

In **alternating current** (AC) systems, the movement of electric charge periodically reverses direction. AC is the form of **electric power** most commonly delivered to businesses and residences. The usual waveform of an AC power circuit is a **sine wave**. Audio and radio signals carried on electrical wires are also examples of alternating current. An important goal in these applications is recovery of information encoded (or ***modulated***) onto the AC signal.

In contrast, **direct current** (DC) is the unidirectional flow of electric charge, or a system in which the movement of electric charge is in one direction only. Direct current is produced by sources such as **batteries**, **thermocouples**, and **solar cells**. The electric charge flows in a constant direction, distinguishing it from AC. A term formerly used for direct current was ***galvanic current***.

8) Difference between Current and Voltage **Current** is the rate at which electric charge flows past a point in a circuit. **Voltage** is the electrical force that would drive an electric current between two points.

Comparison chart

Current versus Voltage comparison chart		
	Current	**Voltage**
Symbol	I	V
Definition	Current is the rate at which electric charge flows past a point in a circuit. In other words, current is the rate of flow of electric charge.	Voltage, also called electromotive force, is the potential difference in charge between two points in an electrical field. In other words, voltage is the "energy per unit charge".
Unit	A or amps or amperage	V or volts or voltage
Relationship	Current is the effect (voltage being the cause). Current cannot flow without Voltage.	Voltage is the cause and current is its effect. Voltage can exist without current.
Measuring Instrument	Ammeter	Voltmeter
SI Unit	1 ampere =1 coulomb/second.	1 volt = 1 joule/coulomb. (V=W/C)
Field created	A magnetic field	An electrostatic field
In series connection	Current is the same through all components connected in series.	Voltage gets distributed over components connected in series.
In a parallel connection	Current gets distributed over components connected in parallel.	Voltages are the same across all components connected in parallel.

Symbols and Units

An uppercase italic letter *I* symbolizes current. The standard unit is Ampere (or Amps), symbolized by A. The SI unit for current is **Coulomb/second**.

1 ampere = 1 coulomb/second.

One ampere of current represents one coulomb of electrical charge (6.24×10^{18} charge carriers) moving past a specific point in the circuit in one second. The device used to measure current is called an **Ammeter**.

An uppercase italic letter *V* symbolizes voltage.

1 volt = 1 joule/coulomb.

One volt will drive one coulomb (6.24×10^{18}) charge carriers, such as electrons, through a resistance of one ohm in one second. The **Voltmeter** is used to measure voltage.

Written and updated by

Dr. Altaf Hussain

(Assistant Professor)

Department of Physics,

The Islamia University of Bahawalpur

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