MEASURING e/m FOR THE ELECTRON

Purpose: To understand how the motion of charged particles is influenced by a constant magnetic field and to measure the charge to mass ratio.

Theory: In 1897 J. J. Thomson performed a series of wide-ranging experiments with far-reaching consequences (the "discovery of the electron"). These results were crucial to the development of the understanding of the electrical properties of matter. His experiments confirmed that the speed of the electrons is significantly less than that of electromagnetic waves, c; and gave an (e/m) of about 2000 times larger than that of a Hydrogen atom ionised in an electrolysis experiment. It was not obvious at the time whether the large charge to mass ratio was a consequence of a small mass, with the same unit of charge that was instrumental in electrolysis, or whether it was owing to a large intrinsic charge. What he was able to show was that this new particle, with its characteristic charge-to- mass ratio was a constituent of every material that he was able to utilise as a cathode. This independence showed that the particles of the beam are a common constituent of matter, which we now call the electron.

Technological importance of this experiment

Although LCDs and plasma displays are being introduced almost all TVs in use today rely on a device known as the cathode ray tube, or CRT, to display their images. The fine beam tube you will use to perform this experiment is an elementary CRT. The manipulation of the trajectory of an electron beam by applying (time-dependent) electromagnetic forces which you will demonstrate is a key ingredient for displaying information on a TV screen. The principle that a charged particle's trajectory in uniform electric and magnetic fields is dependent on its mass is used in a device called a mass spectrometer.

Principle of the fine beam tube

Electrons are ejected from a heated cathode into a partially evacuated tube. Collisions between the electrons and residual gas atoms or molecules yield positive ions along the path of the electron beam. The ions serve to partially focus the beam, owing to the Coulomb attraction which prevents the scattered electrons from straying far from the beam axis. Collisions between electrons in the beam and gas atoms in the tube excite the latter, which subsequently decay by emitting light. This is how we can see the trajectories of the electrons in the beam.

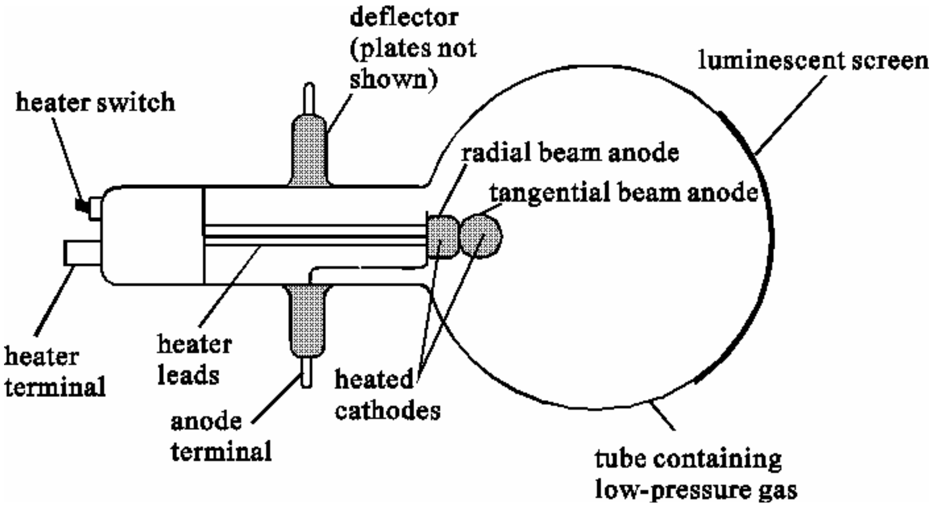

Figure 1. A schematic of the fine beam tube.

A magnetic field perpendicular to the axis of the tube can be applied by means of a pair of Helmholtz coils. Each coil comprises *N* turns of copper wire through which a current *I* is caused to flow by means of a low voltage supply. When the coils are connected correctly and placed in the appropriate place, the magnetic induction *B* at the centre of the fine beam is:

$$B = \frac{\mu_0 \cdot 0.715 \cdot n}{R} \cdot I_B \qquad \left(Tesla = \frac{Volt.\sec}{m^2} \right) \tag{1}$$

where *a* is the coil radius. For the coils used in this experiment the parameters are $N = 320$ and $R = 0.068$ m ($\mu_0 = 1.256\times10^{-6}$ Volt.sec/A.m.).

When an electron moves with speed υ perpendicular to a magnetic field of intensity **B**, a magnetic force **F** acts on the electron. The magnitude of this force is given by

$$F = Be\upsilon \tag{2}$$

When the magnetic field is applied, the electrons follow a circular path. It is well known that a particle following a circular orbit must have an acceleration of magnitude υ^2/r pointing towards the centre of the circle. Therefore for an electron of mass *m* in an orbit of radius *r* the force acting on it must have magnitude:

$$F = \frac{m\upsilon^2}{r} \tag{3}$$

From equations (2) and (3) it follows that the charge to mass ratio, (*e/m*), for the electron is given by:

$$\frac{e}{m} = \frac{\upsilon}{Br} \tag{4}$$

Conservation of energy allows us to calculate the speed of the electrons in the beam. The high voltage, *V*, supplied to the anode of the fine beam tube is related to the speed, υ, thus:

$$eV = \frac{1}{2} m\upsilon^2 \tag{5}$$

$$\upsilon = \sqrt{\frac{2eV}{m}} \tag{6}$$

Finally,

$$\frac{e}{m} = \frac{2V}{B^2 r^2} \tag{7}$$

To calculate the radius r:

$$r = \frac{x^2 + y^2}{2y} \tag{8}$$

where all the quantities on the right hand side can be measured in equation (7).

Procedure:

1. Energise the Helmzholtz coil and observe with reference to the screen that
   - i) the radius (r) decreases with increase in coil currents I_B at fixed V_a values,
   - ii) the radius (r) increase with increase in anode potential V_a, indicating a higher electron beam velocity, with fixed I_B values.

   Explain the reasons of the above observations.
2. At different fixed values of V_a, calculate the value of B as a function of the coil current I_B using eq.(1) and measure each corresponding radius (r). Determine the value of (e/m) by plotting the graph of $1/r^2$ versus $B^2/2\ V_a$. The slope of the graph gives (e/m)/2 V_a where V_a is fixed.
3. Repeat the previous calculations by plotting V_a against B^2r^2 (e/2m) for various anode potentials at a fixed B value. Compare the previous and present obtained (e/m) values.
4. Calculate the theoretical value of the ratio (e/m) for an electron by dividing the theoretical value of the electronic charge by the theoretical value of its mass.
5. Determine the percentage error in your experimental result by comparing the obtained experimental value of (e/m) with its theoretical value.

Questions:

1. What is the reason behind the experimental determination of (e/m) value?

2. Why was the earth's magnetic field not used to deflect the electron beam in the deflection tube used in the present experiment?
3. What experimental differences, if any, would result if the tube produced a beam of protons rather than electrons?

References: Electron *e/m* Skills and Discovery Laboratory