THE DETERMINATION OF THE CHARGE TO MASS RATIO FOR AN ELECTRON

I. Introduction

The charge to mass ratio for electrons may be found by observation of the motion of electrons in a uniform magnetic field. An electron with velocity, v, experiences a magnetic force, F= evB sin(θ) in a magnetic field B. If the velocity, v, is perpendicular to the magnetic field B, the force, F, will be a centripetal force and the electron will move in a circular orbit, of radius R, whose axis is parallel to the magnetic field B. In this case, the motion of the electron is determined by Newton's second law for centripetal motion:

$$F_c = \frac{mv^2}{R}$$

The centripetal force F_c is just the force evB. Therefore, $evB = mv^2/R$.

In this experiment we will control the electron velocity by acceleration of the electrons through a measurable potential difference, V_a . The velocity of the electrons can thus be found by applying conservation of energy to the acceleration process. If the electrons are accelerated from rest, the final kinetic energy, $1/2\ mv^2$, equals the change in potential energy, eV_a.

$$1/2\ mv^2 = eV_a$$

From this expression the velocity may be obtained as a function of the accelerating potential:

$$v = \sqrt{\frac{2eV_a}{m}}$$

Substitution of this value for velocity into the equation $evB = mv^2/R$ yields:

$$eB = \frac{m}{R}\sqrt{\frac{2eV_a}{m}}$$

Squaring both sides and rearranging terms, we obtain an expression for e/m in terms of measurable quantities:

$$\frac{e}{m} = \frac{2V_a}{B^2R^2} \qquad \text{[eqn. 1]}$$

Thus, in order to measure e/m we need:

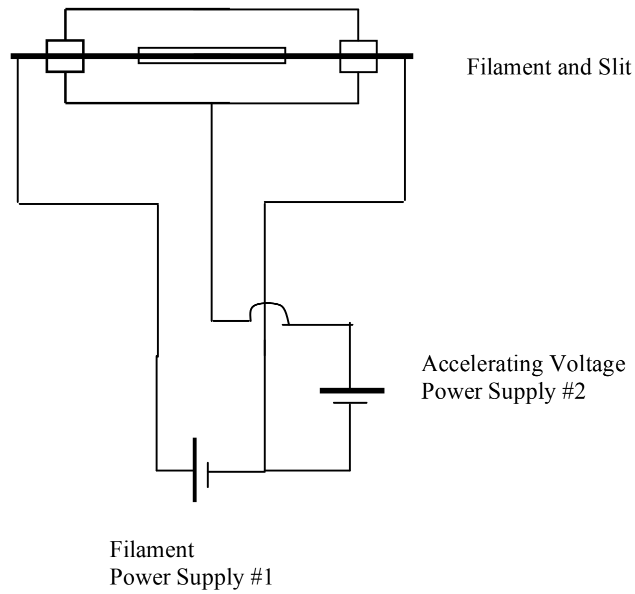
1. A source of electrons.
2. A controllable and measurable accelerating potential V_a.
3. A uniform magnetic field B of known strength.
4. A means of measuring the orbit radius R.

II. Description of Apparatus

We shall employ a commercial apparatus designed to meet the requirements of this experiment. You will observe that this apparatus consists of two essential parts: 1.) an evacuated tube and 2.) a set of Helmholtz coils. The function of each is as follows:

1. <u>The e/m tube</u>. (Refer to figs. 1 and 2)

Fig. 1



This tube contains a source of electrons, a set of electrodes for acceleration of the electrons, and a set of calibrated bars for the measurement of radii.

a.) Electron source

Electrons are emitted from a tungsten filament which lies on the axis of a second cylindrical electrode. In operation, power supply #1 capable of sending a current of several amperes through this filament produces thermionic emission of electrons.

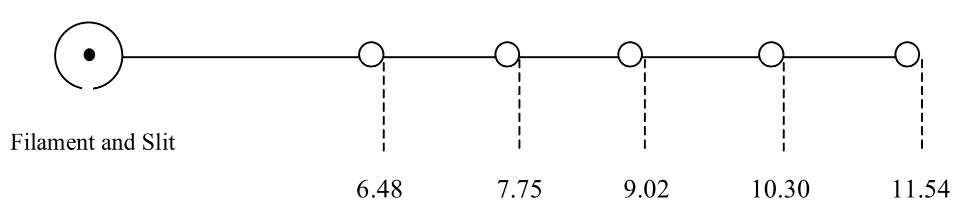
b.) Accelerating potential

The electrons are accelerated from the filament to the surrounding cylindrical carbon electrode by a potential difference V_a. A collimated beam of electrons emerges from a slit in the side of the cylindrical electrode. Power supply #2, supplies the accelerating potential. This power supply contains a voltmeter for measurement of the accelerating potential, V_a.

c.) Crossbars

The filament and cylindrical electrode are mounted on a staff with crossbars (see fig. 3). The electrons emerging from the slit will, in the presence of a magnetic field, follow a circular orbit. The diameter can be determined if the circular orbit is adjusted so that the electrons beam just touches the outer edge of a bar on the staff. These diameters are shown in Fig. 3. One adjusts the orbit by varying the magnetic field produced by the Helmholtz coils. The orbit is made visible by the introduction of a small amount of mercury vapor during manufacture of the tube.

Fig. 2



Distance (in cm) from filament to edge of Crossbar .

2. <u>The Helmholtz Coils</u>

The Helmholtz coils supply a magnetic field of known and controllable magnitude. The size of these coils is such that an essentially uniform field will exist over the circular path of the electrons. The strength of the field is determined by controlling the current through the windings. It can be shown that the magnetic field on the axis of the coils and midway between the coils is given by

$$B_{coil} = \frac{32\pi NI}{S\sqrt{125}} x10^{-7} \text{Tesla} \qquad \text{[eqn. 2]}$$

where

N = number of turns of wire on each coil. N=72
I = current in amperes
S = mean radius of one coil in meters S= 33 cm = .33 m

For the values N and S for this apparatus, the magnetic field from the Helmholtz coils is given by:

$$B_{coil} = 1.962x10^{-4} I \ \text{Tesla} \qquad \text{[eqn.3]}$$

where the variable current I (in amperes) supplied to the coils is measured with an ammeter.

One should note that the field supplied by the Helmholtz coils <u>is not the total </u>magnetic field. The field strength B in the e/m equation is the vector sum of the coil field and the earth's magnetic field. In operation, the axis of the coils is aligned parallel to the earth's field. Alignment is accomplished with a dip needle.

III. Collection of Data

Set the accelerating voltage, V_a at a convenient value, say 20 volts. Darken the room sufficiently so that the electron beam in the tube will readily visible but have enough light in the room so that the cross bars on the staff are also visible. Then, with the accelerating voltage applied, use the filament power supply to adjust the filament current to get a visible beam. Be especially careful above 3 amperes. For most tubes the proper filament current is between 3.5 and 4.5 amperes. <u>Never run the filament current higher than the minimum required for proper electron emission since a high current shortens the life of the filament</u>.

With zero current through the Helmholtz coil, note that the electron beam is deflected by the earth's magnetic field. Send a current through the Helmholtz coils and adjusthe size of the current so that the electron beam is straight. This adjustment must be made with some care. A convenient method is as follows: Hold a straight edge above the tube with one end directly above the slit in C and the length along the beam. Set the Helmholtz coil current so that the beam appears straight as compared with the straight edge. It will be noted that there is some latitude in this setting. Next increase the current through the Helmholtz coils until the beam first shows a curvature as compared with the straight edge and record the Helmholtz coil current. Then decrease the current through the coils until the beam first shows a curvature in the opposite direction and again record the current through the coils. An average of these two values gives a good value of the current required to straighten the electron beam. Use this value of the Helmholtz coil current to compute B. Since this gives the value of the Helmholtz coil field which will just neutralize the earth's field, it is a measure of the earth's magnetic field at the spot where the experiment is This eliminates any need of measuring the earth's field by any and, if done with some care, is sufficiently accurate for this experiment. (Alternatively, your instructor may determine the earth's magnetic field by measuring with a gaussmeter.)

Earth's Magnetic Field Determination

coil current (increasing)	coil current (decreasing)	Average	Earth's Magnetic Field

Increase the current through the Helmholtz coils sufficiently so that the electron beam describes a circle of small size. If the length of the slit in the cylinder has been set parallel to the axis of the Helmholtz coils, the electron beam will describe a cork-screw spiral, either upward or downward, due to the magnetic field of the filament current. If the filament current is now reversed, the spiral will reverse, i.e., go downward if it previously went upward and vice versa.

In order to remove this spiral effect, rotate the tube on its axis of mounting until the center of the electron beam strikes the center back of the cylinder. It is best in doing this to have the filament current in such a direction that the slit in the cylinder sends the light from the filament downward away from the eyes of the observer. This makes it easier for the observer to see the beam during the measurements that follow this setting. It will be observed that the electron beam has a sharp outer edge and a general haze of light inside the circle which it describes.

In measuring the diameter of the circle made by the beam, adjust the current through the Helmholtz coils so that the outside edge of the beam strikes the outside edge of one of the cross bars on the staff. The distances shown in figure 2 were measured from the slit to each cross bar in turn so that the recorded distances are the diameters of the circles.

The outside edge of the beam is used because it is determined by the electrons which have the highest velocity. The electrons which leave the negative end of the filament fall through the greatest potential difference between filament and cylinder, thus have the greatest velocity. It is this potential difference between filament and cylinder which V_a represents as it is connected in figure 1. Also, any electron which makes an ionizing collision with a mercury atom loses energy to the atom, has its velocity reduced, and is bent into a circle of smaller radius by the magnetic field. By further ionizing collisions, these electrons produce the haze of light seen inside the circle of the beam. Thus, the electrons which produce the outside edge of the beam at the selected bar on the staff (on the opposite side of the circle from the slit) are making their first ion-zing collisions and have described a semi-circle determined by the measured conditions of the experiment.

While V_a represents the accelerating potential between the filament and the gray cylinder, the filament does not have a single, well defined potential because of the voltage drop across it that creates the filament current. Experimentally one is limited to measuring the potential difference between the cylinder and the filament ends. To get the best estimate of the accelerating voltage corresponding to the middle of the filament (where most of the electrons originate), use the average voltage from the measuring the potential differences between the cylinder and each end of the filament.

Use values of V_a ranging from 20 volts to 60 volts, adjusting the coil current to permit the electron beam to hit each bar on the staff for each voltage value. The values of e/m obtained should give an average value within a few percent of the accepted 1.759×10^{11} coulombs/kg.

Accelerating Voltage	Radius	Coil Current	Coil Magnetic Field	Total Magnetic Field	e/m (Coul/kg)

Average	
Deviation	

IV. Results:

Experimental value (average)	Accepted value	% Difference
	1.759×10^{11} Coul./kg	

V. Conclusions: