DETERMINATION OF $e/m$ FOR ELECTRONS

Physics 302
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1 Introduction

The $e/m$ vacuum tube has been designed for determining the ration of charge to mass of an electron. The beam of electrons in the tube is produced by an electron gun mounted with its center line coincident with the vertical axis of the tube. The gun consists of an indirectly heated cathode which supplies the electrons; a grid, charged to a positive potential with respect to the cathode, which serves to focus the electron beam; and a circular plate, which is held at a high positive potential and thus accelerates the electrons. The electron stream is projected vertically through a small hole at the center of the disk. The bulb and disk are coated with a material which fluoresces when struck by electrons. The tube contains a trace of inert gas that aids in focusing the electron beam as well as to cause the beam to make a visible trace.

The tube is immersed in a uniform magnetic field produced by a set of Helmholtz coils which causes the stream of electrons to move in a circular path the radius of which decreases as the magnetic field increases. By proper control of the magnetic field the beam can be made to coincide with any one of the four circles on the disk.

2 Theory

When a charged particle such as an electron moves in a magnetic field in a direction at right angles to the field, it is acted on by a force, the value of which is given by

$$F = Bev$$  \hspace{1cm} (1)

where $B$ is the magnetic flux density, $e$ is the charge on the electron, and $v$ is the velocity of the electron.

This force causes the particle to move in a circle in a plane perpendicular to the magnetic field. The radius of this circle is such that the required centripetal force is furnished by the force exerted on the particle by the magnetic field.

$$\frac{mv^2}{r} = Bev$$  \hspace{1cm} (2)
where \( m \) is the mass of an electron, and \( r \) is the radius of the circle.

If the velocity of the electron is due to its being accelerated though a potential difference \( V \), it has a kinetic energy

\[
\frac{1}{2} mv^2 = eV
\]  

(3)

Substituting the value \( v \) from Eq. 3 to Eq. 2

\[
\frac{e}{m} = \frac{2V}{B^2 r^2}
\]  

(4)

Thus when the accelerating potential, the flux density of the magnetic field, and the radius of the circular path described by the electron beam are known, the value of \( e/m \) can be computed.

The magnetic field which causes the electron beam to move in a circular path has the magnetic flux density \( B \) which, in terms of current through the Helmholtz coils and certain constants of the coil is

\[
B = \frac{8\mu_0 NJ}{\sqrt{125a}}
\]  

(5)

Where \( N \) is the number of turns on each coil, \( a \) is the mean radius of the coil, and \( I \) is the current through the coils.

Substituting Eq. 5 in Eq. 4 gives

\[
\frac{e}{m} = 3.29 \times 10^6 \frac{V}{I^2 r^2}
\]  

(6)

Eq. 6 is the working equation for this apparatus. The value of \( r \), the radius of the electron beam, can be varied by changing either the accelerating potential or the Helmholtz coils current. For any given set of values, the value of \( e/m \) can be computed.

3 Experimental Procedure

1. Make certain the potentiometers on all power supplies are fully counterclockwise before you plug them in.

2. Place 30V accelerating potential on the anode and 20V on the focusing grid. Raise slowly the heating filament voltage (take about 1 minute) to 5.9V. Do not exceed this value! There should be now a visible blue beam exiting through the hole in the plate and striking the glass wall.
3. Increase the Helmholtz coils current until the electron beam describes a circle. Adjust its value until the sharp outside edge of the beam strikes the smallest circle.

4. Record this value I in your data table. Determine and record the field current required to cause the electron beam to strike other circles. This is the value of the current to be used in computing e/m. Since there will be some uncertainty in determining when the beam strikes the circles, take several readings for each circle.

5. Compute the e/m for each value of I. (Put your data in a spreadsheet.)

6. Repeat the above and determine e/m using another value for accelerating voltage. Compare your results with the published value of e/m, which is 1.76 x 10^{11} C/kg.

   Suppose your error in I is +/- 2%, your error in V is +/- 1% and your error in r is +/- 0.05cm. How much variation do you expect in your value of e/m for the largest and smallest circle?

   Since the whole e/m tube is in a magnetic field, the beam is travelling in the magnetic field before it passes through the center hole in the top plate. How does this tend to affect your results?