The Electron Charge-to-Mass Ratio

**Equipment**

This experiment investigates the path of an electron in a magnetic field. The apparatus consists of an electron gun contained within a helium filled tube. The cathode and anode are connected to a variable voltage supply ranging between 100-300 volts. The cathode is heated by an electric current, which releases electrons from the metal’s surface. The applied electric field then accelerates these electrons towards the anode. Some of these accelerated electrons continue on this path through a hole in the anode, thereby creating an electron beam. Electrons from this beam collide with atoms in the gas filled tube, exciting the atoms. As the atoms return from this excited state they fluoresce green, thereby indicating the path of the electron beam. The tube is positioned between field coils, which produce an almost homogeneous magnetic field inside the tube. Consequently the electrons, of charge $-e$, are subject to a force, $F_B = -e v \times B$, which is perpendicular to both the velocity of the electrons, $v$, and the magnetic field, $B$. This constant force, normal to the velocity, causes the electrons to travel on a circular path, but does not change the speed of the motion. For the circular path of the electrons the equation of motion is $F_B = ma_n$, where $a_n = \frac{v^2}{r}$ is the normal acceleration for orbital motion of radius $r$. This gives the equation $evB = m \frac{v^2}{r}$ and consequently an expression for the charge-to-mass ratio of the elementary charge: $\frac{e}{m} = \frac{v}{Br}$.

**The experiment and conclusions**

Carefully look over and identify the following equipment. Check that wires are connected:
- Cathode heater: 6.3 V AC output from power supply A.
- Electron gun electrodes: 0-300 V output from power supply A
- Voltmeter: output Voltmeter
- Field coils: output 0-20 V from power supply B

Set the acceleration voltage and field coil current to zero. Turn on power supply A. Wait until the cathode begins to glow then increase the acceleration voltage until you see a green beam inside the tube. Without touching the glass tube move a bar magnet near to and around the beam.

Assuming that we know nothing yet about electrons, but that we do understand the behaviour of an object moving in an electric field and a magnetic field, what do your observations tell us?

Increase the current in the field coils (if necessary, also adjust the acceleration voltage) until the green beam first bends then eventually forms a single, clear circle. Can you explain these observations?
The cathode releases negatively charge particles: electrons. The equipment is designed to determine their charge-to-mass ratio \( e / m \).

Keeping the acceleration voltage constant, increase the current in the field coils. What happens to the radius of the beam, and why?

Now keep the current in the field coils constant and increase the acceleration voltage. What happens to the radius of the beam in this case, and why?

Carry out a series of measurements varying the acceleration voltage and the magnetic field strength (magnetic flux density). For example, adjust the current in the field coils somewhere in the range of 1-2 A, then adjust the acceleration voltage to give three different voltage values such that the electron beam radius takes values in the range of about 3-5 cm.

<table>
<thead>
<tr>
<th>( I ) (A)</th>
<th>( U ) (V)</th>
<th>( r ) (m)</th>
<th>( B ) (T)</th>
<th>( B^2r^2 ) (T²m²)</th>
<th>( 2U ) (V)</th>
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**Homework assignment**

Calculate the magnetic flux density from the current in the field coils using the expression

\[
B = \frac{N\mu_0 I}{(5/4)^3 \cdot 2R}
\]

where

\[ N = 130 \text{ (number of turns or winding of the field coils)} \]
\[ \mu_0 = 4\pi \times 10^{-7} \text{ Hm}^{-1} \text{ (the permeability of vacuum)} \]
\[ R = 0.15 \text{ m (radius of the field coils)} \]

From the expression for the electron charge-to-mass ratio (\( \frac{e}{m} = \frac{v}{Br} \)), derive the equation

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

where \( U \) is the acceleration voltage. This equation can be interpreted as the equation of a straight line.

Plot a graph of \( 2U \) on the y-axis against \( B^2r^2 \) on the x-axis. If possible draw a line of best fit. Determine the gradient of your slope and hence find the value of \( e / m \). Compare your value to the accepted value. Which factors contribute to the inaccuracy of your result?