Laboratory 5: Motion of an electron in a magnetic field and the Charge-to-Mass Ratio of the Electron.

Part 1: Introduction. In this experiment, you will determine the charge-to-mass ratio of the electron by observing the motion of a beam of electrons moving in a uniform magnetic field.

Part 2: Apparatus. The apparatus consists of a glass bulb containing an electron beam system, coils to produce the magnetic field and associated power supplies and meters. The glass bulb contains about 1 Pa of gas; inelastic collisions with the gas molecules make the beam barely visible. The electron beam is produced by boiling electrons off an indirectly-heated cathode and accelerating them toward an anode. Useful accelerating voltages are in the range of about 150V to 250V; do not exceed an accelerating voltage of 250V. A digital meter should be used to measure this voltage accurately.

There are two coils on the same axis which produce the magnetic field. Each coil has 130 turns and a radius of 150mm. The coils are also a distance of 150mm apart. Coils in this particular configuration are known as Helmholtz coils and are frequently used in the lab to produce a nearly uniform magnetic field over a fairly large volume. The two coils are wired in series and the maximum current for these coils is 2.0A. A digital meter should be used to measure this current.

Part 3: Procedure. Turn on the heater current carefully; do not exceed 4.5A even for very short periods of time. The heater in the bulb will take a few minutes to reach its stable operating temperature. Turn on the accelerating potential; do not exceed 250V. Turn on the coil-current power supply and the digital multimeters. You should see the electron beam as a faint glow.

The beam is barely visible. For best observations, you should make the room as dark as possible and remain inside for at least five minutes while your eyes adjust to the darkness. Use a flashlight preferably with a red filter or light from a red LED to read the meters so as to affect this so-called night vision as little as possible.

Experiment with the settings on the coil current and the accelerating voltage (stay below the maximums given above). With the coil current held constant, measure the radius of the electron beam for at least three different accelerating voltages. Do this for at least two different coil currents. Similarly, holding the accelerating voltage constant, measure the radius of the electron beam while changing the coil current. Do this for at least two different accelerating voltages. Take additional sets of data (radius of beam, accelerating voltage and coil current) throughout the range of the accelerating voltage and the coil current. Be sure to estimate errors for all measured values.

Determining the radius of the beam is difficult due to a number of reasons which include the dark room and distortion due to the curved glass bulb. Your TA will explain how to use a ruler, a pointer and a mirror to make this measurement from outside the Helmholtz coils.

Part 4: Analysis and Questions. Calculate $e/m$ for each of your sets of data. Average these values and compare this to the accepted value. Show that the units work out properly. Make suitable plots which verify the dependence of the radius of the electron orbit on the accelerating potential and the magnetic field. Comment on any sources of error.
Answer the following questions:

1) Derive an expression for the magnetic field in the center of the Helmholtz coils. Start by calculating the field along the axis of a single coil using the law of Biot and Savart and use superposition to find the field in the center of the two-coil configuration. Recall that the center is a distance of half the coil radius from each coil.

2) The kinetic energy of the electrons is given by $eV$, where $V$ is the accelerating potential. Since the magnetic force on the electrons is always perpendicular to their velocity, the kinetic energy of the electrons does not change and the electrons undergo uniform circular motion. Using this information, the force on a moving charged particle in a magnetic field and Newton’s second law, derive an expression for $e/m$ in terms of the magnitude of the magnetic field, the radius of the electron orbit and the accelerating potential.

3) Perhaps the most difficult part of this experiment, and certainly one that limits the accuracy of your results, is the determination of the radius of the electron orbit. Determine the uncertainty in $e/m$ due to your estimated error in the radius.