**Union College Spring 2019**

**Physics 121 Lab 6 Introduction**

**Measuring the Electron’s Charge to Mass Ratio Using Electric and Magnetic Fields**

The electron is a fundamental particle of nature and so its charge and mass are two of the input parameters in the architecture of the nature. This experiment, which was first conducted by J. J. Thomson in 1897, yields a measure of the ratio of these two quantities. Any other experiment which yields a measure of either value, then, leads to information of the other (for example, the Millikan Oil Drop experiment led to a measure of the electron’s charge).

**A. Derivations of Relevant Equations**:

1. As discussed in class, when an electron is in a magnetic field and has a velocity perpendicular to the magnetic field, it will follow a circular path. Write the equation for the velocity, *v*, of the electron’s motion in terms of the radius, *r*, the magnetic field, *B*, and the electron’s charge, *e*, and mass, *m*.

 (1)

2. To obtain the electron’s charge to mass ratio, we need to be able to input electrons of known speed. We know that electrons can start from rest and be given a known kinetic energy by accelerating them across a specific potential difference *V*. Write an equation that relates an electron’s final velocity to the potential difference it experiences. (In the lab, we will accelerate an electron across the gap of a capacitor of known *V*.)

 (2)

3. Substitute in your *v* from Equation (2) into your Equation (1) and rearrange to obtain an expression for e/m of an electron in terms of *V*, *B*, and *r*.

 (3)

4. Lastly, we need a known magnetic field, *B*. In future class discussions we will learn about the magnetic field of a current, *I*, in a circular loop of wire of radius *R*. In this lab, we will use an arrangement called “Helmholtz coils,” in which a pair of circular coils, each with *N* turns and radius *R* are aligned co-axially and separated by a distance equal to their radius. Each has a current, *I*, running in the same direction. The magnetic field produced by these currents at the center of the arrangement (at point *P* in the figure, which is a distance *R*/2 from the center of each coil) is directed along the axis of the coils with a magnitude given by

 $B=\frac{8μ\_{0}}{\sqrt{125}}\frac{NI}{R}$, (4)

where $μ\_{o}=4π×10^{-7} \frac{T∙m^{2}}{C∙m/s}$.

B. **Getting Familiar with the Equipment**:

1. The Helmholtz Coils.

Note the circuit with the coils, power supply and ammeter. Each of these coils has *N* = 130 turns. Measure the radius of the coils using a ruler. Record *N*coil and *R*coil. Use a compass to determine the direction of magnetic north and turn the coils so that the axis is aligned magnetic East-West (so that the magnetic field of the Earth is perpendicular to that produced by the coils).

Write the equation for magnetic field inputting these values, so that the only variable is *I*.

2. The electrons and accelerating potential:

To measure the radius of electrons’ motion, we need to see the path the electrons take. For this purpose, inside the glass bulb at your station, electrons will move through neon gas; the electrons will collide with neon atoms, which will fluoresce after being excited by the collisions, lighting the electrons’ path. Also inside the glass bulb, near the bottom, is a filament, from which electrons will be evaporated, and a small capacitor which will create the accelerating potential.

(a) With the lab lights off (note that you have a small desk lamp at your station), turn on the power supply labeled ‘filament’ and set it to about 7.5 volts. Wait a few minutes and see if the filament at the bottom of the glass tube starts to glow.

(b) When you see a glow, then turn on the supply labeled “accelerator” and set the voltage to 150 volts using the knob on the right. You should now see an orange-ish horizontal beam of light at the bottom of the glass bulb.

(c) Use a magnet to determine whether there are moving charges in the beam and whether they are positive or negative charges.

(d) There is another adjustment to this apparatus that is worth exploring just a bit—this is the back voltage of the accelerating potential. On the accelerator power supply, switch to the -50 V reading. When you make the switch, the left meter on the power supply probably reads about 10v. While one partner watches the horizontal beam in the glass tube, the other slowly adjusts this power up and down using the knob on the left (but do not go above 20 v). Note how the beam changes, and set this “back voltage” to the optimum beam. Then switch the accelerator power supply back to the 500V display.

3. Applying the magnetic field.

Turn on the Helmholtz coils voltage and slowly turn the current up. Do you see the horizontal beam start to bend upward? Turn up the current until the beam makes a circle. If needed, turn the bulb so that the beam closes back on itself. Adjust the current so that the beam hits the topmost pin.

4. Measuring the radius of the electrons’ path:

The pins inside the bulb are manufactured to be a given distance from the starting point of the electrons. Considering that these distances are some integer metric values, use a metric ruler to determine the diameters of the circles for each pin.

5. Preliminary Measurement: With the accelerating voltage set to 150v, and the Helmholtz coils current set so that the electron beam hits the outermost pin, read the current from the ammeter and voltage from the voltmeter and use Equations (4) and (3) to infer your preliminary value of *e/m*. Compare this to the expected value. Does the experiment work?

**C. Doing the Experiment**:

Without letting the current through the coils get too large (try to keep the current through the coils under 2A, but if needed don’t let the current stay above 2 A for more than a few seconds), obtain values of *V*acc, *I*coils, and *r*. Find at least 3 combinations of *V*acc, and *I*coils for each r. (NOTE: you won’t be able to get the beam to reach the bottom pin.)

Be sure to estimate the uncertainties in ALL measurements.

Make a plot with 2(Vacc) on the y-axis and (Br)2 on the x-axis. Consider your derived equation for *e/m* (Equation 3) and note that this plot should produce a straight-line. What should the slope of this line be?

Do a linear regression to obtain a measure of the slope with uncertainty.

Infer the value, with uncertainty, for the ratio *e/m*.

*e/m* =

Note that you have not taken into account the Earth’s magnetic field. Is this a significant source of systematic error? It would be systematic and not random, since it would always produce an error in the same direction. Compare the strength of the Earth’s magnetic field (5x10-5 T) to the values in your data table produced by the Helmholtz Coils, and determine the percent error that ignoring this effect causes. Comment, additionally, on why you turned the coils so that the Earth’s magnetic field was directed perpendicular to the coils axis. What would the effect of a large magnetic field of the Earth be considering its direction with respect to the motions of the electrons?