LAKE FOREST COLLEGE
Department of Physics

Physics 115 **Experiment #8: *e/m* of an electron v3** Spring 2025

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Table:

Preliminary Instructions
Create a folder for you and your lab partner on Teams. Save a copy of these instructions for each student to that folder. Include your name in the filename. As you edit this document put your text in a different color. Save one copy of the *Excel* template with both your and your partner's name included in the filename.

Pedagogical purpose
Study charged particles moving in a magnetic field.

Experimental Purpose
Determine the ratio of the charge of an electron (e) to the mass of an electron (m).

Part I: Magnetic field as a function of current

A pair of identical circular coils of wire, with a separation equal to the coil radius, is called a Helmholtz Pair or Helmholtz Coils. The magnetic field near the center of the pair is surprisingly uniform. The field generated is proportional to the current through the coils. Define the z-axis to run along the axes of the coils from the front to the back of the appartus. The positive z axis is directed away from you. If we include a constant external magnetic field B_{0z} caused by the Earth and the science building, then we have

$$B_z = KI + B_{0z} \qquad (1)$$

1. With the probe tip inside the Zero Gauss Chamber, zero the sensor (press "zero probe" 2×). Make sure that the meter is on the mT (millitesla) scale (DC).

2. Use a compass to determine the direction of the Earth's magnetic field. Align the planes of the coils perpendicular to this magnetic field.

3. Position the magnetic field sensor to measure the magnetic field at the center of the coils. Place the tip of the sensor at the center of the system and align the sensor perpendicular to the planes of the coils. It is important that the axis of the probe is parallel with the magnetic field. Note that the magnetic field sensor will display a positive value when $\vec{B}$ points towards the probe.

4. Connect the power supply in series with a DMM and the coils. The connections to the ammeter should be arranged so that a positive current corresponds to a positive magnetic field (directed away from you). **Draw a schematic of the setup. Include a caption.**

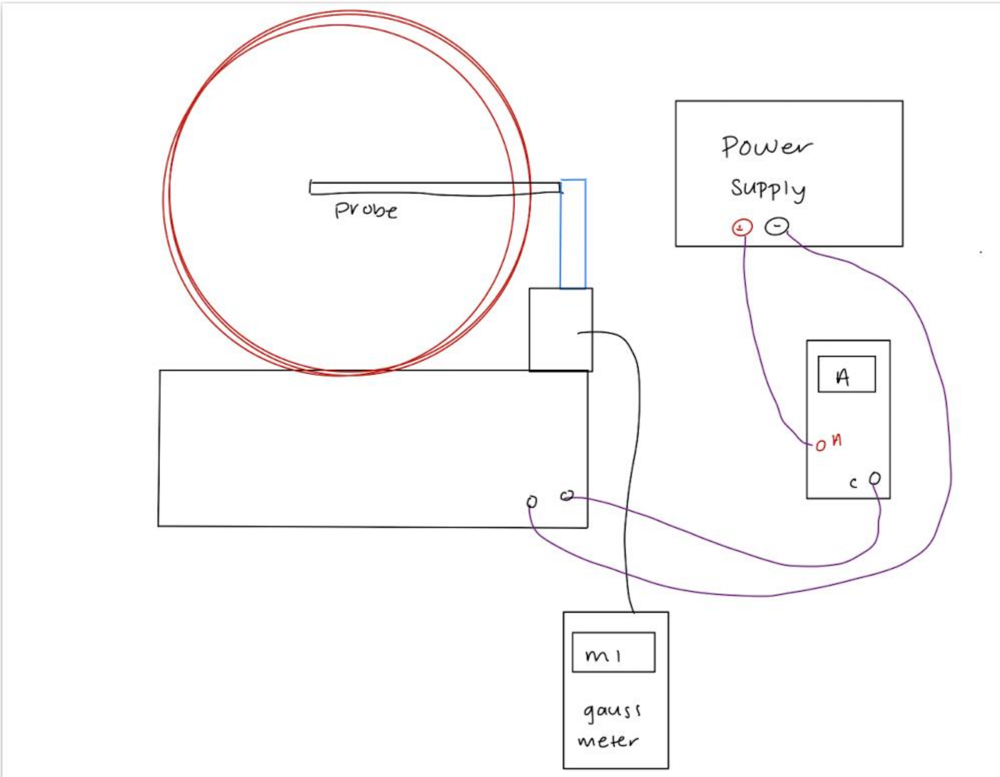

Figure 1. Magnetic Field Apparatus. The Topward DC Power Supply Provides current, measured in amps, to the red wire coils to product a magnetic field. The Fluke Multimeter, connected in series, measures the true output of the power supply. The LakeShore Gauss measures the power of the magnetic field, in milliTesla (mT), through the probe in the center of the coils.

5. Adjust the current supply so that about 1 A of current flows into the red jack on the front panel (that is, the positive output of the power supply is connected to the red jack). This will cause current to flow clockwise around the coils (as viewed from the front). This should create a magnetic field directed away from you. Check your prediction with the small compass provided. **Describe your observations.**

The magnetic field switches from being perpendicular to the Gause Meter to parallel to it. The compass spins rapidly as it readjusts to the magnetic field. Once it settled, the blue, positive, was facing forwards and red, negative, was facing back towards the Gause meter.

6. Measure the magnetic field at the center of the coils at a minimum of 4 different currents between 0 and +2 amps (also include 0 amps). Then reverse the leads on the Topward power supply and take magnetic field readings for at least four more currents between 0 and -2 amps. Check that this creates a magnetic field directed towards you. Record your data for both positive and negative currents together in Table I. **Insert the table here; include a caption**.

I(A)	B_z(mT)
0.01	0
0.51	0.41
1	0.8
1.5	1.15
2	1.55
-0.5	-0.38
-1	-0.8
-1.5	-1.2
-2	-1.58

	K(mT/A)	B_{0z}(mT)
Value	0.7851	-0.0073
Unc	0.00441	0.005696

Table 1. Magnetic Field Measurements. I represents the current in amps produced by the Topward DC power supply, as measured by the Fluke multimeter. B_z represents the magnetic field in milliTesla, as measured by the LakeShore Gaussmeter. The direction of the current was reversed by switching the positive and negative nodes of the power supply.

Turn off the current when not taking data, otherwise the coils may overheat.

7. Plot all of your B_z vs. I data and fit your results to a straight line. **Insert your graph here**; **include a caption.**

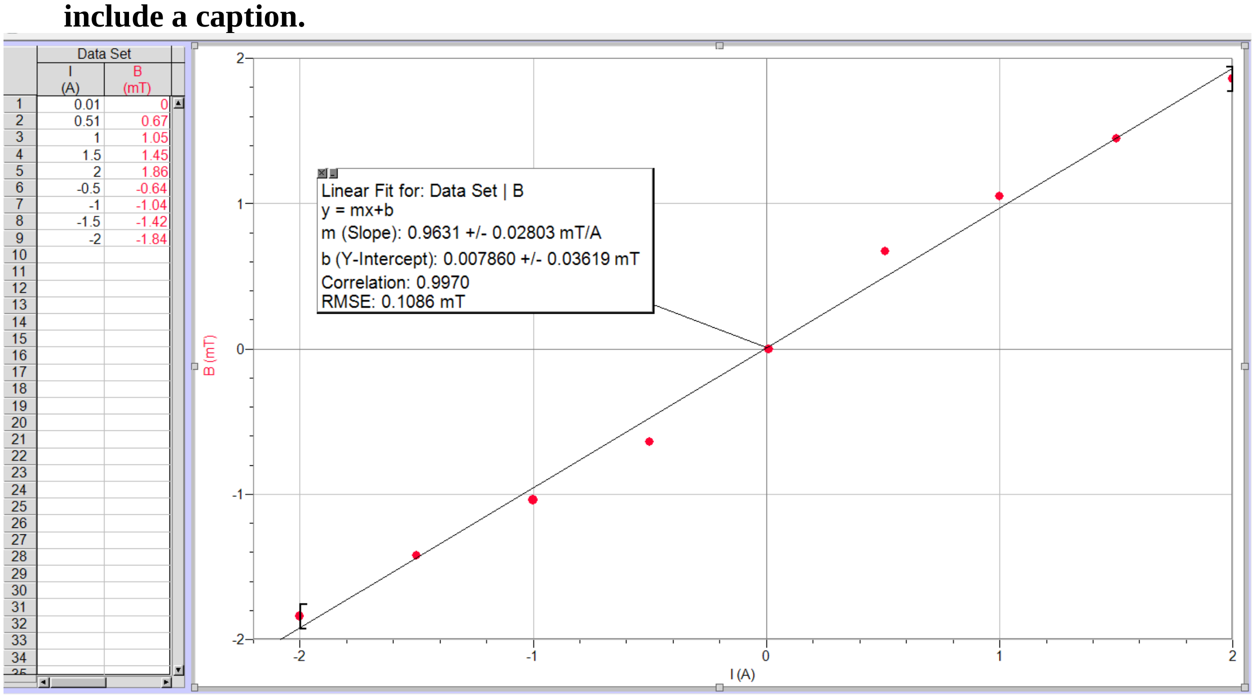

Figure 2. Magnetic Field vs. Current graph. Current, in amps, is on the x-axis and the magnetic field, in milliTesla, is on the y-axis. The slope of the fitted line represents the change in milliTesla per amp and the intercept represents the initial strength of the magnetic field at 0 A. The uncertainty of these values represents the absolute uncertainty of the respective measurements.

8. Record the slope, *K*, and offset, B_{0z}, in your Excel sheet. **Insert this table here.** We will use these parameters in Part II to convert the current measurements into magnetic field strengths.

9. Return the Topward power supply leads to their original positions for positive current (clockwise) and positive magnetic field (directed away from you). Have the instructor insert the electron beam tube in between the coils and connect the socket to the end of the tube.

Part II: Deflecting an electron beam with a magnetic field.

10. Electrons are released essentially at rest from a hot filament and accelerated through a potential difference *V*. Use conservation of energy to **show that** the speed, *v*, of the electrons after this acceleration is given by

$$v = \sqrt{\frac{2eV}{m}} \qquad (2)$$

11. The magnitude of the magnetic force on an electron moving with a speed, *v*, directed perpendicular to a magnetic field *B* is $F_B = evB$. Using Newton's second law and the fact that the electron will move in uniform circular motion with radius *R*, **show that**

$$v = \frac{eBR}{m} \qquad (3)$$

12. Substitute equation 3 into 2 and solve for e/m. The result should be

$$\frac{e}{m} = \frac{2V}{B^2R^2} \qquad (4)$$

Insert your derivations for steps 10, 11, and 12 here.

$$\Delta K = -q\Delta V$$
$$\frac{1}{2}mv^2 - \frac{1}{2}m(0)^2 = -(-e)(V-0)$$
$$\frac{1}{2}mv^2 = eV$$
$$v^2 = 2eV\left(\frac{1}{m}\right)$$
$$v = \sqrt{\frac{2eV}{m}}$$

$$|q|vB\sin\emptyset = \frac{mv^2}{R}$$
$$|e|vB = mv^2\left(\frac{1}{R}\right)$$
$$eB = mv\left(\frac{1}{R}\right)$$
$$mv = eBR$$
$$v = \frac{eBR}{m}$$

$$\frac{eBR}{m} = \sqrt{\frac{2eV}{m}}$$
$$\left(\frac{eBR}{m}\right)^2 = \frac{2eV}{m}$$
$$\frac{e}{m} = \frac{2V}{B^2R^2}$$

Figure 3. Magnetic Field Equation Derivations. V represents the voltage, e the charge of an electron, m the mass of the electron, B the magnetic field, and R the radius of the circle. Using v, the velocity of the electrons, it is possible to solve for e/m, the charge to mass ratio of the particle.

13. Set up a second DMM to measure the accelerating voltage (*V* in equations 2 & 4). Set the accelerating voltage to 200 V. Adjust the beam tube so that the electron beam is directed downward.

14. Drive a positive, clockwise current through the coils and watch the electron beam bend due to the magnetic field. Check that the direction of the bending follows what you would expect based on the direction of the magnetic field. **Is the direction of the bending in agreement with your expectations? Insert a picture of the circular path of the electrons.**

The beam initially bends down, as expected in the positive magnetic field.

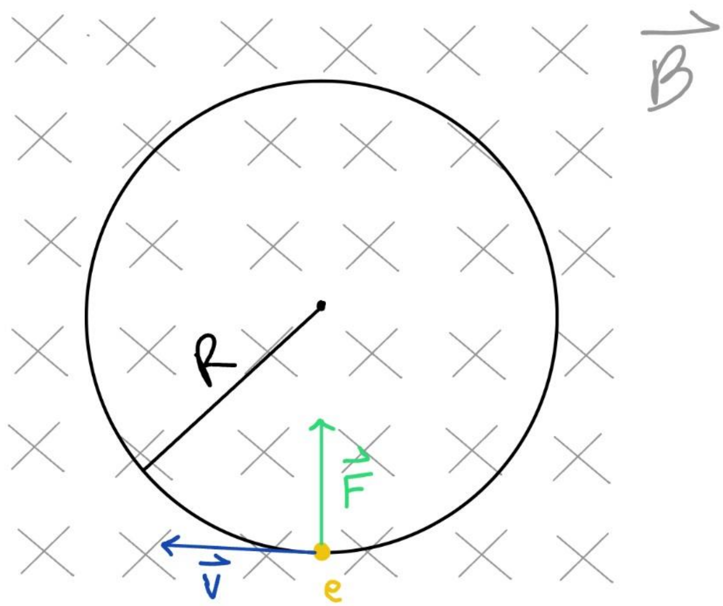

Figure 4. Path of Elections in Magnetic Field. The force on the electrons is centrifugal, making the beam arc in a circle. The velocity vector, v, and the magnetic force on the electron, F, are constantly 90° from each other. The magnetic field, B, goes back into the plane of the page, so the force on the particle is upwards.

15. Record your data in Table II for the following trials (steps 16-19) containing the accelerating potential, beam trajectory diameter, and current in the coils, and the calculated magnetic field (using equation 1). For each trial use Excel to calculate the magnitude of the magnetic field from the current and your results of part I. Use equation 4 to calculate the ratio *e*/*m* for each trial.

16. Adjust the tube so that the electron beam follows a circular path. Increasing the current in the coils creates a stronger magnetic field which causes the electron beam to bend into a tighter circle. Note, the beam should go just in front or just behind the rule but not touch it. It should be on the side that produces the minimum helix. Determine the current necessary to achieve *diameters* of the trajectory of 10 cm, 9 cm, and 8 cm. The current adjustment should be made so that the *outer* edge of the electron beam matches up with the markings on the ruler. This is because the gas in the tube slows down the electrons somewhat. The outer edge of the electron beam corresponds the electrons that have been slowed down the least. Record your data in Table II.

17. Repeat step 16 with an accelerating voltage of 300 V. Record your data in Table II.

18. Now we will reverse the initial direction of the electrons and the magnetic field. Adjust the beam tube so that the electrons are initially directed <u>upward</u>. Reverse the leads at the Topward power supply to drive current in the opposite direction through the coils. With this current direction repeat step 16 with an accelerating potential of 200 V. Record your data in Table II.

19. Repeat step 18 with an accelerating voltage of 300 V. Record your data in Table II.

20. **Paste Table II here; include a caption.**

Voltage (V)	Diam (cm)	I(A)	B_z(T)	R(m)	e/m (C/kg)
200	10.0	1.14	0.000888	0.05	2.03E+11
200	9.0	1.28	0.000998	0.045	1.98E+11
200	8.0	1.43	0.001115	0.04	2.01E+11
300	10.0	1.47	0.001147	0.05	1.82E+11
300	9.0	1.57	0.001225	0.045	1.97E+11
300	8.0	1.76	0.001374	0.04	1.98E+11
200	10.0	-1.19	-0.000942	0.05	1.80E+11
200	9.0	-1.32	-0.001044	0.045	1.81E+11
200	8.0	-1.46	-0.001154	0.04	1.88E+11
300	10.0	-1.47	-0.001161	0.05	1.78E+11
300	9.0	-1.62	-0.001279	0.045	1.81E+11
300	8.0	-1.82	-0.001436	0.04	1.82E+11
				Average	1.89E+11
				Std Dev	9.54E+09
				Rel Unc	0.05038

Table 2. Mass Charge Ratio Measurements. The voltage (V) and current (I) were measured by Fluke multimeters at set diameters. The magnetic field, B_z, was calculated using the equation 0.7815mT/A(I) – 0.0073mT, derived from the slope of the earlier line. The radius was calculated by halving the diameter. e/m was calculated using the equation derived above.

21. Calculate the average and the standard deviation for your values of *e*/*m* in Table III. Use the ratio test to compare your value for *e*/*m* to the one from the National Institute of Standards and Technology (NIST) of $1.758\,820\,010\,76 \times 10^{11}$ C/kg with an uncertainty of 53 C/kg (from the 2018 CODATA recommended values). **Paste Table III here; include a caption.**

	accepted	measured
e/m (C/kg)	1.75882E+11	1.89277E+11
Std Dev (C/kg)	53	9.5E+09
Rel Unc	3.01338E-10	0.0504
Ratio Test	1.405	

Table 3. Measured and Standard Comparison. The accepted values comes from NIST and the measured value comes from the values above. The accepted value agree with the measured value according to the ratio test. The measured value has much higher uncertainties than the accepted value.

22. Rotate the tube so that $\vec{v}$ is not initially perpendicular to $\vec{B}$ and observe the helical trajectory of the electron beam. **Insert a photo of the beam here; include a caption. Explain how the helical path of the electrons depends on the direction of the initial velocity.**

Figure 5. Path of Electron Beam. The beam had a diameter of 10cm with a voltage of 200V and a current of 1.14A. It initially bends down but curves into a ring when current is provided. The electron form a blue-green beam. The beam is fuzzy since the gas inside that vacuum chamber, which allows us to observe the beam, slows down some of the electrons.

Discussion questions:

1. Describe the difficulties encountered in these measurements and suggest possible systematic problems.

The calculations do not account for gas in the glass envelope that slows down some electrons. The furthest edge of the beam represents the fastest travelling electrons, but it is hard to see by eye. It is also unlikely that the Gaussmeter was perfectly in the center of the magnetic field since that was also done by eye, which would have thrown off the magnetic field measurements and calculations.

2. Describe the effect of the magnetic field on the electron beam.

The magnetic field provides a force that acts on the electrons, since it acts on all points around it. It curves the beam as the force is centrifugal.

3. Suppose that protons were emitted in the vacuum tube instead of electrons. How would this effect the experiment?

If protons were emitted the beam would curve in the opposite direction as the electron beam because protons are positively charged while electrons are negatively charged.

Conclusion:

Summarize what you conclude from the results of your experiment.

The magnetic field follows the equation 0.7851±0.00441mT/A(I) – 0.0073±0.0057mT. This leads to a charge per mass ratio of 1.89±0.0095x10^{11}C/kg which agree with the standard accepted value of 1.75x10^{11}±53C/kg according to the ratio test.

The radius of the ring is dependent of the voltage charging the electron emitting material, which effects the initial velocity. The radius of the ring is also dependent on the current, which effects the strength of the magnetic field and the force acting on the particles.

Final remarks

Adjust the formatting (pagination, margins, size of figures, etc.) of this report to make it easy to read. Save this report as a PDF document. Upload it to the course Moodle page. Ensure that your Excel file, Logger Pro file, and all pictures are saved to the Team.

Clean up your lab station. Put the equipment back where you found it. Remove any temporary files from the computer desktop. Make sure that you logout of Moodle and your email, then log out of the computers. Ensure that the laptop is plugged in. Check with the lab instructor to make sure that they received your submission before you leave.