Department of Biological, Chemical, and Physical Sciences
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Experiment 6: Electrons in Magnetic Fields/AC Circuits

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Section 221-006
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Statement of Objectives

The objective of the lab was to measure an electrons charge to mass ratio by observing its interaction with an external magnetic field. We also observed the relationships in a LRC circuit.

Theory

Part A: Charged Particles in Magnetic Fields

When moving charged particles move through a magnetic field, they feel a force from that field. This force is given by the equation:

$$F = qv \times B \tag{1}$$

where F is the force,
q =charge,
v = velocity,
B = magnetic field.

Because of the cross-product, the force will only be present if the velocity of the charged particle and the magnetic fields are not parallel. When the magnetic field and the velocity of the particle are always perpendicular, the particle will be deflected in a circular motion. This also gives the equation:

$$F = \frac{mv^2}{r} \tag{2}$$

These two forces are equal to each other. Therefore, for an electron:

$$evB = \frac{mv^2}{r} \tag{3}$$

Because this experiment took place in a cathode-anode tube, the velocity of the electron is dependent upon potential difference in the tube. Using this fact, and solving for the ratio of e/m, the following equation is received:

$$\frac{e}{m} = \frac{2V}{r^2 B^2} \tag{4}$$

where V is the potential difference in the tube

The magnetic field in the experiment is provided by a Helmholtz coil, which has the equation:

$$B = \frac{8\mu_0 IN}{5\sqrt{5}R} \tag{5}$$

where I = current in the coil,
N = # of turns of wire,
R = radius,
μ_0 = permeability of free

Substituting (5) into (4) yields the equation:

$$\frac{e}{m} = \frac{125VR^2}{32\mu_0{}^2 I^2 N^2 r^2} \tag{6}$$

If I^2 was to be plotted vs. V, the slope of the graph would be:

$$slope = \frac{125R^2}{32\mu_0{}^2 N^2 r^2 \frac{e}{m}} \tag{7}$$

Part B: Alternating Current Circuit

In an LRC (inductor, resistor, and capacitor) circuit, the resonance condition of the circuit is when the current is at a maximum. This occurs at certain angular frequencies of the signal. These angular frequencies are given by the equation:

$$\omega = \frac{1}{\sqrt{LC}} \tag{8}$$

Equipment List

- Bainbridge Tube
- Helmholtz Coil
- DC Ammeter
- Power Supply
- Multimeter
- Resistor
- Capacitor
- Inductor
- Oscilloscope
- Sine Wave Function Generator

Procedure

Part A: Charged Particles in Magnetic Fields

The radius of the Helmholtz coil was measured and recorded. The current through the Bainbridge tube was increased to an amperage between 3.5 and 4, but not exceeding 4A. The potential difference was then set to 30V. The current running through the Helmholtz coil was increased until the circular electron beam struck the furthest metal pin. This current was then recorded. The current was then increased and the current required for the electron beam to strike each metal pin was recorded. This process was then repeated for 50, 70, and 90V.

Part B: Alternating Current Circuit

The capacitance of the capacitor was measured and recorded. The inductance of the inductor was also measured and recorded. The LRC circuit was then constructed. The leads from both channels of the oscilloscope were placed to measure the voltage across the resistor. The displace selector on the oscilloscope was changed to the x-y position and the Time/div knob was also placed in the x-y position. The leads were then changed so that channel 1 now measured the voltage across the whole circuit. The Lissajous figure was set up again and sketched. The frequency of the sine wave generator was turned up until the amplitude of the voltage across the resistor was at its maximum and the frequency recorded.

Data

Part A: Charged Particles in Magnetic Fields

The radius of the Helmholtz coil was 31.75 cm. The number of turns in the Helmholtz coil was 100, N = 100. The following table shows the currents required for the electron beam to strike each metal pin:

Metal Pin Amperage Requirements

	30V	50V	70V	90V
d_1 = 65mm	1.98A	2.53A	3.03A	3.39A
d_2 = 78mm	1.64A	2.13A	2.52A	2.85A
d_3 = 90mm	1.41A	1.82A	2.15A	2.40A
d_4 = 103mm	1.24A	1.62A	1.88A	2.13A
d_5 = 115mm	1.11A	1.42A	1.67A	1.92A

Table A-1

Part B: Alternating Current Circuit

The capacitor measured 6.5nF, the inductor 0.96H, and the resistor 51.1kΩ. The resonance frequency was observed at 2025Hz.

Lab Sketches For Part B:

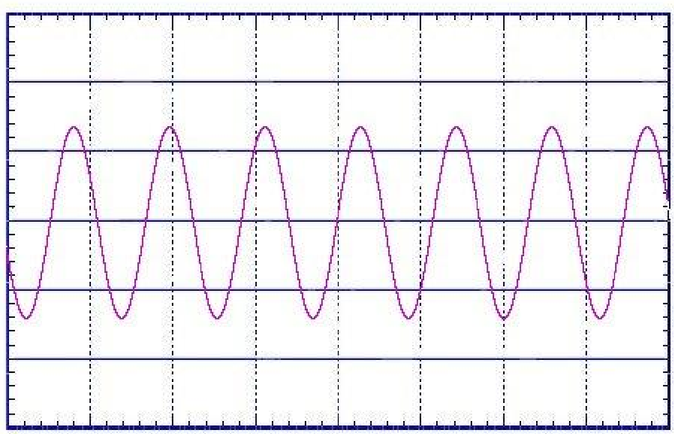


Figure 1 – Graph above verifies Ch 1 and Ch2 are in phase

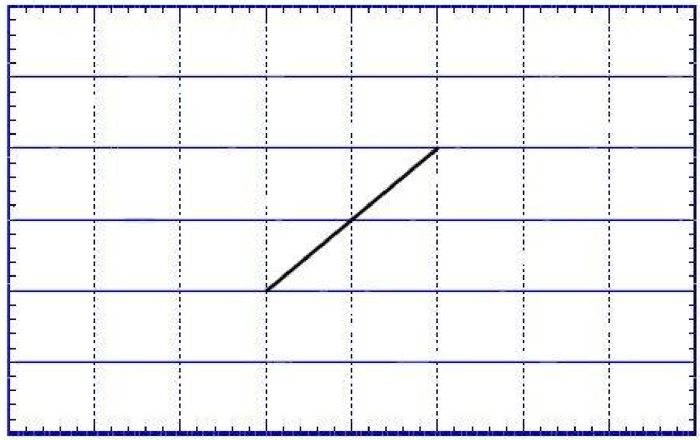


Figure 2 – Lissajous Graph of Figure 1

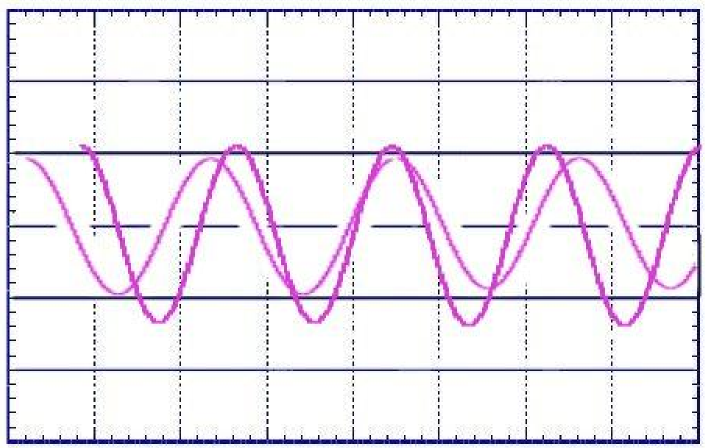


Figure 3 – Graph of Ch 1 and Ch 2 – Shows Resistor Lagging By 1/5ms

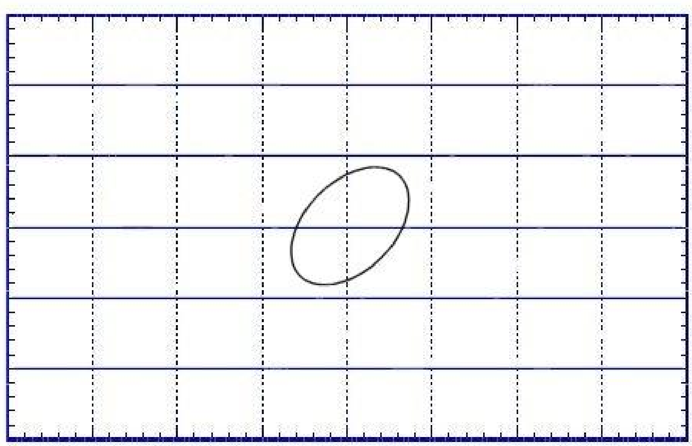
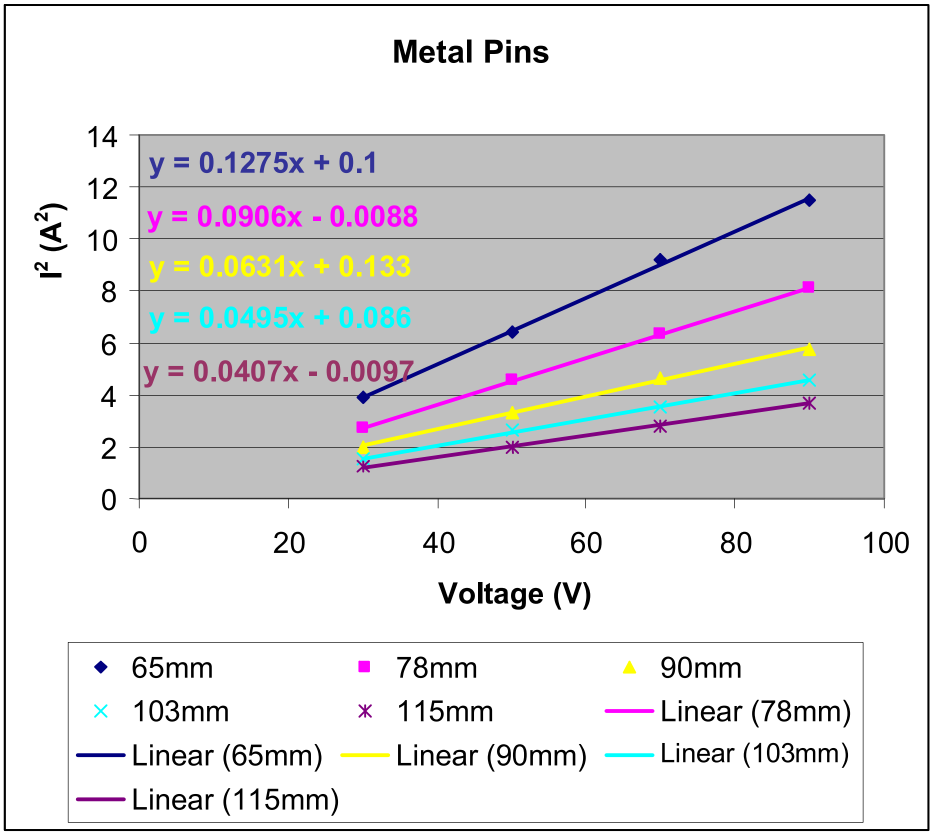


Figure 4 – Lissajous Graph of Figure 3

Analysis

Part A: Charged Particles in Magnetic Fields



Graph A-1

Metal Pins

Radius (m)	Slope	e/m
.0325	.1275	$1.85162*10^{11}$
.0390	.0906	$1.80955*10^{11}$
.0450	.0631	$1.95152*10^{11}$
.0515	.0495	$1.89936*10^{11}$
.0575	.0407	$1.85309*10^{11}$

Table A-2

The average experimental value for e/m is $1.87303*10^{11}$ and the standard deviation is $4.845549*10^{9}$. The theoretical value is $1.76*10^{11}$.

Part B: Alternating Current Circuit

Since the frequency value read in was the linear frequency, and the angular frequency is required, the data needed to be converted to the angular frequency. This was done using the equation:

$$\omega = 2\pi f \qquad (9)$$

where f is the linear frequency

The theoretical value was found using equation (8).

Resonance Frequency (Hz)

Theoretical	2014
Experimental	2025

Table B-1

Discussion of Results

Part A: Charged Particles in Magnetic Fields

With a theoretical value of $1.76 \cdot 10^{11}$, we have a resulting error of only 6.4%. This is a relatively small margin of error considering the circumstances in which the amperage was measured. In a darker room with some form of magnification to find the point in which the beam hits the center of the metal pins, our error percentage would have dropped even further.

Part B: Alternating Current Circuit

The experimental value for the resonant frequency was found to be 2025 Hz. Using Equation 8, the theoretical value for the resonant frequency was 2014 Hz. This represents a 0.5% error.

Conclusion

Part A: Charged Particles in Magnetic Fields

The experimental frequencies were very close to the theoretical frequency in each case. These results act to verify equation 4 in that the ratio e to m is equivalent to the relationship between V, R, I, N, and r. They also verify equation 8 in that the angular frequency is inversely proportional to the square root of LC.