Lab III: Mass to Charge Ratio of an Electron

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Abstract:

By recreating J.J. Thompson's Helmholtz coil experiment, we learn how to observe the behavior of electrons by manipulating electric fields and derive the e/m ratio. We find that our results only match previous experiments for a certain current range.

Introduction:

The purpose of conducting this experiment is to develop experience observing elementary particles using electric and magnetic fields. It is hard to visualize particles that will never be observed with the human eye. Proving their existence had to be shown indirectly. J.J. Thompson did so by manipulating the existing theories of magnetic fields and electricity to coax the electron to reveal itself.

Figure 1: Equations used in derivation of e/m

$$(1)\quad B = \frac{[N\mu]I}{\left(\frac{5}{4}\right)^{1.5} a}$$

$$(2)\quad v = (2eV/m)^{0.5}$$

$$(3)\quad e/m = v/Br = \frac{2V\left(\frac{5}{4}\right)^{3} a^{2}}{[N\mu I r]^{2}}$$

Table 1: meaning of terms in Figure 1 equations

Equation Term	Definition/Value
B	magnetic field
v	particle velocity
e/m	charge to mass ratio
V	voltage, see Table 3
a	coil radius, 15.172 cm, derived in Table 2
N	number of turns per coil, 130
μ	permeability constant
I	current, see Table 3
r	radius of beam, see Tables 1 and 3

In 1887, JJ Thompson accelerated a beam of electrons through a known potential. This showed that electrons are a particle with both mass and a charge. Using the equation for a magnetic field (Eq 1) and algebraically combining it with the equation for the velocity of an electron (Eq 2), Thompson theorized and proved that the e/m ratio can be derived (Eq 3). Cathode rays had been developed prior to Thompson's experiment, where an electron gun would shoot a beam of electrons into a vacuum tube filled with an elemental gas. The direction of the beam could be manipulated by the presence of an electric field. Thompson's apparatus consists of 2 coils of copper wire with a Helium filled vacuum tube between them. The Helium tube contains an electron gun, where a heated filament causes an anode to shoot electrons to a deflection plate. The beam of electrons was then manipulated into an arc by a magnetic field induced by a voltage sent though the coils. Based on equation 3 and Thompson's results, the proportion of the electron's velocity divided by the induced magnetic field and radius is a constant value of 1.7588 Coulombs/ Kilogram. The ratio was found to be constant, regardless of the voltage and current driven through the coils. The results of this experiment contradicted with the conclusions of Young's Double slit experiment, that matter is a wave. The combination of these conflicting results helped develop the current dual particle-wave model of matter.

Methods:

We assembled the PASCO Model SE-9638 electron/mass ratio apparatus and connected it to an Ammeter, voltmeter, and power supply according to the diagram shown (Figure 3). The photo below (Figure 2) shows how we interpreted the diagram. We also made sure that both coils were connected to the power supply. We incremented the current by 0.25 amps for each measurement. To measure the radius of the beam, we placed measuring tape across the diameter of the Helmholtz coil. To decrease measurement error, we took a photo of the beam and counted its diameter in pixels. We set up a scale for pixels to centimeters for the photo by counting the number of pixels for 10cm. Then we converted the diameter from pixels to cm according to the scale, and divided it by two to find the radius. The results for this are shown in Table 2. The diameter of the coil was calculated from the average of two randomly selected photos. We used the same pixels to cm ration for each photo that we used to calculate the radius of the beam. The results for this are shown in Table 3. Using equation 3 and the bolded values in Table 1, we found the e/m for the measurement, as shown in Table 4.

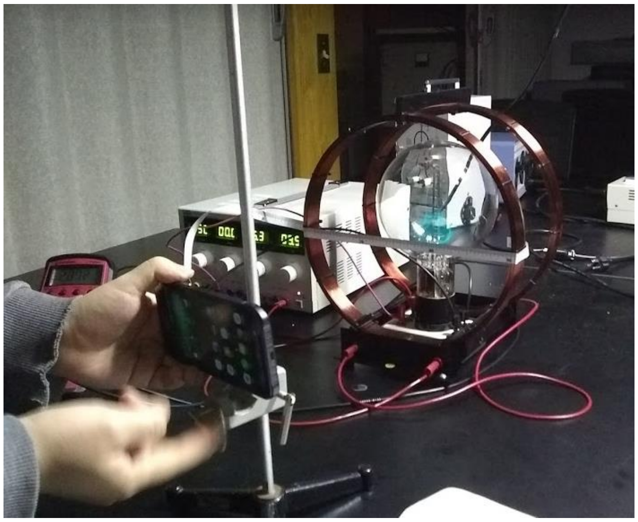
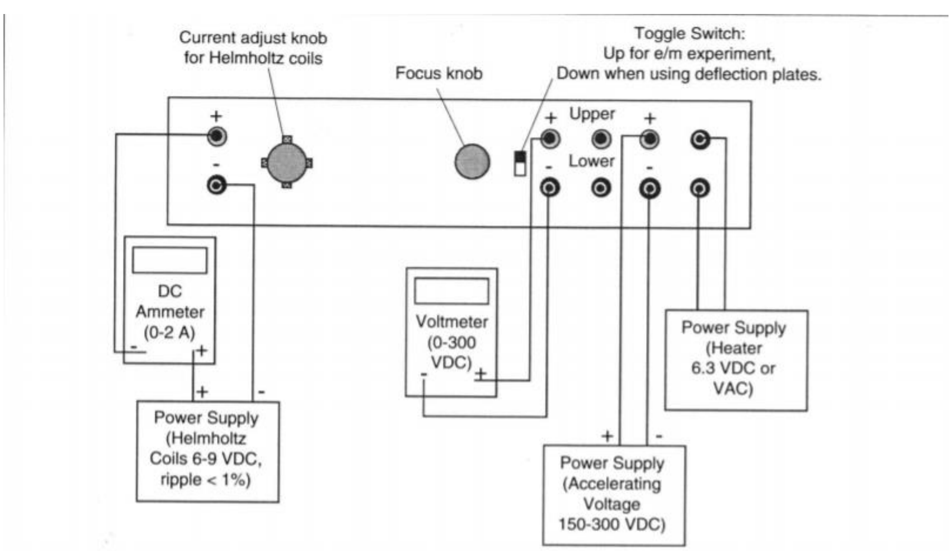


Figure 2: Equipment Setup



Results:

Table 2: Data used to calculate the radius of beam

Photo #	Pixels per cm	D (out, pixels)	D (in, pixels)	Average R(+/- 0.5 cm)
1	102.4	335	309	1.572265
2	102.8	333	311	1.56614786
3	98.5	333	307	1.624365482
4	98.4	329	306	1.613313008
5	97.9	360	339	1.784984678
6	98.1	365	336	1.786442406
7	96.9	400	370	1.986584107
8	102.5	477	444	2.246341446
9	102.5	482	442	2.253658537
10	98.7	535	490	2.596251266
11	99	535	488	2.583333333
12	97.4	724	674	3.588295688
13	97.6	720	673	3.568135246
14	98	299	275	1.464285714

Table 3: Data used to calculate an average R for Equation 3

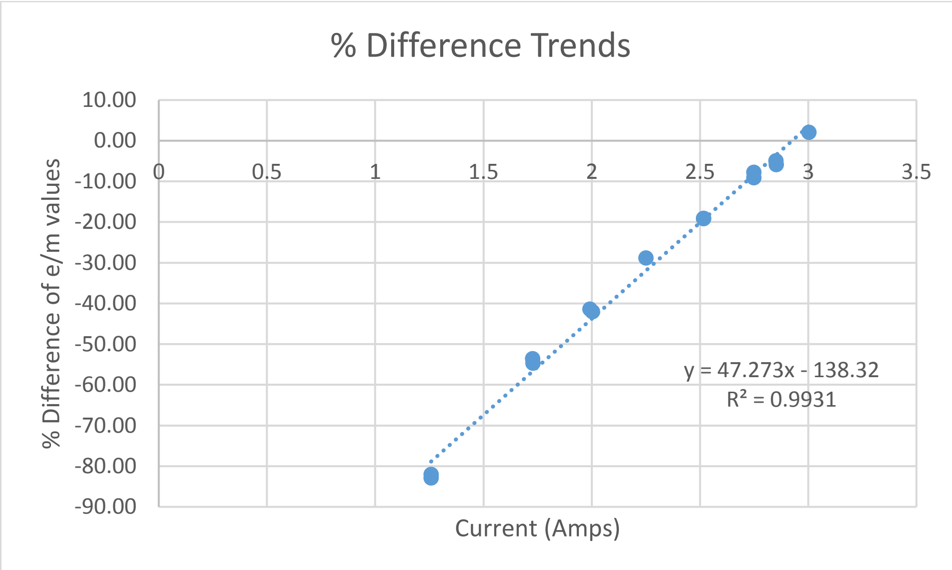
Photo #	Pixels per cm	D (pixels)	D(+/- 0.5 cm)	R(+/- 0.5 cm)	Average R(+/- 0.5 cm)
8	98.1	2982	30.3976	15.1988	15.1726
13	99	2999	30.2929	15.1465	15.1726

Table 4: Shows measured quantities and experimentally calculated e/m value

Average R (+/- 0.5 cm)	V (volts)	I (amperes)	e/m	~~%~~ Difference	% Error
1.572265	9.9	2.853	1.658E+11	-5.90	-5.73118
1.56614786	9.9	2.851	1.67E+11	-4.98	-4.86127
1.624365482	9.5	2.749	1.61E+11	-9.11	-8.71617
1.613313008	9.5	2.749	1.63E+11	-7.75	-7.46532
1.784984678	8.7	2.517	1.45E+11	-19.08	-17.421
1.786442406	8.7	2.516	1.45E+11	-19.17	-17.4892
1.986584107	7.8	2.25	1.32E+11	-28.83	-25.199
2.246341446	6.9	2.004	1.15E+11	-42.08	-34.7623
2.253658537	6.9	1.991	1.15E+11	-41.45	-34.3359
2.596251266	6	1.729	1.00E+11	-54.70	-42.9497
2.583333333	6	1.727	1.02E+11	-53.56	-42.2447
3.588295688	4.4	1.258	7.28E+10	-82.94	-58.6292
3.568135246	4.4	1.258	7.36E+10	-82.01	-58.1601

1.464285714	10.3	3.003	1.80E+11	2.04	2.058222

Figure 3: % difference trends when compared to change in current



Discussion/Conclusion:

We reached less than 10% error on 5 of the values, for the other 9, we did not. As we decreased the current, the magnitude of the percent difference decreased at a linear rate. Looking back to the equations we used to derive the e/m ratio, the velocity equation did not account for linear air resistance. It is likely that the presence of helium gas slowed down the electrons leaving the electron gun. With higher current, the rate of electrons leaving the gun increased, decreasing the effect of linear air resistance. This led to the e/m values being close to 5% error.

References:

1. Handout

2. Equipment Manual

3. Modern Physics Textbook

4. Microsoft Excel for Data

5. Photoshop for pixel counting of photos

Acknowledgements:

I would like to thank my lab partner, Chen Zhang for helping me collect data and Dr. Liu for helping us set up the equipment.