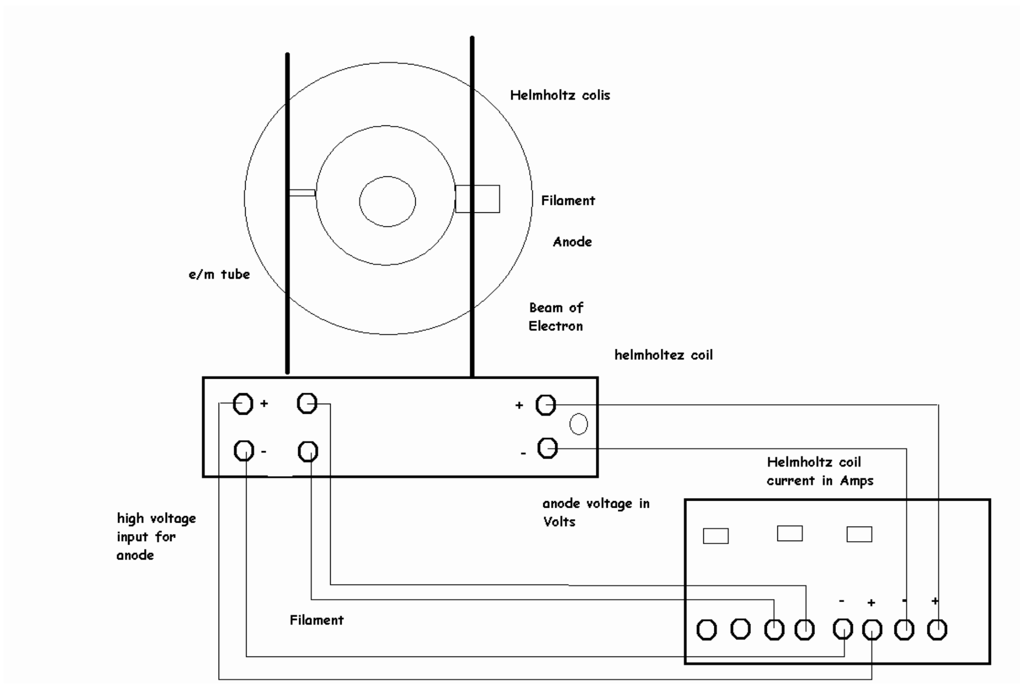
Physics Formal Lab



Charge To Mass Ratio For An Electron

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Abstract

How electrons behave in the presence of a magnetic field was the purpose of this lab. In particular, how there is a force acting on the electron in a magnetic field related to its velocity; or in other words the force acting on the electrons will cause them to move in a circular path. Measuring the charge to mass ratio of an electron using an apparatus which fires electrons into a uniform magnetic field produced by Helmholtz coils; the particles follow a circular path. The anode voltage was set at 200v; the radius of the curvature of the electrons was changed by adjusting the Helmholtz coils current. Its radius ranges from 11cm to 6 cm; the strength of the magnetic field and the speed of the moving particles, one can figure out the charge to mass ratio. The value found for the ratio of electrons to mass to in this experiment would be 1.89×10^{11} coulombs/kg. Comparing this experimental value to the theoretical value which is 1.76×10^{11} coulombs/kg makes a 7.38% experimental error. One of the reasons that this error can occur is related to earth's magnetic field and causing force on the electrons. In conclusion a charged particle will experience a force when moving through a magnetic field and also as the radius of the coil increases as electron flow the magnetic filed decrease. This can also prove that these two are inversely proportional.

Introduction

In 1897 J.J. Thomson made the first measurements of the charge to mass ratio of an electron (e/m), using cathode ray tub. Thomson accelerated electrons through a potential difference and down a tube. Part way through the tube the electrons passed through a magnetic field and were deflected from their original path. Thomson used the measurements of the deflection to determine e/m. The charge-to-mass ratio of the electron involves two numbers which are independently regarded as fundamental constants of physics. Yet this ratio itself can be said to be a fundamental constant in its own right because first, its determination actually led to the discovery of the electron by

Thomson , and second, because any equation of motion which involves electrodynamics forces on the electron brings the charge and mass together as this ratio. Just before 1900, many workers were doing experiments with electrical discharges in low pressure gases, and in particular, with "cathode rays", strange emanations from discharge cathodes, which could be collimated into thin beams by the use of masks having small “pinholes" in them. These rays usually caused a blue or green phosphorescent glow wherever they en countered the walls of the glass tube in which they were produced; the ray position, or trajectory, was usually detected in this manner. Several facts were known:

1. Cathode rays are bent in a magnetic field.
2. The rays are deflected toward a strong positive charge brought into their vicinity.
3. The rays are actually charged negatively. This was determined by measuring a charge accumulated on a "catcher" placed in such a beam.

There was a general suspicion that cathode rays consisted of fast negatively charged particles, but this was not proven before J. J. Thomson performed his classic experiments in 1897. Due to his experiments and theories in 1906 he was awarded the Nobel Prize in physics for his researches into the discharge of electricity in gases.

Theory

Any charged particle having a charge q traveling with a velocity v through a uniform magnetic field will experience a force given by:

$$F = qv \times B \qquad \textbf{(1)}$$

Where F is the force of the on the charged particle (in Newtown’s), q is its charge (in Coulombs), v is the particle’s velocity (in m/s) and B represents the magnetic filed vector (in Tesla). When the velocity and the magnetic field are aligned at right angles to each other, and in the case of electrons, the magnitude of the force is:

$$F = evB$$

Where e is the charge of the electron. The force is directed opposite of $v \times B$, since e is negative, and therefore points perpendicular to both v and B in a direction given by the 'left' hand rule, as shown below in Figure 1.

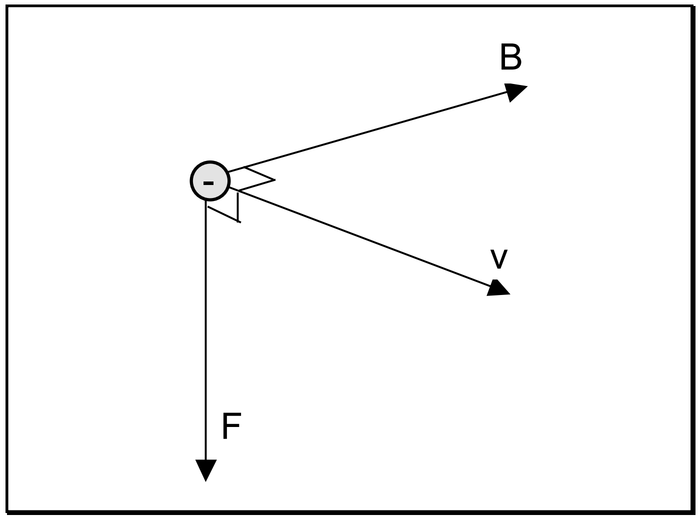


Figure 1: 'Left' Hand Rule for Electron

Since the direction of v is continuously changed by this force at every point, the electron beam will trace out a circular path in a plane perpendicular to the B-field. The centripetal force must exactly cancel the force due to the B-field since the e-beam in the absence of any other factors will trace out a perfect circle. This leads us to:

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

Solving for e/m gives us:

$$\frac{e}{m} = \frac{v}{Br} \qquad \textbf{(2)}$$

Therefore, for a known magnetic field B, radius r, and electron velocity v, the charge-to-mass ratio can be calculated. The electron velocity can be determined based on the kinetic energy of the electrons, which is equal to the charge e times the voltage applied to the anode.

$$eV_A = \tfrac{1}{2} mv^2 \qquad \textbf{(3)}$$

Using this to calculate v, and plugging it into equation (1) leads to

$$\frac{e}{m} = \frac{2V_A}{B^2 r^2} \qquad \textbf{(4)}$$

The magnetic field is supplied by the Helmholtz coils. They are constructed so that the distance between the two loops is approximately equal to their radius .This arrangement gives maximum uniformity of the field over a large volume near the center. Each of the coils contains 130 turns. The magnetic flux density at the center is given by (derive this report):

$$B = \frac{8\mu_0 NI}{a\sqrt{125}} \qquad \textbf{(5)}$$

Where N = number of turns in each coil,

I = current through the coils in amperes,

a = radius of coils in meters, and

μ_o = permeability of free space.

At the end it is noticeable that the force acting on the electrons will cause them to move in a circular path shown in below in Figure 2

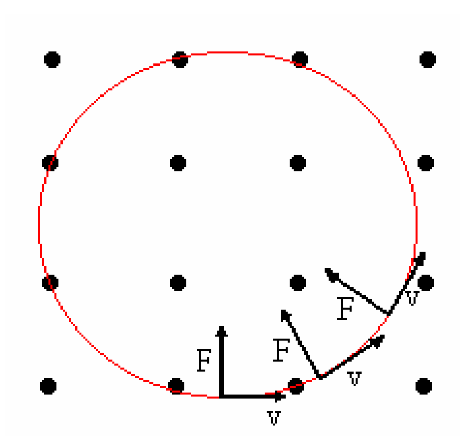


Figure 2

Purpose

To observe the circular motion of an electron beam in a nearly-uniform magnetic field and deduce the charge-to-mass ratio of the electron from measurements of the orbital radius. Based on theoretical calculations and experimental evidence, both the charge and the mass of an electron are constants, as is the ratio of the two. The magnetic field will induce a force on the electron which is perpendicular to both the direction and the magnetic field, and will force the electron beam to curve. The radius of curvature can be used to calculate the charge-to-mass ratio, since the curvature is directly related to both the mass of the electron and its charge.

Method

In this experiment the equipments were set up as in figure3.

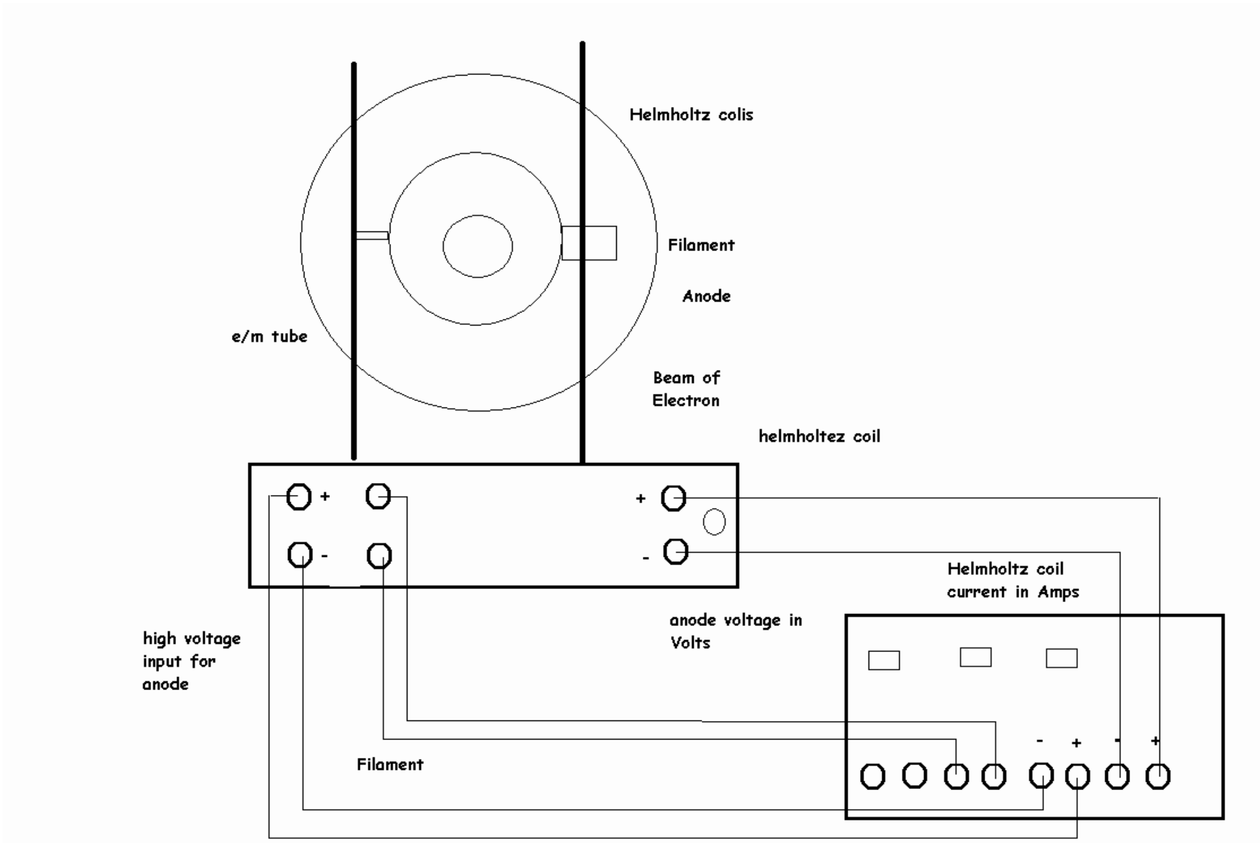


Figure 3

At the base of the e/m apparatus are inputs for the heater filament voltage (the cathode from which the electrons will be emitted), the anode voltage (the voltage through which the electrons will be accelerated), and the Helmholtz coil current. 6 volts from the output of the power supply was applied to the heater inputs located on the base of the e/m apparatus. The discharge tube power supply was turned on and the cathode glow red hot. After the anode voltage was slowly increased and the blue-green beam was seen. The electron beam travels straight in the absence of a B-field, but when the B-field is applied, the beam is deflected. With the anode voltage set to 200 volts, the radius of the curvature of the electron beam is changed by the Helmholtz coil current. (Figure 4). The radius and the current were observed and recorded; also the same experiment and observation were done at setting the anode voltage at 400 volts.

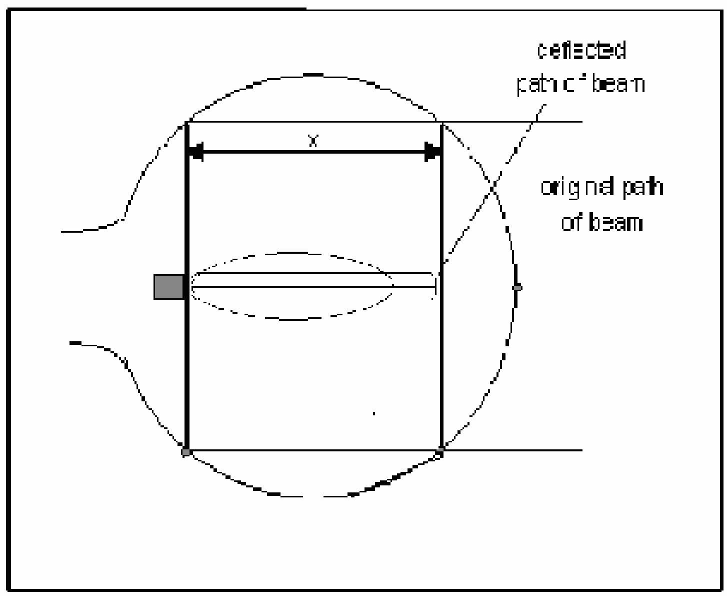


Figure 4: Electron Beam Deflection

Results

By using the data observed from the experiment in the lab , the experimental value for charge to mass of an electron will be 1.89×10^{11} coulombs/kg which leads to 7.38% error in comparing it to the theoretical value which is 1.76×10^{11} coulombs/kg.

Data

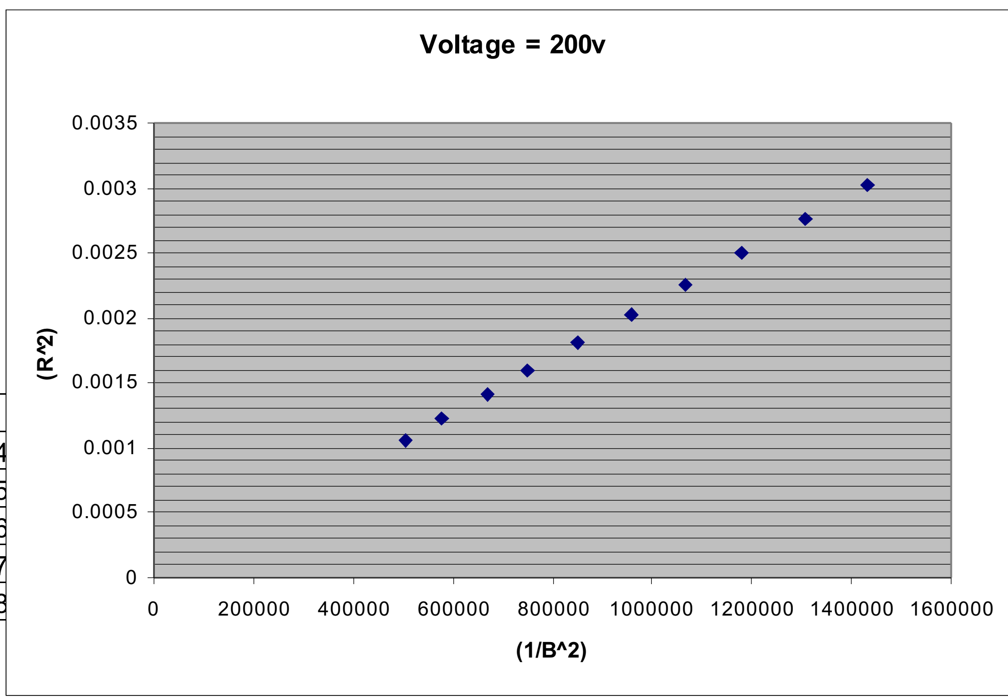
The data that was observed by this experiment was

When the voltage is set to 200 volts the data would be

I	r	B	1/B^2	R	R^2	slope		error
1.08	0.151	0.00083605460	1430641	0.055	0.003025	4.73E+08	1.89E+11	7.731033
1.13	0.151	0.00087476083	1306837	0.0525	0.002756	4.74E+08	1.9E+11	8.003597
1.19	0.151	0.00092120830	1178377	0.05	0.0025	4.71E+08	1.89E+11	7.369216
1.25	0.151	0.00096765578	1067968	0.0475	0.002256	4.73E+08	1.89E+11	7.821773
1.32	0.151	0.00102184451	957702	0.045	0.002025	4.73E+08	1.89E+11	7.731033
1.4	0.151	0.00108377448	851377.5	0.0425	0.001806	4.71E+08	1.89E+11	7.369216
1.49	0.151	0.00115344569	751632.8	0.04	0.0016	4.7E+08	1.88E+11	7.009219
1.58	0.151	0.00122311691	668442.5	0.0375	0.001406	4.75E+08	1.9E+11	8.277197
1.7	0.151	0.00131601186	577404.8	0.035	0.001225	4.71E+08	1.89E+11	7.369216
1.82	0.151	0.00140890682	503773.7	0.0325	0.001056	4.77E+08	1.91E+11	8.643617

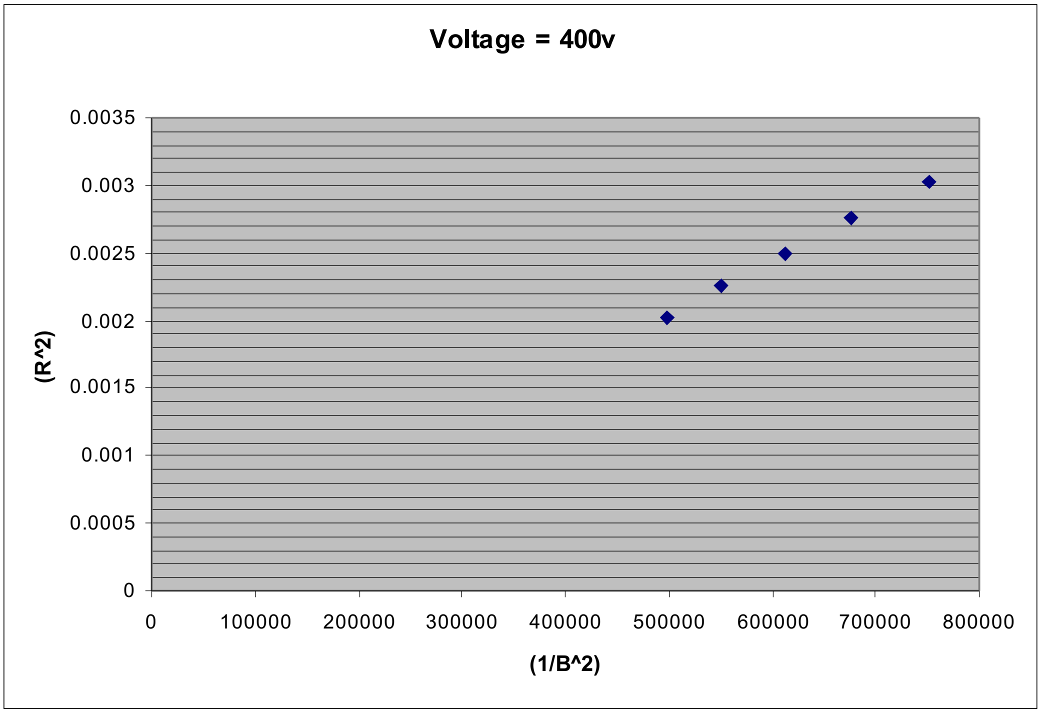
When the voltage is set to 400 volts the data would be

The graph of (1/B^2) against (R^2) when the voltage is 200v.



I		error
1.4	779E+11	8.19984
1.5	494E+11	9.78989
1.6	137E+11	9.69554
1.7	426E+11	7.29047
1.8	853E+11	8.10281

The graph of (1/B^2) against (R^2) when the voltage is 400v.



<u>Sample calculation</u>

When the values are:

V = 200v

I = 1.49A

Ų = 4π x 10^{-7}

N = 130

a = 0.151m

R = 0.04m

By using equation (5) the magnetic field produced by the coils will be

$$B = \frac{8x4\pi \; x10 \wedge -7x130 \; x1.49}{0.151 \; x\sqrt{125}}$$

B = 0.00115344569 Tesla

Then using equation (4) the e/m can be calculated

$$e/m = \frac{\frac{1}{(B^2)}}{\frac{(R^2)}{2v}}$$

$e/m = 1.87 \; x10^{11} \; c/kg$

but the way it was done by using the graph($(\frac{1}{B^2})$ vs R^2) that is shown in this report in data section the best fit line was find by using the graph which its slope was 4.75 x 10^8. By having the slope now it is possible to find the charge to mass ratio of an electron by multiplying the slope of the best fit line with 2 times the mass by referring to equation (4).

Slope = 4.75 x 10^8

V = 200v

$$e/m = 2(200 \; v) x 4.75 \; x \; 10^8$$

$e/m = 1.89 \; x10^{11}$

Now for the percentage error (which is the average for both 200v and 400v)

$$error = \frac{|experimental - theoretical|}{theoretical} x100$$

Error = (| $1.89 \; x10^{11}$ - $1.76 \; x10^{11}$ | / $1.76 \; x10^{11}$) x 100 = 7.38%

Discussion

Well although there is no questions in the lab manual to discuss Thomson found many principles of atoms and about rays and now it is being used television screens … it should be interesting to see the lab that was done had a major part of modern physics. Back in 1897 the atom was still thought of as an indivisible unit, and space was filled with"luminiferous ether" so that light waves had something to propagate through. This was the same year that Thomson performed the original e/m experiment in Cambridge, England. He knew that metals heated to very high temperatures in an electric field would emit a strange form of energy called "cathode rays". The nature of these rays was completely unknown; they could be observed through their effect on photographic plates, but were otherwise quite unlike light; the rays carried a current somehow, and were completely invisible.

Thomson reasoned that the rays might be a set of uniform particles, perhaps an ionized atom or a molecule. If this were the case, he could bend a beam of cathode rays with a magnetic field and extract information about the charge-to-mass ratio of these particles. His method was essentially the same as this lab, although he used a simpler apparatus. The fact that he came up with the same q/m no matter what the strengths of the fields were told him that he had indeed isolated a new kind of particle, one with a small amount of negative charge and an incredibly small mass. The cathode ray was soon renamed the electron, although its original nomenclature survives in the phrase "cathode ray tube" (CRT), which is applied to television screens, computer monitors, and oscilloscopes.

This simple discovery kicked off a whole new branch of physics; soon afterwards the proton was discovered, and somewhat later the neutron. The techniques developed in this research were later applied to the proton, neutron, and electron themselves in hopes of finding still more fundamental particles. As the experiments were performed at higher energies, new and unexpected particles came to light. It is fair to say that this simple experiment sparked a line of research which drastically changed our way of thinking about the universe.

Aside from the thrill of repeating an important and historic experiment, this lab is an ideal forum for exploring the motion of charged particles in electric and magnetic fields. At the end of the day, it is to be known how to calculate the electromagnetic force on a particle in any field configuration.

Conclusion

In this experiment you will observe the behavior of electrons in a magnetic field and determine a value for the electron charge-to-mass ratio e/m. Although it ended up with a 7.38% error it is still an acceptable value for this experiment. The final observed value for e/m turned out to be 1.89×10^{11} coulombs/kg. Considering the inherent difficulties associated with the experiment, the results are astonishingly accurate. One difficulty was accurately measuring the radius of the beam on the ruler due to that the room was not dark enough and it made it hard to see the exact radius of the beam. Second the Helmholtz coils where not orient parallel to the direction of the earth's magnetic filed (about 15°east of geographic north); so the effect of the earth's magnetic filed was not minimized and it had its effects in this experiment. At the end it was very interesting lab with very good results.

References

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