The Charge to Mass Ratio of Electron

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Abstract

In 1897, Thomson showed that cathode rays were composed of previously unknown negatively charged particles (now called electrons), which he calculated must have bodies much smaller than atoms and a very large charge-to-mass ratio. The aim of this experiment is to find this known constant by using a similar design as in the Thomson's experiment.

1 Introduction and Theoretical Motivation

Electron is one of the fundamental subatomic particles which has same but opposite charge with proton and has a mass of 1/1836 of the mass of proton. His discovery of a particle with a much smaller mass compared to proton led Thomson to build an atomic model which is analogous to the raisin pie, pie is the core structure of atom with positive charge and raisins are negatively charged small tiny electrons distributed over positive pie.

Since we knew the charge to mass ratio of electron by Thomson's experiment, Milikan's experiment in 1923 through which we obtained the charge of the electron, automatically gave the mass of the electron as well.

The charge to mass ratio of the electron is rather special since it is a limiting value, i.e. this ratio of electron is the biggest one among all particles.

Accelerating the electrons in an electric field first and then replacing these electrons in a magnetic field which is perpendicular to the direction of their motion will cause their trajectories to be curved. Depending on the magnetic field, the curved trajectory may become a closed path.[1]

Kinetic energy of an electron accelerated in a potential V is

$$K = \frac{1}{2} m_e v^2 = q_e V \tag{1}$$

And following equation holds for a particle with charge q and which moves in a magnetic field along a circular path.

$$q_e v B = \frac{m_e v^2}{r} \tag{2}$$

[1] Advanced Physics Experiments by Erhan Gülmez (Boğaziçi University Publications, 1999, ISBN 975-518-129-6)

Combining Equation 1 and 2, we get

$$B^2 = \frac{m_e}{q_e}\frac{2V}{r^2} \tag{3}$$

2 Apparatus and Experimental Procedure

In this experiment, we used fine beam tube set including Helmholtz coil, DC power supplies, ammeter and voltmeter.

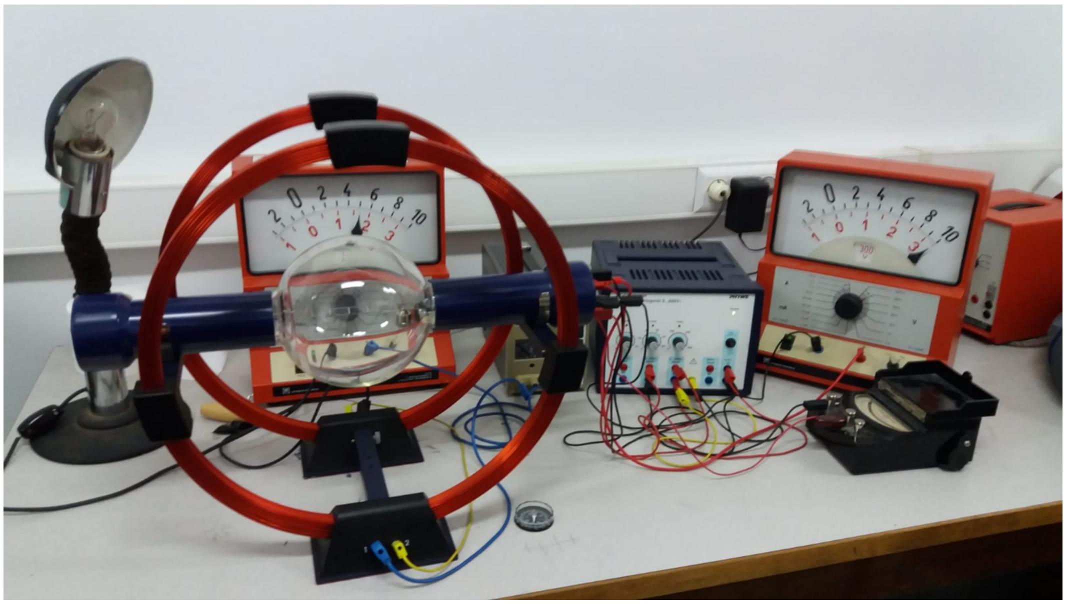


Figure 1: General view of apparatus

The fine beam tube is a tube which is filled with a very low pressure hydrogen gas. The electrons traveling through this gas excite the hydrogen atoms. The excited hydrogen atoms emit light along the electron's trajectory when they deexcite. Blue light is dominant in this deexcitation and the result is a very thin beam.[2]

A Helmholtz coil is a device for producing a region of nearly uniform magnetic field, named after the German physicist Hermann von Helmholtz. It consists of two electromagnets on the same axis.[3]

We first turned on the power supplies and tried to get familiar with the setup. We observed the behavior of the trajectory when different current and voltage values were applied.

The current through coils was used to arrange magnetic field according to following expression.

$$B = \frac{8\mu_0 IN}{\sqrt{125}r_c} \tag{4}$$

[2]Advanced Physics Experiments by Erhan Gülmez (Boğaziçi University Publications, 1999, ISBN 975-518-129-6)

[3]`https://en.wikipedia.org/wiki/Helmholtz_coil`

where I is the current passing through the coil, N is the number of turns, r_c is the radius of the coils. We are informed that values for the coil radius and the number of turns are 20 ± 1 cm and 154 turns, respectively.

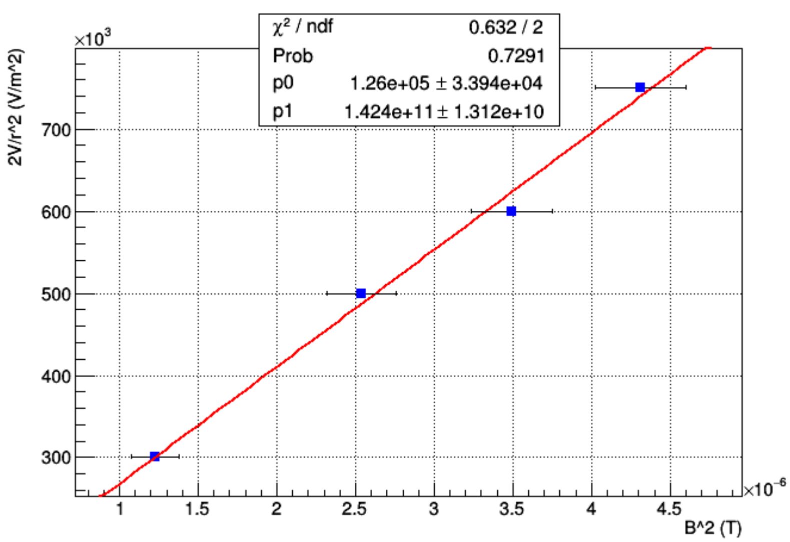
We arranged current (implicitly, magnetic field) and voltage[4] so that we got certain radius values for the circular trajectory of the electrons. The radius values were 2.0, 3.0, 4.0 and 5.0 cm$\pm$0.1. We obtained each radius value for four different V and I combinations. Then we plotted B^2 versus $\frac{2V}{r^2}$ graph for the data of each radius value. The slope of the graphs gave us $\frac{q_e}{m_e}$.(See Equation 3) Then we calculated the weighted average of the $\frac{q_e}{m_e}$ values we found from each graph.

3 Data and Analysis

For $r = 2$ case, B and V combinations and corresponding B^2 and $\frac{2V}{r^2}$ values are given below.[5]

V(Volt)	I(Ampere)	$B^2(Tesla^2)(10^{-6})$	$2V/r^2(Volt/meter^2)(10^6)$
150	3.0	4.3	0.75
120	2.7	3.5	0.60
100	2.3	2.5	0.5
60	1.6	1.2	0.3

Corresponding graph is given below.[6]



[4]The sensitivities of current and voltage are $\pm 0.1A$ and $\pm 10V$, respectively.
[5]For whole data and corresponding graphs, see Appendix.
[6]In the label of x-axis of the graph, the unit is mistakenly written as T, it should obviously be T^2.

The error bars for the y values were also put, but they are not visible since they are small.

From the graph, we read slope[7] as $1.4 \pm 0.1 \times 10^{11}$. Then we obtained the slope ($\frac{q_e}{m_e}$) from other graphs as well, and calculated weighted average of them, and found it as

$$\frac{q_e}{m_e} = 1.5 \pm 0.5 \times 10^{11} C/kg \tag{5}$$

while the known value of the charge to mass ratio of electron is

$$\frac{q_e}{m_e} = 1.758820 \times 10^{11} C/kg$$

4 Conclusion

Our result is considerably near to the known value. However, still, the known value is not in the range of our result. A possible source of error is the inhomogeneity of the magnetic field near to the edges. Though Helmholtz coil is supplying us an approximately homogeneous field, still, it is not ideal. This effect harms our use of Equation 3 since B is not constant and not equal to the B in Equation 4 everywhere. Besides, while deriving Equation 3, we assumed that after speeding up and sending to the magnetic field, the velocity of electrons doesn't change. But it is not the case since we observed that if we apply small voltages, the trajectory is not visible after some point, which shows that electrons lose energy along the way by hitting to the hydrogen atoms, which is a theoretically expected situation as well. This non-uniformity of velocity is another source of error.

Our fits in the graphs are not passing through the origin. Theoretically, if B is zero, then radius of the trajectory must be infinite (straight line) by Equation 2, and $2V/r^2$ had to be zero as B^2 was zero. However, our fits are not like that. This fact is another explanation for the deviation of our result from the expected known value.

One may wonder whether or not the velocity of the electrons were so big that we had to consider relativistic effects. Velocity of the electrons can be calculated from Equation 1. Plugging in the maximum value of the voltage we used (290 V) into equation, we found that the velocity of electrons is still just 0.03 of the speed of light. Thus, there is no relativistic effects involved.

5 Appendix

All data sets and graphs as well as the sample code used in analysis can be found in the following github link: `https://github.com/beratgonultas/phys442/tree/master/electron`

[7] Here, p0 is y-intersect and p1 is slope.