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Physics Department

Charge to Mass Ratio of the Electron

Experiment 8

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1 Abstract

Aim of the experiment is measuring the charge to mass ratio of the electron. To measure it we apply electromagnetic force to electron and observe circular path. From this relation we found ratio. We take 4 different data set. After analyzed them, we combine each of them with weighted average. Finally we found the charge to mass ratio of the electron as 2.0 $\times 10^{11}$ C/kg with 0.2 $\times 10^{11}$ C/kg uncertainty. We measured 1.2 σ away from the theoretical value.

2 Introduction

The experiment with a pumped-out glass bulb, in which an electric circuit is completed by electrons emitted from a hot wire, is credited to the US inventor Thomas Alva Edison (1847-1931), who patented it in 1883. The phenomenon is known as the "Edison effect" and many electronic devices use it nowadays. Experiments with beams of negative particles were performed in Britain by Joseph John ("J.J.") Thomson, and led to his conclusion in 1897 that they consisted of lightweight particles with a negative electric charge, nowadays known as electrons. Thomson was awarded the 1906 Nobel Prize.

The word "elektron" in Greek means amber, the yellow fossilized resin of evergreen trees, a "natural plastic material" already known to the ancient Greeks. It was known that when amber was rubbed with dry cloth–producing what now one would call static electricity–it could attract light objects, such as bits of paper.

During the 1800s it became evident that electric charge had a natural unit, which could not be subdivided any further, and in 1891 Johnstone Stoney proposed to name it "electron." When J.J. Thomson discovered the light particle which carried that charge, the name "electron" was applied to it. The many applications of electrons moving in a near-vacuum or inside semiconductors were later dubbed "electronics."[1]

3 Theory

An electron moving in a uniform magnetic field travels in a helical path around the field lines. The electron's equation of motion is given by the Lorentz relation. If there is no electric field, then this relation can be written as;

$$F_B = -e(\nu \times B) \tag{1}$$

where $\mathbf{F_B}$ is the magnetic force on the electron, -e = -1.6×10^{-19} coulombs is the electric charge of the electron, ν is the velocity of the electron, and **B** is the magnetic field. In the special case where the electron moves in an orbit perpendicular to the magnetic field, the helical path becomes a circular path, and the magnitude of the magnetic force [2]

$$F_B = e\nu B \tag{2}$$

For an electron of mass m moving at speed ν in a circle of radius **R**, the magnitude of the centripetal force $\mathbf{F_C}$ is

$$F_C = \frac{m\nu^2}{R} \tag{3}$$

Therefore,

$$e\nu B = \frac{m\nu^2}{R} \tag{4}$$

The initial potential energy of the electrons in this experiment is **eV** , where **V** is the accelerating voltage used in the electron-beam tube. After the electrons are accelerated through a voltage **V**, this initial potential energy is converted into kinetic energy (1/2)mν^2 . Since energy is conserved, it follows that

$$eV = \frac{1}{2}m\nu^2 \tag{5}$$

Combining Equation 4 and 5 yields;

$$B^2 = \frac{m_e}{q_e}\frac{2V}{r^2} \tag{6}$$

Helmholtz coils field strength will be determined using the expression;

$$B = \frac{8\mu_0 IN}{\sqrt{125}r_c} \tag{7}$$

Where **I** is the current passing through the coil, **N** is the number of turns, and $\mathbf{r}_c$ is the radius of the coils.

Combining Equation 6 and square of Equation 7;

$$\frac{64\mu_0^2 I^2 N^2}{125 r_c^2} = \frac{m_e}{q_e}\frac{2V}{r^2} \tag{8}$$

If take q_e/q_m from equation, we get;

$$\frac{q_e}{m_e} = \frac{2V}{r^2}\frac{125 r_c^2}{64\mu_0^2 I^2 N^2} \tag{9}$$

4 Experiment

4.1 Apparatus

- Fine Beam Tube set
- Helmholtz Coils
- DC Power Supply (0-300V)
- Filament Power Supply (6.3V AC, 5 A)
- AC Ammeter(0-3 A)
- DC Power Supply (0-5 A)
- DC Ammeter(0-5 A)
- DC Voltmeter(0-300 V)
- Connecting Leads

4.2 Setup

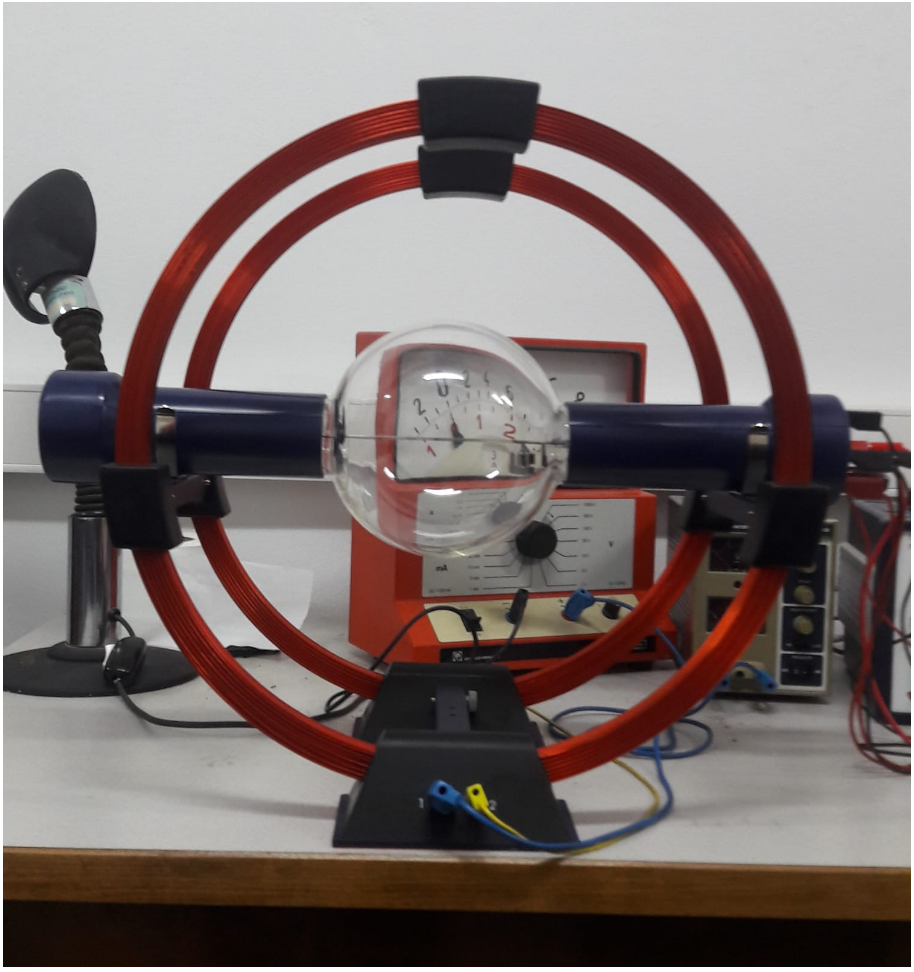

Figure 1: Image of the setup

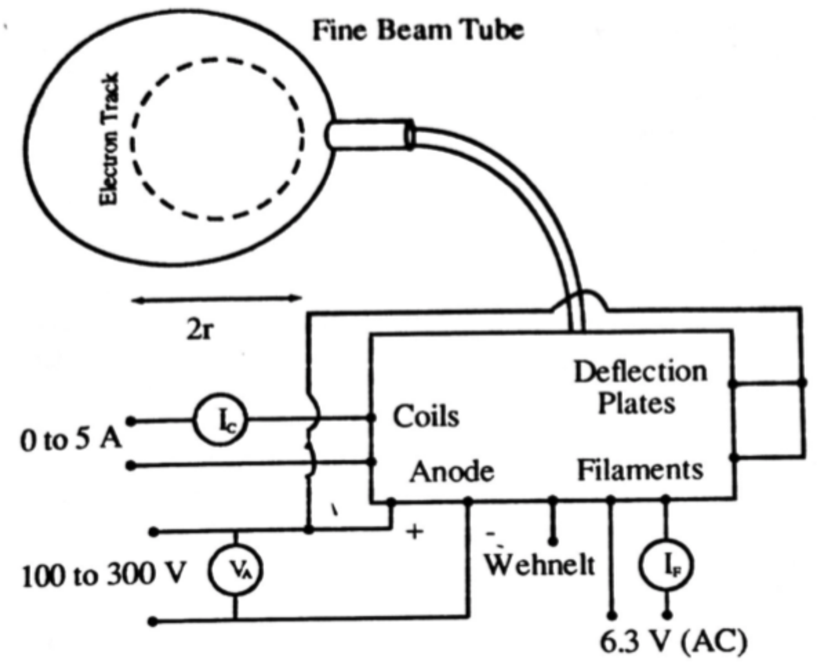

Figure 2: The Fine Beam tube and the Helmholtz Coil connections.[3]

4.3 Procedure

- First make sure that circuit in Figure 2 is connected.
- Set voltage of electron filaments.
- Then set current to coils.
- Turn of the light and see the electrons path.
- Arrange the radius of circle path 2cm.(first stick). Change the voltage and current with constant radius. Take at least 5 data set.
- Repeat previous step for radius equal to 3 cm, 4 cm, and 5 cm.
- Make Current versus Voltage graph for each radius. Fit the data and calculate q_e/m_e ratio for each data set.
- Calculate Weighted Average of q_e/m_e ratio and its uncertainty.

5 Raw Data

Number of Turns(N)	154
Radius of Coils(r_c)	0.2m

r=0.020m	Current(A)	0.9 ± 0.1	1.5 ± 0.1	2.2 ± 0.1	2.7 ± 0.1
± 0.002m	Voltage(V)	60 ± 10	70 ± 10	90 ± 10	130 ± 10
r=0.030m	Current(A)	1.3 ± 0.1	1.5 ± 0.1	1.6 ± 0.1	1.8 ± 0.1
± 0.002m	Voltage(V)	80 ± 10	100 ± 10	110 ± 10	130 ± 10
r=0.040m	Current(A)	1.2 ± 0.1	1.3 ± 0.1	1.5 ± 0.1	1.6 ± 0.1
± 0.002m	Voltage(V)	120 ± 10	140 ± 10	180 ± 10	200 ± 10
r=0.050m	Current(A)	1.1 ± 0.1	1.2 ± 0.1	1.3 ± 0.1	1.4 ± 0.1
± 0.002m	Voltage(V)	160 ± 10	180 ± 10	200 ± 10	220 ± 10

Table 1: Voltage and Current data set for 4 different radius

Reason we set ± 0.002cm error to radius is that we could not decide exactly electron hit the center of the stick.

6 Data Analysis

We made Current(I) versus Voltage(V) graph for each data we get for 4 different radius. The equation of the fit function will be;

$$V = Constant \times I^2 \tag{10}$$

We change Equation 9 to this form;

$$V = \frac{q_e}{m_e} \frac{32\mu_0^2 N^2 r^2}{125 r_c^2} \times I^2 \tag{11}$$

Then **Constant** will be equal to;

$$Constant = \frac{q_e}{m_e} \frac{32\mu_0^2 N^2 r^2}{125 r_c^2} \tag{12}$$

Finally q_e/m_e will be equal to

$$\frac{q_e}{m_e} = Constant \times \frac{125 r_c^2}{32\mu_0^2 N^2 r^2} \tag{13}$$

In this equation $\mathbf{r}_c$ and **N** does not have uncertainty since manufacturer of the setup was not give it. Of course, the theoretical value of μ_0 has uncertainty but it is very small when we compare it to other uncertainties. To sum up, there are uncertainty that we consider on **r** and **Constant**. By error propagation formula, the uncertainty of q_e/m_e is following;

$$\sigma_{q_e/m_e} = \frac{125 r_c^2}{32\mu_0^2 N^2} \times \sqrt{\left(\frac{\sigma_{Constant}}{r^2}\right)^2 + \left(\frac{Constant \times \sigma_r}{2r^3}\right)^2} \tag{14}$$

We take theoretical value of Magnetic Constant(μ_0) as;

$$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{H/m} \approx 1.2566370614\ldots \times 10^{-6}\ \mathrm{N/A^2}. \tag{15}$$

6.1 r=0.020m ± 0.002m

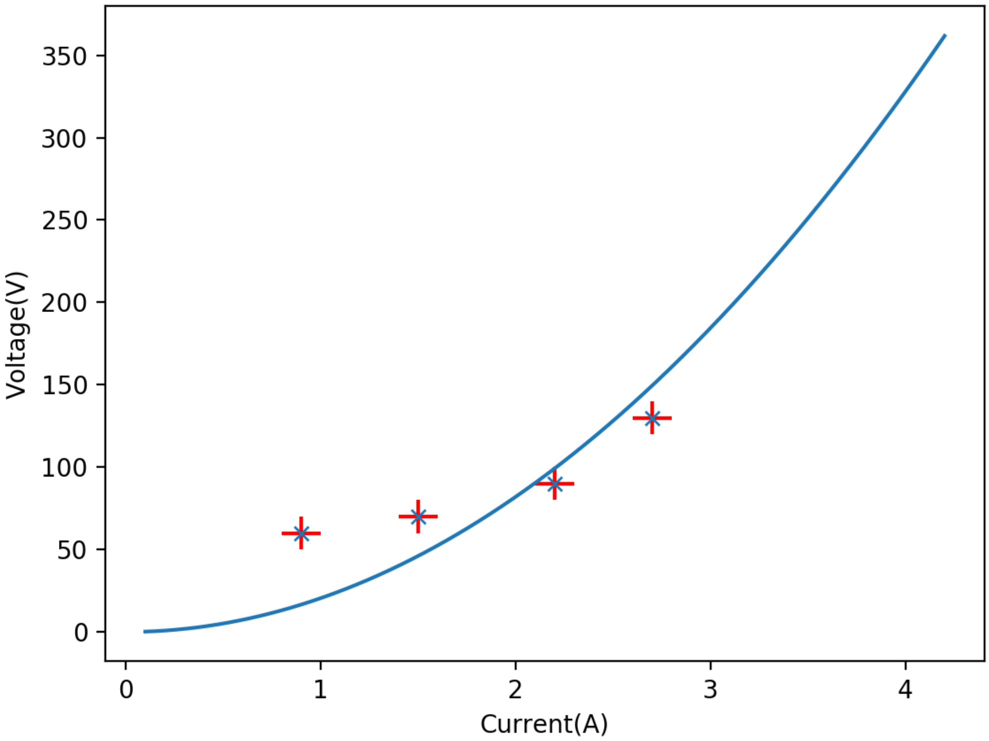

Figure 3: Current(A) versus Voltage(V) graph for r=0.020m ± 0.002m

We found Constant of fit function of graph by ptyhon (scipy.odr package) as;

$$Constant \ = \ 20 \pm 4 \ V/A^2 \tag{16}$$

Then, we found q_e/m_e ratio by Equation 13 and 14;

$$\frac{q_e}{m_e} \ = \ 2.1 \pm 0.6 \times 10^{11} \ C/kg \tag{17}$$

6.2 r=0.030m ± 0.002m

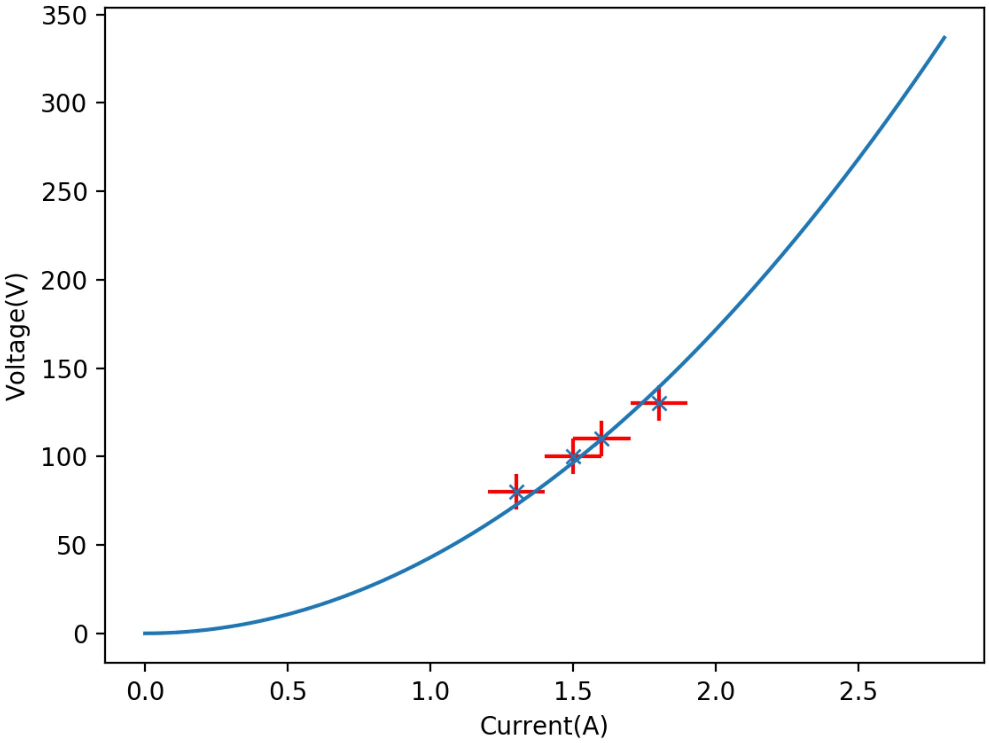

Figure 4: Current(A) versus Voltage(V) graph for r=0.030m ± 0.002m

We found Constant of fit function of graph by ptyhon (scipy.odr package) as;

$$Constant \ = \ 43 \pm 1 \ V/A^2 \tag{18}$$

Then, we found q_e/m_e ratio by Equation 13 and 14;

$$\frac{q_e}{m_e} \ = \ 2.0 \pm 0.3 \times 10^{11} \ C/kg \tag{19}$$

6.3 r=0.040m ± 0.002m

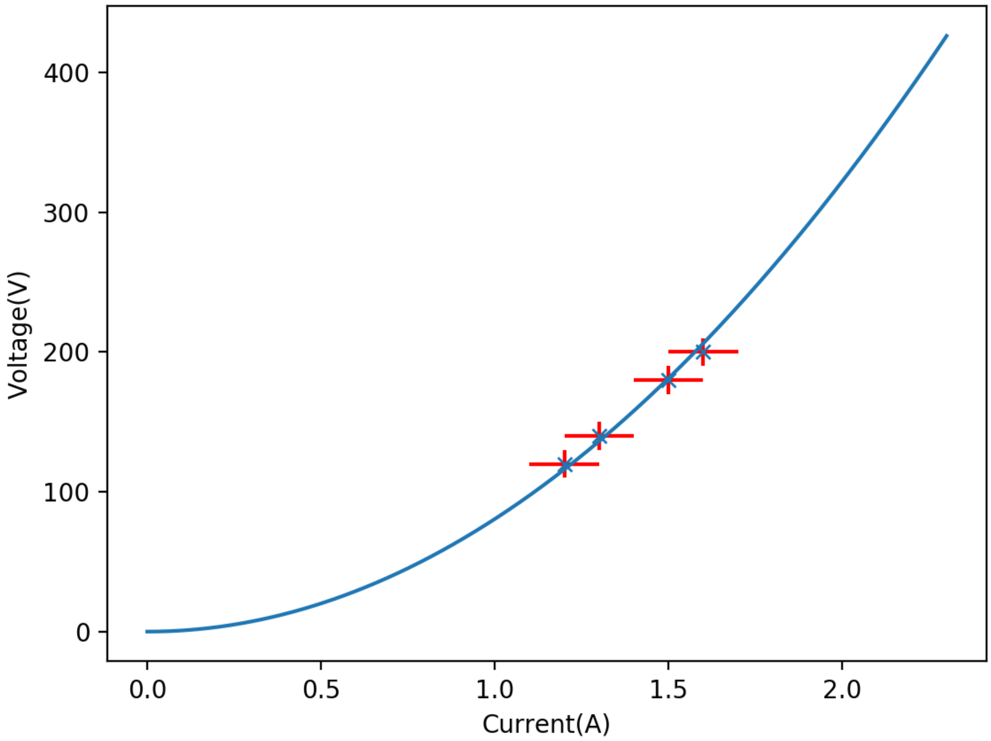

Figure 5: Current(A) versus Voltage(V) graph for r=0.040m ± 0.002m

We found Constant of fit function of graph by ptyhon (scipy.odr package) as;

$$Constant \; = \; 80 \pm 1 \; V/A^2 \tag{20}$$

Then, we found q_e/m_e ratio by Equation 13 and 14;

$$\frac{q_e}{m_e} \; = \; 2.1 \pm 0.2 \times 10^{11} \; C/kg \tag{21}$$

6.4 r=0.050m ± 0.002m

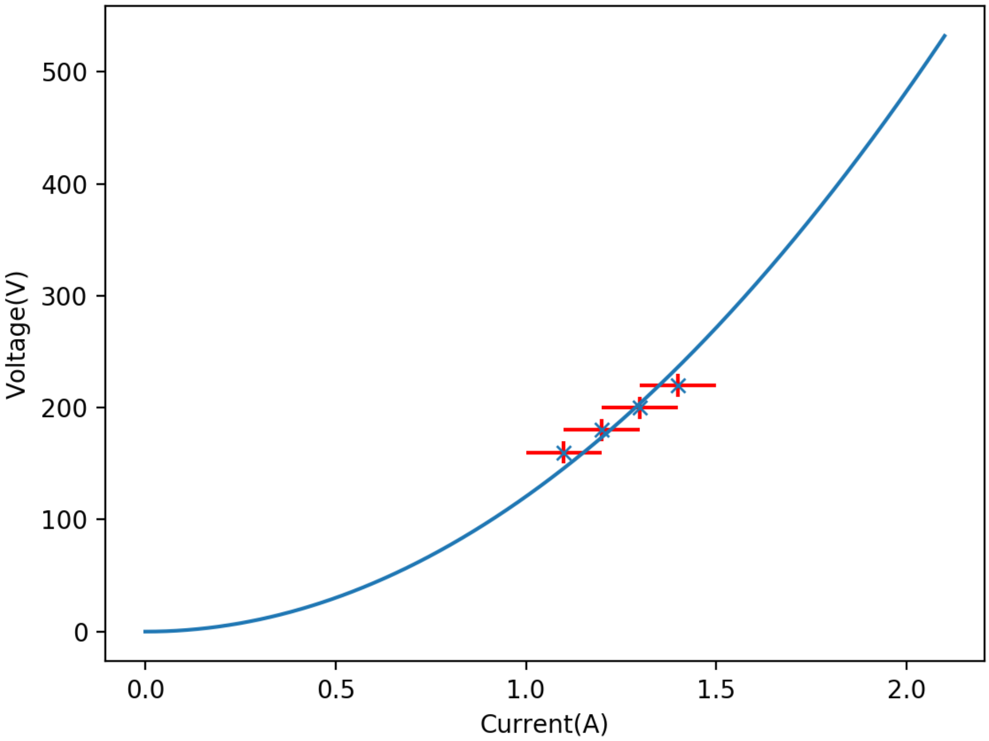

Figure 6: Current(A) versus Voltage(V) graph for r=0.050m ± 0.002m

We found Constant of fit function of graph by ptyhon (scipy.odr package) as;

$$Constant \;=\; 121 \pm 4\; V/A^2 \tag{22}$$

Then, we found q_e/m_e ratio by Equation 13 and 14;

$$\frac{q_e}{m_e} \;=\; 2.0 \pm 0.2 \times 10^{11}\; C/kg \tag{23}$$

6.5 Weighted Average

	r=0.020m ± 0.002m	r=0.030m ± 0.002m	r=0.040m ± 0.002m	r=0.050m ± 0.002m
q_e/m_e	2.1 ± 0.6	2.0 ± 0.3	2.1 ± 0.2	2.0 ± 0.2

Table 2: All q_e/m_e ratio and their uncertainties we found found from each r value

$$Weighted\ Average = \frac{\sum_{i=1}^{N} \Delta Vi/\sigma_i^2}{\sum_{i=1}^{N} 1/\sigma_i^2} \tag{24}$$

$$\sigma_{WA} = \sqrt{\frac{1}{N^2} \cdot \sum_{i=1}^{N} (\sigma_i)^2} \tag{25}$$

By using Equation 24 and 25 , we found weighted q_e/m_e ratio and its uncertainty as;

$$\frac{q_e}{m_e} \;=\; 2.0 \pm 0.2 \times 10^{11} C/kg \tag{26}$$

Where the theoretical value is;

$$\frac{q_e}{m_e} = 1.758820024 \pm 0.000000011 \times 10^{11} C/kg \tag{27}$$

7 Conclusion

To evaluate error of the measurement;

$$Error = \frac{|1.758820024 \times 10^{11} - 2.0 \times 10^{11}|}{0.2 \times 10^{11}} = 1.2 \tag{28}$$

As seen in Equation 28, our measured q_e/m_e value is 1.2σ away from the theoretical value. And our percentage of uncertainty is 10%. The reason we found rather small σ away from the theoretical value is big uncertainty. If we have small uncertainty, our error would be high.

As seen in our raw data, Voltage and Current value increase linearly but Voltage have a relation with square of the current value. Reason of this situation is arise from significant figure we read on Ammeter and Voltmeter. Voltmeter had only 1 significant figure and Ammeter had 2 significant figure. This situation also affect the uncertainty.

While we arrange radius of circular path of electron, we point it on a measurement stick in setup. It is possible that we might have mistake while arrange it. Even if we add uncertainty to this value. It affect our calculation. Instead of ladder like stick, ruler would give us better solution. In this way, we could take various radius data.

It has a very small effect but error propagation work well with small uncertainties. Radius data have uncertainties between 10% and 4%. Constant we found from graph(radius equal to 2.0cm) have 20% uncertainty. Because of this reason, uncertainty we calculate have a mistake. Effect is not as high as order.

References

[1] History of the Electron [Accessed Date: 15.05.2019]
https://www-spof.gsfc.nasa.gov/Education/whelect.html

[2] The Charge-to-Mass Ratio of the Electron [Accessed Date: 15.05.2019]
http://demoweb.physics.ucla.edu/content/experiment-6-charge-mass-ratio-electron

[3] Advanced Physics Experiments, Erhan Gulmez, Bogazici University Publications, 1999,ISBN 975-518-129-6

[4] Constants [Accessed Date: 15.05.2019]
https://physics.nist.gov/cuu/Constants/

[5] Orthogonal distance regression (scipy.odr) [Accessed Date: 15.05.2019]
https://docs.scipy.org/doc/scipy/reference/odr.html

Appendices

Python codes of Data Analyses part;
https://github.com/sinaaktas/q-m-Ratio/blob/master/qm%20ratio.ipynb