Charge-to-Mass Ratio of the Electron Josephine Brozny

Abstract/Introduction

The purpose of the Mass-to-Ratio experiment is to calculate the ratio between the mass and charge of a particle. This is done by using an e/m tube which produces a stream of negatively charged particles which is manipulated manually by adjusting current. We can calculate the e/m by averaging the measured currents at the different voltages of 40,60, and 80 as well as measuring the amount of turns which is 72, and lastly the different distances from the filament to inside crossbars. My average value for e/m was 1.76 x 10^11 (+/-) 5.5 x 10^9 C/kg which agrees with the accepted value of 1.759 x 10^11 (+/-) 5.9 x 10^9 C/kg.

Description of Experimental Procedure

First, I made sure everything was powered off. The filament power supply, Helmholtz coils, and anode power supply were all not producing power as well as the filament power supply voltage also at a zero state. Then I rotated the Helmholtz coils in order to position the e/m tube to be parallel to the compass. For my experiment it had already been positioned perfectly by a past group, but I checked to make sure the angle was as close to 23.5 degrees as possible and the dip needle read 0. Then I could begin to turn the power on. First, I switched the anode power supply on and set the voltage to 40V. Next was switching the filament power supply. I placed the black cloth over the apparatus in order to more effectively see the glowing beam appear as I turned the voltage knob. I made sure not to exceed 4.5 A as instructed. Next, I turned on the Helmholtz apparatus power supply and began turning the knob for the current. I adjusted the current knob until the beam appeared to be as straight as possible against the filament wall, and recorded this current as I0. I did this 2 more times to get 3 total recordings for I0. I then increased the current until the beam created a circle, and hit the different lengths of the crossbar. I recorded the current for each crossbar (1-5) for each voltage (40,60,80) with a total of 15 current recordings.

Results

I calculated my average I0 to be 0.171 (+/-) 0.007 Amps. I measured I(tot) for each crossbar and each voltage with a total of 15 values, and subtracted I0 from each I(tot) to get another 15 values of I(net). This was a result of equation 2. We were also given the distance in cm from the filament to inside crossbars on our lab sheet, which was recorded in the attached scanned sheets. Lastly, we were also given the number of spins which was 72 for our apparatus. We were able to use these measurements as well as the constants provided to utilize equation 7 and result in 15 e/m values. Taking the average of these values I calculated the average e/m to be 1.76 x 10^11 C/kg (+/-) 5.5 x 10^9 C/kg which is in agreement with the accepted value of 1.759 x 10^11 (+/-) 5.9 x 10^9 C/kg. I calculated the standard deviation to be 6.47142×10^{10} C/kg for random errors in the experiment.

My data input and calculations can be seen handwritten in my lab notebook pages attached.

The uncertainty of I0 is (+/-)0.001 since there was no deviation from the number during recording.

Charge to Mass Ratio of the Electron

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Initial Current (I_0)

Trial 1: 0.171 ± 0.01 A
Trial 2: 0.173 ± 0.01 A
Trial 3: 0.171 ± 0.01 A

I_{0av} = 0.171 ± 0.03

(40 Volts) ± 0.1V

I_{total} = 2.154 A → 5th bar (farthest)

$I_{net,5}$ = 2.154 − 0.171 = 1.983 A

$I_{tot,4}$ = 2.388 A	$I_{net,3}$ = 2.713 − 0.171 = 2.542 A
$I_{tot,3}$ = 2.713 A	$I_{net,2}$ = 3.068 − 0.171 = 2.897 A
$I_{tot,2}$ = 3.068 A	$I_{net,1}$ = 3.611 − 0.171 = 3.440 A
$I_{tot,1}$ = 3.611 A	$I_{net,4}$ = 2.388 − 0.171 = 2.217 A
(± 0.01 A)	

* forgot to write uncertainty so I wrote on side, same for all
→ Used in eq 7

(60 Volts) ± 0.1V

$I_{tot,5}$ = 2.576 A	$I_{net,5}$ = 2.576 − 0.171 = 2.405 A
$I_{tot,4}$ = 2.899 A	$I_{net,4}$ = 2.899 − 0.171 = 2.728 A
$I_{tot,3}$ = 3.326 A	$I_{net,3}$ = 3.326 − 0.171 = 3.155 A
$I_{tot,2}$ = 3.723 A	$I_{net,2}$ = 3.723 − 0.171 = 3.552 A
$I_{tot,1}$ = 4.436 A	$I_{net,1}$ = 4.436 − 0.171 = 4.265 A
(± 0.01 A)	

Uncertainty for current
↓
± 0.04

(80 Volts) ± 0.1V

$I_{tot,5}$ = 2.962 A	$I_{net,5}$ = 2.962 − 0.171 = 2.791 A
$I_{tot,4}$ = 3.238 A	$I_{net,4}$ = 3.238 − 0.171 = 3.067 A
$I_{tot,3}$ = 3.709 A	$I_{net,3}$ = 3.709 − 0.171 = 3.538 A
$I_{tot,2}$ = 4.391 A	$I_{net,2}$ = 4.391 − 0.171 = 4.22 A
$I_{tot,1}$ = 5.226 A	$I_{net,1}$ = 5.226 − 0.171 = 5.655 A
(± 0.01 A)	

(Tube #9)

Distance in cm from Filament to Inside Crossbars

1 = 6.33 cm	r_1 = 3.165 cm	= 0.03165 m
2 = 7.54 cm	r_2 = 3.77 cm	= 0.0377 m
3 = 8.77 cm	r_3 = 4.385 cm	= 0.04385 m
4 = 9.98 cm	r_4 = 4.99 cm	= 0.0499 m
5 = 11.22 cm	r_5 = 5.6 cm	= 0.056 m
(± 0.07 cm)		

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Radius of Helmholtz Coils
(inner) a=64.5 cm
(outter) a=62.5 cm

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$(64.5+62.5)/2 = \frac{63.5}{2} = 31.75$ cm radius → 0.3175m

9. $\frac{e}{m} = \frac{3.91}{\mu_0^2} \cdot \frac{a^2}{N^2} \cdot \frac{V}{I^2 r^2}$ $\mu_0 = 4\pi \cdot 10^{-7}$ Tm/A
$N = 72$ turns

$(e/m)_{40,5} = \frac{3.91}{(4\pi \cdot 10^{-7})^2} \cdot \frac{(.3175)^2}{(72)^2} \cdot \frac{40}{(1.983)^2(.056)^2}$

$(e/m)_{40,4} = \frac{3.91}{(4\pi \cdot 10^{-7})^2} \cdot \frac{(.3175)^2}{(72)^2} \cdot \frac{40}{(2.542)^2(.0499)^2}$

$(e/m)_{40,3} = \frac{3.91}{(4\pi \cdot 10^{-7})^2} \cdot \frac{(.3175)^2}{(72)^2} \cdot \frac{40}{(2.897)^2(.04385)^2}$

$(e/m)_{40,2} = \frac{3.91}{(4\pi \cdot 10^{-7})^2} \cdot \frac{(.3175)^2}{(72)^2} \cdot \frac{40}{(3.441)^2(.0377)^2}$

$(e/m)_{40,1} = \frac{3.91}{(4\pi \cdot 10^{-7})^2} \cdot \frac{(.3175)^2}{(72)^2} \cdot \frac{40}{(2.217)^2(.03165)^2}$

$(e/m)_{40,5} = 1.56 \cdot 10^{11}$ C/kg $(e/m)_{40,2} = 1.15 \cdot 10^{11}$ C/kg
$(e/m)_{40,4} = 1.20 \cdot 10^{11}$ C/kg $(e/m)_{40,1} = 3.91 \cdot 10^{11}$ C/kg
$(e/m)_{40,3} = 1.19 \cdot 10^{11}$ C/kg

$(e/m)_{60,5} = \frac{3.91}{(4\pi \cdot 10^{-7})^2} \cdot \frac{(.3175)^2}{(72)^2} \cdot \frac{60}{(2.405)^2(.056)^2}$

$(e/m)_{60,4} = \frac{3.91}{(4\pi \cdot 10^{-7})^2} \cdot \frac{(.3175)^2}{(72)^2} \cdot \frac{60}{(2.728)^2(.0499)^2}$

$(e/m)_{60,3} = \frac{3.91}{(4\pi \cdot 10^{-7})^2} \cdot \frac{(.3175)^2}{(72)^2} \cdot \frac{60}{(3.155)^2(.04385)^2}$

$(e/m)_{60,2} = \frac{3.91}{(4\pi \cdot 10^{-7})^2} \cdot \frac{(.3175)^2}{(72)^2} \cdot \frac{60}{(3.552)^2(.0377)^2}$

$(e/m)_{60,1} = \frac{3.91}{(4\pi \cdot 10^{-7})^2} \cdot \frac{(.3175)^2}{(72)^2} \cdot \frac{60}{(4.265)^2(.03165)^2}$

$(e/m)_{60,5} = 1.59 \cdot 10^{11}$ C/kg $(e/m)_{60,2} = 1.61 \cdot 10^{11}$ C/kg
$(e/m)_{60,4} = 1.56 \cdot 10^{11}$ C/kg $(e/m)_{60,1} = 1.59 \cdot 10^{11}$ C/kg
$(e/m)_{60,3} = 1.51 \cdot 10^{11}$ C/kg

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$(e/m)_{80,5} = \frac{3.91}{(4\pi \cdot 10^{-7})^2} \cdot \frac{(.3175)^2}{(72)^2} \cdot \frac{80}{(2.791)^2(0.056)^2}$

$$(e/m)_{80,4} = \frac{3.91}{(4\pi\cdot10^{-7})^2}\cdot\frac{(.3175)^2}{(72)^2}\cdot\frac{80}{(3.067)^2(.0499)^2}$$

$$(e/m)_{80,3} = \frac{3.91}{(4\pi\cdot10^{-7})^2}\cdot\frac{(.3175)^2}{(72)^2}\cdot\frac{80}{(3.538)^2(.04385)^2}$$

$$(e/m)_{80,2} = \frac{3.91}{(4\pi\cdot10^{-7})^2}\cdot\frac{(.3175)^2}{(72)^2}\cdot\frac{80}{(4.22)^2(.0377)^2}$$

$$(e/m)_{80,1} = \frac{3.91}{(4\pi\cdot10^{-7})^2}\cdot\frac{(.3175)^2}{(72)^2}\cdot\frac{80}{(5.055)^2(.03165)^2}$$

$(e/m)_{80/5} = 1.58\cdot10^{11}$ C/kg $(e/m)_{80/2} = 1.52\cdot10^{11}$ C/kg

$(e/m)_{80/4} = 1.64\cdot10^{11}$ C/kg $(e/m)_{80/1} = 1.50\cdot10^{11}$ C/kg

$(e/m)_{80/3} = 1.60\cdot10^{11}$ C/kg

Average: $1.76\cdot10^{11}$ C/kg

In[ ]:=
```
ivalues = {1.56 * 10^11, 1.20 * 10^11, 1.19 * 10^11, 1.15 * 10^11,
   3.91 * 10^11, 1.59 * 10^11, 1.56 * 10^11, 1.51 * 10^11, 1.61 * 10^11, 1.59 * 10^11,
   1.58 * 10^11, 1.64 * 10^11, 1.60 * 10^11, 1.52 * 10^11, 1.50 * 10^11}

Mean[ivalues]
StandardDeviation[ivalues]
```

Out[ ]= $\{1.56\times10^{11}, 1.2\times10^{11}, 1.19\times10^{11}, 1.15\times10^{11}, 3.91\times10^{11}, 1.59\times10^{11}, 1.56\times10^{11}, 1.51\times10^{11}, 1.61\times10^{11}, 1.59\times10^{11}, 1.58\times10^{11}, 1.64\times10^{11}, 1.6\times10^{11}, 1.52\times10^{11}, 1.5\times10^{11}\}$

Out[ ]= 1.64733×10^{11}

Out[ ]= 6.47142×10^{10}

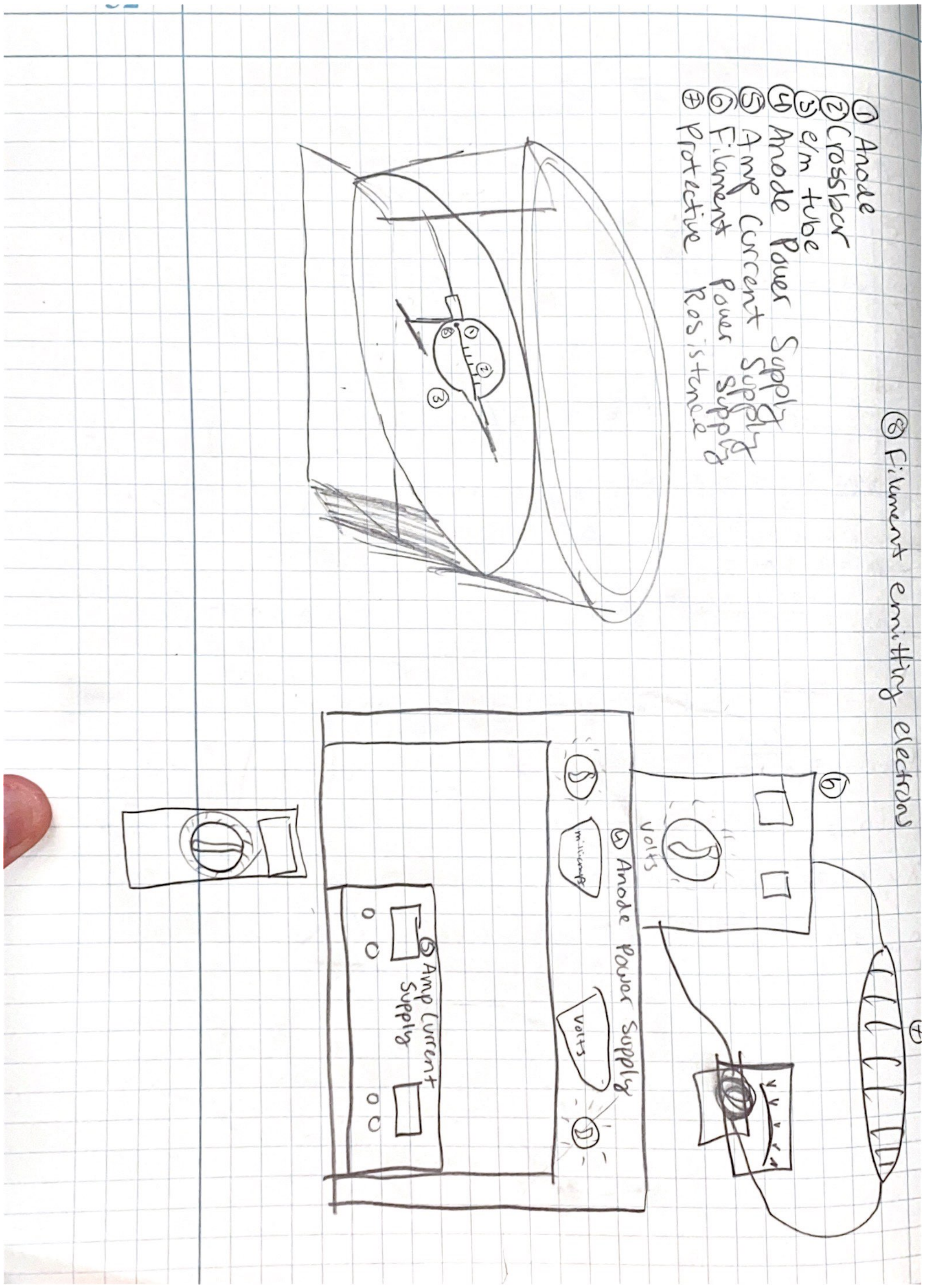
Discussion

I was able to calculate the e/m to be 1.76 x 10^11 C/kg (+/-) 5.5 x 10^9 C/kg which is in agreement with the accepted value of 1.759 x 10^11 (+/-) 5.9 x 10^9 C/kg. Although it is in agreement, there were sources of error that could have contributed to my experiment. A systematic error is that the uncertainty in the voltmeter is (+/-) 0.1V, the meter stick uncertainty was (+/-) 0.0005m, the angle of the apparatus may have been slightly off to Earth's tilt and didn't completely cancel out the magnetic field, the air temperature could have effected the mercury in the tube and ultimately the electron beam. I calculated the standard deviation to be 6.47142×10^{10} C/kg for random errors in the experiment.

Conclusion

In conclusion, the experimental value for the charge to mass ratio of an electron was recorded to be 1.76 x 10^11 C/kg (+/-) 5.5 x 10^9 C/kg which is in agreement with the accepted value of 1.759 x 10^11 (+/-) 5.9 x 10^9 C/kg. The random and systematic errors were present but kept to a minimum in this experiment.

Scanned Sheets from Lab Notebook



1 Anode
2 Crossbar
3 e/m tube
4 Anode Power Supply
5 Amp Current Power Supply
6 Filament Power Supply
7 Protective Resistance
8 Filament emitting electrons
Volts
milliamps
4 Anode Power Supply
Volts
5 Amp Current Supply

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Initial Current (I_0)

Trial 1: 0.171 ±0.01 A

Trial 2: 0.17~~3~~ ±0.01 A I_{0av} = 0.171 ± 0.0[illegible]

Trial 3: 0.171 ±0.01 A

(40 Volts) ±0.1V

I_{total} = 2.154 A

$I_{tot,4}$ = 2.388 A

$I_{tot,3}$ = 2.713 A

$I_{tot,2}$ = 3.068 A

$I_{tot,1}$ = 3.611 A

(± 0.01 A)

→ 5th bar (farthest)

$I_{net,5}$ = 2.154 − 0.171 = 1.983 A

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(Tube #9)

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$(e/m)_{40,3} = \frac{3.91}{(4\pi \cdot 10^{-7})^2} \cdot \frac{(.3175)^2}{(72)^2} \cdot \frac{40}{(2.897)^2(.04385)^2}$

$(e/m)_{40,2} = \frac{3.91}{(4\pi \cdot 10^{-7})^2} \cdot \frac{(.3175)^2}{(72)^2} \cdot \frac{40}{(3.441)^2(.0377)^2}$

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Average: $1.76\cdot 10^{11}$ C/kg