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Determination of the Charge of an Electron

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Abstract

The purpose of this experiment was to determine the fundamental charge of an electron. This was accomplished by measuring the terminal velocities of drops of oil and measuring the voltages required to suspend the oil drops in an electric field while taking into account the effects of pressure on the viscosity of air. The voltage readings were calibrated by comparing the voltage displayed on the Millikan Oil Drop apparatus to the voltage reading of a Fluke multimeter, providing a 0.7% correction to the readings from the apparatus. Through this process, I found the charge of an electron to be $2.5 \times 10^{-19} \pm 1.5 \times 10^{-19}$ C. The fundamental charge of an electron is reported to be 1.6×10^{-19} C (Haynes, 2014). My finding is within 58.2% of the reported charge of an electron. The result of this experiment could be improved further by taking data from more oil drops and taking better measurements of air pressure and temperature to provide for better corrections to the air viscosity.

Introduction

This Millikan Oil Drop Lab is based on Millikan's experiment outlined in his paper *On the Elementary Electrical Charge and the Avogadro Constant* in 1913 (Millikan, 1913). This experiment was an important step in determining the fundamental electric charge to a level of precision and accuracy that had previously not been possible. I will discuss the calibration of the Millikan Oil Drop apparatus, the results obtained from the measurement of the oil drops, and will provide tables and graphs to accompany the data presented in this report.

Methods

Following the procedures in the lab manual (Phys 451L, 2022), the experiment began by finding the relationship between the distances shown on the output computer screen from the microscope and the actual distance that was being observed by the microscope on the Millikan Oil Drop apparatus. This was accomplished by observing a small wire with a known diameter of 0.266 ± 0.002 mm (Phys 451L, 2022) in the oil drop chamber and measuring its diameter on the computer screen, which came out to be approximately 16.0 ± 0.5 mm. This provided a ratio to apply to the measured computer screen distances, allowing them to be translated into the actual distances that are being observed. With this, the spacing between the horizontal lines on the screen was measured to be approximately 12.0 ± 0.5 mm which corresponds to an actual observed distance of 0.200 ± 0.008 mm.

The voltage readings of the plates on the apparatus were calibrated next. This was done by recording the voltages displayed by the apparatus and an attached multimeter at set voltages and comparing them to find a linear least-squares fit. This fit was then used to apply a 0.7% correction to any readings from the apparatus voltages for use in calculations. This fit can be seen in Figure 1.

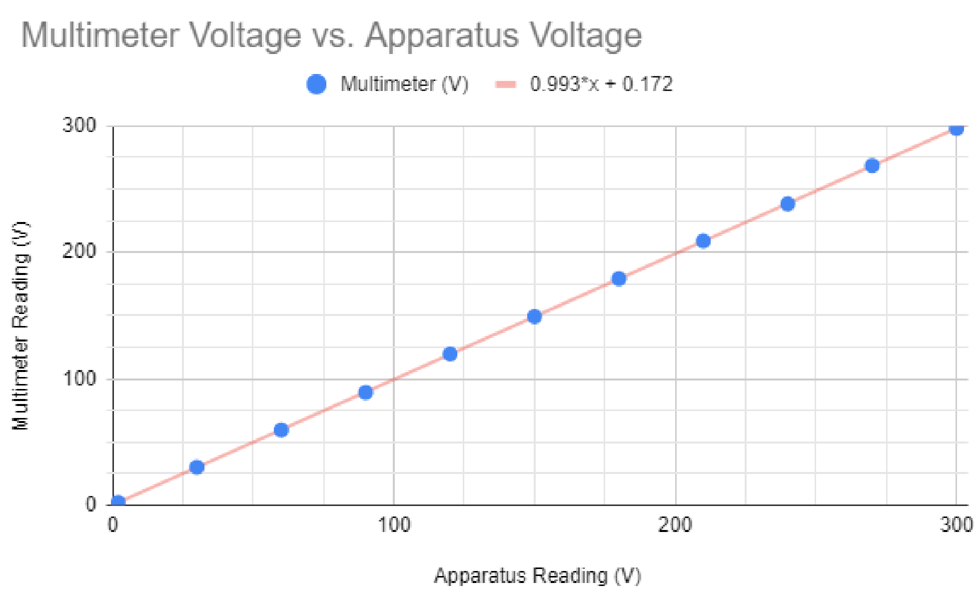
With these calibrations, the measurement of the oil drops began. Oil, with a known density of $981 \pm 5\ \mathrm{kg/m^3}$ (Phys 451L, 2022), was atomized and sprayed into the chamber of the apparatus. Drops of oil observed by the microscope were displayed on the computer screen and were isolated to begin measurements. The terminal velocity of each oil drop was measured by varying the voltage of the plates until the drop was at the top of the screen, then the voltage was turned off and the time taken for the drop to fall a distance of 0.800 ± 0.032 mm was recorded. This was done three times for each oil drop to obtain a more precise and accurate fall time. The plate voltage required to suspend the oil drops was found by varying the voltage on the apparatus until the oil drops no longer ascended or descended on the screen. This voltage was then recorded and the 0.7% correction was applied.

The atmospheric pressure of the room was recorded to find the pressure corrected viscosity of the air. The pressure was measured to be 858.5 ± 0.5 mb or 65.25 ± 0.04 cm Hg. The temperature of the room was found to be approximately 23° Celsius. This was then compared to a viscosity graph and a starting value, η_0, for the pressure corrected air viscosity, η, was found to be $1.84 \times 10^{-5}\ \mathrm{N \cdot s/m^2}$ (Hogan & Hasbun, 2016).

Using the data gathered from the oil drops, the voltages, and the air viscosity, the velocities, radii, masses, and charges of each oil drop were calculated. These measurements and calculations will be detailed in the results of this report. The velocities were found using the equation $v = \frac{distance}{time}$, the radii were found with the use of the equation $a = \sqrt{\frac{9\, \eta\, v_g}{2\, \rho_{oil}\, g}}$ (where η is the pressure corrected viscosity of the air, v_g is the terminal velocity of the oil drop, ρ_{oil} is the density of the oil, and g is the acceleration due to gravity), the masses were calculated with $m = \frac{4}{3}\pi a^3 \rho_{oil}$, and the charge was found with $q = \frac{m\,g\,d}{V}$ (where d is the distance between the two plates and V is the voltage applied to the plates). To obtain the pressure corrected viscosity of air, the equation $\eta = \frac{\eta_0}{1+\frac{b}{p\,a}}$ was used, where η_0 was the starting value of $1.84 \times 10^{-5}\ \mathrm{N \cdot s/m^2}$ stated earlier, b is a constant of 6.17×10^{-6} m · cm Hg, and p is the atmospheric pressure. These equations and how they were derived are presented in research from Hogan and Hasbun (2016).

Results

The results of the calibration of the voltage on the apparatus are detailed in Figure 1. Voltage measurements were taken at 2 V (the lowest the apparatus could go to) up to 300 V with nine other measurements taken at even spaced intervals. We can see from the fitting in Figure 1 that a coefficient of 0.993 (a 0.7% correction) can be used to account for the differences in the voltage on the apparatus.



(**Figure 1**: Multimeter Voltage vs. Apparatus Voltage providing 0.7% correction as indicated by the red fit line.)

The measurements of the fall times and balancing voltages for each drop can be seen in Table 1. The average fall time was calculated and the correction to the voltage was applied (both are also shown in Table 1).

Drop	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg. Time (s)	Balancing Voltage (V)	Corrected Voltage (V)
1	6.43	6.17	6.32	6.31	12	11.9
2	1.28	1.28	1.25	1.27	58	57.6
3	30.86	29.72	30.68	30.42	11	10.9
4	10.16	9.74	9.98	9.96	12	11.9
5	11.99	12.4	12.18	12.19	260	258.2
6	6.62	6.59	6.52	6.58	105	104.3
7	9.18	8.96	9.04	9.06	154	152.9
8	4.87	5.00	4.96	4.94	196	194.6
9	5.27	5.22	5.17	5.22	58	57.6
10	6.46	6.18	6.46	6.37	62	61.6
11	8.48	8.72	8.32	8.51	60	59.6
12	26.91	26.62	27.88	27.14	22	21.8
13	9.68	9.69	9.33	9.57	36	35.7
14	2.69	2.75	2.81	2.75	224	222.4
15	2.15	2.22	2.26	2.21	137	136.0

(**Table 1**: Fall times and balancing voltages for each measured oil drop.)

The calculated velocities, radii, masses, and surface charges of the oil drops are shown in Table 2. The associated errors were also calculated and displayed in the table for each oil drop. The pressure corrected viscosity of air was found to be $1.687 \times 10^{-5} \pm 0.003 \times 10^{-5}\ \mathrm{N \cdot s/m^2}$ and was used in the calculations for the data in Table 2.

Drop	Fall Time (s)	Velocity (10^-6 m/s)	Radius (10^-8 m)	Mass (10^-17 kg)	Charge (10^-19 C)
1	6.31 +- 0.14	126.5 +- 5.8	99.9 +- 2.3	410.0 +- 28.3	168.7 +- 11.7
2	1.27 +- 0.02	628.3 +- 27.5	222.7 +- 4.9	4537.2 +- 301.3	386.3 +- 25.7
3	30.42 +- 0.62	26.2 +- 1.2	45.5 +- 1.0	38.7 +- 2.6	17.4 +- 1.2
4	9.96 +- 0.22	80.1 +- 3.7	79.5 +- 1.8	206.6 +- 14.3	85.0 +- 5.9
5	12.19 +- 0.21	65.5 +- 2.9	71.9 +- 1.6	152.6 +- 10.1	2.9 +- 0.2
6	6.58 +- 0.06	121.3 +- 5.0	97.9 +- 2.0	385.0 +- 24.0	18.1 +- 1.1
7	9.06 +- 0.12	88.1 +- 3.7	83.4 +- 1.8	238.1 +- 15.2	7.6 +- 0.5
8	4.94 +- 0.07	161.4 +- 6.9	112.9 +-2.4	590.8 +- 38.2	14.9 +- 1.0
9	5.22 +- 0.05	152.9 +- 6.3	109.8 +- 2.3	544.5 +- 34.3	46.4 +- 2.9
10	6.37 +- 0.17	125.3 +- 6.0	99.5 +- 2.4	404.2 +- 29.3	32.2 +- 2.3
11	8.51 +- 0.21	93.8 +- 4.4	86.0 +- 2.0	261.7 +- 18.6	21.5 +- 1.5
12	27.14 +- 0.66	29.4 +- 1.4	48.2 +- 1.1	45.9 +- 3.3	10.3 +- 0.7
13	9.57 +- 0.21	83.4 +- 3.8	81.1 +- 1.9	219.5 +- 15.2	30.1 +- 2.1
14	2.75 +- 0.07	290.2 +- 13.5	151.3 +- 3.5	1423.9 +- 100.4	31.4 +- 2.2
15	2.21 +- 0.06	361.1 +- 17.6	168.8 +- 4.1	1976.5 +- 145.4	71.2 +- 5.2

(**Table 2**: Fall time, velocity, radius, mass, and surface charge for each oil drop.)

In order to find the charge of an electron from this data, I took the ratios of all the calculated charges against the smallest calculated charge. I then subtracted off the leading whole number and multiplied the smallest calculated charge by the remaining decimal values. I then took the average of these values as they now represented the measurement of a single charge. The result of this provided me with my finding of the value of the fundamental charge of an electron at $2.5 \times 10^{-19} \pm 1.5 \times 10^{-19}$ C.

Conclusions

My finding of $2.5 \times 10^{-19} \pm 1.5 \times 10^{-19}$ C for the fundamental charge is close to the reported value of 1.6×10^{-19} C (Haynes, 2014). My finding is within 58.2% of this reported value and this value is within the margins of error of my measurement. That being said, there is a difference of 0.91×10^{-19} C between by result and the reported value. The difference of 58.2% shows that there is much room for improvement. The result of this experiment could be improved further by taking data from more oil drops and taking better measurements of air pressure and temperature to provide for better corrections to the air viscosity. This experiment might also benefit from more precise control over the voltage applied to the plates.

References

Haynes, W. M. (2014). *CRC handbook of chemistry and physics* (95th ed.). CRC Press.

Hogan, B., & Hasbun, J. E. (2016). *The Millikan Oil Drop Experiment: A Simulation Suitable For Classroom Use*. Digital Commons @ the Georgia Academy of Science. https://digitalcommons.gaacademy.org/gjs/vol74/iss2/7/?utm_source=digitalcommons.gaacademy.org%2Fgjs%2Fvol74%2Fiss2%2F7&utm_medium=PDF&utm_campaign=PDFCoverPages

Millikan, R. A. (1913, August 1). *On the Elementary Electrical Charge and the Avogadro Constant*. Physical Review Journals Archive. https://journals.aps.org/pr/abstract/10.1103/PhysRev.2.109

Phys 451L. (2022). *Millikan Oil Drop Experiment: The charge of the electron* (1.2).