Experiment 40: The Millikan Oil Drop

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Abstract

The final results for this experiment were $4.47 \times 10^{-3} cm \pm 20\%$ *and* $0.01649 g \pm 0.66\%$ *for the radius and mass, respectively. The slopes for the linear lines for the graphs were* $1.431 \times 10^{-12} \pm 1.146 \times 10^{-23}$ *and* $0.01656 \pm 4.988 \times 10^{-4}$.

1 Introduction

The Millikan Oil drop experiment considers an oil droplet falling in air can be used to determined the charge of an electron, or in the case for this experiment, the charge measured is not that of the electron, but the charge proportional to the charge of the electron and the number of elementary charges. Some quantities of the oil drop can be measured like the radius of the drop, its charge, and its mass The apparatus is a cylindrical, enclosed area where oil can be sprayed and and electric field could be applied. The containment keeps air currents from interfering with the procedure. There also exists a radioactive source within which makes it possible to change the number of electrons on any drop of oil. The apparatus has a control switch, which gives the observer the ability to turn the electric field on or off. The basic quantities that will be measured from the experiment is one result for the velocity under gravity of a particular droplet and about four values for the velocity of the droplet falling a certain distance under an applied electric field. The ratios of the velocities can be takes to give a dimensionless quantity which can be plotted with the charge on the droplet. This will produce a linear line. Another graph can be produced by plotting the velocity ratio as a function of discrete numbers of n. These numbers are determined a bit through trail and error, until a sequence can be found which produces a straight line through the origin or near enough to it.

$$nQ = \frac{mgx}{v_g} \frac{(v_g + v_f)}{V} \tag{1}$$

The charge Q can be calculated using this equation where g is the force of gravity, m is the mass, and x is the separation of the plates.

$$Q = \frac{mgx}{v_g n} \frac{(v_g + v_f)}{V} \tag{2}$$

$$m = \frac{4}{3}\pi r^3(\rho - \rho') \tag{3}$$

The mass can be calculated with this equation

$$v_g = \frac{2r^2(\rho - \rho')g}{9\eta}(1 + b/pr) \tag{4}$$

The relation of the velocity under gravity to radius, densities, gravity, and viscosity of medium. Corrected by Millikan, $b = 6.17 \times 10^{-4}$, and p is the pressure in cmHg.

$$r^2 - (b/p)r - \frac{9v_g\eta}{2g(\rho - \rho')} = 0 \tag{5}$$

The equation used to find the radius r using the quadratic formula.

$$(1 + \frac{v_f}{v_g}) \tag{6}$$

The formula for velocity ratio that will be used in the graphs shown below.

1.1 Quantities

$$\begin{aligned}
&V - \text{voltage applied to plates} = 508V \pm 1V \\
&v_g - \text{velocity under gravity} = 3.61 \times 10^{-3} cm/s \\
&v_f - \text{velocity under electric field} \\
&x - \text{separation of plates} = 0.760cm \\
&n - \text{number of electrons on the drop} \\
&\rho, \rho' - \text{The density of oil and air, respectively} \\
&= 0.887 \pm 0.002 gm/cm^3, 0.0012 g/cm^3 \\
&\eta - \text{viscosity of medium} = \\
&= 1.82 \pm 0.002 \times 10^{-4} \text{cgs units}
\end{aligned} \tag{7}$$

$$
\begin{aligned}
r^2 + (b/p)r - \frac{9v_g\eta}{2g(\rho-\rho')} &= 0 \\
(b/p) &= \frac{6.17\times10^{-4}cm^2}{7.59cmHg \pm 3cmHg} \\
&= 8.13\times10^{-5}cm/Hg \pm 40\% \\
\frac{9v_g\eta}{2g(\rho-\rho')} &= 3.44\times10^{-9} \pm 5.1\% \\
r &= 4.47\times10^{-3}cm \pm 20\%
\end{aligned} \tag{8}
$$

$$
\begin{aligned}
m &= \frac{4}{3}\pi r^3(\rho-\rho') \\
&= \frac{4}{3}\pi(4.47\times10^{-3}cm \pm 20\%)^3(0.877 \pm 0.002gm/cm^3 - 0.0012g/cm^3) \\
&= 0.01649g \pm 0.66\%
\end{aligned} \tag{9}
$$

$$
y = (1.431\times10^{-12} \pm 1.146\times10^{-23})x - 1.77\times10^{-24} \pm 1.181\times10^{-23} \tag{10}
$$

Equation of straight line of velocity ratio and charge

$$
y = (0.01656 \pm 4.988\times10^{-4})x - 0.9388 \pm 0.002799 \tag{11}
$$

Equation of straight line of velocity ratio and n

$$
\begin{aligned}
Chargeaverage &= slope \times \frac{mgx}{v_g} \\
&= (1.431\times10^{-12} \pm 1.146\times10^{-23} \\
q &= Ne \\
(1.431\times10^{-12} \pm 1.146\times10^{-23} &= Ne \\
N &= q/1.602\times10^{-19}coulombs \\
&= 2.2\times10^{6}\times10^{6} \pm 20\%
\end{aligned} \tag{12}
$$

2 Experimental Procedure and Design

The apparatus made use of a camera inside the oil drop container which allowed was the recording of the movement of droplets through a minuscule pin on a computer. The measurements for time can be recorded which a stop clock over a known distance for a falling droplet so the speed of the droplet can be calculated using the two quantities. The screen background was an image which marked the distance between each 'region' of length 0.5mm. A point by point procedure can be outlined via:

1. The first thing to measure was the fall of a droplet under the force of gravity without an applied electric field, so the electric field was turned off and a few sprays of oil were added into the container where they took several seconds or so to appear on screen.

2. The stop clock was started and stopped as the droplet entered and exited the region of 0.5mm. The time for the drop under only gravity was recorded and later used to get the speed using the distance.

3. There were four more measurements to be made with the same droplet of oil. All falling the same distance, but now under the force of an applied electric field. The electric field can be used to move the droplets back up and down the screen depending on the charge of the droplet.

4. The droplet was then risen to above the region so that the measurement of its fall under the applied field can take place.

5. The time for this fall was measured for 4 different falls of this droplet and each varied because the charge can change if the electric field is taken away.

6. The ratio of velocities $(1 + (v_f/v_g))$ was calculated and used to plot a graph with the charge Q, calculated using equation 2. The slope of this line could be used to find the quantity q, that is the number of elementary charges times the charge of the electron.

7. A plot of the velocity ratio divided by n, and n was also plotted where n would be determined by trail and error until a straight line (nearly) through the origin was found.

3 Results

The data and some calculated values are shown in figure 3. The values for radius and mass determined were $4.47 \times 10^{-3} cm \pm 20\%$ and $0.01649 g \pm 0.66\%$. The slope of charge was determined by LoggerPro to be $1.431 \times 10^{-12} \pm 1.146 \times 10^{-23}$ and the slope through the origin of the n vs velocity ratio graph was determined to be $0.01656 \pm 4.988 \times 10^{-4}$.

4 Discussion

The results for the the experimental radius and mass seemed reasonable. The possible sources of errors are possible the state of the oil drop container. The cleanliness of it can effect the amount of oil that goes through the pinhole and gets measured. Measurement error with the stop clock could also effect the time of drop that is measured. The results for the graphs look linear for both figures, which is expected. The value for the number of elementary charges was calculated to be more than 10^6, which seems too high to be reasonable. I'm uncertain on what, if anything, went wrong when determining that result from $q = Ne$, where q is determined from equation 2.

5 Conclusion

The experiment seems to produce reasonable results for the mass and radius of the oil drop and there is uncertainty on the value obtained for the number of elementary charges.

References

[1] Physics 323, Laboratory Manual. University of Victoria, 2023.

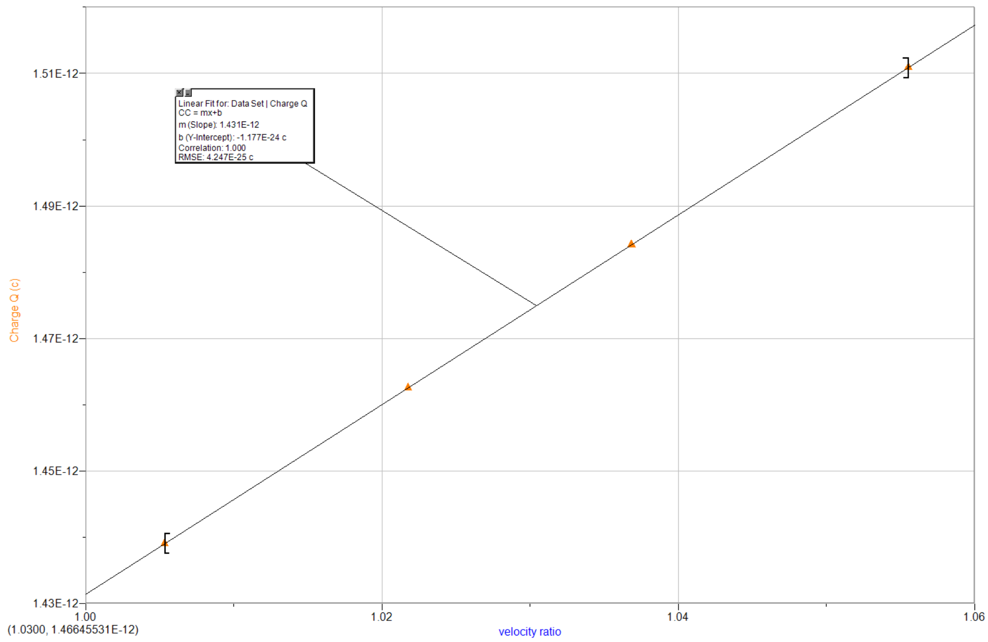

Figure 1: The graph of the velocity ratio vs. charge q. This produces a straight line. The equation of which is shown.

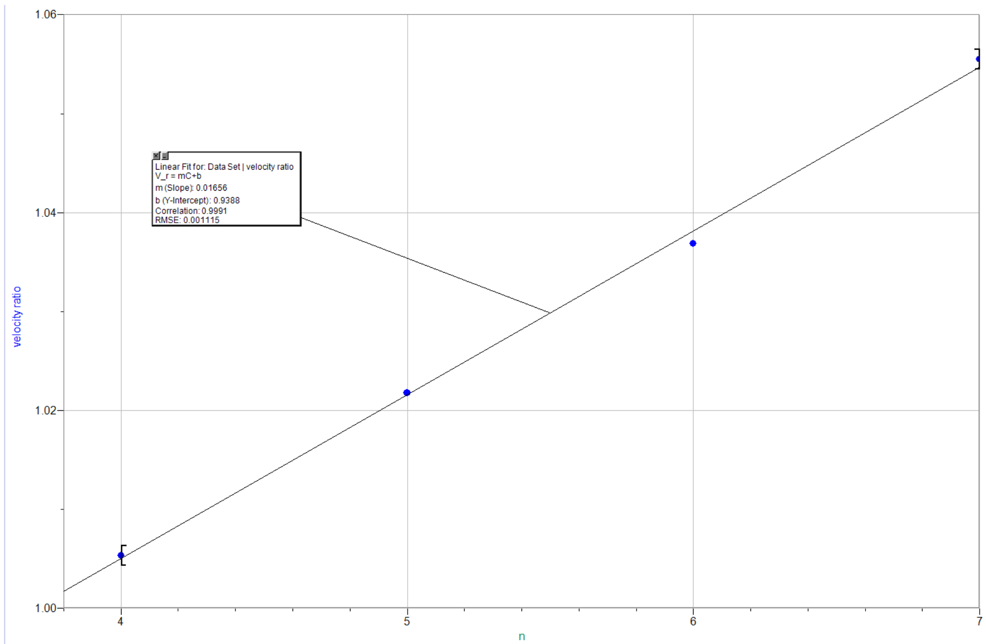

Figure 2: The graph of the n vs. velocity ratio. This produces a straight line. The equation of which is shown.

X	Y	velocity ratio	n	Charge Q (c)	V_r/n
0.0000361	0.0000193	1.005	4	0.000	0.251
	0.0000786	1.022	5	0.000	0.204
	0.000133	1.037	6	0.000	0.173
	0.0002004	1.056	7	0.000	0.151

Figure 3: The data collected in the experiment as well as some calculated columns in loggerpro of the data. X is the v_g, Y is v_f, columns three, four, and five are self-evident, and the final column is the velocity ratio divided by n.