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Revisiting the Millikan Oil Drop Experiment

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Abstract

We present the findings of a simulated oil drop experiment to determine the charge of an electron. An apparatus with an oil chamber, telescope and CCD camera were used to keep track of 12 individual drops of oil of various sizes. Before taking any measurements, the voltage was calibrated by comparing 7 different voltage measurements from the apparatus with a voltmeter. Those measurements were plotted against each other to achieve calibration, which was included in the measurements taken from the oil drops. The distance between each division on the CCD program was also calculated by sticking a thin wire of known diameter into the opening of the oil drop chamber and scaling the division on the screen based on wire diameter. For each drop we measured the fall time and balancing voltage, which allowed the drop radius, velocity, and charge to be calculated. The charge of an electron was calculated using the ratios method, where for each charge calculated the largest whole number was subtracted, then the remaining decimal was divided by the smallest trail charge, and finally multiplied by the smallest measured charge. The average charge of an electron was found to be $5.4 \times 10^{-20} \pm 3.9 \times 10^{-20}$ Coulombs. While this is not too far off from the published value of an electron, this experiment could have benefited from more oil drop measurements and trying different types of oils to compare the results.

Introduction

This experiment attempts to recreate and revisit the Millikan oil drop experiment by calculating the charge of an electron through repeated fall time and balancing voltage measurements for 12 different oil drops. Not only was the original oil drop experiment performed by Millikan extremely important, but it was also the next big step in calculating the charge of a single electron since J.J. Thomson had discovered the electron in 1897 and had measured its charge-to-mass ratio (aps.org). In the revisited experiment, a lot of issues must be accounted for: viscosity of the air, calibration of the voltage and the variability of the oil drop sizes. The main purpose of this paper is to highlight the amount of precision needed to achieve the published value for the charge of an electron, and to revisit one of the most fundamental scientific experiments that has changed the way we approach modern physics.

Methods

This experiment will use the following equipment:

- Two atomizers for the special mixture of oil
- A CCD camera which is attached to the oil drop apparatus
- Oil drop apparatus, manufactured from United Scientific Supplies INC. model MODAO1 (diagram of oil drop apparatus is Figure 1)
- A telescope connecting the apparatus to the CCD camera

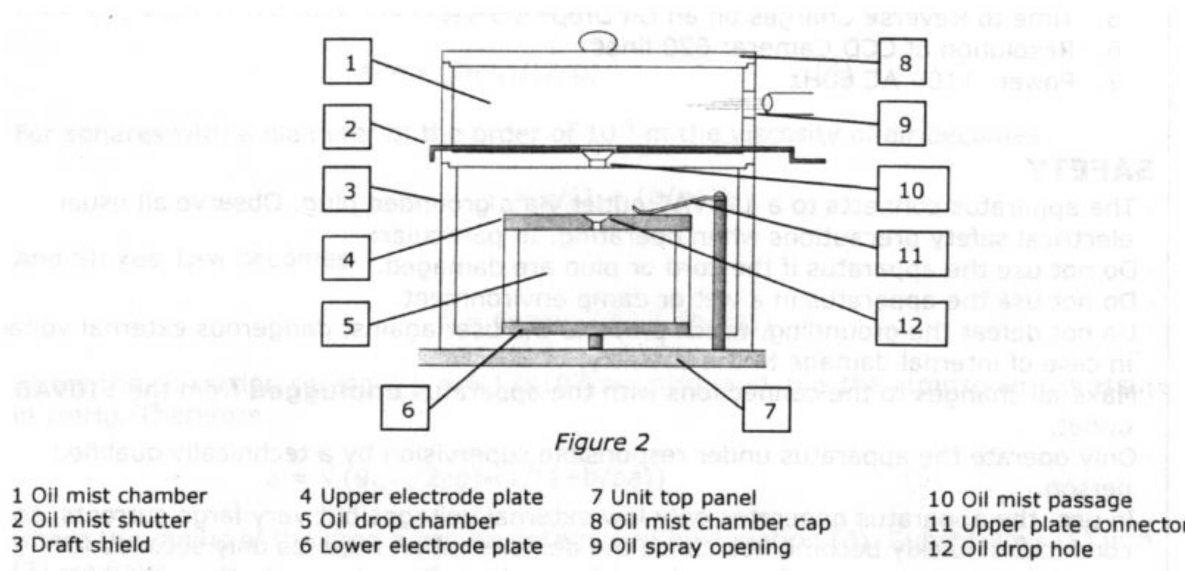

Figure 1: This image was taken from the United Scientific Supplies manual; it shows the various components of the oil drop apparatus.

The experiment begun by calibrating everything. The vertical scale division seen on the CCD camera screen was calibrated by sticking a small wire of known diameter into the oil drop hole, which was then scaled to the vertical divisions seen on the screen. This allowed for a more accurate travel distance of each individual oil drop to be known for calculations. Next, the voltage on the oil drop apparatus was calibrated by comparing the voltage read on the oil drop apparatus to a voltmeter reading. 7 different calibration measurements were made, and then the voltmeter reading was plotted against the apparatus voltage, the slope was taken and then factored into our 'Balance Voltage" measurements for each individual oil drop.

With calibrations finished, oil drop measurements could be taken. Using the atomizer, a fine oil mist was sprayed into the oil apparatus, and down into the oil drop hole. As the drops showed up onto the camera screen, a drop was chosen based on visibility. Usually, the smallest visible drops were chosen to take measurements from. Once a viable drop was chosen, the voltage on the apparatus was changed until the drop was balanced and not falling or floating upwards. This balancing voltage was recorded. Then the voltage was varied such that the oil drop could be moved to the top of the screen, and then dropped through two of the vertical divisions. The fall time was measured for the oil drop to fall through two vertical divisions. This was repeated 3 times per oil drop, and then averaged. Altogether, 12 viable oil drops were observed and recorded.

By measuring the balancing voltage and fall time for each drop, the velocity, oil drop radius and the oil drop charge was calculated. To calculate the velocity, using simple kinematics, it was $v_g = d/t$, where d is the distance travelled and t is the fall time for each drop. To calculate the oil drop radius, we used the force balance equation between the gravitational force and Stoke's drag force as follows:

$$F_d = 6\pi\eta a v_g \quad \text{(Stoke's equation)}$$

$$F_g = mg \text{ (Gravitational force)}$$

Therefore, by equating the two forces:

$$mg = 6\pi\eta a v_g$$

We also know that mass is the product of volume and density. So, by substituting that expression in for the mass, and solving for the oil drop's radius we get the following expression:

$$a = \frac{mg}{6\pi\eta v_g}$$

After calculating each of the oils drop's radii, the charge for each drop was calculated. Start off with the force balance between the gravitational force and the force from the electric field:

$$mg = qE$$

We know that the electric field can be written in terms of voltage and distance. This is explained in *Introduction to Electrodynamics by David J. Griffiths.*

$$mg = q\frac{V}{d}$$

rearrange to solve for q, the charge of the oil drop:

$$q = \frac{mgd}{V}$$

Once all the oil drop charges have been calculated, the ratios method was utilized to get the experimental charge of a single electron. The ratios method is as follows: take each calculated oil drop charge and divide by the smallest charge value that is in the data set, then subtract off the nearest whole number from that ratio. After that, multiply that number by the smallest charge value in the dataset. Do that for each drop and average all of them together to get the charge of a single electron. This method was used because the size of the oil drops varied, so it was accurate to conclude that each oil drop has only exactly one electron per oil drop.

Results

<u>Calibration of the oil drop apparatus voltage</u>

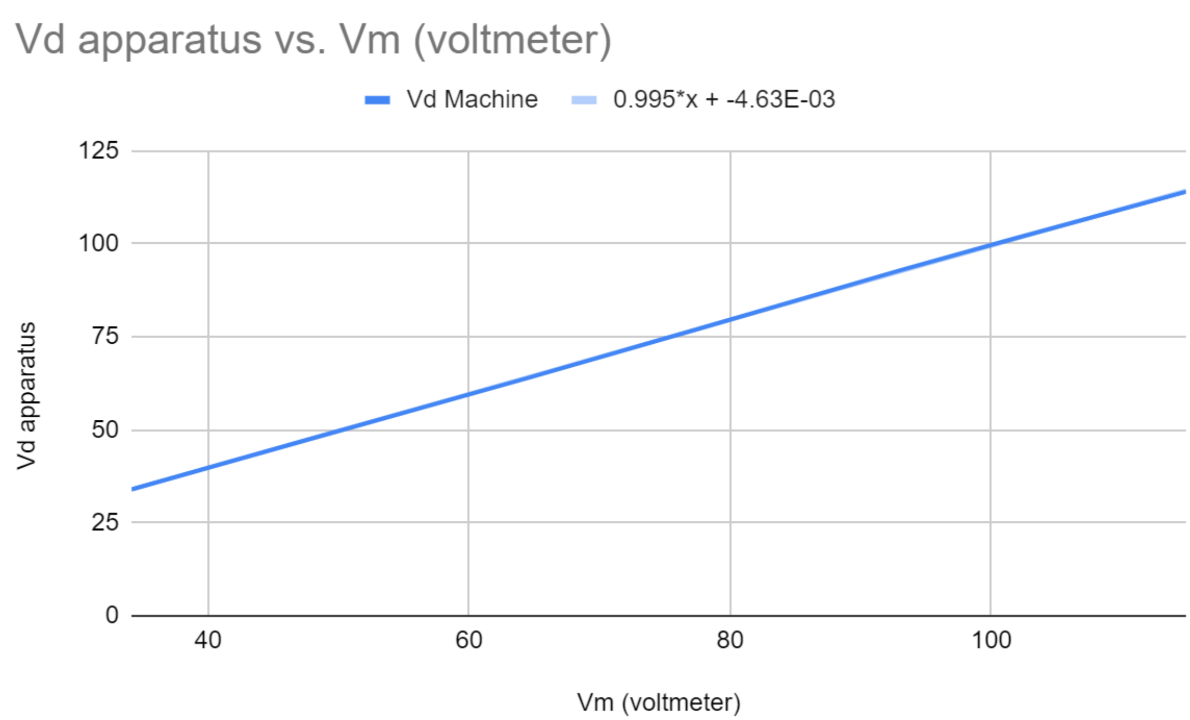

figure 2: This chart is for the calibration of the oil drop apparatus. Vd is the voltage read from the apparatus, while Vm is the voltage measured from a voltmeter. A linear line was used to find the relation between the two. Both axis are measured in volts.

From figure 2 the balance voltage was calibrated. Using the Linear equation between the two voltage values, the ratio (slope) is 0.995, which means that the balanced voltage seen on the apparatus was multiplied by 0.995 to get the calibrated voltage. The calibrated voltage value was used in the calculations.

<u>Oil Drop characteristics Table</u>

Drop	Fall Time (s)	Velocity (m/s)	Balance Voltage	Radius (m)	Mass (kg)	Charge of oil drop (C)	Scaled Charge
1	62.3 ± 5.12	6.80E-06	9	2.41E-07	5.78E-17	3.15E-19	1.50E-20
2	40.2 ± 4.96	1.06E-05	30	3.01E-07	1.12E-16	1.84E-19	3.45E-20
3	36.3 ± 7.42	1.20E-05	44	3.21E-07	1.35E-16	1.51E-19	1.50E-21
4	22.7 ± 4.49	1.87E-05	27	4.00E-07	2.64E-16	4.79E-19	2.85E-20
5	13.9 ± 0.164	3.06E-05	27	5.12E-07	5.52E-16	1.00E-18	1.02E-19
6	11.5 ± 0.909	3.70E-05	13	5.63E-07	7.34E-16	2.77E-18	1.27E-19
7	17.1 ± 2.06	2.49E-05	16	4.62E-07	4.05E-16	1.24E-18	4.20E-20
8	5.92 ± 0.319	7.21E-05	78	7.86E-07	2.00E-15	1.25E-18	5.40E-20
9	4.73 ± 0.123	9.10E-05	20	8.83E-07	2.83E-15	6.94E-18	9.45E-20
10	34.3 ± 5.32	1.20E-05	35	3.21E-07	1.35E-16	1.90E-19	4.05E-20
11	3.24 ± 0.155	1.33E-04	79	1.07E-06	5.00E-15	3.10E-18	1.05E-20
12	10.6 ± 0.177	4.01E-05	48	5.86E-07	8.28E-16	8.46E-19	9.60E-20

Table 1: This is the table for all the oil drop characteristics, as well as the charge and size of each oil drop.

From table 1 the charge of a single electron was calculated by taking the average of all the scaled charges. The charge for an electron from this experiment is $5.4 \times 10^{-20} \pm 3.9 \times 10^{-20}$ Coulombs.

Conclusions

By revisiting the Millikan oil drop experiment, it is clear that a lot of factors need to be considered. The results presented in this report are $5.4 \times 10^{-20} \pm 3.9 \times 10^{-20}$ coulombs for the charge of an electron. The published value of the electron charge is 1.60×10^{-19} coulombs (Griffiths). The percent error for this experiment is 66.25%, which is quite far off from the published value. To make this experiment better more oil drops could be observed and recorded. Another source of error comes from possible lag time between the free-falling oil drop and the image of the oil drop falling on the CCD camera screen. It was also assumed that the oil drops are spherical, so the calculations involving the size of the oil drops were computed assuming all the drops were perfect spheres.

References

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