Millikan Oil Drop Experiment

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Abstract

The Millikan oil drop apparatus is used to find the charge of electrons on a single oil droplet. A flashlight is mounted to the apparatus and used as a source of light in order to see the oil droplets inside the droplet viewing chamber. An atomizer filled with mineral oil is used to allow droplets to be inserted between the plates in the droplet viewing chamber. Once the droplets have been spotted, the plate charging switch is used to force the droplets up and down. Once an appropriate droplet is in control, the droplet can be measured in time. Using the viewing scope, the selected droplet is measured when falling due to gravity over a specific grid. The same is done when the droplet is forced up using the plate charging switch. With the data collected, the charge of an electron can be calculated. The resulting data shows that for the initial drop the charge is $4.32482 * 10^{-19} \pm 3.030177 * 10^{-19} C$ and the charge found after ionizing the $9.06303417 * 10^{-19} \pm 3.89455 * 10^{-20} C$.

I Introduction

The Millikan Oil Drop experiment is proceeded through to discover the value of an electron by measuring an oil droplets time falling and time rising. By understanding simple variables it is possible to calculate the charge on the oil droplet using the Millikan oil drop apparatus. The droplet falls between two plates, one positively charged and one negatively charged with a certain voltage running through, allowing for the droplet to be forced up. The droplet falls on its own due to gravity, both methods falling and forcing are timed over a specific grid. This is how the velocity of the droplet is found while also factoring air resistance requiring the viscosity of air and the density of the oil used in the experiment. Droplets in this experiment will fall and rise at different times, however, this predicts how many excess electrons the droplet is carrying. After selecting a droplet thought to give good data, time measurements began, around 15 to 20 data point for rise and fall are recorded. After the initial data is recorded, the droplet can be ionized and the charge of the droplet can change. After the data points are recorded, the non-ionized recordings and the ionized recordings are compared. If the forced raised time is different from the initial time, it is evident that there must have been charge added to the droplet.

II Experimental Method

Observing the forces on an oil drop will determine the charge by the oil drop. The droplet falls through air pulled by gravity and reaches terminal velocity in milliseconds. The forces for this are as follows

$$mg = kv_f. \tag{1}$$

Where m is the mass of the droplet, g is gravity, k is the friction coefficient, and v_f is the velocity the droplet falls at. The oil droplet falls in an electrical field, where the droplet falls due to gravity and rises due to the charge of the plates,

$$qE = mg + kv_r. \tag{2}$$

E is the electric intensity, q is the charge of the droplet, and v_f is the velocity of the rise.
Removing k from equations (1) and (2) gives

$$q = \frac{mg(v_f + v_r)}{Ev_f}. \tag{3}$$

The mass of the oil droplet also has to be found. To find this the equation for the volume of a sphere is implemented,

$$mg = \frac{4}{3}\pi a^3 \rho g. \tag{4}$$

Where a is the radius of the droplet and p is the density of the mineral oil. By By substituting equation (4) into equation (3),

$$q = \frac{4\pi a^3 \rho g(v_f + v_r)}{2(Ev_f)} \tag{5}$$

Since it is improbable to find the radius of the oil droplet just by observing it, Stokes' Law can be used to help. Simply by knowing the viscosity of air, η. Thus, using equation (4) and Stokes' Law,

$$a = \sqrt{\frac{9\eta v_f}{2\rho g}} \tag{6}$$

However, the viscosity must be corrected

$$\eta_{eff} = \eta\left(\frac{1}{1+\frac{b}{pa}}\right) \tag{7}$$

where b is a constant, p is atmospheric pressure, and a is the radius found in equation (6). Combining the equation (6) and (7) allows

$$a = \sqrt{\frac{9\eta v_f}{2\rho g}\left(\frac{1}{1+\frac{b}{pa}}\right)} \tag{8}$$

Equation (8) is complete and substituting it back into equation (5) gives:

$$q = \frac{4\pi}{3}\rho g\left[\sqrt{\frac{9\eta v_f}{2\rho g}\left(\frac{1}{1+\frac{b}{pa}}\right)}\right]^3 \frac{(v_f+v_r)}{Ev_f} \tag{9}$$

Electric intensity gives:

$$E = \frac{V}{d} \tag{10}$$

where V is the potential difference across the parallel plates and d is the distance between the plates. By substituting equation (10) into equation (9) for E gives:

$$q = \left[\frac{4\pi d}{3}\sqrt{\left(\frac{1}{\rho g}\left[\frac{9\eta}{2}\right]^3\right)}\right] \times \left[\sqrt{\left(\frac{1}{1+\frac{b}{pa}}\right)^3}\right] \times \left[\frac{(v_f+v_r)\sqrt{v_f}}{V}\right] \tag{11}$$

Alternatively instead of solving for a and using equation (11), q can be solved by

$$q = \frac{4\pi}{3} \times \left[\sqrt{\left(\frac{b}{2p}\right)^2 + \frac{9\eta v_f}{2\rho g}} - \frac{b}{2p}\right]^3 \times \frac{\rho g d(v_f+v_r)}{Vv_f} \tag{12}$$

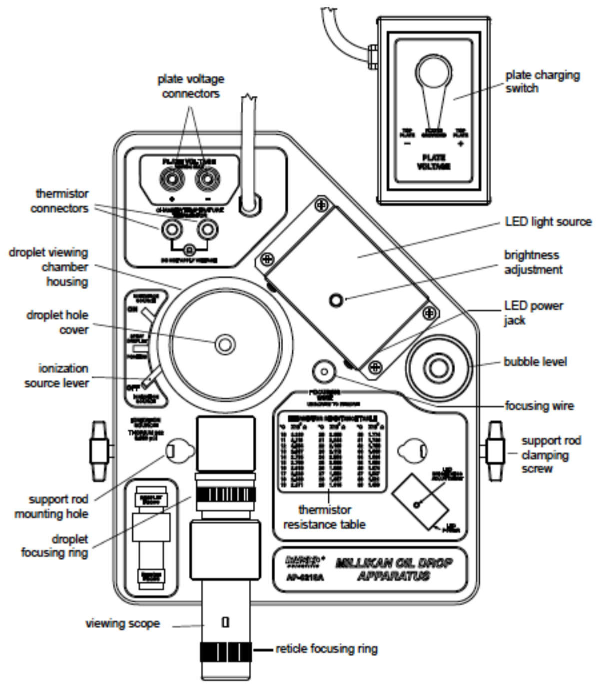

Figure 1: Diagram labeling useful components on the apparatus.

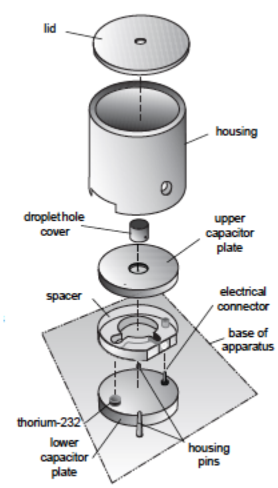

Figure 2: Diagram of where the droplet is controlled in the apparatus.

III Data Analysis and Results

Table 1 : **Timed results** The first column displays the time of the free fall of the droplet, the second column shows the time of the droplet forced up, the third column shows the ionized droplets free fall, and the final column shows the time of the ionized droplet forced up.

Trial	Fall	Forced	fall Ion	Forced Ion
1	7.65	3.37	8.54	1.63
2	8.11	4.63	10.48	1.6
3	8.04	3.11	9.82	1.57
4	8.66	3.85	9.57	1.73
5	9.17	2.72	9.9	1
6	8.68	2.08	9.52	0.85
7	8.38	1.84	9.24	0.78
8	9.22	2.04	9.28	1.37
9	10.84	3.67	9.44	0.87
10	9.55	1.64	7.64	1
11	8.84	1.49	8.88	0.44
12	10.58	1.31	8.07	0.55
13	9.6	0.96	10	0.54
14	10.35	1.3	10.35	0.45
15	9.56	1.4	10.5	0.41
16	9.52	1.31	10.14	0.34

The data in this table includes the fall and rise time of the droplet before ionization as well as the droplet after ionization. The droplet was observed and recorded over in seconds over a certain distance. The mean of each of the recorded times is taken. Then the distance used was the size of the grid at 0.5 mm, with this data the velocity of the droplet can be determined by

$$\frac{0.005m}{mean\ of\ each\ of\ the\ times\ (s)}.$$

This calculation puts the data into the proper units.

Parameters

Plate seperation: $d = 0.00767m$
Oil density: $\rho = 886\frac{kg}{m^3}$
Air Viscosity: $\eta = 1.18765 * 10^-5\frac{N*s}{m^2}$
Atmospheric pressure: $p = 100420Pa$
Gravity: $9.81\frac{m}{s^2}$
Potential voltage: $V = 506V$
Constant b: $8.2 * 10^-3Pa * m$

Data

Falling velocity: $(5.45 \pm 0.02) * 10^-5 \frac{m}{s}$
Forced velocity: $(2.19 \pm 0.38) * 10^-4 \frac{m}{s}$
Ionized falling velocity: $(5.29 \pm 0.02) * 10^-5 \frac{m}{s}$
Ionized forced velocity: $(5.28 \pm 0.02) * 10^-4 \frac{m}{s}$

A Matlab code (appendix) using equation (12) is used to solve the charge on the droplet as well as the ionized charge. This could be done by hand but the use of Matlab reduces the time to calculate with a simple script.

IV Calibration, Errors, and Measurement Precision

The initial part of this lab wasn't all too bad. The time it took to set up the apparatus didn't take all that long. The light had to be calibrated to in the right position to see the droplets fall, as well as the voltage and scope. The apparatus also had to be level with the surface of the table, a bubble on the top of the apparatus had to be centered to ensure that everything would run smooth. There was also a problem with oil clogging the hole in the apparatus. Every now and again we had to clear out the oil. Once we were able to trouble shoot everything we were able to start taking data.

There was error in our experiment, one of the first problems that we encountered was coming in on the first hot day of the year. The air conditioning in the building was running high and the droplets would not stay in place, in fact they started to float up at most points in the experiment. With some construction of air barricades we were able to reduce the air circulation through the apparatus, the remaining air error contributed to our systematic error. Stopping and timing also contributed to our error. [1] As described in An introduction to error analysis the human reaction time is skewed and not a perfect measuring device. This random error can explain why the time in our data set might be slightly different from each other especially because of how fast some of the times were.

V Conclusions

We were in 2 standard deviations of the expected value while the gaussian interval is 95 percent. While our numbers were off we were still in the correct magnitude. However, many errors previously stated could have lead to this issue to our numbers being off. we found that the charge before ionizing the droplet was $4.32482 * 10^{-19} \pm 3.030177 * 10^{-19} C$ and after ionization was $9.06303417 * 10^{-19} \pm 3.89455 * 10^{-20} C$. Giving us 6 electrons on the droplet before ionizing and 12 droplets after the ionization. We found that from other results ours was very different leading us to believe that error contributed to a large percentage of our problem. The result A. Franklin found was e = 2.810 $\times 10^{-10} esu$[4], very far off from out result.

VI Discussion

The appreciation of being a scientist comes from the truth, it comes from built up years of hard work. It is there by essential that a scientist for one can communicate to people who don't understand but also to give the truth. Everything that a scientist studies or experiments with is done to better understand the world around us. However, there might be some incentive in some point of a scientist career to lie about results.

Corruption is bad regardless, it can never be a good thing for a society. A scientist goal is to understand the world around him or her better than anyone else, with the hope that their discoveries better society in one way or another. It can be pretty obvious that this is bad but can have some serious effects. If we take a serious subject in todays world like climate change, it's a serious issue that needs to be taken serious. Research like climate change or other serious threats to this planet, ignoring this research or deviating from the correct results may have drastic results in the future. It may also have the affect of leading other scientist down the wrong path.

Furthermore, the corruption of scientific integrity could affect political campaigns, the economy, etc. Scientific integrity doesn't just include making up the data, it could also include alternating it, leaving out important information, or even leaving out certain errors in the experiment. But this is a contradiction to the work of a scientist. By acting in corruption the scientist help a certain person or corporation, a small group in society to benefit off of the work of the scientist. However, the main purpose of a scientist is to better society. This is inefficient and the very reason it is treated as a very important topic. There are significant consequences to acts like this, the effects can be catastrophic to many fields and this matter should be taken serious.

When conducting this experiment I found that it was very time consuming and frustrating. An incentive that I had to make up data was my grade that I would receive on this lab. It makes sense to me why some scientist would then do this, it may not be right but there are things certain people may want. I had to think back to Cargo Cult Science [3], the experiment might have gone horribly and the data is just as bad. However, I realized that the errors in my experiment might actually help people. In this case communicating the wrong things I did in lab with students who didn't do the yet helped them out. [2] The JYEL has helped me out by allowing me to think in other ways when it comes to scientific work. I have been allowed hands on experience and reflected back on the work. This experience has also allowed me to reflect back on others people discoveries and findings. Comparing my findings to others and seeing what was done differently made it easier to see where I stand in the experiment, giving me a good insight of wha I should expect to see as an experimental physicist. This Millikan Oil Drop experiment is my first full contribution to the scientific community.

VII References

References

[1] Taylor, John R. An introduction to error analysis: the study of uncertainties in physical measurements. Sausalito, CA: U Science , 1997. Print.

[2] Junior Year Experiential Learning description

[3] Cargo Cult Science by Richard Feynman

[4] A. Franklin, "Millikan's Oil-Drop Experiments," The Chemical Educator 2, 1 (1997).

[5] Sections 10 - 13 of R. A. Millikan, "On the Elementary Electrical Charge and the Avogadro Constant," Phys. Rev. 2, 109 - 143 (1913).

[6] G. LaRue et al., "Observation of Fractional Charge of (1/3)e on Matter," Phys. Rev. Lett. 46, 967-970 (1981).

[7] Sections I and V of I.T. Lee et al., "Large bulk matter search fractional charge particles," Phys. Rev. D 66, 012002 (2002).

Appendix

The code we used to solve for the charge:
Input

```
function millikan
d = 0.00767; %seperation of the plates (m)
rho = 886; %density of oil (kg/m^3)
g = 9.81; %(m/s^2)
n = 1.1865*10^-5; %viscosity of air (N*s/m^2)
b = 8.2*10^-3; %constant Pa*m
p = 100420; %barometric pressure (pascals)
%a = 1.1 * 10^-5; %radius of the drop (m)
vf = 5.45*10^-5; %velocity of fall (m/s)
vr = 2.17*10^-4; %velocity of rise (m/s)
v = 500; %potential difference across the plates (volts)
```

```
%q = (((4*pi*d)/3)*sqrt((1/(rho*g))*((9*n/2)^3)))*(sqrt((1/(1+(b/(p*a))))^3))*(((vf+vr)*sqrt(vf))/v)%charge carried by the droplet (coulombs)
q = (4*pi)/3*(((sqrt((b/(2*p)^2)+((9*n*vf)/(2*rho*g))))-(b/(2*p)))^3)*((rho*g*d*(vf+vr))/(v*vf));
elec = q/(1.60*10^-19);
fspec = 'The charge of the electron is %g C. \nThe accepted value for e is 1.60*10^-19 C. \nNumber of electrons %g\n';
fprintf(fspec,q,elec);
end

Output
>> millikan
The charge of the electron is 9.24796e-19 C.
The accepted value for e is 1.60*10^-19 C.
Number of electrons 5.77998
```

```

Input
function millikan_ion
d = 0.00767; %seperation of the plates (m)
rho = 886; %density of oil (kg/m^3)
g = 9.81; %(m/s^2)
n = 1.1865*10^-5; %viscosity of air (N*s/m^2)
b = 8.2*10^-3; %constant Pa*m
p = 100420; %barometric pressure (pascals)
%a = 1.1 * 10^-5; %radius of the drop (m)
vf = 5.28506*10^-5; %velocity of fall (m/s)
vr = 0.000528751; %velocity of rise (m/s)
v = 500; %potential difference across the plates (volts)
%q = (((4*pi*d)/3)*sqrt((1/(rho*g))*((9*n/2)^3)))*(sqrt((1/(1+(b/(p*a))))^3))*(((vf+vr)*sqrt(vf))/v)%charge carried by the droplet (coulombs)
q = (4*pi)/3*(((sqrt((b/(2*p)^2)+((9*n*vf)/(2*rho*g))))-(b/(2*p)))^3)*((rho*g*d*(vf+vr))/(v*vf));
elec = q/(1.60*10^-19);
fspec = 'The charge of the electron is %g C. \nThe accepted value for e is 1.60*10^-19 C. \nNumber of electrons %g\n';
fprintf(fspec,q,elec);
end

Output
>> millikan_ion
The charge of the electron is 1.98212e-18 C.
```

```
The accepted value for e is 1.60*10^-19 C.
Number of electrons 12.3883
```

The code we used to solve for the error:

```
function error
    function fractional_uncertainty(dx,xbest)

        fractional_uncertainty = dx/(abs(xbest));

        fspec = 'fractional uncertainty is %g \n';

        fprintf(fspec,fractional_uncertainty);

    end

    function sum_and_difference(dx,du)
    %for independent random errors
        sum_and_difference = sqrt((dx)^2 + (du)^2);

        fspec = 'sum and difference is %g \n';

        fprintf(fspec,sum_and_difference);

    end

    function product_and_quotient(dx,x,du,u)
    %for independent random errors
        product_and_quotient = sqrt((dx/x)^2 + (du/u)^2);

        fspec = 'product and quotient is %g \n';

        fprintf(fspec,product_and_quotient);

    end

    function power_err(delq,delx,dx,delz,dz)
    %for independent random errors
    power_err = sqrt((abs(dx)*((delq)/(abs(delx))))^2 + (abs(dz)*((delq)/(abs(delz))))^2) ;

    fspec = 'Power error is %g \n';

    fprintf(fspec,power_err);

    end

```

```
    function power_err2(n,dx,x)

    power_err2 = abs(n)*((dx)/(abs(x)));

    fspec = 'Power error is %g\ n';

    fprintf(fspec,power_err2);

    end

    function sum_and_difference2(dx,du)
    %always
    sum_and_difference2 = dx + du;

    fspec = 'sum and difference is %g \n';

    fprintf(fspec,sum_and_difference2);

    end

    function product_and_quotient2(dx,x,du,u)
    %always
    product_and_quotient2 = (dx/(abs(x))) + (du/(abs(u)))
        ;

    fspec = 'product and quotient is %g \n';

    fprintf(fspec,product_and_quotient2);

    end

end
```