Lab: Millikan's Oil-Drop Experiment AP Physics

Background
From 1909 to 1913, Robert Millikan performed a series of experiments designed to measure the charge of an electron. His general strategy was to place charges (electrons) on very small drops of oil, and then place those oil-drops in an electric field. By considering the Force of gravity, the electric Force, and the drag Force (air friction) acting on the drops, Millikan collected enough data that he was able to determine that the fundamental quantity of charge (the electron) is $-1.60 \times 10^{-19} C$. For his experiments, Millikan won the Nobel Prize in Physics in 1923.

Learn more about Robert Millikan in The Millikan Experiment, from *The Mechanical Universe* (YouTube).

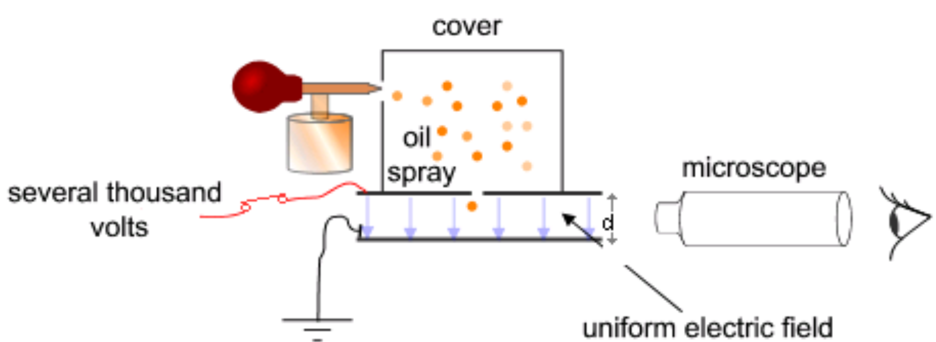
Objectives
To observe the motion of charged particles in an electric field (a modified version of Millikan's experiment), and to perform a data analysis of information "collected" in a statistical simulation of Millikan's experiment.

Equipment
Millikan oil-drop device (set up in class)
Group "data" collected in a classroom simulation
Spreadsheet software (LibreOffice *Calc*, Apple *Numbers*, Google *Sheets*, or Microsoft *Excel*)

Procedure

Part A. Millikan's Device

1. **Examine the device that has been set up for this lab.**
   A schematic diagram of Millikan's apparatus is shown here (from *wikipedia.org*):



2. **Read this explanation of the device's basic operation**
   To determine the fundamental unit of electric charge (e^-), Millikan sprayed droplets of oil in to a chamber exposed to an electric field E. The droplets, which are charged by friction in the spraying process, experience an electrostatic force $\mathbf{F}_e$ according to the equation $F = qE$.

   The drops also experience a downward force due to gravity, $\mathbf{F}_g$, and a force of air friction $\mathbf{F}_{drag}$ when in motion. By analyzing the motion of the drops in the absence of the **E** field, it is possible to determine a droplet's mass *m*.

   With this same oil drop, if the Electric field is adjusted so that the droplet is suspended motionless, then the electrostatic force $\mathbf{F}_e$ will be just equal to the $\mathbf{F}_g$.

$$F_e = F_g$$
$$qE = mg$$
$$q = \frac{mg}{E}$$

For a given oil-drop, there will be only one electric field that will suspend it. The strength of the field that supports a given oil drop depends on the mass of the droplet as well as the net charge of that droplet, and a given mass can have a wide variety of different charges, depending on how many electrons have been added to it (or subtracted from it) in the charging process.

How, then, did Millikan determine the magnitude of the fundamental electric charge? (Rhetorical question—we'll see how in the lab.)

3. **Examine the online simulation of the oil drop experiment.**
   Click "Start" on the simulation at https://www.magnus-karlsson.nu/millikan/ and see how gravity affects the oil drops as they appear in the Electric field. You can vary the strength of the Electric field by using the slider at the bottom of the simulation. Are you easily able to create a field that balances the force of gravity acting on that drop?

4. **Draw a free-**body diagram of the forces acting on an oil drop in static equilibrium in an Electric Field. Include E-field lines in your free-body diagram.

5. How did Millikan know what the **Electric Field strength** was? How could he vary it? In the graphic above and in the simulation you performed, you can see that the electric field is maintained between two conducting plates (one positive, one negative) with a potential difference between them. If a 500.0 Volt potential difference exists between the two plates, and there is a 1.50 centimeter distance between them, calculate the strength of the electric field between the plates.

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Part B. Data Analysis

1. **Get a data set of Electric field strengths and charge mass.**
   Download the Common Separated Values (CSV) data at
   https://www.crashwhite.com/apphysics/materials/assignments/lab/millikan/data.csv

2. **Analyze a subset of that data to determine the fundamental quantity of charge, i.e. the charge of an electron.**
   - **a.** How will you calculate the electric field that each droplet has been exposed to, given the potential and gap distance specified in the data?
   - **b.** How will you calculate the charge on a given droplet, floating motionless in the electric field?
   - **c.** Use a spreadsheet to record a subset of the data values you downloaded, and use the spreadsheet's cell-calculation capabilities to identify the charge on each droplet.
   - **d.** Create a bar graph showing the charges of the different droplets. Are there any patterns immediately evident?
   - **e.** To help identify any patterns in your data, copy the column of charges that you've calculated and paste just the values (not the formulas) into a new column, then sort them. What does a bar graph of the charges look like now? Are there are any patterns evident? Can you identify the elementary charge unit from this? If so, do it!
   - **f.** Discuss with the instructor additional ways to pull meaningful data from your results.

DATA NOTES:

If you copy the double-entry list of mass/voltage data provided by Mr. White into a spread sheet, you are going to have to split the entry into two columns and do some other manipulations. Below is a brief outline of how to do that for a Google Sheet. The approach is similar for an Excel spread sheet.

1.) pick a subset (maybe half) of the double-entry data provided by Mr. White at https://www.crashwhite.com/apphysics/materials/assignments/lab/millikan/data.csv
2.) past the double-entry data into a Google Sheet (label your columns), then go to Data and select "split text to columns"
3.) with the columns highlighted, use "control click" on page (this is right-click), then choose "paste values only"
4.) go to Format, then Number, and select Scientific Notation (if the data isn't already in Scientific notation)
5.) create a column in which you determine "q"
6.) copy your "q" values, then "control click" and using "paste values only," paste your q's into a new column;
7.) if you see zeros, go back to Format, then Numbers, and select Scientific Notation;
8.) highlight your new "q" column, then in Data, select "Sort Range by column" to sort from smallest to largest value of "q"
9.) go to Insert, select a bar graph from Chart
10.) So here's the deal. On your graph, you should see several q's that are clumped at a value, then another group clumped at a level a bit higher, then another a bit higher in a stair-step fashion. The trick is to realize that charge in the second clump will be associated with masses that have one more elementary charge unit (which is to say, one more free electron) on them than will the clump on the first level, and the clump on the third tier will have one more elementary charge unit than the clump on the second, etc. This means that if you take the difference between two successive clump values, you should find the elementary charge unit. So look at your graph, determine how many masses are involved with the first step, go to your data, highlight those q's and average them. Do that for, say, the first four clumps. Then make another column and take the difference between successive averages. You will hopefully find that they come out very close to 1.6x10^-19.