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.

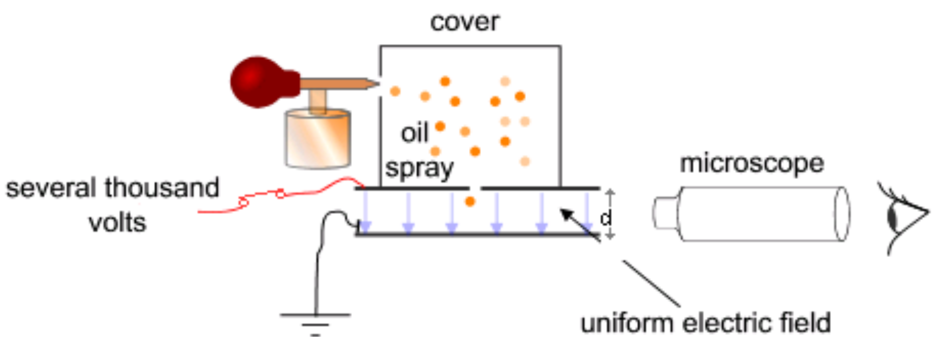
Objectives
To observe the motion of charged particles in an electric field (a modified version of Millikan's experiment), and to perform a data analysis of information "collected" in a statistical simulation of Millikan's experiment.

Equipment
Millikan oil-drop device (set up in class)
Group "data" collected in a classroom simulation
Excel or similar spreadsheet software

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 both 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 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 Java applet that simulates the oil drop experiment.**
   http://www.crashwhite.com/ap/materials/lab/millikan/millikan.html

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

Part B. Data Analysis

1. **Get an individual data set of Electric field strengths and charge mass.**
   Your individual data set is listed at http://www.crashwhite.com/ap/materials/lab/millikan/data.txt . Load the page, select your data, and copy it into Excel for analysis.

2. **Analyze your data to determine the fundamental quantity of charge, i.e. the charge of an electron. To do this:**
   - **a.** Use Excel to calculate the charge q on your first entry (you should know by know how to do a mathematical calculation in Excel—the operation starts with an "=" sign).
   - **b.** The operation FILL DOWN takes the mathematical operation defined in one cell and reproduces that operation in cells below. In the version of Excel we have in lab, this can be done by grabbing the tiny box at the bottom-right corner of the defining cell and dragging downward. Do that to determine a q value for all your data points.
   - **c.** We would like to SORT this list so the smallest q values are at the top. Unfortunately, to do that we need to let Excel know the numbers are really numbers. To do that, copy the column, then execute a SPECIAL PASTE (you can either right click to get this option or find it in the menus at the top of the page) identifying the data as either TEXT or VALUE (depending upon the version of Excel you have). SORT the resulting column.
   - **d.** For the amusement of it, create a bar graph of this data. Print that graph.
   - **e.** On the bar graph as shown on your computer, use the cursor to identify values on the graph (in fact, you will hopefully find that the first one has a height equal close to the elementary charge unit, the second height equal to twice the elementary charge unit, etc). Manually insert at least a few values onto your printed graph.
   - **f.** The graph you will be looking at will be an ever rising set of vertical lines. It is possible to be clever, though, to produce a graph that actually shows levels that are separated by only a single elementary charge unit each. To do this:
     a.) Use Excel to generate a *difference* between two successive cells. Once done, FILL DOWN to get values for all possibilities except the very last cell (it has no value below it, so using it will mess things up).
     b.) Copy the set of cells, then use the SPECIAL PASTE so you can SORT the entries from smallest to largest.

c.) Graph the entries on a bar graph. You should find a graph that has levels that jump by one elementary charge unit each. Print the graph. Off the graph, take what looks like the average value for each level and write it onto the graph.

Part C. Commentary

3.) From the data you were able to glean, assuming it was similar to Millikan's, what would Millikan have concluded was the elementary charge unit. Make this consistent with your graphs and your observations (don't just throw down the actual value—present what your DATA suggest that value should be.

4.) The actual value for the elementary charge unit is $1.6\text{x}10^{-19}$ Coulombs. How did your experimentally determined value match up with the excepted value? Comment.

Additional Notes for the Instructor

Student versions of Millikan's important oil-drop experiment invariable tend to be an exercise in frustration: the equipment is difficult to set up and calibrate, and students don't have enough time to collect the large amounts of data that are required to do any kind of reasonable analysis. This laboratory experience attempts to redress some of those issues.

I typically have one or two oil-drop setups available for students to try out--they quickly come to realize how impressive Millikan's achievement was, given the difficulty of collecting good data. We then move on to the other parts of the activity.

Java-based Millikan Oil-drop simulation
http://www.crashwhite.com/ap/materials/lab/millikan/millikan.html

"Data" collected for the Millikan oil-drop experiment
Students need to have a series of associated mass *m* and Electric field strength **E** values given to them. One easy way to do this is to have the computer generate a series of values, with some appropriate degree of variation built in.

This Perl script (on the next page) will generate just such a list of values, as shown here:

MILLIKAN OIL DROP SIMULATION

```
Hello, Robert! How many trials would you like to run today? -> 10
Mass (kg), Electric Field (V/m)
3.141125e-15, 47948
7.539875e-15, 42096
1.899274e-14, 57932
1.464043e-14, 42669
2.032274e-15, 61792
7.478960e-15, 45478
1.343597e-14, 54768
1.860003e-15, 57540
2.820888e-14, 63565
2.455071e-15, 50167
```

Or, use the list of values provided below.

```
#!/usr/bin/perl -w

# Millikan Simulation, by Richard White, 04 Jan 2008

# This program is designed to produce a set of mass and Electric field
# values that students can use to determine the fundamental unit of charge.

use strict;
use constant Q => 1.602e-19;  # This is the fundamental unit of charge
srand();                      # Get a random number seed (from time).

print "MILLIKAN OIL DROP SIMULATION\n\n";
print "Hello, Robert! How many trials would you like to run today? -> ";
chomp(my $trials=<STDIN>);
print "Mass (kg), Electric Field (V/m)\n";
for (1..$trials) {
    my $num_of_charges = int(rand(30))+1; # figure out how many charges are on
this mass
    my $q_exp = 0;
    for (1..$num_of_charges) {
        my $a_charge = (0.98*Q)+rand(0.04*Q); # Gets an experimental q +/- 2% of
real value
                                        # This is what student will have to
calculate
                                        # based on our values of m and E.
        $q_exp += $a_charge;
    }
    # Determine random E (within a range of 40kv/m - 70kv/m)
    my $e_field = int(rand(30000))+40000;
    # Now calculate the mass associated with this particular droplet
    my $mass = $q_exp * $e_field / 9.80;
    # Now print it all out!
    printf "%3e",$mass;
    print ", $e_field";
#   print ", $q_exp";                     This line will print out the experimental
                                          charge, if desired
    print "\n";
}
```

```
Hello, Robert! How many trials would you like to run today? -> 100
Mass (kg) Electric Field (V/m)
4.937980e-14   60632
4.321721e-15   52647
2.276393e-14   44872
8.030791e-14   50163
2.962090e-14   49044
4.732005e-14   59077
4.174100e-14   57992
4.960104e-14   48952
5.005136e-14   46352
6.642859e-14   49489
3.887032e-14   59319
2.829493e-14   50807
4.830633e-14   58013
4.469596e-14   58069
7.392798e-14   49051
4.347588e-14   45079
7.270707e-14   46223
6.786999e-14   44184
3.918606e-14   64954
9.247816e-14   69947
5.261497e-14   41260
1.066637e-13   67231
2.349782e-14   51351
2.301734e-14   58440
3.025052e-14   66089
7.776158e-15   68620
5.074844e-14   44347
7.092548e-14   57040
3.839430e-14   65297
4.392078e-14   54831
3.244045e-14   58319
6.191518e-14   51219
4.236038e-14   49077
1.058786e-13   66779
1.064524e-15   64442
4.069455e-14   58047
6.639241e-14   52069
5.347799e-14   48092
7.004022e-14   59415
7.503251e-14   58932
1.329164e-14   54534
1.189132e-14   42766
2.897705e-14   59183
1.981432e-14   67417
7.693153e-14   52286
3.119519e-14   48936
3.661623e-14   52020
```

```
9.333270e-14   60053
8.918723e-14   65714
6.779061e-14   59220
2.699842e-14   55098
```

Students can set up a spreadsheet to help them calculate and sort charge values for each simulated oil drop using any spreadsheet software. Plotting the values unsorted looks like a discouraging mess.

Sorting the values and plotting them as a bar graph, though, will reveal the quantized nature of the electron. Strategies for determining that charge include selecting the lowest value indicated, finding the average distance between clustered sets of data, etc.