

Name: _____ Period: _____ Due Date: _____

MILLIKAN OIL DROP EXPERIMENT

Performing the Experiment

MILLIKAN OIL DROP EXPERIMENT – Version 3

Objective:

This experiment closely approximates the original Millikan oil drop experiment. You will use the computer simulation to determine as much as possible about the electrical charges on the droplets. You will do this by determining the drift velocities of the droplets under various conditions.

Theory:

When an electrically charged object is placed in an electric field, an electrical force is exerted on it. This force is given by:

$$\mathbf{F}_e = \mathbf{E} q \quad (\text{equation 1})$$

The electric field strength (\mathbf{E}) can be calculated from the voltage between the plates divided by the distance between the plates. This force will be upward for negatively charged droplets.

The droplet is also in the earth's gravitational field, so it has the following downward force acting on it:

$$\mathbf{F}_g = m g \quad (\text{equation 2})$$

To be completely correct, the equation for the downward force on the droplet (\mathbf{F}_g) should use the apparent mass of the droplet. This is the mass corrected for the buoyant (*upward*) force of the air acting on the droplet. The buoyant force is equal to the weight of the air displaced by the droplet – a minor correction. The apparent mass is thus given by the equation:

$$m_a = \left(\frac{4}{3}\right) \pi r^3 (\text{density}_{\text{drop}} - \text{density}_{\text{air}}) \quad (\text{equation 3})$$

The total force acting on the droplet, when an electric field is present, is the vector sum of these two forces:

$$\mathbf{F}_t = \mathbf{E} \tilde{q} \left(\frac{4}{3}\right) \pi r^3 (\text{density}_{\text{drop}} - \text{density}_{\text{air}}) g \quad (\text{equation 4})$$

For small droplets moving through air, the terminal velocity is proportional to the force acting on the droplet. Using this relationship to compare the velocity of the droplet when the electric field is off (v_g) and when the electric field is on (v_t):

$$\frac{v_t}{v_g} = \frac{Eq - \left(\frac{4}{3}\right)\pi r^3 (\text{density}_{\text{drop}} - \text{density}_{\text{air}})g}{-\left(\frac{4}{3}\right)\pi r^3 (\text{density}_{\text{drop}} - \text{density}_{\text{air}})g} \quad (\text{equation 5})$$

solving for q yields:

$$q = \frac{4\pi r^3 (\text{density}_{\text{drop}} - \text{density}_{\text{air}})g}{3E} \bullet \frac{v_g - v_t}{v_g} \quad (\text{equation 6})$$

Notice that you need know only the two velocities, the radius (r) of the droplet, the voltage, and the electric field strength to calculate the charge. You will use this equation to calculate the charge on a droplet in a number of different trials. In this experiment the quantities E , d and g will be constant throughout. The radius of the droplet and v_g will change only if you lose the droplet and have to start with a new one. When using this equation, downward velocities should be negative and upward velocities positive.

Characterizing each new droplet:

Each time you do start with a new droplet, you must first determine its radius. The viscous force, f , (*think of it as friction, and like friction it resists the action of other forces*) on a droplet falling through a fluid of viscosity μ , is given by Stoke's law:

$$f = 6 \pi \mu r v \quad (\text{equation 7})$$

where v is the terminal velocity and r is the radius of the droplet.

If Stoke's law holds, then for a droplet falling at constant velocity with no electric field, the viscous force must be equal in magnitude to the gravitational force.

$$F_g = m_a g$$

Therefore,

$$6 \pi \mu r v = \left(\frac{4}{3}\right) \pi r^3 (\text{density}_{\text{drop}} - \text{density}_{\text{air}}) g$$

Solving for the radius yields:

$$r = 3 \left\{ \frac{\mu v}{2g(\text{density}_{\text{drop}} - \text{density}_{\text{air}})} \right\}^{1/2} \quad (\text{equation 8})$$

By measuring the drift velocity of a droplet with the electric field off and knowing the typical density of air ($\text{density}_{\text{air}} = 1.29 \text{ kg/m}^3$), the density of the droplets (128 kg/m^3), and the typical viscosity of air ($\mu = 1.81 \times 10^{-5} \text{ N-s/m}^2$), you can determine the radius of the droplet. Once the radius is calculated, the apparent mass of the droplet can be calculated using equation 3 above.

Procedure:

In this version of the experiment, the velocity of a droplet is measured in a constant electrical field as its charge is changed. Your instructor will choose a standard voltage; it will be between 100 volts and 400 volts. The voltage will need to be changed temporarily to drag a droplet up and down the screen, but when measuring velocities, the voltage must always be set at the standard voltage.

Brownian motion of the droplet is noticeable in this experiment. Brownian motion is the result of the thousands of random collisions between the droplet and air molecules. The droplet is deflected slightly by each collision. Brownian motion will add a slight randomness to your experimental data.

A. Determine the drift velocity under the influence of gravity alone:

Inject a new droplet by pressing <N>. Adjust the voltage to get control of the droplet. Drag the droplet to near the top of the grid and measure the drift velocity due to gravity alone (v_g). It is essential that you calculate the velocity in units of m/s. As you proceed with the experiment, repeat the determination of v_g each time you introduce a new droplet, since each droplet has a different size.

B. Determine the drift velocity under the influence of both gravity and the standard voltage (v_t):

Move the droplet into the central area of the grid before making the next change to reduce the probability of losing the droplet. Press <R> to restore this standard voltage and measure the velocity of the droplet under the influence of both gravity and the standard electric field (v_t). Use the zoom in <+> and zoom out <-> keys if you wish. Limit magnifications to powers 1X, 2X, 4X, and 8X. Note both the number of divisions that the droplet moves and the division spacing. Calculate the velocity (v_t) in units of m/s.

You now should repeat the measurement of the velocity of the droplet under the influence of both gravity and the standard electric field (v_t) many more times with different charges on the droplet. Record downward velocities as negative numbers and upward velocities as positive numbers. You can change the charge on the droplet by pressing the <Z> key. This simulates exposing the droplet to X rays which cause ionization. If you lose a droplet, you can get a new one, but you will need to determine its radius by measuring its v_g . For best results, record from twenty to forty readings. Millikan and his co-workers measured the charges of thousands of droplets of oil. In one case, Millikan kept one droplet in the field of view for over four hours.

C. Analyzing the data:

Make your own data table, modeling it after the data table in Version 2. Calculate v_g and v_t for each trial. Calculate the radius of each droplet used. Finally calculate the charge in coulombs for each trial. Sort the charges in order and plot a histogram of the values.

The charges in the histogram will fall into clearly differentiated groups. Average the charges of all the members of each group. The averages should all be integer multiples of the fundamental unit of electric charge.

Assign the integer 1 to the smallest average charge, and number the other averages in order with integers from 2 up to 8. Then graph the average charge vs the assigned integer value. This should be a straight line whose slope is equal to the fundamental unit of electric charge.

Include copies of your data table, histogram, and graph with the write-up for this lab.

Use a separate sheet (or sheets) of paper to answer the following questions.

Questions: Answers must be given in whole sentences and paragraphs.

1. Some of the droplets were not affected by the electrical field. Why not?
2. Why do some of the droplets require a negative rather than a positive balancing voltage?
3. What is the percentage difference between the mass of the droplet and the apparent mass of the same droplet?
4. Derive equation 6 from equation 5. Show all the algebraic steps.
5. Each time a new droplet is injected, the radius can vary over a range of ~20%. How much change can this possibly introduce into your calculation of the mass of the droplet?
6. What is the smallest charge that you measured?
7. What is the average step size on the charge histogram?
8. What is your best estimate of the smallest electrical charge difference? How did you get that?
9. Does your experimental data and interpretations support the idea of quantized electrical charge? Explain.
10. If we had neglected the buoyancy of the air, how big an error would have been introduced into the calculation of the charge? Explain how you determined this error.