Name: ______________________________________ **P**eriod: _____ **D**ue Date: ___________

MILLIKAN OIL DROP EXPERIMENT

Performing the Experiment

MILLIKAN OIL DROP EXPERIMENT – Version 2

Objective

This experiment is a slightly simplified version of the original Millikan Oil Drop experiment. You are to 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 electric force is exerted on it. This force is given by:

$$\mathbf{F_e = E\ q}$$

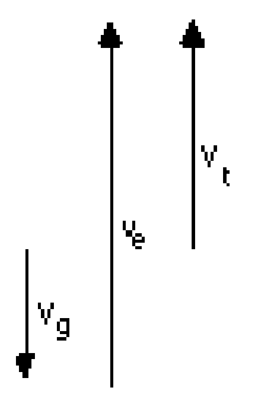
The electric field strength is given by the voltage between the plates (V) divided by the distance between the plates (d), therefore, we can write:

$$\mathbf{F_e = (V/d)\ q = V\ q/d}$$

Notice that if the voltage is held constant, the electrical force on the droplet is proportional to the charge on the drop.

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

$$\mathbf{F_g = m\ g}$$



The net force, $\mathbf{F}_t$, acting on the droplet is the vector sum of these two forces.

$$\mathbf{F_t = F_e - F_g = V\ q/d - m\ g}$$

For small objects moving through air under the influence of a constant force (*like these droplets*), the drift velocity is proportional to the net force ($\mathbf{v} \propto \mathbf{F}$). (*The reason the droplets do not accelerate is that they reach terminal velocity almost instantly. For small uniform droplets it is safe to assume that the proportionality constant is the same for all forces and all droplets.*)

Therefore,

$$v_t = v_e - |v_g|$$

By measuring the drift velocity, you get an indirect measure of the net force acting on the droplet. With this simulation, you can easily measure drift velocities. Specifically, you can measure the drift velocity of the droplet under the influence of gravity alone ($\mathbf{v_g}$), by disconnecting the voltage from the plates. Then, you can measure the drift velocity of the droplet under the influence of both gravity and the electric field ($\mathbf{v_t}$), by reconnecting the batter to the plates. By vector arithmetic, you can then determine the velocity due to the electric field alone ($\mathbf{v_e}$). From this you can infer some information about the force due to the electric field alone ($\mathbf{F_e}$). The electric force, $\mathbf{F_e}$, is proportional to the charge on the drop, **q**. The trick is to find the proportionality constant that relates the drift velocity due to the electric field, $\boldsymbol{v}_e$, to the force due to the electric force, $\mathbf{F_e}$, to the charge on the droplet, **q**. The relationship between the electric force and the charge is well known. The relationship between the drift velocity and the electric force is harder to come by.

So we will start with a less direct approach; one that allows us to avoid the difficult problem of finding the proportionality constant. We will reexamine the problem of finding **q** from $\boldsymbol{v}_e$ a little later.

The essential relationships are $\boldsymbol{v}_e \propto \mathbf{F_e} \propto \mathbf{q}$ and $\boldsymbol{v}_t \propto \mathbf{F_t} = \mathbf{F_e} - \mathbf{mg}$ and $\boldsymbol{v}_g \propto \mathbf{F_g} = \mathbf{mg}$. Unfortunately, the proportionality constants are not known. If we can assume that the proportionality constants relating velocity to force are the same for all drops, then we can take a ratio of the last two expressions and eliminate the proportionality constant. Thus,

$$\mathbf{v_t / (-|v_g|) = F_t /(-|F_g|) = (F_e - |mg|) /(-|mg|) = (V\ q/d - |mg|) /(-|mg|)}$$

There will be more to say about this later, but this provides our best method of finding **q** on a droplet.

Procedures

Organize all the data for parts **A** and **B** in the data tables below.

Similar to Millikan method, you will measure the velocity of a series of, in your case, identical droplets in a constant electrical field as the charge is varied. Millikan's droplets were not uniform in size and mass, so it made sense for him to keep one droplet, whose mass has been determined, and zap it with x-rays periodically to change its charge. Since your droplets are identical, you should simply select a new droplet.

Your droplets are identical in size and mass, so you'll use a series of new droplets with random charges. Your instructor will specify your personal standard voltage. The voltage can to be changed temporarily to drag a droplet up and down the screen, but the voltage must be set to this standard voltage whenever you measure the velocity in the presence of an electric field. Use the **<M>** and **<R>** keys liberally to save and retrieve the voltages you need.

Standard Voltage = ________________ V   Instructor's initials:_____________

A. Determine the drift velocity (v_g) of droplets under the influence of gravity alone

Inject a single droplet by pressing **<N>**. Adjust the voltage to get control of the drop. Drag the droplet to the top of the grid. With the droplet slightly above the top line of the grid, press **<D>**. The plates are disconnected from the voltage supply and the droplet begins to drift slowly downward. As the droplet crosses the top line of the grid, press **<T>** to start the timer. After the specified time interval a second mark appears on the screen. Quickly reset the voltage to keep the drop on the screen. Count the number of divisions the droplet fell in the specified time interval.

If the droplet did not cover 10 to 15 lines, adjust the timer duration accordingly. The general rule is to measure velocities when the displacement is at least 10 division and the time is at least 10 seconds. Drag the droplet back to the top, and re-measure it. Once you have a satisfactory measurement, record this timer value and the other information in Table IIa. Use the distance and timer value to calculate the drift velocity due to gravity alone ($\mathbf{v_g}$). Since all our droplets are identical is size and mass, you only need to complete this part of the experiment one time. Use the zoom-in and zoom-out buttons, the <+> and <–> keys, to adjust the magnification. Use the **<Tab>** and **<Shift><Tab>** keys to adjust the timer duration.

Table IIa – Finding the Drift Velocity due to Gravity Alone

	Spacing (μm)	# of Divisions	Drift Timer (s)	$\mathbf{v_g}$ (m/s)
1				
2				
3				
4				

Average drift velocity = $\mathbf{v_g}$ = ______________ m/s

You must complete one run at each of the following magnifications.

1X, 2X, 4X, and 8X

At each magnification adjust the timer until the droplet covers between 10 and 15 divisions in time of no less than 10 s. Estimate the number of divisions to the nearest tenth of a division. Keep trying until you get the first tick mark to sit precisely on the top line. Record the average drift velocity due to gravity here.

Millikan had to measure the drift velocity due to gravity alone for every droplet he studied. Then he had to measure the velocity due to gravity and the electric field for as many different charges as he could manage to create with the single droplet. He used x-rays to zap the apparatus and the droplet and thus was able to change the charge on his droplet more or less at will. One experimental difficulty was that he had no control of what the new charge would be. After each zap he had to capture the droplet anew and the measure its drift velocity under controlled conditions.

DO NOT use the zapping feature of this program. Inject new droplets when you need a new charge to measure.

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

Catch each new droplet and store its balancing voltage using the **<M>** key. Briefly restore the standard voltage and observe the direction of motion. Drag the droplet to the top or bottom, as appropriate. Measure the velocity of the droplet under the influence of both gravity and the standard electric field (**v_t**). Note that if you lose a drop, just start over with a new drop. (*Adjust the timer and magnification in order to get 10 to 15 divisions in each velocity measurement. Use magnifications 1X, 2X, 4X and 8X only.*)

You should repeat the measurement of the velocity of the droplet under the influence of both gravity and the standard electric field on 40 separate droplets. Introduce new droplets using the **<N>** key. Calculate the velocity due to the electric field alone (**v_e**) by vector arithmetic (**$v_e = v_t - |v_g|$**). Some droplets will move down and some will move up, so be sure to set up your notation to note the + and − directions of **v_t**. Record all downward motions as negative. Note both the number of divisions (*to the nearest 1/10th of a division*) that the droplet moves and the division spacing in each case. Don't stop until you get measurements on 40 droplets.

Millikan and his co-workers measured the charges of thousands of droplets of oil. The oil droplets were not of a consistent size, like yours are, and his charges covered a larger range that this simulation does. Millikan had other handicaps as well, such as no fine voltage control. Nevertheless, in one case, Millikan kept the same droplet in the field of view for over four hours, including many changes in the charge on the droplet.

Fill-in the Top Section of Data Table II

First, fill in the items at the top of **Data Table II** that are available from the main screen of the simulation (Distance between plates, Radius of droplet, and Standard Voltage). The density of the droplet material has been set within the program to 128 kg/m^3. Calculate the volume of a spherical droplet from the given radius, and then use the volume and density to calculate the mass of the droplet. List the drift velocity due to gravity alone, **v_g**, from **Table IIa**. Finally, calculate a specific combination of constants you will need later, **mgd/V**.

To get the mass of the droplets, you need the radius of the droplets, **r** in meters, and the density of the material in the droplets, ρ = 128 kg/m^3. The mass of the droplet is equal to the density of the material times the volume of the droplet (*all droplets have the same mass*);

$$\boldsymbol{m} = \rho \times \text{volume} = \rho \times \left(4/3 \right) \pi r^3 = \frac{128 \times 4}{3} \pi r^3$$

In this experiment, the quantity (**mgd/V**) is constant for all of the trials and only needs to be calculated once.

Gather Data for the Bottom section of **Data Table II**. For each trial collect

Spacing (μm) # of Divisions Drift Timer (s)

When the droplet moves downward, the # of Divisions must be recorded as a negative number. When multiplied by the Spacing (μm)/1,000,000 this produces a negative displacement in meters, and when divided by the Drift Timer produces a negative velocity, **v_t** in m/s.

When the droplet moves upward all these quantities, the # of Divisions, the displacement, and **v_t**, are positive.

Complete Data Table II.

With the information given above you can now calculate the drift velocity due to the electric field alone, $\mathbf{v_e}$. The drift velocity to due the electric field alone is the vector sum of the drift velocity due to gravity alone and the drift velocity due to gravity and the electric field together.

$$\mathbf{v_e} = \mathbf{v_t} - |\mathbf{v_g}|$$

The drift velocities must be added as vectors. Both vectors are vertical. $\mathbf{v_g}$ always points downward, so it always appears as a negative quantity in the vector sum. $\mathbf{v_t}$ may point upward or downward, so be sure to include the correct sign (+ or –, respectively) when you perform the vector addition.

In the first instance, we are not going to use $\mathbf{v_e}$ to calculate the charge on the droplets. Instead we will use the ratio $\mathbf{v_t} / \mathbf{v_g}$ so that we can avoid finding the proportionality constant discussed earlier.

Calculating Actual Charges from the ratio of $\mathbf{v_t} / \mathbf{v_g}$

As discussed above, $\mathbf{v_t} / \mathbf{v_g} = \mathbf{F_t} / \mathbf{F_g} = (\mathbf{F_e} - \mathbf{mg}) / \mathbf{mg}$. Use this relationship to compute the charge on each droplet. Here is the derivation of the equation you need for this calculation:

$$\frac{v_t}{-|v_g|} = \frac{Eq - mg}{-|mg|}$$

$$\frac{v_t}{-|v_g|} = \frac{(V/d)q - mg}{-|mg|}$$

$$\frac{v_t}{-|v_g|} = \frac{(V/d)q}{-|mg|} + 1$$

$$q = \left(\frac{v_t}{-|v_g|} - 1\right)\left(-|mgd|/V\right) \qquad \textit{Equation 1}$$

Notice that you need to know only the two measured velocities, $\mathbf{v_t}$ and $\mathbf{v_g}$, the mass of the drop, **m**, the standard voltage, **V**, the plate separation, **d**, and the acceleration due to gravity in order to calculate the charge on a droplet. All these must be in standard SI units; m/s, m/s, kg, volts, meters, and m/s^2 respectively.

After making the measurements you will find that the values of $\mathbf{v_t}$ fall into groups of nearly equal values. Some groups will have only a single example. Other groups will have several examples. Organize these groups on a separate sheet of paper and find the average in each group. Then use Equation 1 to find the charge on the droplets in each group.

Finally, find the difference in the charges between successive groups. These differences should all be integer multiples of the smallest difference, which is equal to the fundamental unit of electric charge.

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

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

1. Explain why are some of the drops were not affected by the electrical field?

2. Explain why do some of the drops move downward with the standard field applied?

3. Do the $\mathbf{v_e}$ values seem to clump together in groups rather than spread out evenly over the range of values? What does this tell you about the charges on the drops?

4. What is the average $|\Delta \mathbf{q}|$? What electrical does this charge difference correspond to? What does it mean?

5. Are there any forces acting on the droplet, which were not considered in the discussion of the experiment?

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

6. What is the smallest charge that you measured? How does it compare with your average $|\Delta \mathbf{q}|$?

7. What is the average charge difference between successive droplets? Does that tell you anything about the size of the fundamental quantum of electric charge? What?

8. What is your best estimate of the minimum electrical charge? Explain how you came to that conclusion.

9. Does your experiment support the idea of a quantized electrical charge? Explain

Data Table II - Distance between plates = **d** = ______________ mm (screen) Radius of droplet = **r** = ______________ μm (screen)

Distance between plates = **d** = ____________________ m (calc) Radius of droplet = **r** = ____________________ m (calc)

Volume of droplet = ____________________ m^3 (calc) Density of droplet = ρ = ____________________ kg/m^3 (given)

[Recall, ***mass* = *density*** × ***volume***; calculate the mass of the droplet] ———→ Mass of droplet = **m** = ____________________ kg (calc)

Standard Voltage = **V** = ____________________ V (screen) $\mathbf{v_g}$ = (*same value for all droplets*) = ____________________ m/s (Table IIa)

(**mgd**/**V**) = ____________________ C (calc)

Table of Drift Times and calculated total velocities ($\mathbf{v_t}$) and velocities due to the electric field ($\mathbf{v_e}$).

	Spacing (μm)	# of Divisions	Drift Timer (s)	v_t (m/s)	v_e (m/s)		Spacing (μm)	# of Divisions	Drift Timer (s)	v_t (m/s)	v_e (m/s)
1						11					
2						12					
3						13					
4						14					
5						15					
6						16					
7						17					
8						18					
9						19					
10						20					

Data Table II - Continued

Table of Drift Times and calculated total velocities (**v_t**) and velocities due to the electric field (**v_e**). Continued

	Spacing (μm)	# of Divisions	Drift Timer (s)	v_t (m/s)	v_e (m/s)		Spacing (μm)	# of Divisions	Drift Timer (s)	v_t (m/s)	v_e (m/s)
21						31					
22						32					
23						33					
24						34					
25						35					
26						36					
27						37					
28						38					
29						39					
30						40					

Now, collect and average the ***various*** groupings of **v_t** and list the averages in order from smallest (*most negative*) to largest (*most positive*):

v_t $\times 10^5$=_______ _______ _______ _______ _______ _______ _______ _______ _______ _______ _______ _______ _______ _______ _______ _______ m/s

(*Most negative*) (*Most positive*)

Now calculate the charge for each velocity grouping, then compute the charge differences, and then find the best value of the quantum of electric charge.

|q| $\times 10^{19}$= _______ _______ _______ _______ _______ _______ _______ _______ _______ _______ _______ _______ _______ _______ _______ _______C

|Δq| $\times 10^{19}$ = _______ _______ _______ _______ _______ _______ _______ _______ _______ _______ _______ _______ _______ _______ _______C

Use the **Δq**'s to find the best estimate of the fundamental quantum of electric charge. Its symbol is; ***e*** = ____________________ (*It's a bit tricky*.)