

TRINITY VALLEY SCHOOL – PHYSICS DEPARTMENT

MILLIKAN OIL DROP EXPERIMENT

User's Manual – Updated and edited version of the Vernier User's Manual ©1988

Purpose: This handout contains background information on the Millikan Oil Drop experiment, an explanation of how to use the Vernier Software program, *Millikan Oil Drop Experiment*, and instructions on how to conduct computer based experiments with this program. You should appreciate that it took Robert Millikan years to build and refine his apparatus. It took additional years to collect and analyze the data. All you need to do is read the instructions below and complete the exercises in the section titled “A Little Practice,” before you attempt the experiments.

Introduction

Historical Prelude

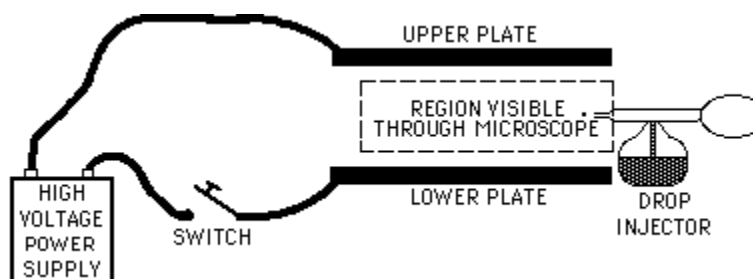
Robert Andrew Millikan attained, almost single-handedly, a significant milestone in the development of Physics. This was his measurement of the quantum of electric charge using his lab-built apparatus to conduct the famous Oil Drop experiment. He also conducted an experimental verification of Einstein's equation for the photoelectric effect. For these two investigations Robert Millikan was awarded the Noble Prize in 1923.

Millikan was born March 22, 1868 in Morrison, Illinois. He entered Oberlin College as a physics major in 1886 and started his teaching career while still at Oberlin. After graduation, he attended Columbia University on a graduate fellowship and completed his Ph.D. in Physics and Electrical Engineering in 1895. After a post-doctoral year in Germany, he returned to the United States and joined the faculty of the University of Chicago. Experiments by Millikan and others had already proven that electric charge comes in discrete packets. Crude attempts had been made to measure the smallest unit of charge. Millikan made the definitive measurement of the smallest unit of electric charge by measuring the smallest increment by which the electric charge on a microscopic droplet of oil can be increased or decreased.

Description

Millikan's Oil Drop Experiment is one of the classic measurements of the 20th Century. His apparatus was cleverly designed and built with a single purpose in mind. The apparatus included a fine-mist atomizer (to create small droplets of nearly uniform size), a three-windowed metal box with metal plates on the top and bottom

connected to a voltage supply, a microscope for viewing the droplets, and an electric light bright enough to make the droplets visible but not bright enough to evaporate them.



Modern laboratory instruments used to reproduce Millikan's experiments use commercially available plastic spheres of known uniform radius and density instead of oil. This simulation also assumes we are using the plastic spheres with identical mass and radius. Millikan used oil in his experiments and the size and mass of each droplet had to be determined before it could be used in experiments to measure its electric charge. We will not be going to that extreme.

Small droplets of oil were originally injected into the region above the top, positively charged plate and a number of uncharged droplets would drift into the region between the plates through a small hole in the top plate. Once the droplets were between the plates, they could be viewed through the microscope as bright pinpoints of light. The computer simulation of this apparatus injects only a single droplet, usually charged, into the region between the plates.

Due to its weight, the single droplet immediately begins to fall slowly downward. It has such a small mass that it reaches terminal velocity almost instantly. Millikan used a radioactive source to ionize his droplets once they were between the plates. When the voltage supply is on, a charged droplet moves at a different pace, either up or down. In our simulation, droplets arrive already charged, at least most of them do.

Once he "caught" a charged droplet with the electric field, Millikan could adjust the voltage on the plates and/or the plate separation until the droplet hovered, suspended in place. In that state of equilibrium, the weight of the droplet pulling it downward and the electric force from the plates pulling it upward are equal and opposite.

With the voltage off, Millikan could use the rate of fall to estimate the mass of a particular droplet. With the voltage on, he could use the voltage and other physical parameters to calculate the electric force on the droplet. We can use the fine adjustment control to make small voltage changes in order to raise or lower the droplet and thus keep it in the field of view for a long period. This was painstaking work with the original apparatus and Millikan's notebooks show that he studied hundreds of droplets for hours at a time. Other hundreds of droplets were lost before they could be fully characterized. This took a great deal of skill and patience.

With knowledge of the mass of a droplet, the magnitude of the electric field between the plates, and the force needed to hold the droplet in equilibrium between the plates, Millikan could calculate the charge on the droplet. It was already known that electric charge is quantized. That is, electric charge comes only in integer multiples of some smallest charge. His plan was to measure the charge on enough droplets and seek out the minimum difference in charge between them. This difference would then correspond to the smallest unit of charge. This is a bit like trying to find the size of an egg by measuring the size of many different omelets – each of which is made up of an integer number of eggs. If you can imagine that omelets only come in sizes ranging from 5 to 50 eggs, you will have some idea of how daunting a challenge Millikan faced. It took seven years to build his apparatus and complete the measurements.

For a given oil droplet, Millikan could not know how many units of electric charge it carried. He knew from the start that he would have to measure the charge on many different droplets. Once he had enough data he knew he should be able to tease out the smallest increment required to produce all the charges he'd measured.

This was a difficult and time-consuming experiment, even for a future Nobel Prize winning physicist like Robert Millikan. Therefore, this experiment is often bypassed in many high school and college laboratory courses. This simulation program makes the process of gaining this experience much easier and a lot quicker.

Getting Started

The following sections will show you how to start the program and will help you become comfortable with the main screen and the commands used to operate the program. Remember that this is a simple DOS program. It is not Windows based and does not operate using a mouse. It may feel a bit clunky, but it is a realistic presentation of what it would be like to complete this type of experiment with real equipment. What it does not include is all the work required to build the apparatus and keep it operating properly. It does not simulate the breakdowns or most of the other common difficulties one routinely encounters doing research.

Starting the Program

Double click the icon for the Millikan Oil Drop Experiment in your Physics Folder. This will bring up the opening screen. Press the <ENTER> key to go to the main screen. You should hear a beep about once per second. Once you hear that the once-per-second beep is working properly, press the key to turn it off.

The Screen

The main screen contains most the information you need to make your calculations. To change the setting of the variable quantities, you must use keys on the keyboard. The keys are described later.

The main screen looks like this when you first start the program.

UPPER LEFT – Voltage display, currently reading 0 V. The upper left box shows the voltage between the plates. A positive voltage means the top plate is positively charged and the bottom plate is negatively charged. When this display reads XXXXX the power supply is disconnected from the plates. The FINE/COURSE adjustment indicator is below the voltage box.



UPPER RIGHT – Direction gauge, showing which direction the droplet is moving. This can be useful whenever the droplet is moving so slowly that it appears to be stationary. It is also useful if you let a droplet get out of the field of view. It is sometimes possible to pull the droplet back into the field of view if you know which way it is moving even when you can't see it. When the droplet is not moving, the direction gauge will read 0. When there is no active droplet the direction gauge is blank, as it is now. The interval timer reads the number of seconds since the timer was started. It is blank until you start the timer to find the velocity of a droplet. The timer runs for 10 seconds and stops. It places marks next to the droplet when it starts and stops.

MIDDLE RIGHT – The injector. A new droplet is injected into the region between the plates each time you push the <N> key. Each new droplet comes with a random charge. You can adjust the voltage to capture it.

LOWER RIGHT – Some of the important keys you will use are listed just below the injector.

LOWER LEFT – This area contains four items of information you may need in order to complete the experimental calculations. The vertical distance between the dotted divisions in the field of view is given in $\mu\text{m}/\text{div}$. This changes with the magnification. The plate separation is given in mm, and the droplet radius is given in μm . The density of the plastic in the droplets is not listed on the screen; it is $128 \text{ kg}/\text{m}^3$. Remember that one-micrometer ($1.0 \mu\text{m}$) is one-millionth of a meter ($1\text{E}-6$ meter) and one millimeter is one-thousandth of a meter ($1\text{E}-3$ meter).

MIDDLE LEFT – A brief summary of some of the keys that you can use to set the voltage on the plates. The <SPACE BAR>, <↑>, <↓>, and the number keys <1>, <2>, <3>, <4>, <5> are the important ones. The function keys are not much help, except for <F10>, which will quickly re-zero the voltage.

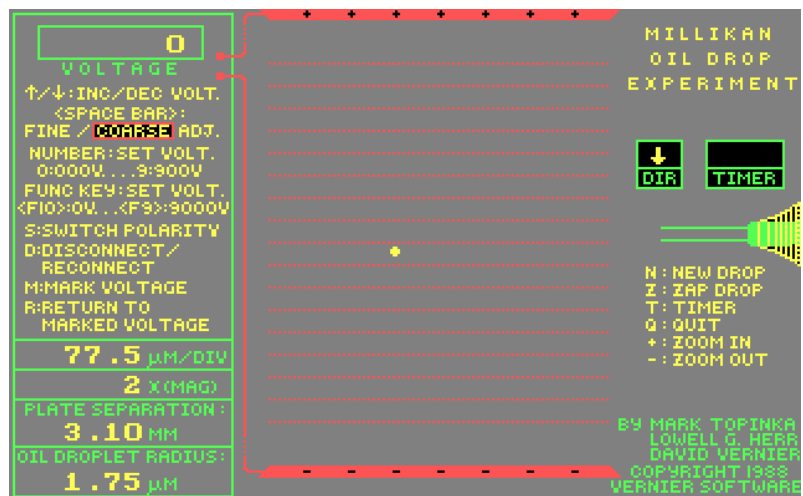
The plates that create the electric field are drawn in solid red. The + and – signs on the plates indicate the relative charges. These can be reversed. The positive plate should usually be on top when you inject a new droplet. Red wires connect the plates to the power supply.

Appearing between the plates there are dotted lines to be used with the interval timer when you need to measure the vertical velocity of a droplet. In the real apparatus these lines are etched into the face of the lens system of the microscope. This was a critical part of the apparatus and the lines had to be precisely etched for the experiment to be accurate and successful.

Because of the magnification of the microscope, only a portion of the region between the plates is actually in view. Thus a droplet can move up or down out of the field of view without necessarily touching either the top or bottom plate. This makes it possible to pull a droplet that is out of sight back into the field of view by making the appropriate voltage adjustments. The only exception occurs when the magnification is 1X. On this setting, when the droplet moves out of the field of view it hits the plate almost immediately.

Here is a screen image with a freshly injected droplet before turning on the voltage. Under the influence of gravity alone, the droplet will fall until it disappears and then a little later hits the bottom plate. Note the direction arrow on the right.

Each droplet contains an unknown charge. To capture the droplet, you must quickly find the voltage needed to hold it suspended in the field of view between the plates. The only clue you have is that the balancing voltages are all between 50 V and 600 V.



Here is a screen image after the droplet has been captured and moved to the top of the screen by “dragging” it up the screen. Note the direction indicator shows the droplet is not moving up or down in this image. The force on the electric charge due to the electric field between the plates exactly balances the force on the mass due to gravity.

You will learn about dragging droplets, and balancing droplets, and other techniques in the next two sections.



The Controls

The keyboard-controls used in this program are described on this page. Lower case and upper case letters work identically. This is the reference section. Read this section to get an idea of the available options, find the location of each key on the keyboard, and then proceed to the section titled “A Little Practice.”

<SPACE BAR> Toggles the FINE/COARSE voltage adjustment. The current choice is boxed in the upper left display. Fine sets the adjustment increment to 1 volt. Coarse sets the adjustment increment to 10 volts.

<↑>, <↓> These two keys raise and lower the voltage in increments determined by the FINE/COARSE setting.

<+> and <-> Zoom in (*see a smaller field of view – ie shorter and narrower*) and zoom out (*see a larger field of view – ie taller and wider*). You might use this feature to get a very accurate velocity measurement by zooming in. The available magnifications are 1X, 2X, 4X, 8X, 16X, 32X, 64X and 100X. When the main screen first appears, the magnification is 2X.

<Tab> and <Shift><Tab> Increase or decrease the timer interval by one second. If you use the **<Tab>** or **<Shift><Tab>** keys to increase or decrease the timer interval, the new time flashes briefly above the Timer box.

<1>, <2>, <3>, <4>, <5>, <6>, <7>, <8> and <9>
The number keys set the voltage in units of 100 volts. The number keys have no effect on the thousands place, but they will zero-out the tens and units places.

VOLTAGE BEFORE	KEY PRESSED	VOLTAGE AFTER
0 volts	<3>	300 volts
783 volts	<0>	0 volts
1000 volts	<8>	1800 volts
56 volts	<4>	400 volts
5934 volts	<0>	5000 volts
-1988 volts	<7>	-1700 volts

<F1>, <F2>, <F3>, <F4>, <F5>, <F6>, <F7>, <F8>, <F9>, and <F10> The function keys set the voltage in units of 1000 volts. Pressing one of these keys sets the next three digits to zero. They are not used very often. The **<F10>** key sets the voltage to 0 volts. You should not need these keys since the highest voltage you will use is not more than 600 V.

VOLTAGE BEFORE	KEY PRESSED	VOLTAGE AFTER
0 volts	<F3>	3000 volts
9873 volts	<F10>	0 volts
-2000 volts	<F1>	-1000 volts

**** Toggle the beeping sound. After you’ve heard it once, you can turn this feature off.

<D> Toggle switch to disconnect/ reconnect the power supply.

<M> Mark the current voltage so you can return to it later by using the **<R>** key.

<N> Inject a new droplet into the field of view. This also removes the previous droplet if it is still active on or off the display screen.

<Q> Quit the program.

<R> Return to the last marked voltage.

<S> Switch plate polarity. This has the same result as swapping the leads on the power supply. Notice the signs on the top and bottom plates change when you toggle this key.

<T> Start the timer. When the timer starts and stops after 10 seconds it leaves marks on the screen beside the drop. These marks can be used along with the timer interval to calculate the vertical velocity of the droplet. The displacements and velocities are positive for droplets that move upward. The displacements and velocities are negative for droplets that move downward.

<Z> Zap the droplet. This exposes the droplet to a brief burst of x-rays, which may cause it to gain or lose electrical charge. This is how Millikan used the x-ray tube in his apparatus. This feature has the bad habit of sometimes freezing the computer on Windows systems.

When possible, it is better if you simply get a new droplet with a new random charge. As long as all the droplets are the same size and mass, this feature should not be used. When droplet sizes and masses vary, then you will have to try using this feature.

A Little Practice

Now that you have some idea of the functionality available and the keys that control them, it is time for a little practice to learn how it really works. Follow the steps below to learn the skills you will need in order to complete your own experimental measurement of the quantum of electrical charge.

Getting a New Droplet

- Press <N> to inject one new droplet into the field of view. Pressing <N> destroys the current droplet.
- Watch a droplet drift all the way to the bottom. Hear it hit the bottom plate?
- New droplets enter from the right and if there is no voltage on the plates they drop out of sight. The new droplet disappears more quickly at high magnification than at lower magnification because the field of view is smaller at high magnification. Change magnification and see the effects.

Adjusting the Voltage

- Press the <↑> and <↓> keys to get a feel for how they change the voltage.
- Press the <SPACE BAR> to switch between FINE and COARSE voltage control.
- For practice, adjust the voltage to 173 volts.

Switching Plate Polarity

- Press the <S> key. Notice that the sign of the voltage changes, along with the signs on the red plates.
- Experiment with the arrow keys again after switching the polarity. Then switch back to + on top.

Setting the Voltage with Number Keys and Function Keys

- Experiment with the keys <1> thru <9> and <F1> thru <F10> to get a feel for setting voltages across a wide range of values. Remember that the <1> thru <9> keys set the 100's value, <F1> thru <F9> set the thousands value.
- Change the polarity with the <S> key. Notice that the only way to change the sign of the voltage is with the <S> key. You cannot arrow up or down to get passed the zero.

Disconnecting the Voltage Source

- Presses the <D> key a few times. When the voltage display reads XXXXX, you know the voltage source has been disconnected from the plates.
- Notice that when the plates are disconnected from the voltage source that the programs beeps at you whenever you attempt to change the voltage. You must reconnect the voltage, using <D> again.

Balancing a Droplet

You should now be comfortable with the main controls for adjusting the voltage on the plates. To balance a droplet you must adjust the voltage until an upward electrical force on the charged droplet just balances the downward force of the droplets weight. When the droplet is perfectly balanced, the direction gauge should read "0". This means the droplet is not moving up or down.

- Note that most droplets are negatively charged, though some are positively charged and some have no charge.
- Set the starting voltage to +100 V. (Press <1>)
- Use the <S> key, if necessary, to switch the polarity so the upper plate is positive.
- All the voltages you need to use are between 50 V and 600 V and between -50 V and -600 V.
- Set the voltage adjustment on COARSE.
- Press the <N> key to get a new droplet. Most of the time the droplet will move, either upward or downward. Watch the direction gauge. You want the direction gauge to read "0."
- If the droplet is moving upward press the <↓> key. If the droplet is moving downward, press the <↑> key. Use the <S> key to switch polarity if necessary.
- If you can't completely stop it using the COARSE setting, use the <SPACE BAR> key to switch to the FINE voltage control setting.
- Catch the droplet and make sure the direction gauge reads "0". Catch several more for practice.

Marking and Returning to a Balancing Voltage

- Once you have a droplet balanced, press the <M> key to save the voltage value. You may now adjust the voltage at will to move the droplet around, the measure its rate of fall, etc.
- Press <R> to restore the last saved voltage. The droplet should immediately stop moving as balance is restored. In Millikan's work this was not always successful. Due to stray radiation or bad luck, the droplet could spontaneously change its charge, in which case returning to the last balancing voltage would not restore the balance. Millikan would occasionally lose droplets for this reason.

Dragging a Droplet

The term *dragging a droplet* refers to moving a droplet to a desired place on the screen. If the droplet is at the bottom of the screen and you want it at the top, you must *drag* it up the screen. You do this by varying the voltage in the manner explained below:

- First, get a new droplet and balance it using the method detailed above.
- Press <D> to disconnect the battery from the plates and let the droplet begin to fall down the screen.
- Reconnect the power source (by pressing <D> again) when the droplet is close to the bottom of the screen. You are now ready to practice "dragging" the droplet to the top of the screen.
- Press <M> to mark the current balancing voltage.
- Increase the voltage until the droplet is moving at a reasonable pace up the screen.
- When the droplet has reached the top of the screen, press the <R> key to return to the balancing voltage (which you marked with the <M> key). The droplet should now be stationary near the top of the screen.

Measuring the Velocity of a Droplet

In all but the simplest forms of this experiment, it will be necessary to measure the velocity of a droplet as it moves up (+) or down (–) the screen. The example below shows how to measure the velocity of a droplet falling under gravity with no electric field present (v_g).

- Balance a drop.
- Mark the balancing voltage (by pressing <M>).
- Drag the droplet to the top of the screen and reestablish the balancing voltage using the <R> key.
- Turn off the voltage (using the <D> key).
- Quickly press <T> to start the interval timer. A mark will appear to the right of the drop. The timer interval should never be less than 10 seconds. Use the <Tab> and <Shift><Tab> keys to change the timer interval.
- After 10 or more seconds, another mark will appear and the timer will stop incrementing.
- Rebalance the droplet using the <R> key. Make sure the droplet moved at least 10 divisions. If it did not, change the magnification or the timer interval, or both.
- You now have all the information you need to compute the velocity of the drop.
- To do this, you must count the divisions between the starting and ending marks. Convert the number of divisions to a displacement in meters using the division spacing in the lower left-hand section of the main screen. Convert the displacement to meters (*which in this case is negative since the droplet moved downward*). The time it took the droplet to fall the measured distance is shown in seconds on the timer display.
- Compute the drop's velocity using the formula: velocity = displacement/time. If you use the distance measured in divisions when you calculate velocity, the result will be in units of divisions/sec. This may be adequate for some experiments. If necessary, you can convert the velocity to $\mu\text{m}/\text{sec}$ (micrometers/second) by multiplying the result by the $\mu\text{m}/\text{div}$ value displayed in the box on the lower left side of the screen. To convert to m/s you need to divide $\mu\text{m}/\text{s}$ by one million.
- Practice measuring the velocity for a few more droplets. Pay particular attention to how the interval timer works.
- Always keep track of the direction of motion. Upward displacements and velocities are positive

Changing the Charge on a Droplet

- In general it is better to start with a new drop. But if you must try...
- Balance the current drop and drag it to the center of the field of view. Decrease magnification to 1X.
- Press <Z> to simulate exposing the droplet to x-rays. Usually, but not always, exposure to x-rays will change the charge on the droplet.
- The droplet should start moving. If it doesn't, try zapping it again. The reason it is no longer balanced is that the charge on the droplet changed so that the electrical force on the droplet also changed. This destroys the balance until you can find the new voltage that reestablishes the balance.
- Try zapping and balancing the same droplet a couple more for practice.

"Zooming" In and Out

- Balance a drop. Drag it close to the center of the screen.
- Increase magnification by pressing <+> several times.
- Change the voltage and notice how the droplet moves more quickly across the viewing area. This is because you are now at a higher magnification, and are therefore examining a smaller portion of the viewing area.
- Allow the droplet to drift towards the bottom of the screen. Now press <+>. The droplet should appear to move to the bottom of the screen or it will already have disappeared out of the viewing area. This is because the microscope in this simulation is fixed on the spot exactly in the middle between the two plates, and if the droplet isn't close to this spot, you won't be able to see it through the microscope at high magnifications. Note: you will be able to see any droplet that is between the plates when the magnification is set to 1X.
- By decreasing the magnification (using the <-> key), you can bring a droplet that is off the screen (but still between the plates) back into the field of view.
- Changing the magnification is often useful because with higher magnifications the droplet drifts more quickly across the screen, so a more accurate reading of velocity is sometimes possible in a shorter amount of time. *(Another way to get a more accurate reading of velocity is to use a low magnification and simply allow the droplet to drift for a longer period of time. To maintain optimum accuracy when measuring velocities, the interval time should never be less than 10 seconds and the displacement should never be less than 10 intervals.)*

Now that you have worked through all these practice procedures, you are ready to begin working on the experiment.

The experiment has several parts. You should complete Version 1 and Version 2. You will not attempt Version 3, although it is interesting to read about what would go on if you were to attempt it. Before you can even think about attempting Version 3, however, the instructor will need to modify the default settings in the program. Since this cannot be accomplished while other students are still using the program, the opportunity to work on Version 3 will not be available until several weeks after we complete this lab.