

Millikan Oil Drop Experiment
TI-83+/TI-84+ Family of Graphing Calculators
By Daniel Blanchard

Introduction

This program for the TI-83+/TI84+ family of graphing calculators allows the student to run a simulation of the classic Millikan Oil Drop experiment. The student has a falling oil droplet and has to adjust the plate voltage until the droplet stops moving. The resulting physical quantities can be used to determine the elementary charge.

The simulation is limited to the process of balancing the forces on the droplet. Historically, Robert Millikan measured the droplet speeds at terminal velocity to find the elementary charge; however, the TI graphing calculators this simulation is written for do not have an internal clock so determining speed is not possible.

The simulation is written using TI basic language and installs on the calculator as a program (accessible by pressing the <PRGM> button). Throughout this manual, actual buttons on the calculator will be designated with the <> notation (like the <PRGM> button used above).

The remainder of this manual is divided into two parts. Part 1 is how to use the program. Part 2 is how to transfer the program onto your graphing calculator.

PART 1: USING THE MILLIKAN PROGRAM

Starting the Program

Press <PRGM>.

Scroll down to “Millikan” and hit <Enter>.

The following screen appears:



Press <Enter>. You will now see a title screen:



Again, press <Enter>. You will find a preliminary menu as follows:



If you select “New Experiment”, all variables and lists of data from previous experiments will be erased. However, if you had to exit the program for any reason during an earlier experiment, you can pick up where you left off by selecting “Continue Old”. Any data saved from the previous invocation of the program will be restored.

Performing the Experiment

Once you select the experiment from the previous screen, you will be at the Main Menu:

```

MAIN MENU
1: NEW DROPLET
2: STORE DATA
3: PLOT CHARGES
4: VIEW DATA
5: SETTINGS
6: HELP
7: EXIT
    
```

Select “New Droplet” by either pressing <1> or since it is already selected, press <Enter>. You are now in the simulation:

```

      .      ↓
-----
V(V) = 0
VSTEP(V) = 100
R(M) = 1.240E-6
N = 0
    
```

This is a split screen. The top half is a graphical area where the droplet moves up or down depending on the net force. Initially, the droplet falls as the voltage across the plates is 0, so only gravity acts. An arrow to the right of the droplet indicates the direction of the net force. The goal is to adjust the voltage and hence the electrostatic force so that the net force is 0 and the droplet stops moving.

The voltage can be adjusted using the arrow keys on the calculator. The up arrow increases the voltage and the down arrow decreases the voltage. Initially, the voltage changes in increments of 100 V. This increment can be decreased by factors of 10 by pressing the left arrow (to a minimum increment of 1 V) and increased by factors of 10 by pressing the right arrow (to a maximum of 10000 V).

In order to stop the droplet, the voltage to balance the forces must be found to a precision of 1 V.

If the droplet at any time hits one of the plates (top or bottom), the droplet is lost and a new droplet must be generated:

```

LOST DROPLET - HIT ENTER
-----
V(V) = 600
VSTEP(V) = 100
R(M) = 1.597E-6
N = 0
    
```

The bottom half of the screen is a data area showing
V(V) = current voltage (adjusted with up, down arrows)
VSTEP(V) = voltage increment size (adjusted with left, right arrows)
R(M) = droplet radius in metres (assuming a spherical shape)
N = number of balanced droplets the student has already stored for analysis.

When a droplet is stopped (net force is 0), the simulation ends and the arrow is replaced by:

```
      .      HITENTER
V(V) = 105
VSTEP(V) = 1
R(M) = 1.077E-6
N = 0
```

Press <Enter> and you will return to the main menu:

```
MAIN MENU
1: NEW DROPLET
2: STORE DATA
3: PLOT CHARGES
4: VIEW DATA
5: SETTINGS
6: HELP
7: EXIT
```

At this point, scroll down to “Store Data” and press <Enter> or just press <2>. This will store the values of

V(V) = plate voltage in volts where droplet was balanced.

R(M) = droplet radius in metres

D(M) = plate separation in metres

The calculator will also calculate the charge in coulombs on the droplet and store the value. This calculation is done internally as follows:

First the volume of the droplet is calculated. Assuming a spherical shape,

$$vol = \frac{4}{3}\pi R^3$$

Now the mass is calculated:

$m = \rho \times vol$ where ρ is the density of oil. In this simulation, the density is a constant and its value is $\rho = 851 \text{ kg/m}^3$.

Finally, the charge in a situation where the gravitational force is balanced by the electrostatic force can be found by

$$Q = \frac{mgD}{V}$$

where

m = droplet mass in kg

g = gravitational field strength near Earth’s surface 9.8 N/kg

D = plate separation in m

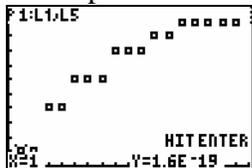
V = voltage to balance the forces in V.

Analyzing the Data

The student will generate many droplets, balance the forces, and store the results. These results can be viewed in two fashions.

It is important to note that the droplets are sorted by charge (smallest to largest) every time a new droplet is stored.

On the main menu, “Plot Charges” can be selected at any time to view a histogram-like graph of the charges that have been stored. The more charges stored, the more apparent the step-like character of the graph becomes:



Press <Enter> to return to the main menu.

On the main menu, students can also select “View Data”. This brings the Select Data menu to the screen:

```
SELECT DATA
1: PLATE SEP (D)
2: DROP RADIUS (R)
3: VOLTAGE (V)
4: CHARGE (Q)
5: RETURN TO MAIN
```

Due to screen limitations and the restrictions in using TI basic, only one variable can be viewed at a time. You will be prompted to press <Enter> until the end of the data is reached and then you will be returned to the Select Data menu.

To ensure the data can be properly organized, each droplet is assigned a number N on each of the following lists. For example, the plate separation, droplet radius, voltage and charge all numbered “2” in each list are all for a particular droplet. **Note that these N values will change as the droplets get resorted by charge and therefore renumbered every time a new droplets values are stored.**

1: PLATE SEP (D) = plate separation

```
N    D(M)
1    2.706E-3
2    2.706E-3
3    2.706E-3
4    2.706E-3
5    2.706E-3
6    2.706E-3
ENTER FOR MORE
```

The plate separation remains the same throughout the experiment. However, if the program is exited at any point, and then restarted to start a new experiment (by selecting “New Experiment”), the plate separation may now change (as if you were using a different apparatus than before).

2: DROP RADIUS (R) = droplet radius

```
N      R(M)
1      1.012E-6
2      1.012E-6
3      1.219E-6
4      1.219E-6
5      1.638E-6
6      1.638E-6
ENTER FOR MORE
```

3: VOLTAGE (V) = voltage needed to balance the forces:

```
N      V(V)
1      613
2      613
3      267
4      267
5      432
6      432
ENTER FOR MORE
```

4: CHARGE (Q) = charge on the droplet

```
N      Q(C)
1      1.60E-19
2      1.60E-19
3      6.41E-19
4      6.41E-19
5      9.61E-19
6      9.61E-19
ENTER FOR MORE
```

Internally, in the calculator, these values are stored as lists. Outside the Millikan program, you can press $\langle 2^{\text{nd}} \rangle \langle \text{LIST} \rangle$ and find the same data in lists D, R, V and Q (corresponding to the actual variables used).

Program Settings

On the main menu, press $\langle 5 \rangle$ (or scroll down to “Settings” and press $\langle \text{Enter} \rangle$) to bring up the following Options Menu:

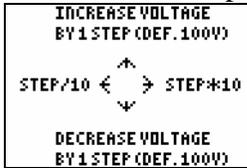
```
OPTIONS
1:ERASE ALL DATA
2:FREEZE DROPLET
3:RETURN TO MAIN
```

Option 1 is obvious. It resets all the variables and erases all the stored data. This is the equivalent of exiting the program, and restarting with the “New Experiment” option. Option 2 is for those of us who are inexperienced in operating video games. If you have problems finding the correct voltage before the droplet hits a plate, you can select this option (press $\langle 2 \rangle$). This causes the droplet not to move up and down while you change the voltage. The arrow that shows the direction of the net force is still displayed, but the droplet never moves and therefore can never hit a plate and be lost. When you select this option, the menu changes to the following:

```
OPTIONS
1:ERASE ALL DATA
2:DROPLET MOVES
3:RETURN TO MAIN
```

Option 2 now is the option to make the droplet move. Pressing <2> on this menu essentially acts as a toggle for droplet motion.

Finally, back at the main menu, a brief help screen showing the function of the keyboard arrows can be displayed by selecting option 6:



Press <Enter> to return to the main menu.

Exiting the Program

Press <7> on the main menu. Exiting the program resets the split screen to the normal calculator screen. If the program is not exited properly, and the screen is not properly reset, simply restart the program, and then exit properly.

Exiting the program does not erase any stored data. Erasing the data can be accomplished in 3 ways:

1. Start the program Millikan and select "New Experiment".
2. From the main menu in the Millikan Program, go to the options menu and select "Erase Data".
3. Use the <2nd><MEM> button on the calculator to erase the data. BE CAREFUL DOING THIS SINCE IF YOU CHOOSE TO RESET THE ENTIRE CALCULATOR MEMORY, YOU WILL ERASE ALL YOUR STORED PROGRAMS LIKE THE MILLIKAN PROGRAM.

PART 2: TRANSFERRING THE PROGRAM TO THE TI CALCULATOR

The Millikan program file is named “millikan.8xp” for the TI-83+ and TI-84+ family of calculators. To transfer the program to the calculator, you will need a cable, and a software application available from the TI website.

Cables:

TI-84+:

Use a USB cable (mini B plug), or a TI Silver Graph-Link cable (USB).

TI-83+:

Use the TI Silver Graph-Link cable in a USB port or the TI black or grey Graph-Link cable in a serial port (9 pin or 25 pin).

Software:

TICONNECT:

If you are using any of the USB cables, download the TICONNECT application from Texas Instruments (education.ti.com). Install the TICONNECT application and run it. Plug your calculator into the USB port and it should be detected automatically. The Millikan program can be installed by “dragging and dropping” it into the TICONNECT main window.

TI Graph-Link:

If you are using a serial port connection with either the black or grey Graph-Link cable, download the appropriate Graph-Link application from Texas Instruments (at education.ti.com) and install it. Run the application with the calculator attached. Use the “Link” menu item to select the proper Com port and cable. Use the file menu to load the millikan.8xp program. Click on the “Send to RAM” button to send it to the calculator. Though this software has been mostly supplanted by the TICONNECT software, the TI Graph-Link software includes an editing application that allows you to easily change the program. Editing can also be done on the calculator itself. Even if you communicate with your calculator using TICONNECT, it is still recommended that you get the Graph-Link software for the editing abilities.

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