

**The Photoelectric Effect**  
**Simulation for the TI-83+ and TI-84+ Family of Graphing Calculators**  
By Daniel Blanchard

**Introduction**

The photoelectric effect was first explained by Albert Einstein in 1905. When a light of high enough frequency is shone on a metal, electrons are ejected from the metal. According to Einstein's explanation, when a photon hits the metal, the electrons will be ejected from the metal with a range of kinetic energies from 0 J up to some maximum kinetic energy given by

$$E_{k\max} = hf - W$$

where

$E_{k\max}$  is the maximum kinetic energy in J

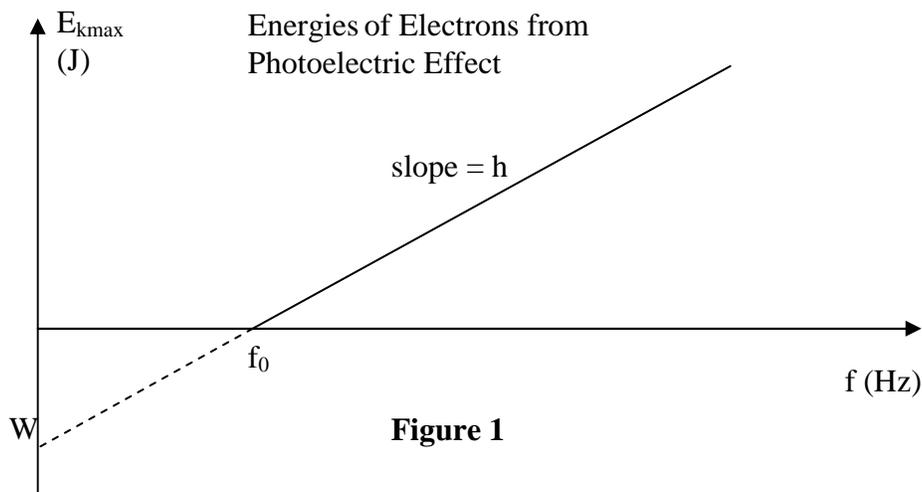
$h = 6.63 \times 10^{-34}$  Js (Planck's constant)

$f$  = photon frequency in Hz

$W$  = work function of the metal in J.

The work function ( $W$ ) of a metal is the minimum energy needed for an electron to be freed from the surface of the metal. The actual energy needed to free any given electron may be more than the work function; hence, the range of possible kinetic energies for ejected electrons. Typical work functions for metals are on the order of a few electron-volts (eV).

A plot of the maximum kinetic energies vs. the photon frequency typically looks like



**Figure 1**

Note that the slope of the graph is Planck's constant and the "y"-intercept is the work function. Also note that the "x"-intercept is labelled  $f_0$ . This represents the threshold frequency. Any photon with a frequency below this threshold does not have enough energy to overcome the metal's work function and it therefore cannot cause an electron to be ejected.

Photon energies can be calculated by  $E_p = hf = \frac{hc}{\lambda}$  where  $c = 3.00 \times 10^8$  m/s is the speed of light in a vacuum and  $\lambda$  is the wavelength of the photon in m.

## The Simulation

The photoelectric simulation for the graphing calculator is a program written in TI-basic macro language and is installed in the calculator's RAM. **PLEASE NOTE THAT DOING A GLOBAL RESET OF THE CALCULATOR'S MEMORY WILL ERASE EVERYTHING IN RAM INCLUDING THIS PROGRAM.**

The simulation is limited to the resources available on the calculator. The graphic window is only 30 pixels high by 94 pixels wide. There is no clock on the calculator so the speeds of the electrons are not accurate. They are only very crudely displayed.

To simplify the simulation and make the experiment easier for the student, **only the most energetic electrons are generated.** Electrons with kinetic energies below the maximum are not generated. Photons are generated one at a time and each photon results in an electron being emitted.

There is also a built in random uncertainty so that the student's simulation will not produce exact results – just like in real life! Even so, the simulation should produce a value for the slope of a graph like **Figure 1** that is within 10% of Planck's constant.

## Running the Simulation

In the remainder of this document, buttons on the calculator will be enclosed in angle brackets <>; for example <ENTER> represents the Enter button in the bottom, right corner of the calculator. When menus appear, items can be selected by either scrolling down to the desired item using the arrow keys and pressing <ENTER> or press the number preceding the desired menu entry.

To start the program, press <PRGM> and select "PHOTEL" off the menu. The line "prgmPHOTEL" appears on the screen. Press <ENTER>. The following title screen appears:

```
*****  
* PHOTOELECTRIC*  
*   EFFECT   *  
*  Copyright  *  
*   July 2008  *  
* D. Blanchard *  
*   <Enter>   *  
*****
```

Press <ENTER> to continue. You will now be at the start menu:

```
START MENU  
1:Start New Expt  
2:Continue Old
```

Choosing the "Start New Expt" option will erase any data stored in the calculator from any previous experiments. This will prevent conflicts. The "Continue Old" option is in

case the program needed to be exited and restarted at a later time. This option will use any data that was stored from an earlier run of the program. Note that if the user does not continue the experiment from the point the program was exited earlier, the data could end up corrupted. Either option will then bring up the Main Menu:

```

MAIN MENU
1:Run Simulation
2:Setup Expt
3:Store data
4:Plot data
5:Set Error
6:Help
7:Exit
    
```

In order for the simulation to produce realistic results, two experimental values must first be entered. Use the “Setup Expt” option to bring up the Setup Menu:

```

SETUP MENU
1:Set wavelength
2:Set Work Func.
3:Start New Expt
4:Return to Main
    
```

The wavelength of the photons that will be generated is the first item. Select “Set Wavelength” off the menu and follow the instructions to enter a wavelength. The wavelengths for the photoelectric effect are to be entered in nanometres. Typical values are in the visible light range extending into the ultraviolet and perhaps into the infrared. Values are typically between 100-800 nm. Press <ENTER> when you are prompted.

You will see the following sequence of screens:

<pre> L=? Enter the photon wavelength (L) in nanometres.         </pre>	<pre> L=?400 Enter the photon wavelength (L) in nanometres.         </pre>	<pre> The wavelength is L = 400 nm  Press Enter         </pre>	<pre> SETUP MENU 1:Set wavelength 2:Set Work Func. 3:Start New Expt 4:Return to Main         </pre>
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Next, you will set the metal work function. Work functions are to be entered in electron-volts. Typical values for many elemental metals run from 2-6 eV. Values of work functions for many elements can be found at [http://en.wikipedia.org/wiki/Work\\_function](http://en.wikipedia.org/wiki/Work_function).

You will see the following sequence of screens:

<pre> W=? Enter metal work function (W) in electron-volts.         </pre>	<pre> W=?2.54 Enter metal work function (W) in electron-volts.         </pre>	<pre> Work Function is W = 2.54 eV  Press Enter         </pre>	<pre> SETUP MENU 1:Set wavelength 2:Set Work Func. 3:Start New Expt 4:Return to Main         </pre>
---	---	--	---

Now you are ready to start the simulation. Select “Run Simulation” off the main menu.

The main simulation screen appears:

```

W = 2.54 eV | DEL=new photon |
V(V) = 0.0
Vstep(V) = 1.0
L (nm) = 400
ENTER=Main Menu
    
```

Press <DEL> to generate a photon:

```

+-----+
|  U=  + |  . |  - |
| 2.54  |  . |  . |
| eV    |  . |  . |
|-----|  . |  . |
| DEL=newphoton |
|-----|  . |  . |
| V(V) = 0.0 |
| Vstep(V) = 1.0 |
| L(nm) = 400 |
| ENTER=Main Menu |
+-----+

```

The photon impacts on the left-hand metal plate. If the photon has enough energy, an electron will be emitted from the plate and will travel towards the right-hand plate:

```

+-----+
|  U=  + |  . |  - |
| 2.54  |  . |  . |
| eV    |  . |  . |
|-----|  . |  . |
| DEL=newphoton |
|-----|  . |  . |
| V(V) = 0.0 |
| Vstep(V) = 1.0 |
| L(nm) = 400 |
| ENTER=Main Menu |
+-----+

```

If the electron hits either plate, it is absorbed. Pressing <DEL> will generate a new photon and subsequently a new photoelectron. If you press <DEL> while an electron is still moving between the plates, the old electron will be removed from the display and a new one will be emitted from the left-hand plate.

If the photon does not have enough energy to cause a photoelectron to be emitted, press <ENTER> to return to the main menu. This can be done at any time. Once at the main menu, change the wavelength to a smaller (more energetic) value. Then return to the simulation and see if an electron can be generated. The photon has to have enough energy to overcome the metal's work function.

The simulation will allow the user to store the data found and check some simplified plots of the data. After a run of the experiment has been completed, from the main menu select "Store data" and the current values of the wavelength of the photon and the corresponding minimum retarding voltage will be stored in the calculator's lists L<sub>1</sub> and L<sub>2</sub>, respectively. These lists can also be accessed outside the program by pressing <2nd><1> <ENTER> or <2nd><2> <ENTER> off the keyboard.

Once at least two data points have been stored, you can start viewing the plots. Select "Plot Data" off the main menu. You will bring up the Graph Menu:

```

+-----+
| GRAPH MENU |
| 1:Plot V vs L |
| 2:Fit V vs L |
| 3:Plot E vs f |
| 4:Fit E vs f |
| 5:Return to Main |
+-----+

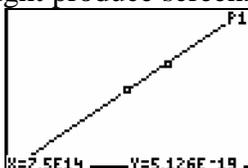
```

You have the option of plotting voltage versus wavelength (option 1) or plotting the kinetic energy of the electrons versus the photon frequency (option 3). Option 2 allows you to view a  $y = ax^b$  function fit to the voltage-wavelength graph and option 4 allows you to view a linear  $y = ax + b$  fit to the energy-frequency graph. As an example, choosing option 4 might produce screens like:

```

+-----+
| Y=A*X+B |
| A = 7.0488E-34 |
| B = -1.602E-20 |
|-----|
| <Enter> |
+-----+

```



Note that the slope A shown for this plot should be Planck's constant  $h$ . The value shown above differs from the actual value due to a random error the simulation generates to make the experiment more realistic.

Option 5, "Set Error", on the main menu allows you to determine how much random error to introduce into the simulation. This random error is applied to the value of the Planck constant  $h$ . The simulation generates a random number between 0 and B where  $B=0.05$  by default. The Planck constant used in the simulation is then set to be  $(1+\text{random\#})6.63 \times 10^{-34}$  Js. This makes  $e$  take a random value 5% on either side of its accepted value. As a result students will get a small error in the values that they measure.

You can change the value of B to be any value from 0 to 1 using option 4. Setting it to 0 means no uncertainty is introduced. Setting it to 1 means the error could be as high as 100%. The variable B sets the *maximum uncertainty*.

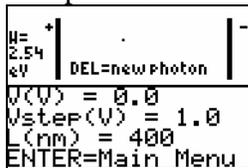
## Performing an Experiment

A typical experiment would be to determine Planck's constant. In order to do this, a specific metal (and the corresponding work function) is chosen by the student. The work function is entered and is not changed for the duration of the experiment.

The student then starts with some arbitrary photon wavelength and adjusts it until the energy is high enough to generate photoelectrons. The electron will travel from the left-hand plate to the right-hand plate and be absorbed. All the electrons generated have the maximum kinetic energy; the goal is to determine this kinetic energy. A voltage can be applied to the plates so that the right-hand plate is the negative plate. Applying enough voltage will cause the electron to stop moving to the right and move back to the left-hand, positive plate.

The student must find the **minimum** voltage needed to stop the electron from hitting the negative plate. The electron should stop as close as possible to the negative plate without actually hitting it before reversing direction.

Voltage can be adjusted using the arrow keys. Below the graphic display, the voltage is listed along with the voltage increment. Initially, the voltage  $V = 0$  V and the increment  $V_{\text{step}} = 1.0$  V:

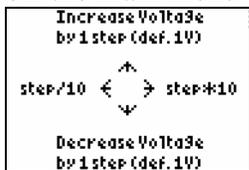


```
W = +
2.54 eV | DEL=new photon | -
V(V) = 0.0
Vstep(V) = 1.0
L(nm) = 400
ENTER=Main Menu
```

Pressing the up arrow will increase the voltage  $V$  by  $V_{\text{step}}$ . Pressing the down arrow will decrease the voltage  $V$  by  $V_{\text{step}}$ . Voltages are limited to the range 0 – 100 V.

Pressing the left arrow will decrease the value of  $V_{\text{step}}$  by a factor of 10 to a minimum value of 0.1 V. Pressing the right arrow will increase the value of  $V_{\text{step}}$  by a factor of 10

to a maximum value of 10.0 V. This same information is available by selecting “Help” off the main menu which produces the following screen:



Through trial and error, the student selects a voltage, generates a photoelectron and checks to see how close it gets to the negative plate before reversing. The voltage is then adjusted up or down to try to find the minimum voltage  $\Delta V$  needed to reverse the electron

The student will try several different wavelength photons, and for each adjust the voltage to find the minimum voltage for the emitted electron.

Once a data table is built up, frequency can be found for each photon using  $f = c/\lambda$ .

The kinetic energy of the photon can then be determined from the potential energy change of the electron:  $E_K = \Delta Vq$  where  $q$  is the charge on one electron ( $1.602 \times 10^{-19}$  C).  $E_K$  can be plotted against  $f$  to produce a graph like in **Figure 1**.

### Transferring the Program to the TI Graphing Calculator

The photoelectric program file is named “photel.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, 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](http://education.ti.com)). Install the TICONNECT application and run it. Plug your calculator into the USB port and it should be detected automatically. The photoelectric 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](http://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 photel.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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