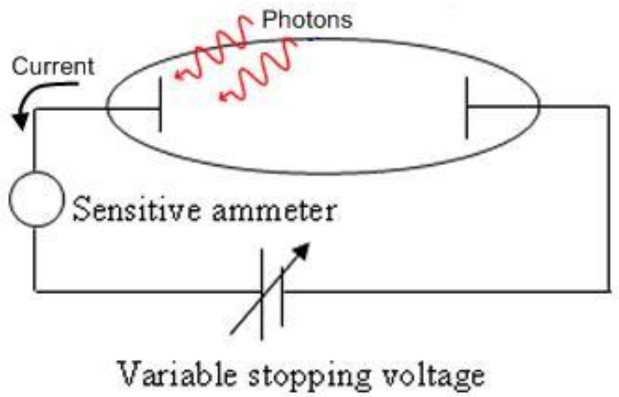
Photoelectric Effect

Physics 227 Lab

Introduction

The photoelectric effect is the liberation of electrons from the surface of a material by absorption of energy from light striking the surface (see Figure 1). The simplest experimental arrangement for observing this effect is shown in Figure 1.

Figure 1:



The cathode is illuminated with monochromatic (Single wavelength) light, and the current (resulting from the photoemission of electrons from the cathode) is measured as a function of voltage.

The most important experimental observations are the following:

1.) The kinetic energy of the photoelectron (as determined by the reverse voltage needed to stop completely the flow of electrons from cathode to anode) is independent of the intensity of the light, but is a linear function of the frequency of the radiation.

2.) There is a minimum frequency below which photoemission does not occur; the value of this minimum depends on the composition of the surface.

3.) The saturation photocurrent is directly proportional to the light intensity.

The experimental observations of the photoelectric effect were first understood by Albert Einstein in 1905. He interpreted them in terms of the quantization of light first postulated by Planck five years earlier. In this model a beam of light is said to be composed of a number of light quanta, or photons, each with energy related to its frequency, f, by

$$E = hf,$$

where h is Planck's constant. Each photon acts like a "particle" of light. The intensity of the light increases when the number of photons increases. The interaction of light with an electron in the photoelectric effect is modeled as a collision in which the electron can absorb the energy of the photon and destroy the photon.

To remove an electron from the surface of a material requires an amount of energy, W, called the work function of the material. The higher the work function, the more tightly bound are the electrons. When an electron is emitted, by conservation of energy, the initial energy of the photon equals the resulting kinetic energy of the electron plus the energy lost in overcoming the work function. That is,

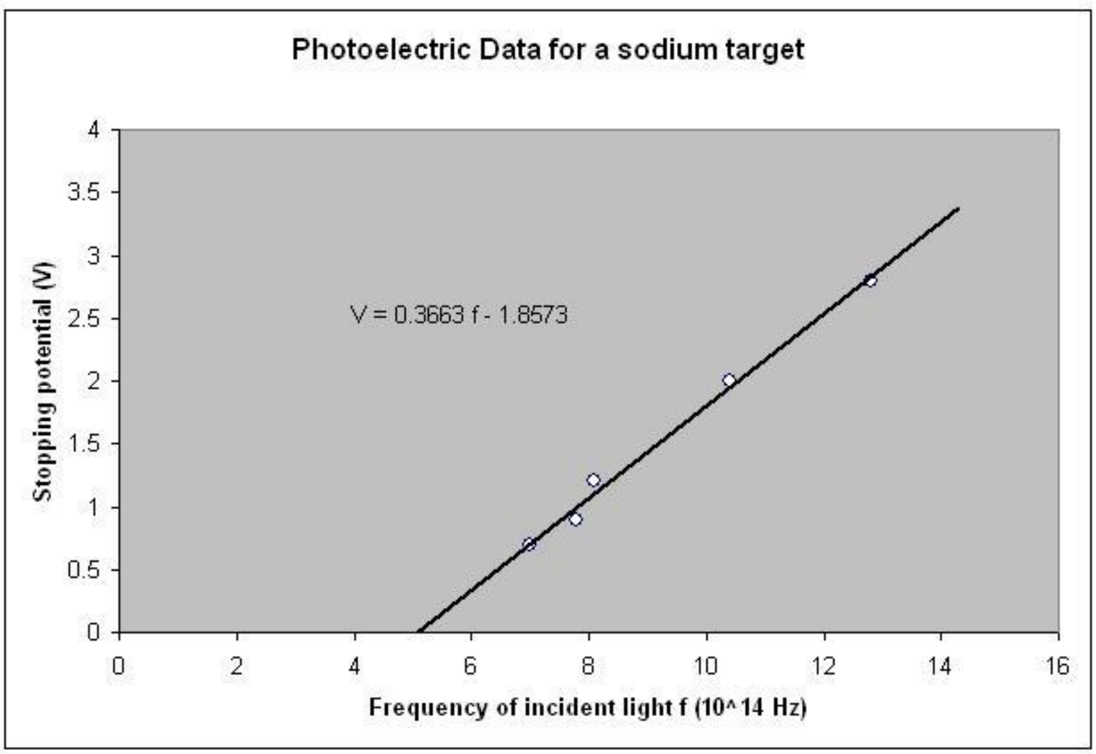
$$hf = \frac{1}{2}mv^2 + W \qquad (1)$$

The negative potential, V_0, needed to stop the electron flow is determined by setting the potential barrier, eV_0, equal to the electron's kinetic energy. Thus equation (1) can be rearranged to yield:

$$eV_0 = hf - W \qquad (2)$$

If the reverse voltage is more negative than this cutoff voltage V_0, no current flows. Note that V_0 is a linear function of frequency, as observed experimentally. Measuring V_0 as a function of frequency should provide values for h and W, as shown in figure 2.

Figure 2:



Part I

Procedure

A.) The photodiode is very sensitive so the first thing we need to do is calibrate the apparatus. This is done by covering the aperture with something dark enough and set the zero adjustment on the amplifier. **Your hand is not opaque enough**, **use thick material or a piece of black velvet.**

Turn the "Voltage Adjustment" knob on the middle of the panel to its counterclockwise limit. Turn on the amplifier using the knob in the top left. Adjust the "Zero Adjustment" knob until the meter on top is at zero. **The zero adjustment should be checked whenever you switch to a new wavelength.**

B.) The voltmeter should read zero or very close to it. Uncover the aperture. **Start with the 505nm light source** and move the apparatus until the radiation is striking the center of the photodiode (*be sure the light is entering the slit on the side with good coverage*).

C.) To find your stopping voltage, again you want the current in the circuit to read zero, so turn the voltage adjust clockwise (which increases the voltage) until the top analog meter returns to the zero you set in part 1. Record this value along with the wavelength you used

D.) Measure the voltage for zero current this way three times by turning the voltage adjust to zero and repeating the process in step 3. Be careful not to pass the zero current value. **The value you need is when the current just reaches zero.**

E.) Take the average of these 3 values and record it in your excel sheet as the stopping voltage

F.) Change the wavelength striking the cathode and repeat step 3 and 4 for each **visible** wavelength.

You should end with three measurements for each wavelength of 470nm, 505nm, 570nm, 605nm, and 655nm.

Question 1

a) Try to measure the two infrared wavelengths using the same method as above, do you get any readings?

b) Disregarding any experimental issues *should* you be able to measure the stopping voltage for the two infrared wavelengths **(880nm, 940nm)?** Explain your answer why or why not *(Hint: Think about the work function of the material).*

Analysis

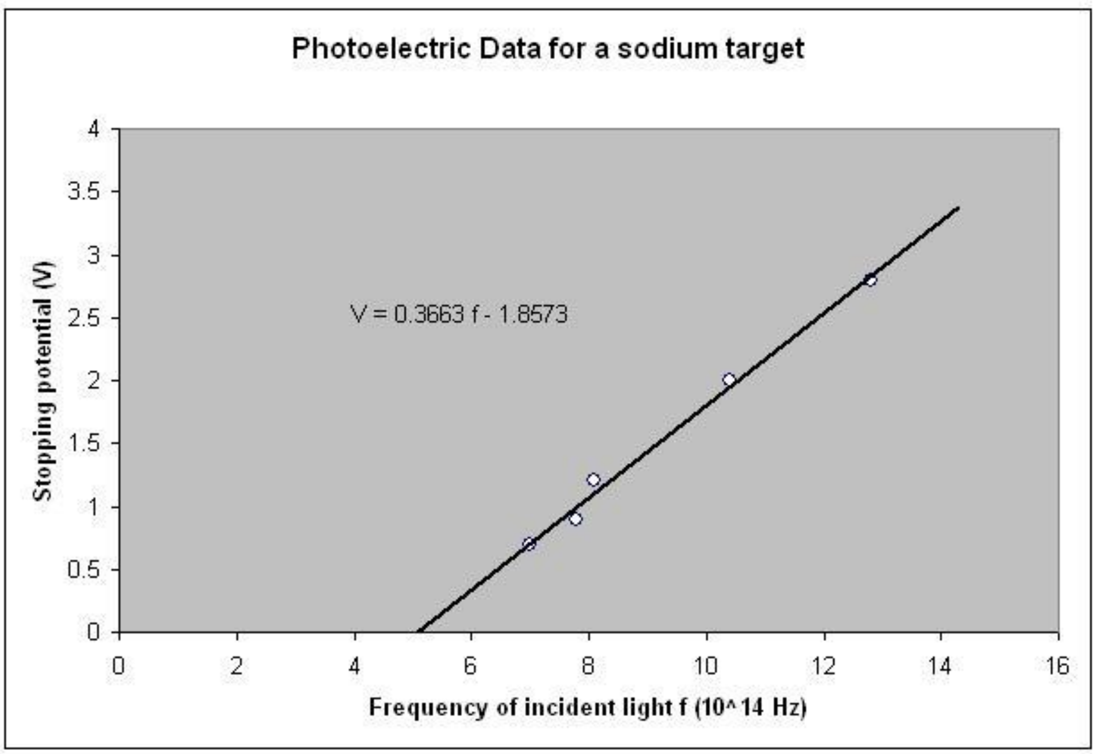
A.) Using excel make a graph of Stopping voltage vs frequency, as shown in **Figure 2**. Use the average of the three stopping voltages you found for each **visible** wavelength.

Note that you will need frequencies and not wavelengths for light. You will need to remember the formula

$$c = \lambda f$$

where c is the speed of light (3e8 m/s), λ is the wavelength, and f is the frequency.

This graph will be printed and included in your report.



Question 2

- **a.** From your graph, compare the trendline you found to **equation (2)** and use this to find **h** and **W.** Record both values **WITH THEIR UNITS** here. You'll have to figure out the units.
- **b.** Find the error in your h from the known value of **h** or **h/e**, use eq2 to figure out which one. BE SURE TO HAVE ENOUGH DECIMAL PLACES TO GET A GOOD VALUE
  "3E-15" will get you docked points on the lab, you need X.XX E-15, at least 2 decimals

$$\boldsymbol{h = 6.626 \; x \; 10^{-34} J.s}$$

$$\boldsymbol{\frac{h}{e} = 4.134 \; x \; 10^{-15} eV.s}$$

$$\boldsymbol{e = 1.602x10^{-19} \; J/eV}$$

Your % error should be rather large, possibly around 30%, in part II we will show why.

Question 3

Now that you know the approximate work function of your material we'll revisit question 1.

- a) Calculate the energy of the photons from the 940nm light using **your h value from Q2a** and the equation

$$E = hf = \frac{hc}{\lambda}$$

- b) Compare this energy to your work function from your fit in **Q2a,** are the photons supplying enough energy to the electrons in the plate to cause a current? (Be sure to check the units)

The next part of this experiment (part 2) investigates the source of the error in Q2b. Whether or not to do part 2 is at the instructor's disgression.

Part II

The reason the error for your h measurement is so high is due to something called a "reverse leakage current" which is an added current in your circuit from the system. This causes us to measure a zero current, when really we haven't gotten to the full zero, where we match both the photoelectric current, and the additional current from leakage, as shown below.

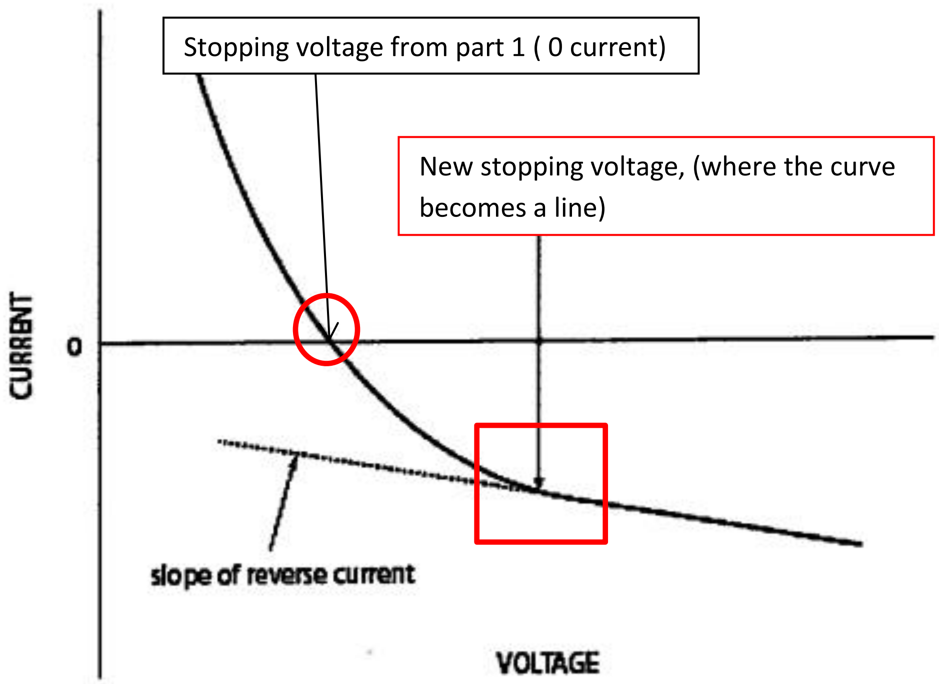


Figure 3:

Now you will measure the above and verify the leakage current in your device.

A.) Return to 505nm light and zero your system again, following the earlier method from part I.

B.) Turn on your second multimeter, this one should be plugged into the "current monitor" outputs. This multimeter must also be set to read voltage, note the conversion factor on the box, it should say either "10mV/nA" or "100mV/nA"

C.) Increase the voltage applied until you find the "New stopping voltage", as shown in **Figure 3.** ***You're no longer looking for zero current.*** This time read your current off the multimeter, not the analog dial, you're looking for the point when the decrease in current is linear.***(Note that this should be a negative value)***

D.) ***To do this start with zero voltage (CCW limit) and very slowly increase it. Watch the current meter while you do this and you should see it plummeting for awhile (400->300->200mV)then at a point the rate will slow (-130->-135->-140) The point when it slows significantly is what you're looking for.***

E.) Record the voltage, $\boldsymbol{V_l}$, **and the current** at this point using the multimeter to measure current. *(Note that the PE box will output current as a voltage, the ratio of mV to nA is printed on the side above where the cables are inserted. YOUR MULTIMETER SHOULD BE MEASURING VOLTAGE)*

Question 4

Find the relative difference between this voltage $\boldsymbol{V_l}$ that you found in Part 2 step **D.)** and the stopping voltage you found earlier in Part 1 step C. Note that this number might be huge

$$\%\boldsymbol{difference} = \frac{(\boldsymbol{V_s} - \boldsymbol{V_l})}{\frac{\boldsymbol{V_s} + \boldsymbol{V_l}}{\boldsymbol{2}}} * \boldsymbol{100}$$

Was this value easy to find? Does this %difference reflect the error from **Q2** earlier?
This is mainly to point out the main source of error for this experiment for conclusions.

<u>**What you need to turn in:**</u>

You should have four questions, and one graph, along with your measurements for h, W and % errors. Be sure that your graph is properly formatted with trendline label formatted with enough decimal points. To do this right click the trendline equation ->format trendline label -> scientific.