Physics 122
Winter 2012
Lab #2
The Photoelectric Effect

Background

In the nineteenth century, it was observed that light falling on a piece of metal could cause electrons to be ejected from the surface of the metal. The classical theory of light as an electromagnetic wave, together with early models of atomic structure let physicists make some simple predictions of what should happen in experiments with this "photoelectric effect." Almost all of these predictions failed miserably.

Explaining the photoelectric effect was one of the great early successes of quantum theory, and won Einstein the Nobel Prize. Einstein's model suggested that light comes in discrete particles ("photons"), and that the energy E of a photon of light is determined by the frequency of the light, through the relation:

$$E = h f$$

where f is the frequency (in Hz) of the light, and h is a constant called "Planck's Constant" (in honor of Max Planck, who first introduced the idea). The accepted value of h is 6.6261×10^{-34} J-s, an extremely small number. In this lab, you will investigate the photoelectric effect, and make a measurement of the value of Planck's Constant.

Procedure

The apparatus for this lab consists of a mercury lamp which will serve as the light source for the experiment, a diffraction grating to spread out the different frequencies of light from the lamp, and a photoelectric cell consisting of a metal plate in an evacuated glass cell. The photoelectric cell is wired up in a box with some electronics, and the whole thing is connected to a voltmeter, which will allow you to measure the energy of electrons emitted from the metal plate.

The mercury lamps used as a light source in this experiment take a long time to warm up. If the lamp isn't already on, turn it on and allow it to warm up. **Warning:** When warmed up, the lamps and their housing are **very hot**. Do not touch the lamp when it's running.

The output of the mercury lamp contains light of five different colors, with wavelengths given in the table below. While the lamp warms up, calculate the frequency of the light associated with each wavelength, and record those values in the table.

When the lamp is warmed up, position the diffraction grating in front of the output slit. Hold a white piece of paper in front of the diffraction grating, 10-20 cm away. You should be able to identify at least two sets of colored lines, corresponding to the colors listed in the table below.

1

(You may not be able to see the ultraviolet line clearly—don't worry about that at this point. The mask on the photoelectric cell has a special coating to make the ultraviolet line visible. Just make sure that you can see at least two sets of the visible lines, and adjust the grating as needed. Also, you may position a large converging lens between the mercury lamp and the diffraction grating to make the lines sharper.)

Color	Wavelength (nm)	Frequency (Hz)
Yellow	578	
Green	546.074	
Blue	435.835	
Violet	404.656	
Ultraviolet	365.483	

Place the detector on the table, far enough back that the lines from the lamp are well separated from one another. Position the detector so that light from one of the blue lines passes through the slit, and falls on the photoelectric cell. (You can flip the small cylindrical light shield out of the way to make sure that the light hits the cell. Remember to put the light shield back in place before recording data.)

With the light hitting the photoelectric cell, press the "PUSH TO ZERO" button on the side of the detector, and watch the voltmeter. After a short time (several seconds) the voltmeter reading should settle down to a steady value. This is the "stopping potential" for that color of light.

Record the stopping potential for each of the colors in one set of lines. When you record the value for the yellow and green lines, you will need to place the appropriate colored filter in front of the detector (they stick to the front mask with magnets) to block light from the room lights. Take two measurements for each color, and calculate an average value.

Color	Stopping Potential Trial 1 (V)	Stopping Potential Trial 2 (V)	Stopping Potential Average (V)
Yellow			
Green			
Blue			
Violet			
Ultraviolet			

A third filter is included with the apparatus, and consists of different patterns of dots which allow you to vary the intensity of the light, while leaving the frequency unchanged. Different zones of the filter allow 100%, 80%, 60%, 40% and 20% of the incident light to pass through.

Choose one of the colored lines, and record the stopping potential for each of the different zones of the transmission filter. Also make a note of approximately how long it takes the voltmeter reading to reach a steady value. Record these values in the table below:

Color:_____		
Transmission (%)	Stopping Potential (V)	Settling Time (s)
100		
80		
60		
40		
20		

Repeat this measurement for a second color of light, and record the results below.

Color:_____		
Transmission (%)	Stopping Potential (V)	Settling Time (s)
100		
80		
60		
40		
20		

Does the stopping potential you measure depend on the intensity of the light hitting the cell?

Analysis

The stopping potential measured in this experiment allows you to calculate the kinetic energy of the electrons as they leave the metal plate in the photoelectric cell. The maximum kinetic energy of an electron leaving the plate is given by:

$$K_{max} = e\, V_o$$

where $e = 1.602 \times 10^{-19}$ C is the charge on an electron, and V_o is the stopping potential you measured. Enter the frequency from the first table and the measured stopping potential from the second table for each color into an Excel spreadsheet. Calculate K_{max} for each of the wavelengths of light. At what speed would an electron (mass of one electron $= 9.109 \times 10^{-31}$ kg) need to be moving to have that kinetic energy?

Make a plot of K_{max} vs. f for the different colors you measured. Einstein's model of the photoelectric effect says that the data should fall on a straight line—are your data consistent with this picture? Fit a straight line to your data using Excel. What does the slope of the line tell you? What does the intercept of the line tell you? Print the graph for your report.

Using the results of your fit, calculate a value of h. How close does your measurement come to the accepted value? Calculate the % difference.