Eva Knoth

PH263 – Lab 7

March 30, 2011

The Photoelectric Effect

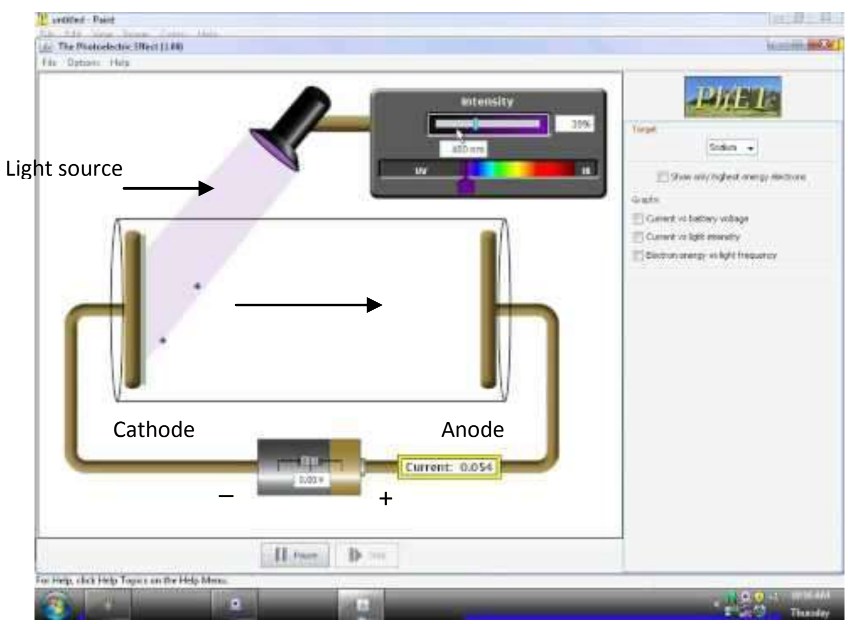
Introduction

The photoelectric effect is the emission of electrons from a substance due to light striking its surface (Knight, 1209). Heinrich Hertz first discovered that an electrode can be discharged by shining ultraviolet light on its surface (Knight, 1208). J.J. Thompson then showed that the electrode emits electrons. Philip Leonard, a student of Hertz, designed an experiment to describe the photoelectric effect. Leonard set up a device consisting of a glass vacuum tube, with an electrode at each end of the tube. The electrodes were connected to an ammeter. Shining light on the cathode, the ammeter detected current, moving freely, from the cathode to the anode. Leonard then connected a battery between the electrodes and studied how the current varied as the potential difference, light intensity, and frequency changed (Knight, 1209).

We will use a virtual simulation to observe the photoelectric effect under idealized conditions. The purpose of this simulation is to understand how changing wavelength, intensity level, voltage, and target material affects current, to gain a deeper understanding of the photoelectric effect and to verify Leonard's observations.

Procedure

The simulation is found online at http:/phet.colorado.edu/simulations/index.php. The interactive simulation, entitled Photoelectric Effect, is under the category Physics > Quantum Phenomena. The simulation was developed by PhET at the University of Colorado at Boulder.



Source: http://phet.colorado.edu/en/simulation/photoelectric. Accessed March 30, 2011

To look at the relationship between current and wavelength, intensity, voltage, and cathode material, the variable was varied while all other parameters remained constant. Current was measured for at least 10 data points. The target material used for data collection of wavelength, intensity and voltage was sodium. Specific values for parameters are listed below:

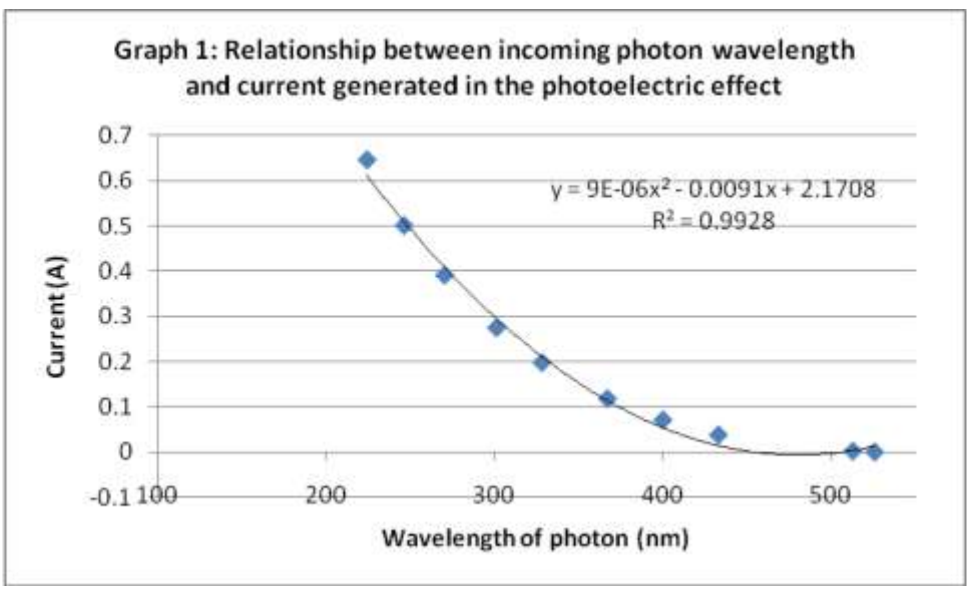
1. Wavelength vs. Current - Intensity level = 50%; V = 0.
2. Intensity vs. Current – Wavelength = 350 nm (ultraviolet light); V = 0
3. Voltage vs. Current – Intensity level = 50%; wavelength = 350 nm
4. Material vs. Current – Intensity level = 50%; wavelength = 150 nm (ultraviolet); V=0

Raw data was collected and analyzed using Microsoft Excel. Graphs for wavelength, intensity and voltage vs. current were constructed and fit to trend lines.

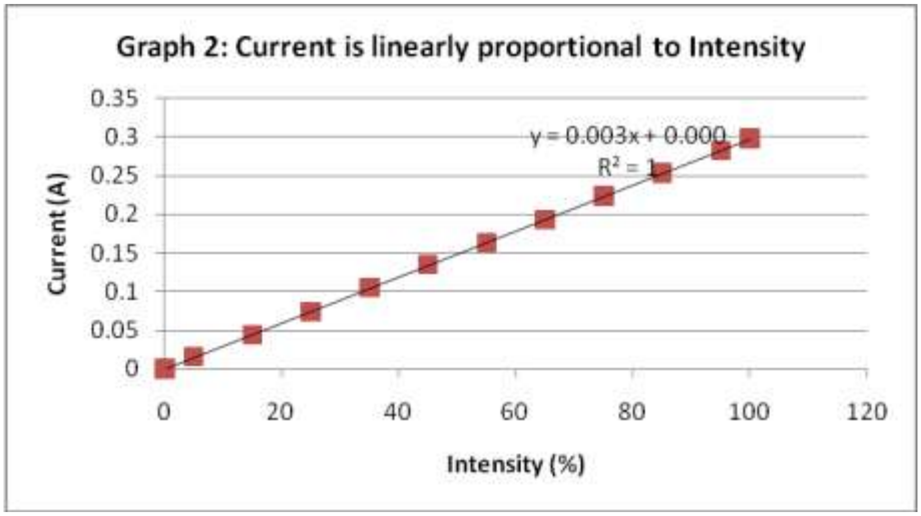
Analysis

Obvious trends are observed between each parameter and current. Current has a non-linear dependence on wavelength. As the wavelength was increased, current decreased. Current appears to be inversely proportional to the square of the wavelength (Graph 1). This relationship is expected because kinetic energy and wavelength are inversely proportional, and current is a measure of how many electrons have enough energy to travel from the cathode to the anode in a given amount of time.

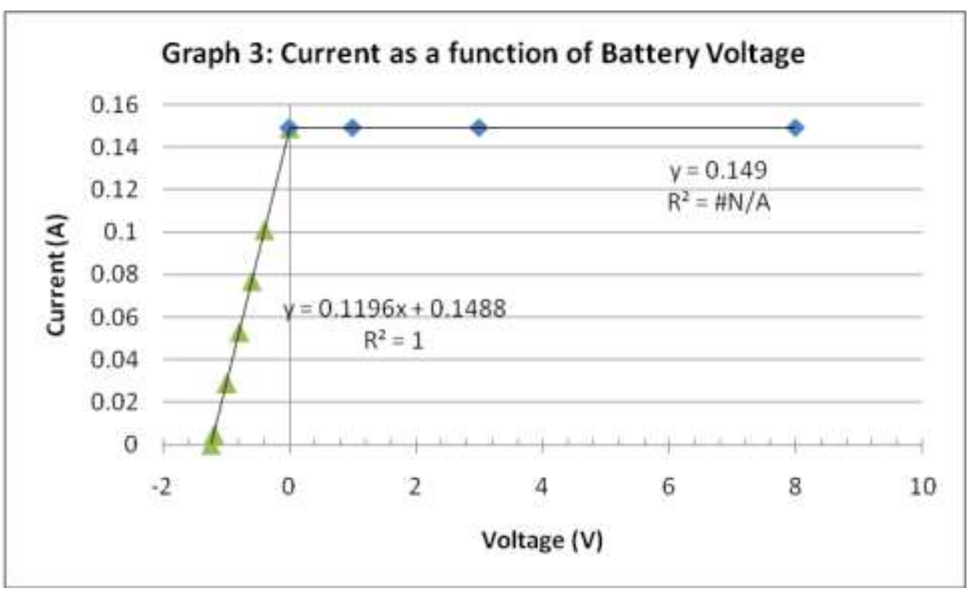
Each photon of light can eject only one electron from the cathode. The current stops when wavelength = 526 nm. Since $E = hc/\lambda$, this corresponds to a photon energy of E = 6.3 eV. Photons with energy higher than 6.3 eV cause current to flow, because higher kinetic energy for the ejected electron is necessary to travel from the cathode to the anode. Photons with less energy eject electrons that cannot reach the anode. A classical physics model assumes continuous energy is available and increases with light intensity. This would predict an inverse linear relationship between current and wavelength, in which a wavelength approaching infinity would cause the energy, and hence current, to approach zero. This is not the observed effect. Therefore, the photon model, in which a packet of light contains a discrete amount of energy, is needed to explain the observed relationship.



As shown in Graph 2, the current is linearly dependent on intensity. This simulation represents intensity as a percentage, when in reality intensity is the number of photons per unit area of the cathode. Current depends on the number of electrons that travel between the electrodes. To be linearly dependent, then an increasing number of photons transfer the energy to both release an increasing number of electrons from the cathode and have them travel to the anode.



Using sodium as the cathode material, the voltage that caused the current to go to zero, V_{stop}, was 1.25 Volts. The same stopping voltage is found when extrapolating from the linear regression on Graph 3. There is no uncertainty in the calculation because the simulation models an ideal condition. As the voltage approaches the stopping voltage, the electrons slow down and fewer reach the anode. At the stopping voltage, the electrons slow down and change direction at the anode, traveling back to the cathode. There is no scale given on the apparatus to determine the closest approach distance.



Copper, Sodium, Platinum, and Zinc were chosen as cathode materials. Sodium had the highest stopping potential, while Platinum had the lowest. Values for the stopping potential are listed below. Each material had a unique stopping potential, independent of light intensity.

Cathode Material	Stopping Potential, V_{stop} (V)
Sodium	5.97
Zinc	3.97
Copper	3.57
Platinum	1.96

Conclusions

Current created by the photoelectric effect is dependent on wavelength of light, light intensity level, potential difference, and cathode material. Current is inversely proportional to the square of the wavelength, while linearly dependent upon light intensity level. Current is linearly dependent upon battery potential until it peaks when all electrons are attracted to and reach the anode. The stopping potential was found to be 1.25 V, which is the potential difference at which zero current flows. Electrons do not have enough energy to reach the anode. V_{stop} is determined by the cathode material, and not light intensity. The metals vary in size and charge and their relative ability to lose electrons determines the magnitude of V stop. The simulation allowed for validation of the observations made by Leonard.

References

R. Knight. *Physics for Scientists and Engineers, 2nd Edition.* Addison Wesley. 2007.