Experiment 4: Using Photoelectric Effect to Estimate Planck's Constant

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Abstract

Utilizing the photoelectric effect, my partner and I sought to experimentally determine the value of Planck's constant, h, and the work function, ϕ, of a Cesium-Antimony Alloy. Planck's constant is determined to be $(2.76 \pm 0.14) \times 10^{-34}$ $[m^2\, kg\, s^{-1}]$ with z-score of 27σ. Also, $\phi = 0.53 \pm 0.04$ $[eV]$, which has a z-score of 19σ.

1 Introduction

In 1905, Albert Einstein published a paper that changed the way that we look at the world—literally. In this paper, Einstein discussed a hypothesis that light is carried as discrete, quantized, packets of energy. Later in 1914, Robert Millikan conducted experiment that confirmed Einstein's model. For his work, Einstein was awarded the Nobel Prize in 1921, and attributed the discovery of the *Photoelectric effect*.

The photoelectric effect is the emission of electrons produced from a—usually—metal surface due to incident light. These electrons can be emitted if the individual photons contain enough energy to free an electron from an atom on the metal surface. The amount of energy is known as the work function, ϕ; the exact value is intrinsic to the metal utilized. The excess energy due to the incident photon is transferred to the free electron in the form of kinetic energy.

The goal of this experiment is to use the photoelectric effect to estimate Planck's constant, h as well as determine the ϕ for a metal surface. The specific metal we are using, which is a Cesium-Antimony alloy, has a theoretical work function of $\phi = 1.3 \pm 0.1$ $[eV]$ [1] .

[1] http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=AD0290955

2 Theory

Recall that the energy of a photon is related to its frequency through $E = hf$, where h is the Planck's constant (6.626×10^{-34} $[m^2\,kg\,s^{-1}]$). Using this relationship, one can describe the photoelectric effect:

$$K_{max} = hf - \phi \tag{1}$$

where ϕ is the work function of the particular metal surface. Recall that that the kinetic energy is related to voltage by the relationship $e \cdot V = K$, where e is the charge of the electron. Using this relationship, Equation 1 can be written in terms of the stopping voltage:

$$V_s = \frac{hc}{e\lambda} + \frac{\phi}{e} \tag{2}$$

Equation 2 is of the form $y = mx + b$. With this in mind, a plot of the V_s against λ^{-1} will yield (hc/e) as the slope, and (ϕ/e) as the y-intercept. Therefore, h, and its associated error, can be determined by:

$$\begin{aligned} h &= \tfrac{(\text{slope}) \cdot e}{c} \\ \delta h &= \tfrac{\delta(\text{slope}) \cdot e}{c} \end{aligned} \tag{3}$$

Similarly, ϕ, and its associated error, can be determined by:

$$\begin{aligned} \phi &= (\text{y-intercept}) \cdot e \\ \delta\phi &= \delta(\text{y-intercept}) \cdot e \end{aligned} \tag{4}$$

It can be seen that the voltage is independent of the intensity of incident light—however an increased intensity may yield an increased current.

3 Procedure

1. Take the red laser pointer and note its wavelength.
2. Turn on the detector and set the multimeter to DC.
3. Place laser pointer into holder and secure button with a paper clip.
4. Align laser pointer such that the laser illuminates the photoelectric surface in the detector. Use an acrylic lens to disperse the light across the detector.
5. Set potential to max and adjust the current meter so it is zero nA.
6. Slightly lower the potential and record the current produced.
7. Plot the Current against Potential. Using a linear regression, determine the x-intercept, which is the stopping voltage for the red laser.
8. Repeat steps 1 - 7 for the green and violet lasers.
9. Plot the Stopping voltages against λ^{-1}.

   Fit a linear regression and use the slope and y-intercept to calculate Planck's constant and the work function with equations 3 and 4.

4 Data

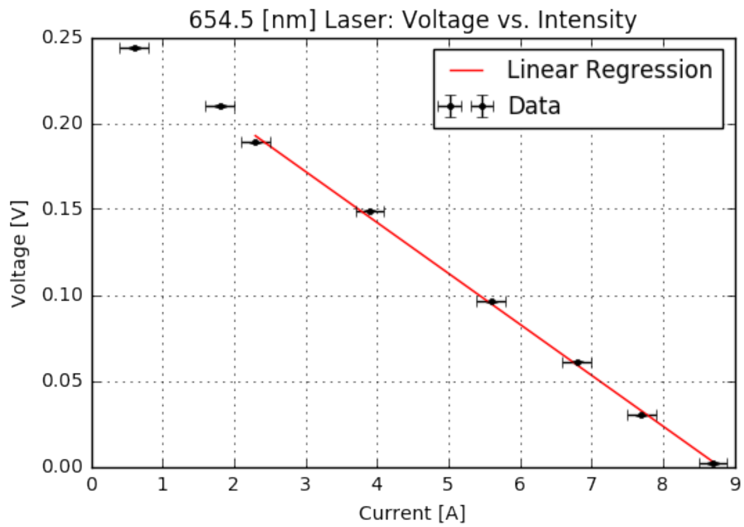

Figure 1: Red Laser Linear Regression, Y-int $= 0.261 \pm 0.004$ $[V]$

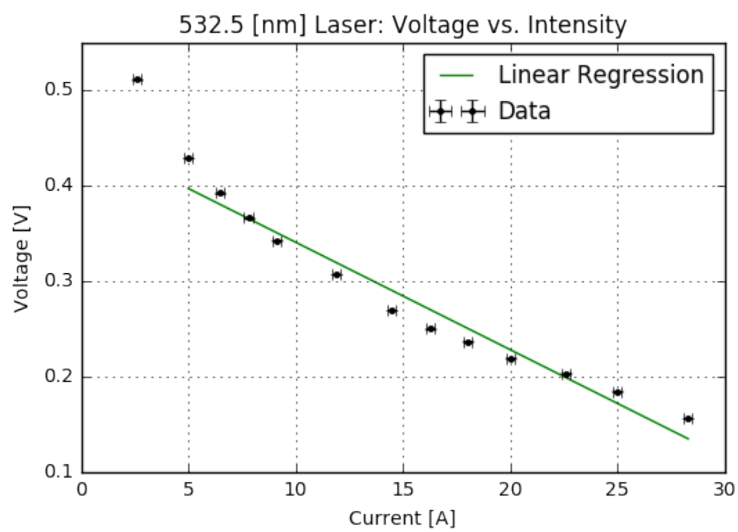

Figure 2: Green Laser Linear Regression, Y-int $= 0.453 \pm 0.012$ $[V]$

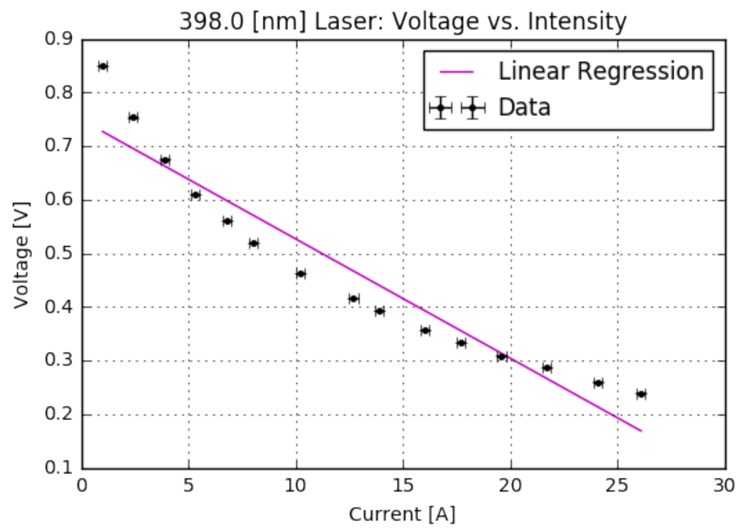

Figure 3: Violet Laser Linear Regression, Y-int $= 0.75 \pm 0.03$ $[V]$

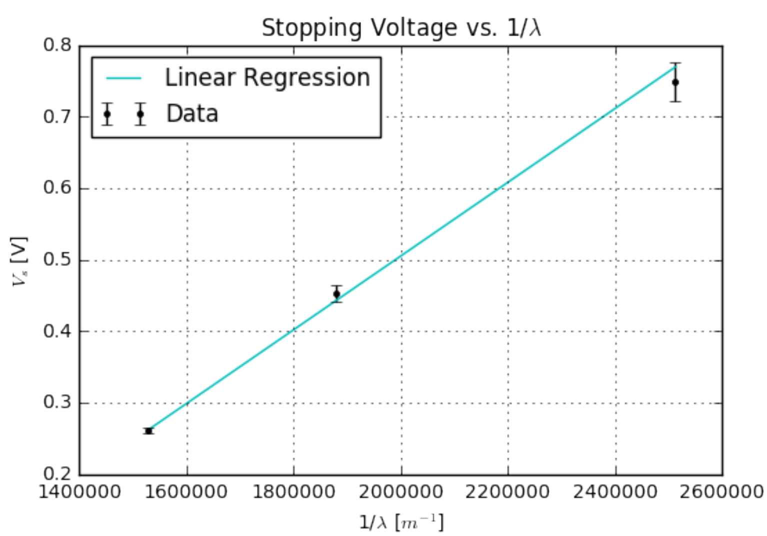

Figure 4: Stopping Voltage Linear Regression, Slope $= (5.17 \pm 0.27) \times 10^{-7}$ $[V \cdot m]$

5 Results

Utilizing Equation 3, Planck's constant, h, is calculated to be $(2.76 \pm 0.14) \times 10^{-34}$—which has a z-score of $\approx 27\sigma$. Similarly, the work function, ϕ, is determined using Equation 4 to be 0.53 ± 0.04 $[eV]$.

6 Discussion

My partner and I were able to successfully calculate an experimental value for Planck's constant $(2.76 \pm 0.14) \times 10^{-34}$ $[m^2\, kg\, s^{-1}]$) which is on the same order as the well known Planck's constants (6.626×10^{-34} $[m^2\, kg\, s^{-1}]$), however our result is about 27σ from the theoretical. Similarly, an experimental work function was determined to be 0.53 ± 0.04 $[eV]$, while the theoretical work function for the cesium-antimony alloy is roughly 1.3 ± 0.1 $[eV]$—which is approximately 19σ. Overall, all of the results achieved are highly inaccurate. However, due the restricted number of data points (3 stopping voltages), it is very likely that this error can be the result of random error.

7 Conclusion

The photoelectric effect was observed and successfully utilized to experimentally determine values for Planck's constant, h, and the work function, ϕ, for the Cesium-Antimony alloy. Experimentally, $h = (2.76 \pm 0.14) \times 10^{-34}$ $[m^2\, kg\, s^{-1}]$ with z-score of 27σ. Also, $\phi = 0.53 \pm 0.04$ $[eV]$, which has a z-score of 19σ. In the future, I would improve results by reducing the amount of ambient light in the room, as well as try a larger variety of lasers to get a better sample of stopping voltages—thereby yielding more accurate experimental values.