Photoelectric Effect

Adams, Jake
jake.adams@mail.utoronto.ca
1003847377

Jiang, Hansen
hansen.jiang@mail.utoronto.ca
1003192403

November 23, 2018

Introduction

The purpose of this experiment was to demonstrate the photoelectric effect and in doing so, confirm quantum theory.

Methods and Materials

- Phototube (PE)
- Power supply
- main controller (with built-in potentiometer)
- 8 LED's
- Variable intensity LED
- Oscillator driven LED
- HP3465A Digital Multimeter (used for measuring photocurrent)
- Fluke 8000A Digital Multimeter (used for measuring stopping potential)
- Oscilloscope
- wave generator

Experimental Procedure

Exercise 1 began with setting up the experimental arrangement. With all the necessary connections made, the first LED (UV at 390nm) was secured into the (powered on) power supply and the phototube brought close enough to where most of the light entered the window. With both multimeters connected and powered on, the potentiometer on the main controller was then turned on and adjusted until the photocurrent went to zero (or as close as physically possible); the stopping potential was then recorded. This process was repeated for each of the remaining 7 LED's.

For the execution of exercise 2, a similar procedure to exercise 1 was followed. Using the variable intensity LED and starting on the first preset, the the potentiometer was adjusted until the photocurrent went to zero, and the stopping potential was measured. This was repeated for the remaining three presets on the variable intensity LED. Next, the photocurrent was independently measured on each of the four presets. This was done by turning OFF the potentiometer and reading the value of the multimeter recording photocurrent.

In the final exercise, the phototube was connected to CH1 of the oscilloscope and the oscillator driven LED was connected to the power supply (in the OFF position). In addition, the wave generator was connected to CH2 of the oscilloscope, as well as the oscillator driven LED. The wave generator was adjusted to produce a square-wave frequency and amplitude in middle range.

Results

Using the different light diodes, a relationship can be plotted with V_{stop}, the stopping potential, vs the frequency of the light, $f = \frac{c}{\lambda}$, where c is the speed of light, and λ is the wavelength of the light. The following is the resulting graph.

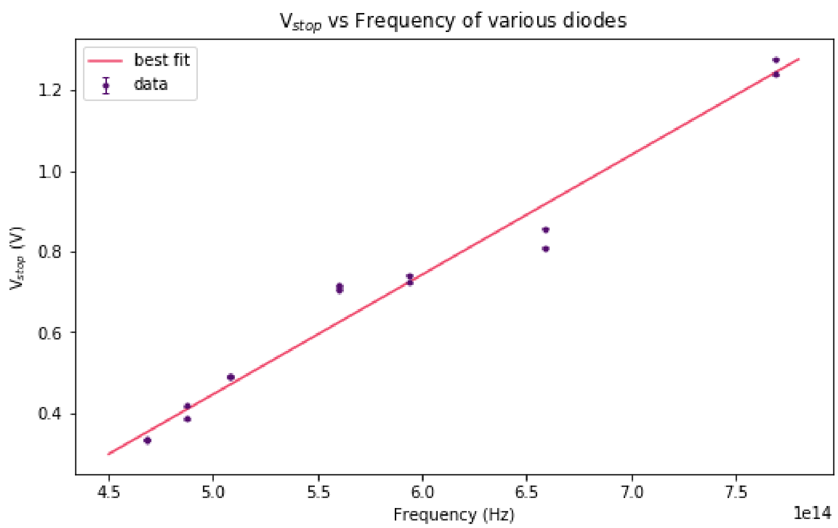

Figure 1: Stopping potential vs frequency of various light diodes

Since the associated error of the digital multimeter measuring the stopping voltage is relatively low, the errors of the data do not appear significant in the plot. The constants calculated by `curve_fit` are

$$
\begin{aligned}
h &= 4.75 \times 10^{-34} \pm 2 \times 10^{-35} \frac{\text{kg m}^2}{\text{s}} \\
E_0 &= 1.66 \times 10^{-19} \pm 1 \times 10^{-20} \text{J} \\
&= 1.04 \pm 0.07 \text{eV} \\
f_0 &= 3.49 \times 10^{14} \pm 3 \times 10^{13} \text{Hz}
\end{aligned}
$$

Plotting the expected value of $h = 6.63 \times 10^{-34} \frac{\text{kg m}^2}{\text{s}}$ against the data and zooming out to view the zero-intercept yields the following.

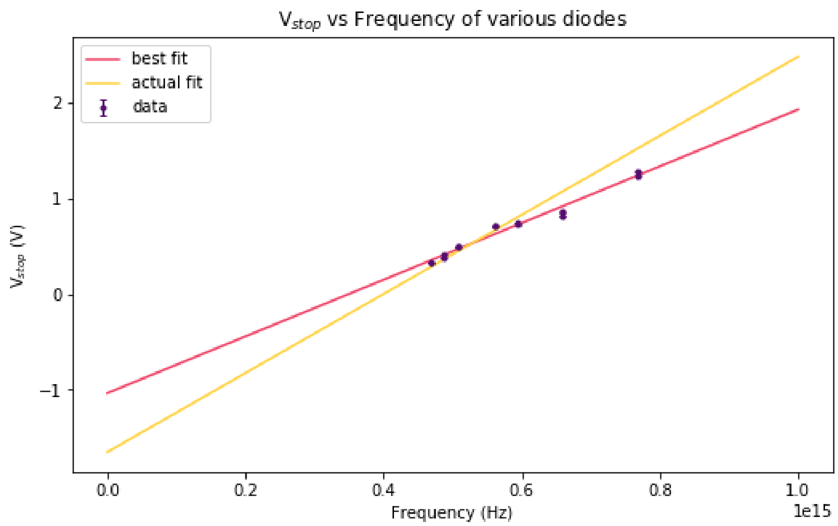

Figure 2: Stopping potential vs frequency of various light diodes

Using the variable intensity LED, the independently measured potential and photocurrent is as follows.

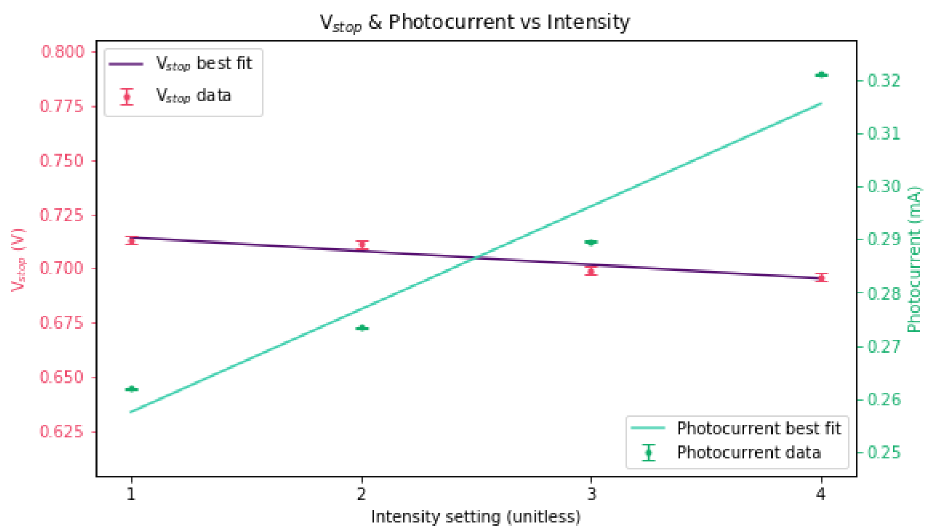

Figure 3: Stopping potential and photocurrent vs arbitrary intensity of one frequency-diode

The vertical axes correspond to the appropriate data as specified by the colour, and the values of these axes are centered at μ, the mean of the set, with range $\pm\frac{\mu}{7}$. The stopping voltage of this diode decreases slightly with the increase in intensity, though it is expected to remain constant. Meanwhile, the photocurrent increases with the increase in intensity, although the variance of each data point does not put them within the range the line of best fit.

The energy absorbed by each electron emitted in the part conducted with the oscillator-driven diode can be calculated by the formula

$$P_e = P_{LED}\frac{A_e}{A_{PC}} \tag{1}$$

where P_e, P_{LED} are the electric powers of each electron, and the total power of the oscillator-driven LED, respectively, A_e is the average area between electrons, and A_{PC} is the photocathode area, with $P_{LED} = 60\text{mW}$ and $A_{PC} = 3.23\text{cm}^2$.

Using $A_e = 0.09\text{nm}^2$, $P_e = 1.67 \times 10^{-17}$. Then, in one second, the energy absorbed by each electron is $E = 1.67 \times 10^{-17}$. Then, using E_0 as above, and finding the characteristic time by the equation

$$P_e = \frac{E_0}{\Delta t} \tag{2}$$

the time needed by an electron to absorb enough energy to escape the photocathode, Δt, is calculated as $\Delta t = 0.00993 \pm 10^{-20}$ s.

Comparatively, the measured time difference for the potential of the system with energy as emitted by the oscillator-driven diode to fall to $1/e$ of its original value is 156.0μs, which is much smaller than Δt as above, as expected by quantum theory.

Discussion

It should be noted that as in Figures 1 and 2, the stopping potential values of the infrared LED were not included, as $f_{infrared} = \frac{c}{935nm} = 3.21 \times 10^{14}\text{Hz} < f_0$. As a result, the energy was not high enough to excite the electrons. The current remained zero despite adjusting the potentiometer, which led to the "stopping voltage" varying from the minimum range of the device, to the maximum.

It should also be noted that the stopping potential of each diode was measured twice. The discrepancy is more noticeable in the shorter wavelengths, as can be seen in Figure 1. As well, the slope of the diodes with the four smallest frequencies and the slope of the diodes with the three largest (excluding the infrared diode) suggest a closer fit to the actual value of Planck's constant, h, although with different values of E_0. This suggests either an error in the method of data collection, or a change in the system around the diode with the third longest frequency (Cyan). This can be compared when isolated.

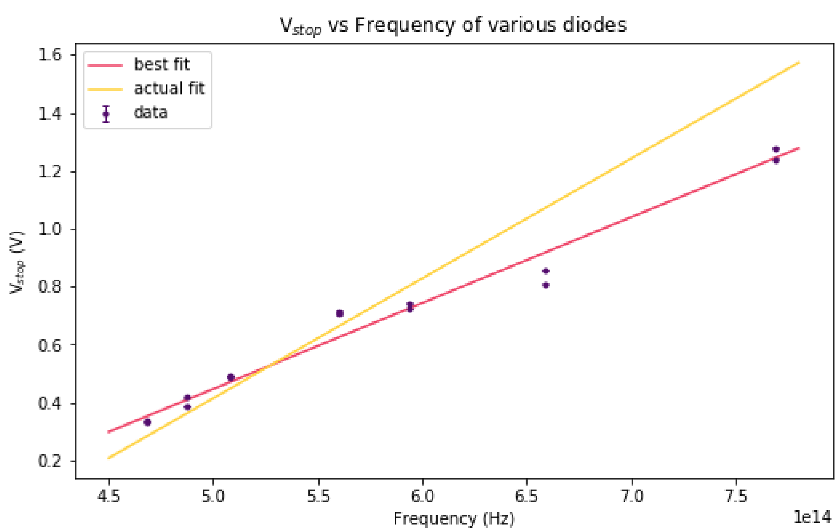

Figure 4: Stopping potential vs frequency of various light diodes

As can be noted, the "actual" fit's slope is accurate to the first four diodes from the left, then again for the last two or three on the right.

As for the value of the work function, when compared to the work functions of known metals, which are predominantly in the range of 4-5eV, E_0 for this system is on the low end.

As noted in the previous section, the second part of this experiment suggested that as expected, photoelectron energy does not depend on light intensity.

Conclusion

Using various LEDs of different frequencies and intensities, and a phototube setup, Einstein's interpretation of the photoelectric effect as described by the equation $eV_{stop} = hf - E_0$ and its various effects, such as the independence of photoelectron energy from light intensity, and the time of absorption of energy per electron in reality vs theory, is concluded to correlate with the data trends, though any further conclusions cannot be made, as the small variance in the data does not suggest strict coherence.