Yizhi Jiao
Physics 20CL
After Lab Note: Photoelectric Effect
Time: 6:30 pm to 9:45 pm, Apr. 5
4:30 pm to 9:30 pm, Apr. 9

This experiment was intended to explore the photoelectric effect. By observing the relationship between the impeding voltage and the current, the stopping voltage was found at given wavelength of light. The Planck's constant could therefore be calculated.

In order to find the stopping voltage at one frequency, the impeding voltage and corresponding current was recorded for both 365nm and 577nm of light. The electromter and voltmeter were not in be able to display a constant number for a long time. Since I was not able to read two numbers at the same time, I had to drop one digit of both the voltage and current. In this way, the number was not varying, and the uncertainties of the data were represented by the resolution limit of the instrument.

$$\begin{aligned}\sigma_V &= \frac{1}{\sqrt{12}} \cdot 0.001 \text{ V} \\ &= 0.0003 \text{ V}\end{aligned}$$

This uncertainty is too small, which underestimate the uncertainty of the data. As shown in the data table and Figure 1, the current never reached zero, which means the stopping voltage was not reached. Thus, a baseline correction was performed to find the stopping voltage.

$$V_{365\text{nm, baseline}} = -0.1535I + 0.4407$$
$$V_{577\text{nm, baseline}} = -0.0408I + 0.1555$$

The baseline was defined as the best-fit line of all data with current smaller than 0.3 nA, and the estimated value was subtracted from the original data. The plot of the baseline is shown in Figure 1. The best-fit line of the rest of data points was counted as the voltage curve, and the stopping voltage was found by finding the intersection of the baseline and the voltage curve.

$$\begin{aligned} V_{365\text{ nm}} &= -6.5565I + 8.8293 \\ V_{577\text{ nm}} &= -6.7249I + 2.8596 \\ V_{365\text{ nm, stop}} &= 1.34 \pm 0.0003\text{ V} \\ V_{577\text{ nm, stop}} &= 0.42 \pm 0.0003\text{ V} \end{aligned}$$

The plot of the voltage curve and data points after baseline correction are shown in Figure 2. Based on all instructions given from PHYS 20AL to 20CL, I was not able to find a method to fit nonlinear data. Obviously, the data are not linear, so a linear regression was not able to fit the data well. Hence, the χ^2 of these two voltage curves are really large:

$$\begin{aligned} \chi^2_{365\text{ nm}} &= \sum_{i=1}^{5} \frac{(V_i - V_{\text{model}})^2}{\sigma^2_{V_i}} \\ &\approx 10^7 \end{aligned} \tag{1}$$

$$\chi^2_{577\text{ nm}} = \sum_{i=1}^{4} \frac{(V_i - V_{\text{model}})^2}{\sigma_{V_i}^2} \approx 10^5 \tag{2}$$

As instructions given in the lab manual, the Planck's constant was calculated by using the following equation:

$$\begin{aligned}
V_s &= \frac{h\nu}{e} - \phi \\
&= \frac{hc}{e\lambda} - \phi \\
\Delta V_s &= \frac{hc}{e}(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}) \\
h &= \frac{e}{c}\frac{\lambda_1\lambda_2}{\lambda_2 - \lambda_1}(V_{s1} - V_{s2}) \\
&= \frac{1.602 \cdot 10^{-19}}{3 \cdot 10^8}\frac{(365 \cdot 10^{-9}) \cdot (577 \cdot 10^{-9})}{(577 \cdot 10^{-9}) - (365 \cdot 10^{-9})}(1.34 - 0.42) \\
&= (4.880 \pm 0.002) \cdot 10^{-34}\ \text{J} \cdot \text{s}
\end{aligned}$$

The uncertainty of the Planck's constant was calculated by using the following equation:

$$\begin{aligned}
\sigma_h &= \sqrt{\left(\frac{\partial h}{\partial V_{s1}}\sigma_V\right)^2 + \left(\frac{\partial h}{\partial V_{s2}}\sigma_V\right)^2} \\
&= \sqrt{\left(\frac{e}{c}\frac{\lambda_1\lambda_2}{\lambda_2 - \lambda_1}\sigma_V\right)^2 + \left(\frac{e}{c}\frac{\lambda_1\lambda_2}{\lambda_2 - \lambda_1}\sigma_V\right)^2} \\
&= \sqrt{2 \cdot \left(\frac{1.602 \cdot 10^{-19}}{3 \cdot 10^8}\frac{(365 \cdot 10^{-9}) \cdot (577 \cdot 10^{-9})}{(577 \cdot 10^{-9}) - (365 \cdot 10^{-9})}\frac{0.001}{\sqrt{12}}\right)^2} \quad 2.1657 \cdot 10^{-37}\ \text{J} \cdot \text{s}
\end{aligned}$$

The calculated interval of the Planck's constant does not include the value in literature:

$6.626 \cdot 10^{-34}$ J $\cdot$ s.

The inaccuracy of the Planck's constant can be explained by the inaccuracy of the stopping voltage. The data of voltage are not linear, but a linear model is used. The χ^2 is really large, indicating the model does not fit the data. The uncertainty of the Planck's constant (0.03%) is also underestimated, because the the majority of uncertainty is from unmeasureable factors, such as the light that leaked into the dark box from the outside.

In conclusion, the Planck's constant was calculated from inaccurate and imprecise measurements, $h = (4.880 \pm 0.002) \cdot 10^{-34}$ J $\cdot$ s. This value is not consistent with the value in literature, $h = 6.626 \cdot 10^{-34}$ J $\cdot$ s. To improve the accuracy and precision of the measurement, the following suggestions are given: First, the bottom sides of the box can be sealed with electrical tape to reduce the light that leaked into the dark box from the outside. Second, the other two filters can be used. All four frequencies of light can plot a meaningful graph of the stopping voltage as a function of frequency of light. Third, more data at lower impeding voltage should be measured because the data at lower impeding voltage can be more linear. The voltage curve may has a transition region between the lower impeding voltage and the baseline region. If more data are measured at lower impeding voltage, the transition region can be excluded from calculation and the stopping voltage can be defined more accurately.

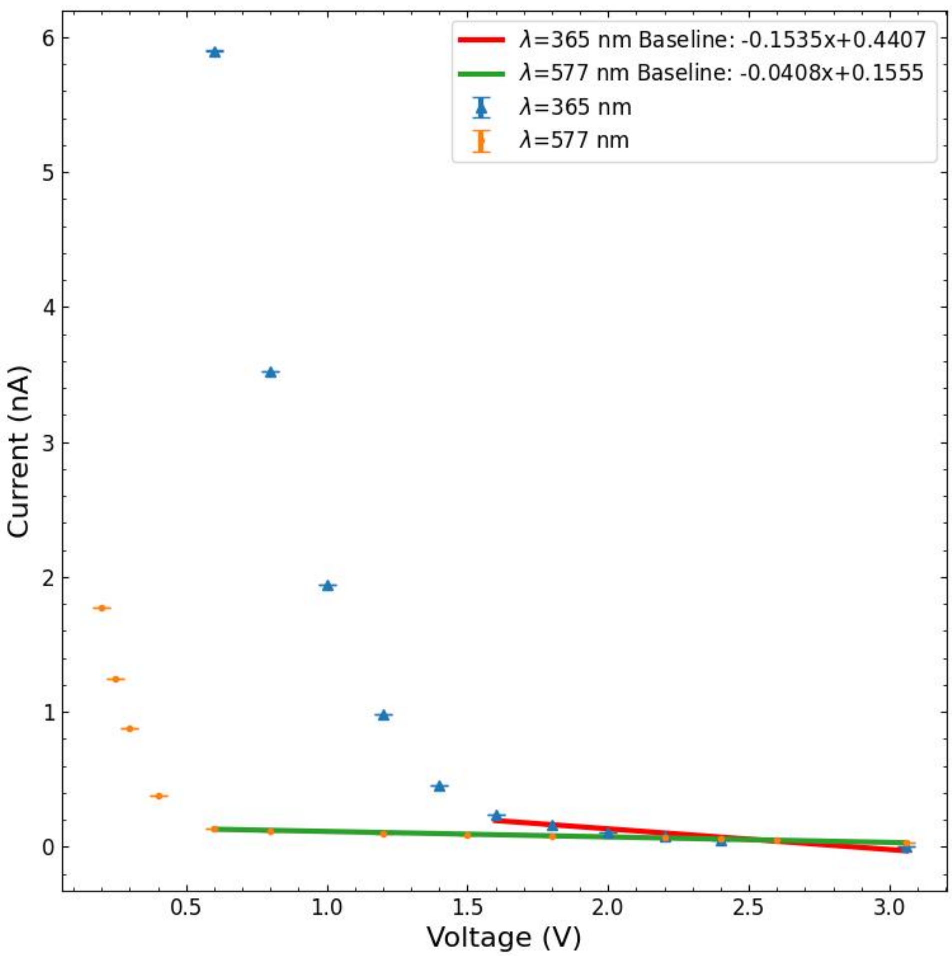

Figure 1: $\chi^2 \approx 10^4$ for 356 nm and $\chi^2 \approx 10^3$ for 577 nm. The error bars, representing σ_V, underestimate the uncertainty and are too small to be seen.

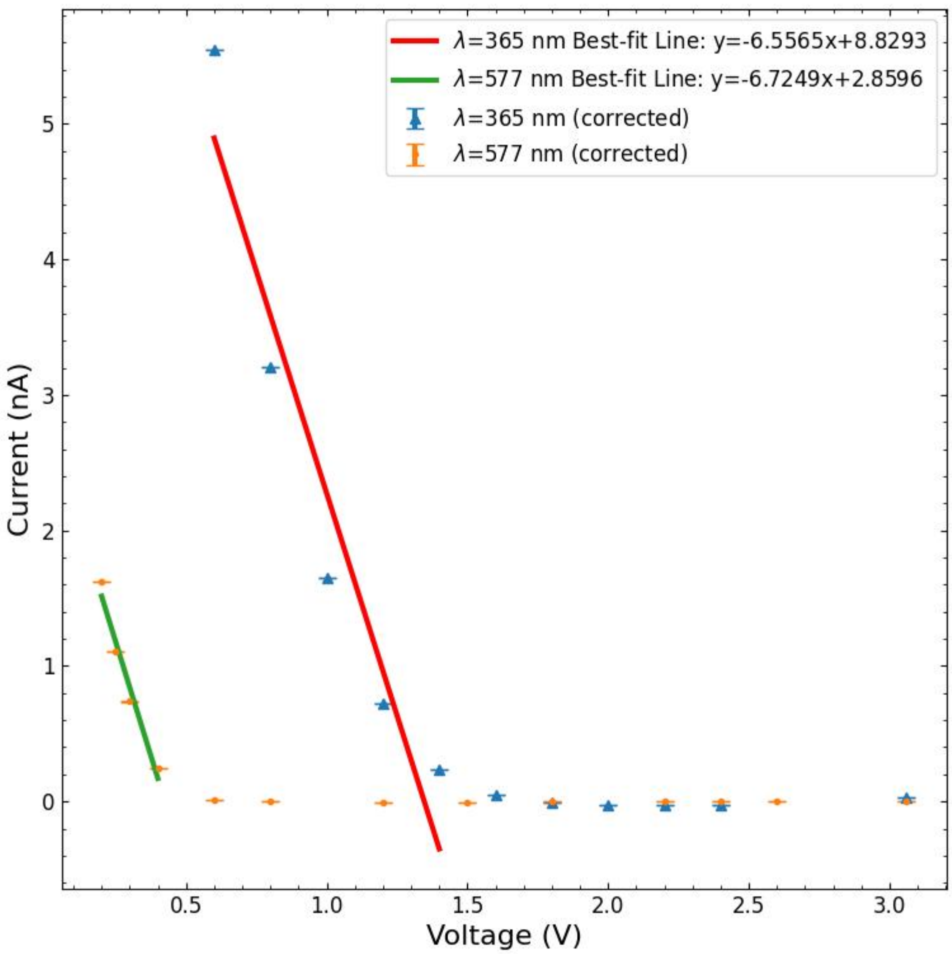

Figure 2: $\chi^2 \approx 10^7$ for 356 nm and $\chi^2 \approx 10^5$ for 577 nm. The error bars, representing σ_V, underestimate the uncertainty and are too small to be seen.