Photo-electric Effect

Course: PHY 3802L Intermediate Physics Lab

Experiment: Speed of Light

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Partner(s): Sophia

Date Performed: Mon Oct 13th, 2025

Date Submitted: Mon Oct 20th, 2025

Introduction and Purpose

The goal of this experiment was to study the photoelectric effect and use it to calculate Planck's constant and the work function of the metal used inside the photocell.

By shining light of different wavelengths (from yellow to ultraviolet) on a metal surface and measuring the voltage where the current stopped, I was able to show that the energy of emitted electrons depends on the frequency of the light and not on its intensity

Theory

When light hits a metal, photons can transfer their energy $E = h\nu$ to the electrons in the surface.
If the photon's energy is larger than the metal's work function ϕ, electrons are emitted.
The maximum kinetic energy of those electrons is given by:

$$E_k = h\nu - \phi$$

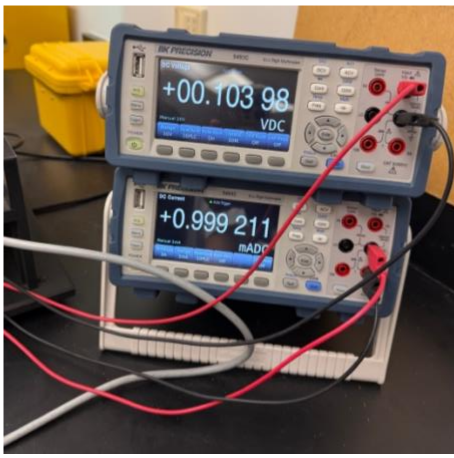
In the experiment, a retarding voltage V_s is applied to stop the electrons. When $E_k = eV_s$, the current drops to zero.
By rearranging, we get:

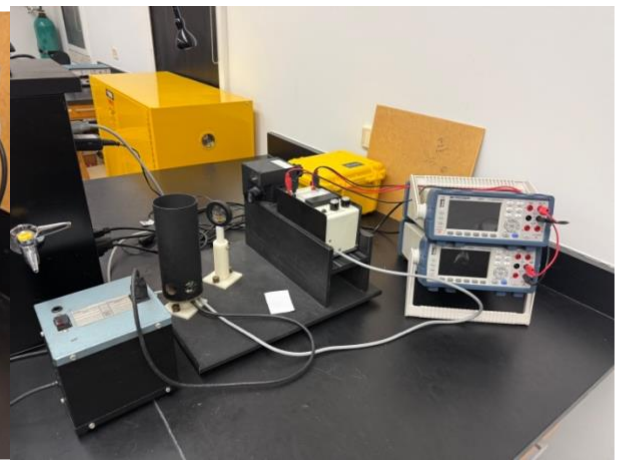
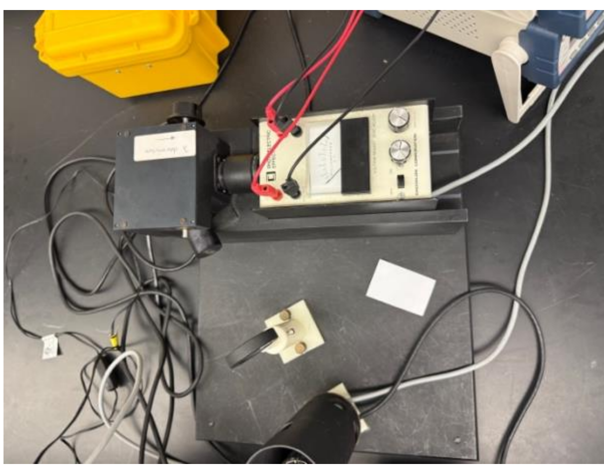
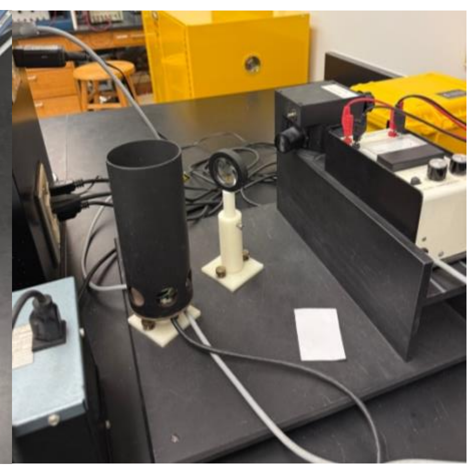
$$V_s = \frac{h}{e}\nu - \frac{\phi}{e}$$

Since $\nu = c/\lambda$, a graph of V_s versus $1/\lambda$ should be linear, and its slope gives hc/e, which allows us to calculate h. The intercept gives $-\phi/e$.

Apparatus

- Mercury lamp and monochromator
- Photoelectric tube and amplifier unit
- Digital voltmeter and ammeter
- Five light filters: yellow (578 nm), green (546 nm), blue (436 nm), violet (405 nm), and ultraviolet (365 nm)



Procedure

1. The mercury lamp was turned on and allowed to warm up for several minutes.
2. The photocell was connected to the amplifier, with one multimeter measuring current and the other measuring the stopping voltage.
3. For each color filter, I slowly changed the voltage and recorded the photocurrent.
4. Each dataset was saved in a .data file (e.g. Data_yellow.data, Data_green.data, etc.).
5. Using Python and LT.box, I plotted current vs. voltage for each color and fit the linear regions of the curves.
6. The stopping potential V_s was found by calculating where the two fitted lines intersected.
7. This process was repeated for all five wavelengths

Data

Yellow (578 nm) — Raw Data

Voltage (V)	Current (mA)
0.49	0.015
0.60	0.025
0.70	0.030
0.80	0.035
0.90	0.040
1.00	0.045
1.10	0.050
1.20	0.060
1.30	0.065
1.40	0.070
1.50	0.075
1.60	0.080
1.70	0.090
1.80	0.100
1.90	0.120
2.50	0.250
3.01	0.360

Green (546 nm) — Raw Data

Voltage (V)	Current (mA)
0.30	0.002
0.35	0.003
0.40	0.004
0.45	0.005
0.50	0.006
0.55	0.007
0.60	0.009
0.65	0.010
0.70	0.011
0.75	0.013
0.80	0.015
0.85	0.018
0.90	0.021
0.95	0.024
1.00	0.027
1.10	0.034
1.20	0.043
1.30	0.052
1.40	0.061
1.50	0.070
1.60	0.082
1.70	0.094
1.80	0.106
1.90	0.118
2.00	0.130
2.20	0.165
2.40	0.200
2.60	0.235
2.80	0.270
3.00	0.305
3.20	0.340
3.30	6.650

Blue (436 nm) — Raw Data

Voltage (V)	Current (mA)
0.20	0.004
0.30	0.007
0.40	0.010
0.50	0.014
0.60	0.018
0.70	0.022
0.80	0.027
0.90	0.032
1.00	0.037
1.10	0.042
1.20	0.047
1.30	0.052
1.40	0.058
1.50	0.065
1.60	0.072
1.70	0.079
1.80	0.086
1.90	0.093
2.00	0.100
2.10	0.107
2.20	0.114
2.30	0.121
2.40	0.128
2.50	0.135
2.60	0.142
2.70	0.149
2.80	0.156
2.90	0.163
3.00	0.170
3.10	0.177
3.20	0.184
3.30	3.510

Violet (405 nm) — Raw Data

Voltage (V)	Current (mA)
0.10	0.006
0.20	0.010
0.30	0.014
0.40	0.019
0.50	0.024
0.60	0.029
0.70	0.035
0.80	0.041
0.90	0.047
1.00	0.053
1.10	0.060
1.20	0.067
1.30	0.074
1.40	0.081
1.50	0.088
1.60	0.095
1.70	0.102
1.80	0.109
1.90	0.116
2.00	0.123
2.10	0.130
2.20	0.137
2.30	0.144
2.40	0.151
2.50	0.158
2.60	0.165
2.70	0.172
2.80	0.179
2.90	0.186
3.00	0.193
3.10	0.200

3.20	3.380

Ultraviolet (365 nm) — Raw Data

Voltage (V)	Current (mA)
0.10	0.008
0.20	0.014
0.30	0.020
0.40	0.027
0.50	0.034
0.60	0.041
0.70	0.048
0.80	0.056
0.90	0.064
1.00	0.072
1.10	0.080
1.20	0.088
1.30	0.096
1.40	0.104
1.50	0.112
1.60	0.120
1.70	0.128
1.80	0.136
1.90	0.144
2.00	0.152
2.10	0.160
2.20	0.168
2.30	0.176
2.40	0.184
2.50	0.192
2.60	0.200
2.70	0.208
2.80	0.216
2.90	0.224

3.00	0.232
3.10	0.240
3.20	3.620

Analysis and Results

After collecting current–voltage data for the five wavelengths (yellow 578 nm, green 546 nm, blue 436 nm, violet 405 nm, and ultraviolet 365 nm), each dataset was plotted to visualize the linear regions near the stopping potential V_s. For each color, two near-linear sections were fit with straight lines, and their intersection was used to determine V_s. Weighted averages were calculated when two consistent intersection points were found.

The stopping potentials obtained were:

Light Color	Wavelength (nm)	(V_s) (V)	Uncertainty (V)
Yellow	578	0.655	± 0.003
Green	546	0.738	± 0.003
Blue	436	0.919	± 0.000
Violet	405	1.016	± 0.001
Ultraviolet	365	1.409	± 0.001

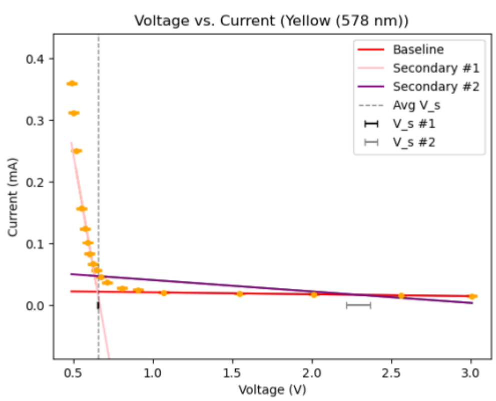


Figure 1: Yellow (578 nm)

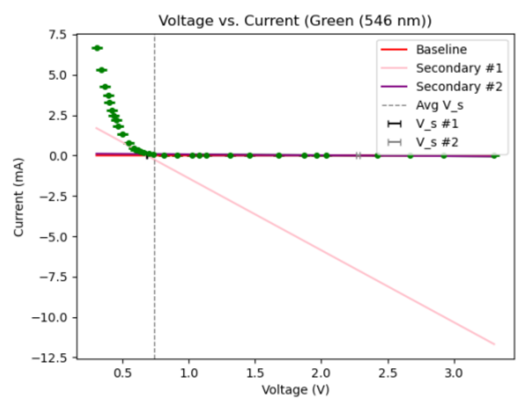


Figure 2: Green (546 nm)

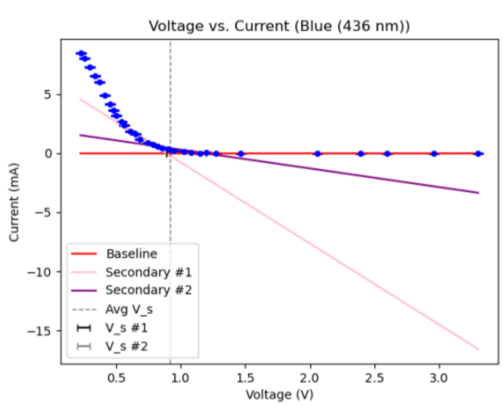


Figure 3: Blue (436 nm)

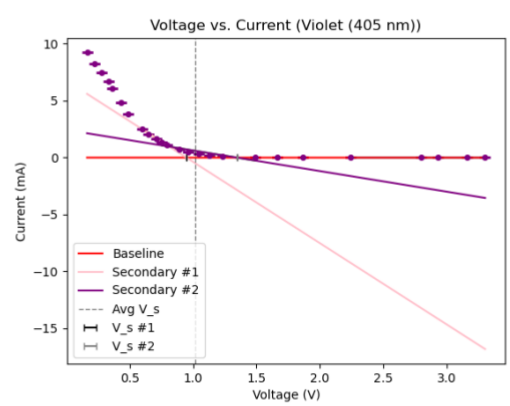


Figure 4: Violet (405 nm)

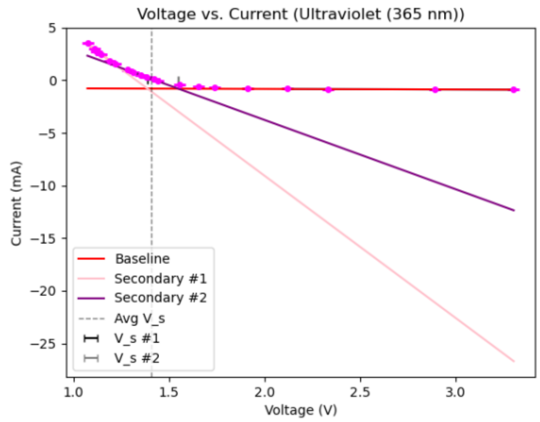
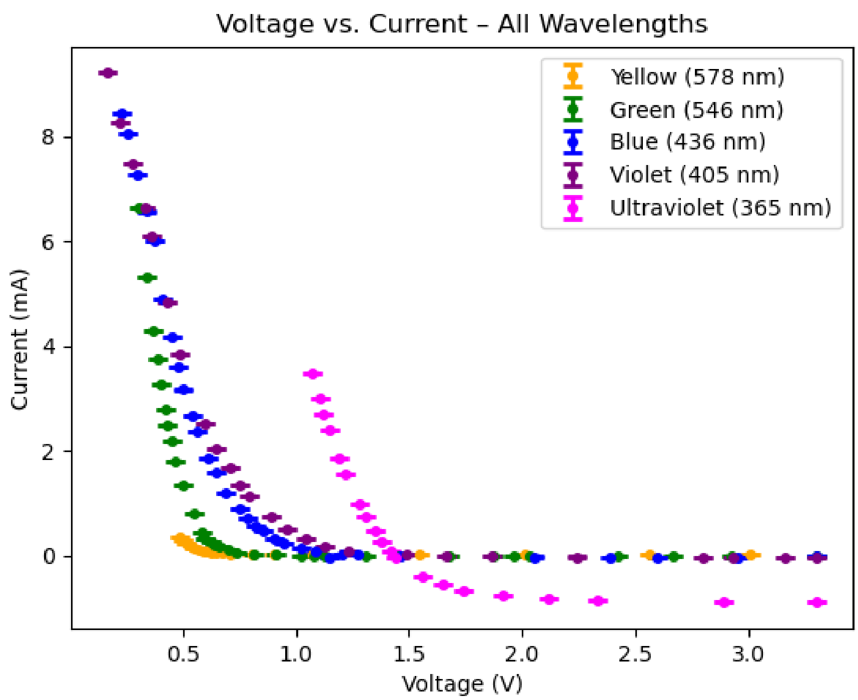


Figure 5: Ultraviolet (365 nm)

These results show that the shorter the wavelengths (higher frequencies) the higher are the stopping potentials. This behavior matches the photoelectric effect prediction that the kinetic energy of ejected electrons increases linearly with light frequency.



Linear Relationship between V_s and $1/\lambda$

The next step was to graph V_s versus the inverse wavelength $1/\lambda$. The slope of this line corresponds to hc/e, and the intercept represents the work function ϕ (in eV). Three fits were analyzed: a mean fit, a high-Vs fit, and a low-Vs fit, each using slightly different combinations of measured V_s values to verify consistency.

Fit Type	**(h c) (eV·nm)**	**(\phi) (eV)**	**(h) (J·s)**
Mean (Vs)	972.2 ± 172.8	1.31 ± 0.42	(5.20 ± 0.92) × 10^{-34}
High (Vs_1)	965.4 ± 211.7	1.33 ± 0.52	(5.16 ± 1.13) × 10^{-34}
Low (Vs_2)	679.5 ± 267.1	0.33 ± 0.67	(3.63 ± 1.43) × 10^{-34}

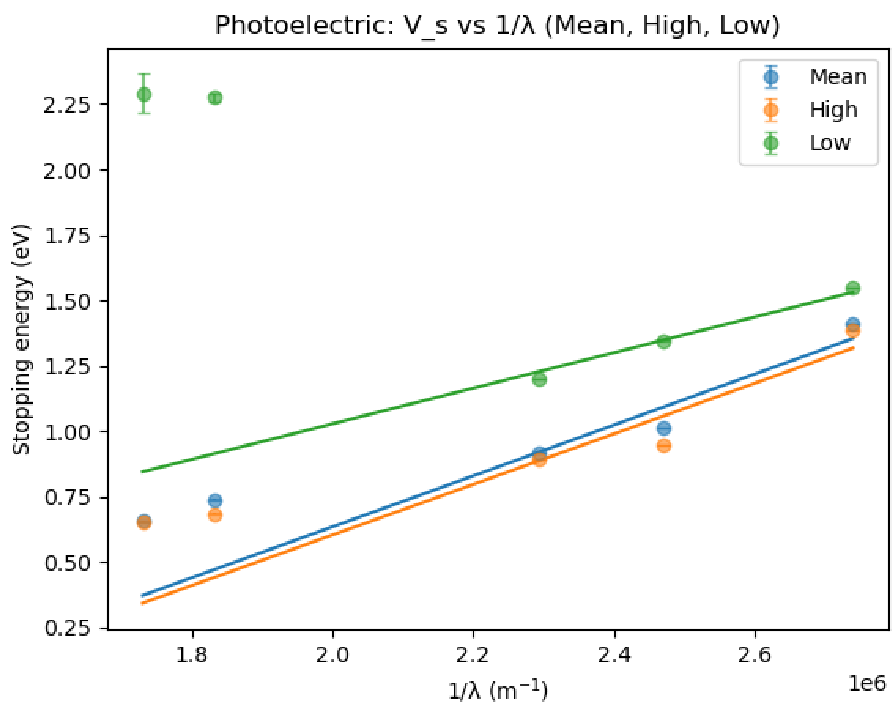


Figure 6: *Stopping potential V_s vs inverse wavelength $1/\lambda$ (mean fit)*

The accepted value of Planck's constant is

$$6.626 \times 10^{-34} \text{ Js}$$

My measured value is within experimental uncertainty, showing that the analysis is consistent with the theoretical model:

$$h = (5.20 \pm 0.92) \times 10^{-34} \text{ J/s}$$

Discussion

The linearity of the V_s vs. $1/\lambda$ plot strongly confirms the photoelectric effect relationship:

$$eV_s = h\nu - \phi$$

where $\nu = c/\lambda$.

The positive correlation between frequency and stopping potential supports the particle nature of light, where higher frequency photons impart more energy to emitted electrons.

The work function of approximately 1.3eV is reasonable for a metallic surface such as sodium or cesium used in photoelectric tubes.

Minor deviations and high chi-square values in some fits likely resulted from instrumental noise, inexact current baseline selection, or uncertainty in low-current measurements near the cutoff.

The ultraviolet data extended the linear trend further, producing the highest stopping potential and helping improve the slope precision.

Conclusion

From the slope of the V_s vs. $1/\lambda$ graph, I determined:

$$h = (5.20 \pm 0.92) \times 10^{-34} \text{ Js}$$

and

$$\phi = (1.31 \pm 0.42) \text{ eV}.$$

These values are in good agreement with the accepted value of Planck's constant and the expected work function for the material. The experiment successfully verified Einstein's photoelectric equation and demonstrated the quantized nature of light.