07 March 2024

Winter 2024

experiment 9

Photoelectric Effect

University of Wollongong in Dubai

SUBMITTED BY:

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PHYS143
Physics for Engineers

Purpose

To study the effect of varying the light intensity, wavelength and frequency have on the energy of the emitted electrons and the magnitude of the photocurrent.

To determine Planck's constant experimentally.

Hypothesis Statement

The stopping voltage and the frequency of light are proportional; as frequency increases, stopping potential increases due to higher energy of the light. However, when wavelength increases, the stopping potential decreases making it inversely proportional to the wavelength of the light. Hence, the value of Planck's constant can be found using the correct formulas.

Materials

- DC Current Amplifier
- DC Power Supply
- Mercury Lamp
- PASCO® 850 Universal Interface
- Photodiode
- Power Supply
- Track

Procedure - Preparation

1. Position the mercury lamp and the photodiode housing onto the track, arranging them as depicted in Figure 1.
2. Switch on the mercury lamp and allow it to warm up for a minimum of 10 minutes. Keep the protective cover in place to prevent direct exposure to the lamp's light.
3. Do not connect any cables or wires to the photodiode at this point.
4. Locate the CURRENT RANGES switch on the DC Current Amplifier and set it to the 10^{-13} A range. Press the calibration button to zero the meter reading. Adjust the knob until the meter displays a reading of 000 A, as illustrated in Figure 2.
5. Press the calibration button and put it in the OUT position for measuring.

   NOTE: From this point forward in the experiment, avoid adjusting any of the knobs or controls on the DC Current Amplifier.

6. On the DC Power Supply, make sure the button is out to select the -4.5 V to 0 V range as shown in Figure 3.
7. Connect the cables to the photodiode:
   a. Connect the special BNC-plug-to-BNC-plug cable between the port marked "K" on the photodiode enclosure and the BNC jack on the DC Current Amplifier.
   b. Connect the red banana-plug patch cord between the port marked "A" on the photodiode enclosure and the red banana jack on the right side of the DC Power Supply.
   c. Connect the black banana-plug patch cord between the black banana jack on the photodiode enclosure and the black banana jack on the right side of the DC Power Supply.

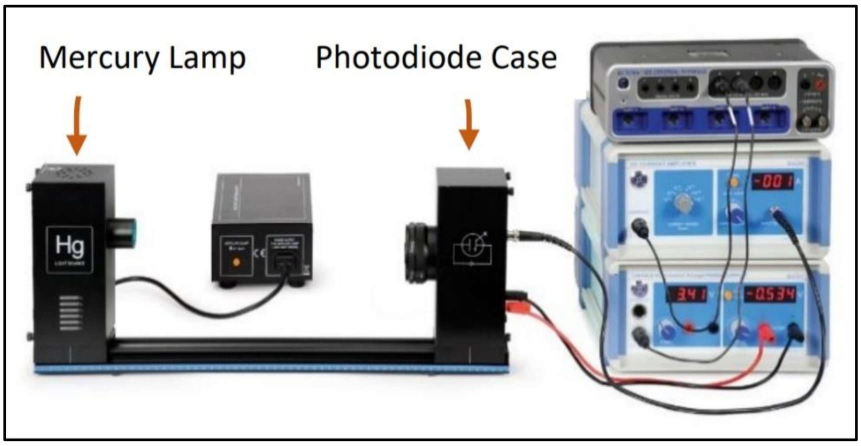

Figure 1: Experimental set-up

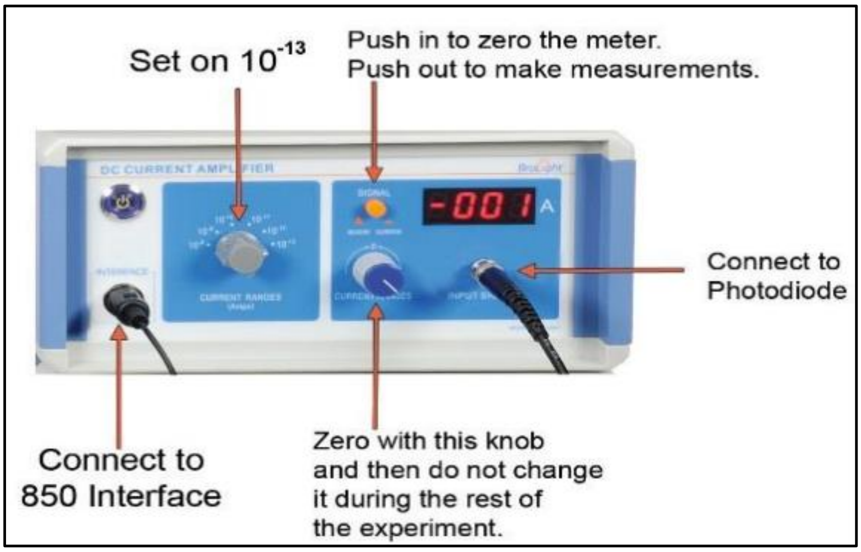

Figure 2: Current Amplifier settings

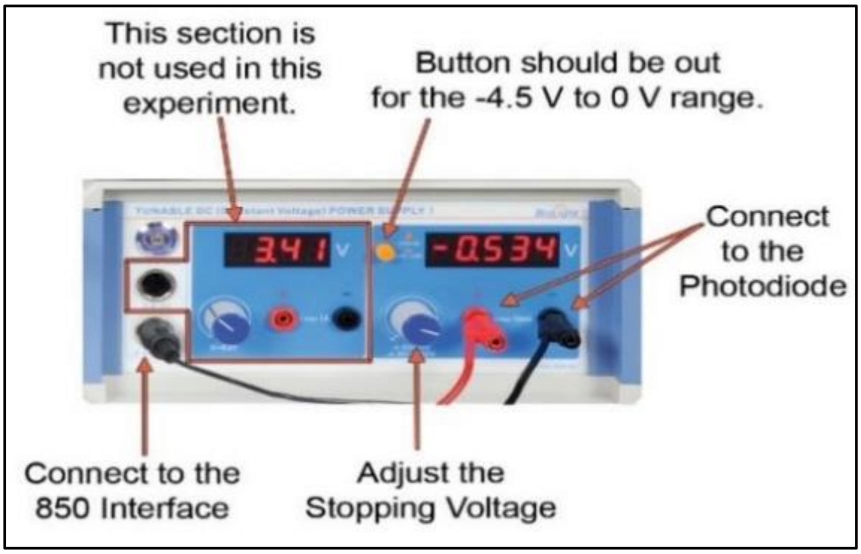

Figure 3: DC Power Supply settings

Procedure - Measurements

1. Uncover the window of the photodiode enclosure. Adjust the dials to a 4mm diameter aperture and 365nm filter for the window of the enclosure.
2. Uncover the window of the Mercury Light Source. Spectral lines of wavelength 365nm will shine on the cathode in the phototube.
3. Turn the VOLTAGE ADJUST knob on the DC power supply till the current on the DC current amplifier is zero.
4. Record the magnitude of the stopping potential for the 365nm wavelength.
5. Repeat the measurements for other wavelengths and apertures. Record the magnitude of the stopping potential for each.

Data, Graphs & Calculations

Item	1	2	3	4	5
Wavelength, λ (nm)	365.0	404.7	435.8	546.1	577.0
Frequency, $v=c/\lambda$ (x 10^{14} Hz)	8.214	7.408	6.879	5.490	5.196
Stopping Potential, V (V)	1.836	1.576	1.384	0.884	0.771

Table 1: Stopping Potential of Spectral Lines, 4mm diameter aperture

Item	1	2	3	4	5
Wavelength, λ (nm)	365.0	404.7	435.8	546.1	577.0
Frequency, $v=c/\lambda$ (x 10^{14} Hz)	8.214	7.408	6.879	5.490	5.196
Stopping Potential, V (V)	1.841	1.678	1.406	0.912	0.787

Table 2: Stopping Potential of Spectral Lines, 2mm diameter aperture

Item	1	2	3	4	5
Wavelength, λ (nm)	365.0	404.7	435.8	546.1	577.0
Frequency, $v=c/\lambda$ (x 10^{14} Hz)	8.214	7.408	6.879	5.490	5.196
Stopping Potential, V (V)	1.806	1.572	1.389	0.880	0.761

Table 3: Stopping Potential of Spectral Lines, 8mm diameter aperture

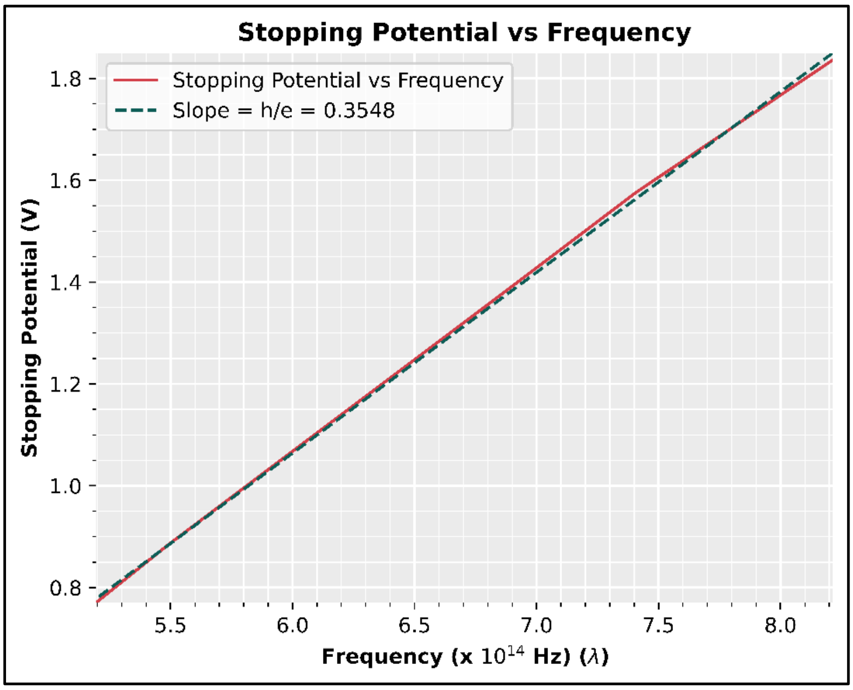

Figure 4: Stopping Potential vs Frequency; Aperture = 4 mm

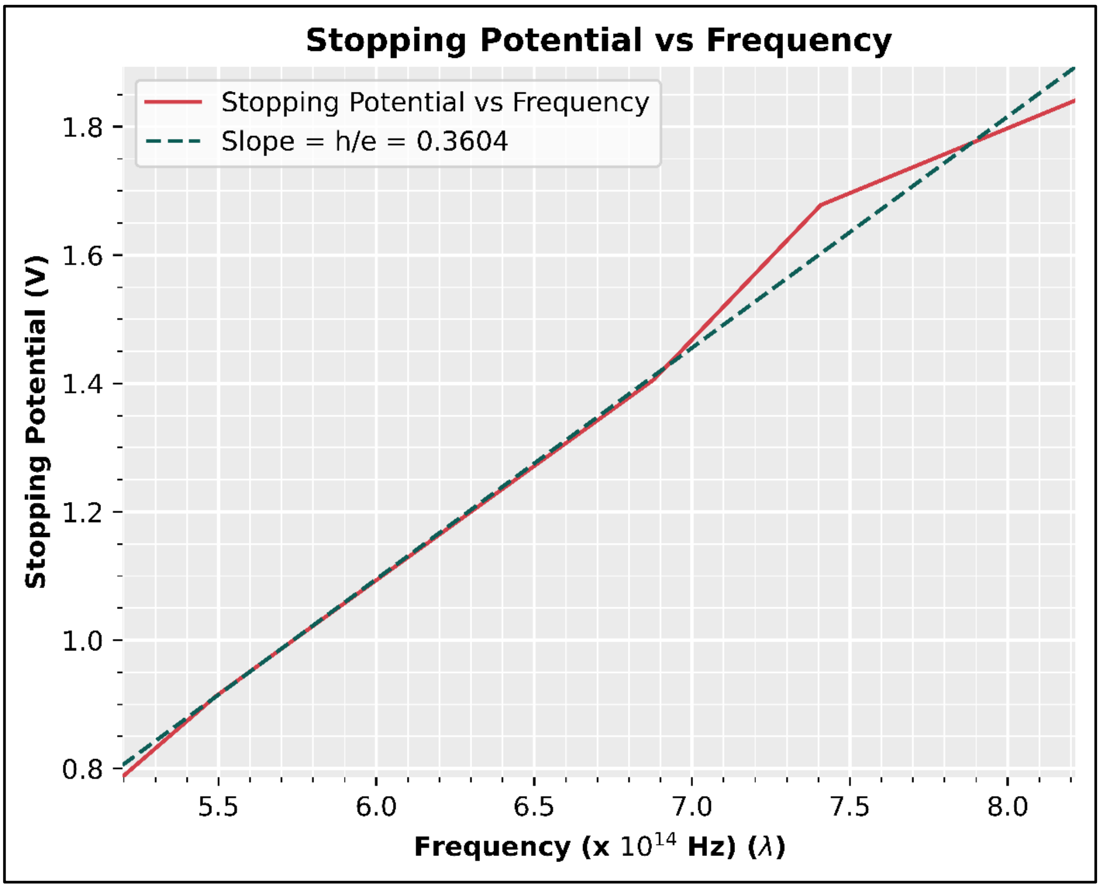

Figure 5: Stopping Potential vs Frequency; Aperture = 2 mm

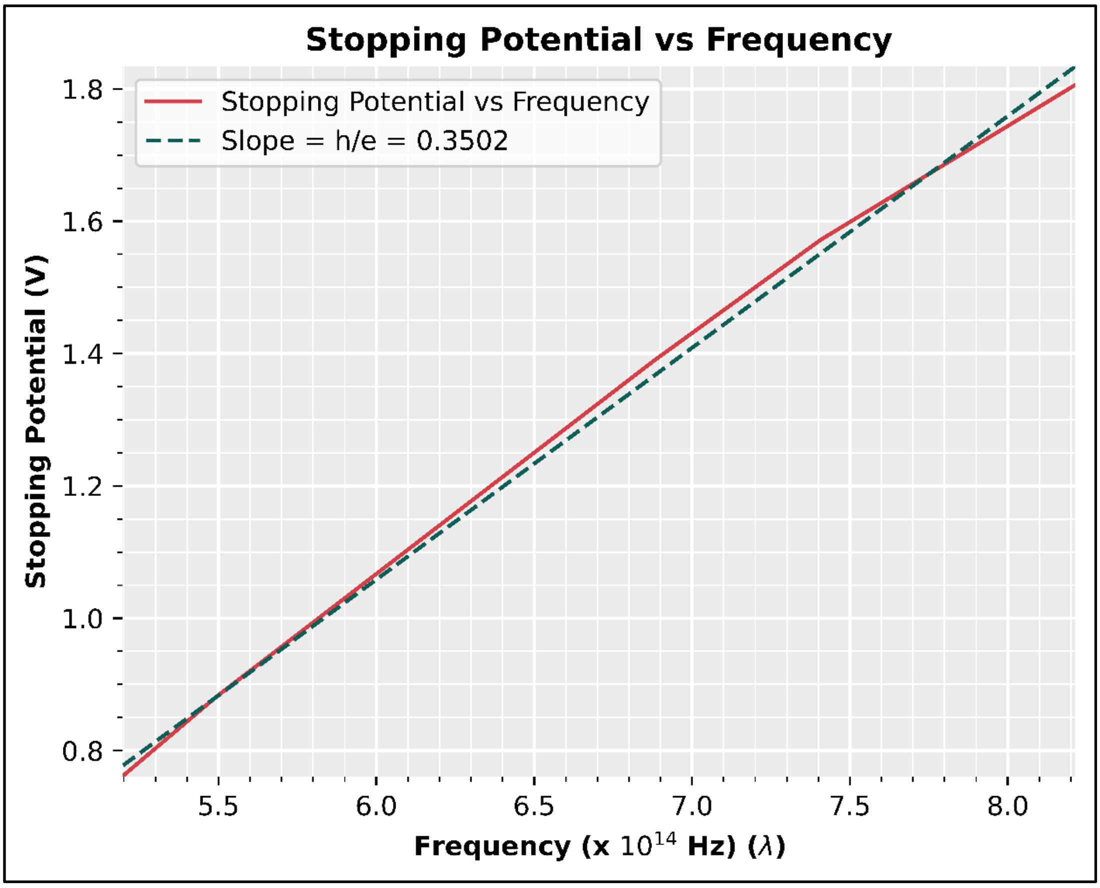

Figure 6: Stopping Potential vs Frequency; Aperture = 8 mm

h = e × slope

$h_0 = 6.626 \times 10^{-34}$ J s

Aperture = 4 mm

Slope = 0.3548×10^{-14}

h = $(1.602 \times 10^{-19}) \times (0.3548 \times 10^{-14}) = 5.6839 \times 10^{-34}$ J s

Percentage Difference = $\left|\frac{h - h_0}{h_0}\right| \times 100 = 14.218\%$

Aperture = 2 mm

Slope = 0.3604×10^{-14}

h = $(1.602 \times 10^{-19}) \times (0.3604 \times 10^{-14}) = 5.7752 \times 10^{-34}$ J s

Percentage Difference = $\left|\frac{h - h_0}{h_0}\right| \times 100 = 12.8403\%$

Aperture = 8 mm

Slope = 0.3502×10^{-14}

h = $(1.602 \times 10^{-19}) \times (0.3502 \times 10^{-14}) = 5.6102 \times 10^{-34}$ J s

Percentage Difference = $\left|\frac{h - h_0}{h_0}\right| \times 100 = 15.3305\%$

Observations

During the experiment, we examined the spectral lines of different wavelengths emitted by a mercury lamp and allowed them to strike the photodiode casing. As we methodically adjusted the wavelengths, we noticed a clear trend: the measured stopping potential reading gradually decreased as we used light with progressively greater wavelengths. This finding clearly supported our initial hypothesis, providing conclusive proof that the proportionality between the stopping voltage and the wavelength of the incident light is inverse in nature, which is consistent with the fundamental principles underlying the photoelectric effect.

We further repeated the same experimental procedure, but this time we included an essential variation: the size of the aperture through which light passes before reaching the photodiode. We attempted to calculate a theoretical value for Planck's Constant (*h*) by graphing the findings for each aperture size (2mm, 4mm, and 8mm). Our study found that the 2mm aperture produced a theoretical value of (5.7752×10^{-34} J s) for Planck's Constant, indicating more precision than the other two aperture sizes. The percentage discrepancy between this theoretical value and the actual Planck's Constant (h_0) was just 12.8%, which was substantially smaller than the deviations observed for the 4mm and 8mm apertures.

Analysis Questions

1. **How does your calculated value of *h* compare to the accepted value?**
   The calculated value of h with respect to 4mm aperture was 5.6839 × 10^{-34} J s in comparison to the actual value, which is 6.626 × 10^{-34} J s. There is a percentage error of around 14.2%.

2. **What do you think may account for the difference – if any – between your calculated value of *h* and accepted value?**
   Experimental errors may account for the difference between the calculated and accepted value of h. Other unaccounted factors and systematic errors may also play a role.

3. **How can you find out the value of Work Function from the graph of the Stopping Potential versus Frequency?**
   The work function is given by the y-intercept (c) of the slope divided by e. In other words, $\frac{c}{e}$

4. **How does your calculated value of *h* for each different aperture compare to the accepted value, $h_0 = 6.626 \times 10^{-34}$ *J s*?**
   The calculated value of h for the 2mm aperture is 5.7752 × 10^{-34} J s whereas for the 8mm aperture the value is 5.6102 × 10^{-34} J s. This is compared to the accepted value of h= 6.626 × 10^{-34} J s. Both the values are similar to the accepted value, and the percentage of error for both are minimal.

5. **How does light intensity affect the Stopping Potential?**
   The intensity and number of incident photons have no effect on the stopping potential. However, the frequency of the incident light determines the stopping potential. The higher the frequency of the incident light, the higher the stopping potential.

Conclusion

1. **What was the purpose of this lab?**

This lab's purpose was to study the effect of varying the light intensity, wavelength, and frequency on the energy of the emitted electrons and the magnitude of the photo-current and determine Planck's constant through the experiment.

2. **How does the lab we performed relate to what we are studying in class?**

The theory and concepts taught in class rely heavily on the photocurrent and energy of electrons. They also review the relationship between stopping voltages and frequencies of light. This lab experiment has provided us with practical and in-lab experience to determine Planck's constant and the effects of variations of certain units on emitted electrons.

3. **Give a brief recap of the procedure used.**

The procedure starts with setting up a photodiode enclosure and a Mercury Light Source, enclosed with the protective cover, to measure stopping potentials for various wavelengths. After the Mercury light source heats up, we uncover it to allow specific wavelengths to shine on the phototube's cathode. We then adjust the voltage and ensure zero current on the DC current amplifier. Finally, we repeat the process for different wavelengths, and systematically record the stopping potential values for each for aperture.

4. **What problems did you have during the lab? Did you have to modify your procedure?**

Fortunately, there were no problems during the lab as the experimental results matched the theoretical results. Hence, there was no need to modify the procedure.

5. Do your results make sense? What are the sources of error?

Yes, the results make sense as it matched the theory taught in class. Potential factors that could introduce errors include the lighting of the room, the response time of the equipment to record the data and human error in recording values due to fluctuations. These sources of error could also possibly be the reason for the outlier in Figure 5 at a frequency of 7.4×10^{14} Hz.

6. What did you learn from this lab?

This lab has laid a strong basis for the understanding of the effects of varying light intensity, wavelength, and frequency on the energy of the emitted electrons and magnitude of photocurrent. It has also provided us with real-life understanding of the concepts taught in the lecture.

7. If you were to repeat this lab in the future, how would you modify or improve the procedure?

If we were to repeat this experiment again in the future, we will exercise greater caution with the calibration of the equipment as outlined in the preparation part, ensure the mercury lamp is hot enough to begin the experiment, and carefully turn the knobs to get accurate readings for current to prevent any outliers.

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