Faculty of Science
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Laboratory Report Cover Page

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Lab/Tutorial Report No.	Lab Experiment #1

Report Title	Lab 1 - The Photoelectric Effect

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Appendices

Introduction

This laboratory experiment primarily focuses on investigating the photoelectric effect, a phenomenon in which the properties of light, such as its intensity (frequency) and wavelength (colour), lead to the emission of electrons from a surface, typically a metal. Prior to Einstein's groundbreaking discoveries, the prevailing scientific consensus held that light propagated as a wave. According to this wave theory, it was assumed that the greater the intensity (brightness) of light, the more energetic the emitted electrons would be. However, Albert Einstein introduced a revolutionary concept, proposing that light consisted of discrete packets of energy known as photons. He further suggested that the energy of emitted electrons was directly linked to the wavelength (colour) of these light particles. In this meticulously designed experiment, we aim to investigate and analyze the intricate interplay between photons and electrons under carefully controlled experimental conditions. By doing so, we seek to gain a deeper understanding of how an electric field and incident light influence electrons' precise movement and behaviour.

Theory

Light can eject electrons from materials, usually metal, when it strikes them. This is known as the photoelectric effect, which states that light generates electricity. The intensity (frequency) and the wavelength (color) do affect the ejection of electrons. The minimum work function required to release electrons is defined as $\varnothing$. In the photoelectric effect, the energy is conserved hence the following equation represents the energy throughout this process:

$$E_{\text{light}} = Ke + \varnothing$$

E is the energy of light which was used to release a single election while the work function (*light* $\varnothing$) is the minimum energy required to release electrons from the metal material. A photon is a light molecule. Each photon contains a quantum of energy E and travels at the speed of light. Only frequency f affects a photon's energy. Furthermore, a photon's energy is:

$$Ef = hf = Ef \;=\; hf \;=\; hc/\lambda$$

where “h” is Planck’s constant and λ is the wavelength. When an electron gets the energy E from a photon, its energy balance is the following equation:

$$Kmax = hf - \varnothing$$

K is the kinetic energy of a photoelectron that leaves the metal e material's surface. The electromagnetic wave (light wave) that struck the metal material supplied the kinetic energy. A photoelectron travels through the electric potential between the electrodes, and as a result, its energy changes by $q\Delta V$ where $q = -e$ and ΔV is the potential difference.

$$\triangle K + \Delta U = 0$$

$$Kf + Ke - e\Delta Vstop = 0$$

$$Elight = e\Delta Vstop - \varnothing$$

The maximum kinetic energy that a photoelectron can have in the presence of the stopping potential, ΔV , is its starting *stop* kinetic energy, which it retains at the photoelectrode's surface. $Ke = \Delta Vstop$

Procedure

To execute the experiment, a list of required materials, are outlined below:

Materials:

- PASCO photoelectric apparatus
  - (Mercury vapor light source, light block, photodiode apparatus, coupling bars, grating and lens assembly)
- Digital Multimeter
- Banana plug Red and black cables (2)
- Magnetic yellow and green filters (for yellow/green lines) (2)

Step by Step Process:

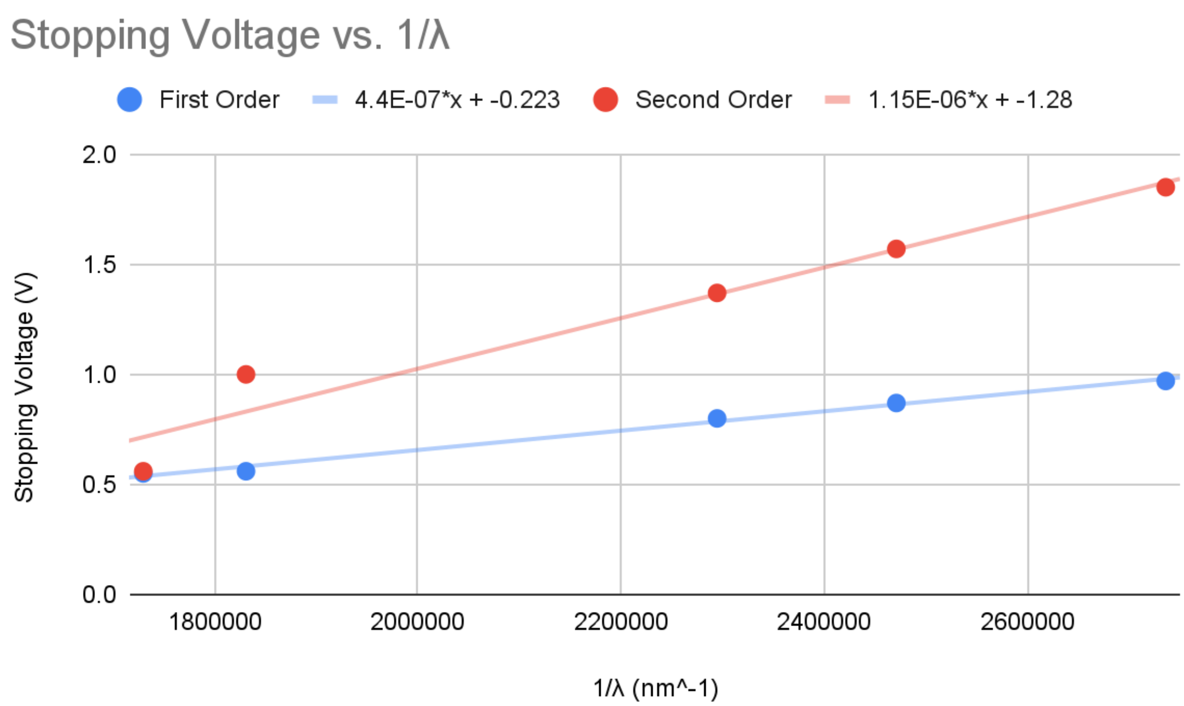
1. Warm up the mercury vapour light source for 5 minutes.
2. Turn on the multimeter, connect cables for DC voltage measurement (V and COM), and set it to measure DC voltage.
3. Check photodiode apparatus battery: (Health of battery to minimize uncertainties)
   - (a) Plug the black cable into the ground terminal.
   - (b) Plug red cable into "+6V MIN" terminal; if <6.0V, replace battery.
   - (c) Plug red cable into "-6V MIN" terminal; if >-6.0V, replace battery.
4. Connect cables to "OUTPUT" terminals on the photodiode apparatus (red to red, black to black).
5. Observe the mercury light spectrum by placing your hand close to the lens; focus on the brighter side. ***Only take measurements on the brighter side**
6. Align the photodiode apparatus across from the lens/grating; adjust the lens/grating for sharp focus.
7. Position one wavelength directly on the photodiode apparatus opening.
8. Remove the light shield and ensure only one light colour enters the photodiode apparatus. Adjust angles if needed.
9. Once a single wavelength is well-positioned and focused, replace the light shield.
10. Attach magnetic filters to filter out unwanted wavelengths for yellow or green lines.
11. Measure stopping potential using the multimeter. Wait for stabilization. Use the "PUSH TO ZERO" button to record data with uncertainty for subsequent measurements.
    - **Note:** During our Experiment multimeter was set to **20 V** to ensure a suitable measurement scale for recording the stopping voltage.
12. Repeat steps 7 - 11 for all visible lines on the bright side, recording light colour and stopping voltage for each (First and Second Order).
13. Switch off all apparatus components when done, including the photodiode apparatus.

* **Note:** Ensure that you follow all safety precautions and laboratory guidelines during the experiment.

Results and Calculations

Light Colour	Wavelength	$\frac{1}{\lambda}$	V_{stop} Iteration #1: (First Order)	V_{stop} Iteration #2 (Second Order)
Yellow	578.0 nm	1730103.806	0.55 ± 0.005 V	0.56 ± 0.005 V
Green	546.1 nm	1831166.453	0.56 ± 0.005 V	1.00 ± 0.005 V
Blue	435.8 nm	2294630.564	0.80 ± 0.005 V	1.37 ± 0.005 V
Blue/Violet	404.7 nm	2470966.148	0.87 ± 0.005 V	1.57 ± 0.005 V
Dark Violet	365.5 nm	2735978.112	0.97 ± 0.005 V	1.85 ± 0.005 V

Table 1.0



Speed of Light: $c = 3 \times 10^{8} m/s$

Charge of Electron: $|e| = 1.602 \times 10^{-19} coulombs$

Planck's Constant: $h = 6.63 \times 10^{-34} J \cdot s$

Δz = uncertainty in h z = h
Δy = uncertainty of c y = c
Δx = slope uncertainty x = slope

First Order:

$slope = \frac{V}{\lambda^{-1}} = 4.4 \times 10^{-7}$

$h = \frac{e(slope)}{c} = \frac{(1.602\times10^{-19})(4.4\times10^{-7})}{3\times10^{8}} = 2.350 \times 10^{-34}$

$Uncertainty = z\sqrt{(\frac{\Delta x}{x})^2 + (\frac{\Delta y}{y})^2} = 2.350 \times 10^{-34}\sqrt{(\frac{0.5 \times 10^{-9}}{4.4\times10^{-7}})^2 + (\frac{0}{3\times10^{8}})^2} = \pm 2.67 \times 10^{-37}$

$\%error = \left|\frac{measured-accepted}{accepted}\right| \times 100 = \left|\frac{2.350\times10^{-34}-6.63\times10^{-34}}{6.63\times10^{-34}}\right| \times 100 = 65\%$

$y\ intercept = \phi = -0.223\ eV$

Second Order:

$slope = \frac{V}{\lambda^{-1}} = 1.15 \times 10^{-6}$

$h = \frac{e(slope)}{c} = \frac{(1.602\times10^{-19})(1.15\times10^{-6})}{3\times10^{8}} = 6.14 \times 10^{-34}$

$Uncertainty = z\sqrt{(\frac{\Delta x}{x})^2 + (\frac{\Delta y}{y})^2} = 6.14 \times 10^{-34}\sqrt{(\frac{0.5 \times 10^{-9}}{1.15\times10^{-6}})^2 + (\frac{0}{3\times10^{8}})^2} = \pm 2.67 \times 10^{-37}$

$\%error = \left|\frac{measured-accepted}{accepted}\right| \times 100 = \left|\frac{6.14\times10^{-34}-6.63\times10^{-34}}{6.63\times10^{-34}}\right| \times 100 = 7.4\%$

$y\ intercept = \phi = -1.28\ eV$

Discussion

Q1.) [Results & Calculations] In your data set, you should have observed the stopping voltage for each color twice (once for a bright first order line, and once for a dim second order line). Was the stopping voltage significantly different for the bright line as opposed to the dim line of the same colour? Comment on your observations.

- Based on our observations, the difference in stopping voltages between the bright lines and dim lines seemed to increase as we moved towards the colours with the smaller wavelengths. This would imply that the intensity of light has an effect on its stopping voltage. The brighter the light, the less its stopping voltage would increase as the wavelength decreases.

Q2.) [Results & Calculations] Does your answer to the previous question support the wave model of light, or the Einstein/Planck model of light? Explain. (Re-read the pre-lab questions if necessary)

- The above answer contradicts the wave model of light, as it is commonly known that the intensity of light has no effect on its stopping voltage. However, in Table 1.0, it is shown that maximum kinetic energy is inversely proportional to the wavelength of a lightwave. We also know that the maximum kinetic energy is equal to the stopping voltage, which means that the stopping voltage and energy of light is related to its colour/wavelength, not its intensity, proving the wave model of light.

Q3.) [Discussion] The threshold frequency is the minimum frequency of light needed to release electrons from a material. Determine the threshold frequency for this apparatus. What is the associated threshold wavelength (the longest wavelength which releases electrons from the apparatus)? Quote your result with uncertainty. (You may need to review the rules for propagating uncertainty)

- The threshold frequency is known as the minimum frequency of light which is required to release an electron from a material. It can be calculated using a rearranged equation. We first need to calculate the energy which can be done with $E = \frac{hc}{\lambda}$. The energy will vary as it is dependent on the wavelength.We now start off with the following equation, E = hf, where “E” is the energy, “h” is Planck constant and “f” frequency. We can rearranged this to solve for “f” value which is the threshold frequency, $f = \frac{E}{h}$. In order to calculate the threshold wavelength, we must use $E = \frac{hc}{\lambda}$ and rearranged the equation hc of to $\lambda = \frac{hc}{E}$. The following chart displays the energy, minimum frequency and the threshold wavelength.

Light	Threshold Wavelength (nm)	Energy (J)	Threshold Frequency (f)
Color	$\lambda = \frac{he}{E}$	$E = \frac{he}{\lambda}$	$f = \frac{E}{h}$
Yellow	578.0 nm ± 0.005	2.145	5.18×10^{14}
Green	546.1 nm ± 0.005	2.271	5.49×10^{14}
Blue	435.8 nm ± 0.005	2.845	6.88×10^{14}
Blue/Violet	404.7 nm ± 0.005	3.064	7.40×10^{14}
Dark Violet	365.5 nm ± 0.005	3.392	8.20×10^{14}

Table 2.0

Q4.) [Discussion] Einstein hypothesized that light comes in packages of energy hf called photons. Does that mean that a bright light of a certain wavelength has the same total energy as a dim light of the same wavelength? Using the concept of photons, explain the difference between a bright light and a dim light

- According to Einstein's model of light, photons are discrete packets of energy that collectively form a wave, which we perceive as light. Applying this concept, a less intense light source would consist of fewer photons, resulting in lower energy than a brighter light source characterized by a higher photon concentration. Consequently, if two light beams of identical wavelength (color) were examined, their total energy values would differ due to variations in photon concentration.

Conclusions

The goal of this experiment was to better understand the photoelectric effect. Two experiments were conducted, one using brighter light (First Order) and one using dimmer light (Second Order), where we would see how the stopping voltage would change as we tested with different wavelengths. We thought of how we could graph these measurements to calculate Planck's constant (h) from the slope using the equation $\Delta V_{stop} = \frac{hc}{e}\frac{1}{\lambda} - \frac{\phi}{e}$. After completing this lab experiment, we were able to get a value for h that was very close to the accepted value, with our percent errors being 65% for first order and 7.4% for second order. Discrepancies could have been caused by other light sources not being filtered out or faulty equipment. We also concluded that the stopping voltage of light is inversely proportional to its wavelength/colour. Overall, this lab was a success and helped us better understand the photoelectric effect phenomenon.

References

W. Moebs, S. J. Ling, and J. Sanny, "university physics volume 1," OpenStax, 19-Sep-2016. [Online]. Available: https://openstax.org/books/university-physics-volume-1. [Accessed: 23-Sept-2023].