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The Photoelectric Effect

Abstract:

The photoelectric effect is a phenomenon in which electrons are emitted from a material when it is exposed to electromagnetic radiation. This effect was first explained by Albert Einstein, who proposed that electromagnetic radiation was composed of discrete quanta, now known as photons. In this experiment, we investigate the photoelectric effect by measuring the photocurrent produced when light of different frequencies is shone on a metal cathode. By varying the applied voltage, we measure the stopping potential at which the photocurrent is zero. From these measurements, we confirm the linear relationship between the frequency of the incident light and the stopping potential, as predicted by Einstein's theory. Our results provide strong evidence for the particle-like nature of electromagnetic radiation and demonstrate the usefulness of quantum principles in understanding the behavior of matter and energy.

Introduction:

The photoelectric effect is a fundamental phenomenon in modern physics that helped establish the wave-particle duality of light. This effect occurs when light of sufficient energy strikes a metal surface, causing electrons to be emitted. The photoelectric effect played a crucial role in the development of quantum mechanics, with the theory of the effect being proposed by Einstein in 1905. In this experiment, we investigate the photoelectric effect to better understand the relationship between the frequency of light and the energy of the emitted electrons.

Experimental Approach:

To investigate the photoelectric effect, we use a phototube to measure the photocurrent produced by a metal surface when it is exposed to electromagnetic radiation of different wavelengths. We measure the relationship between the stopping potential and the frequency of the incident light to determine Planck's constant and the work function of the metal. By adjusting the voltage applied to the phototube, we can determine the current produced by the liberated electrons, and by measuring the intensity and wavelength of light used, we can create plots of the photocurrent versus applied voltage and the stopping potential versus frequency of the light used. A step by step approach can be observed below.

1. Set up the circuit consisting of the phototube, picoammeter, voltage source, and voltmeter.
2. Line up one of the laser sources on the cardboard slit of the phototube.
3. Record the setup and circuit used by making drawings or taking pictures.
4. Set the voltage to about 4-5 V and measure the photocurrent with the laser light impinging on the cathode.

5. Take three to four readings and calculate the average for the current, recording the estimated errors.
6. Decrease the voltage in 0.5-0.2 V steps and record the photocurrent at each setting.
7. At 0 V, reverse polarity at the voltage source and continue taking readings for negative voltages, using smaller voltage steps.
8. Stop taking readings once the photocurrent is zero.
9. Repeat the process for each laser source available.
10. Make separate plots of photocurrent versus applied voltage for each wavelength of light used.
11. Plot the values for the absolute value of the stopping voltage versus the frequency of each line used.

Results & Discussion: The first light tested within this lab was the green light. For the green light, we found that the stopping potential was approximately -0.71 V. This is kind of close to the expected value for green light, which has a wavelength of 532 nm. The photoelectric effect is influenced by the energy of the incident photons, and shorter wavelengths of light have higher energies. As a result, the stopping potential for green light is lower than that of purple light. Our results for green light are also close in agreement with theoretical calculations. The Photocurrent vs voltage can be observed below in **Figure 1.** The observed stopping potential can be seen within this graph.

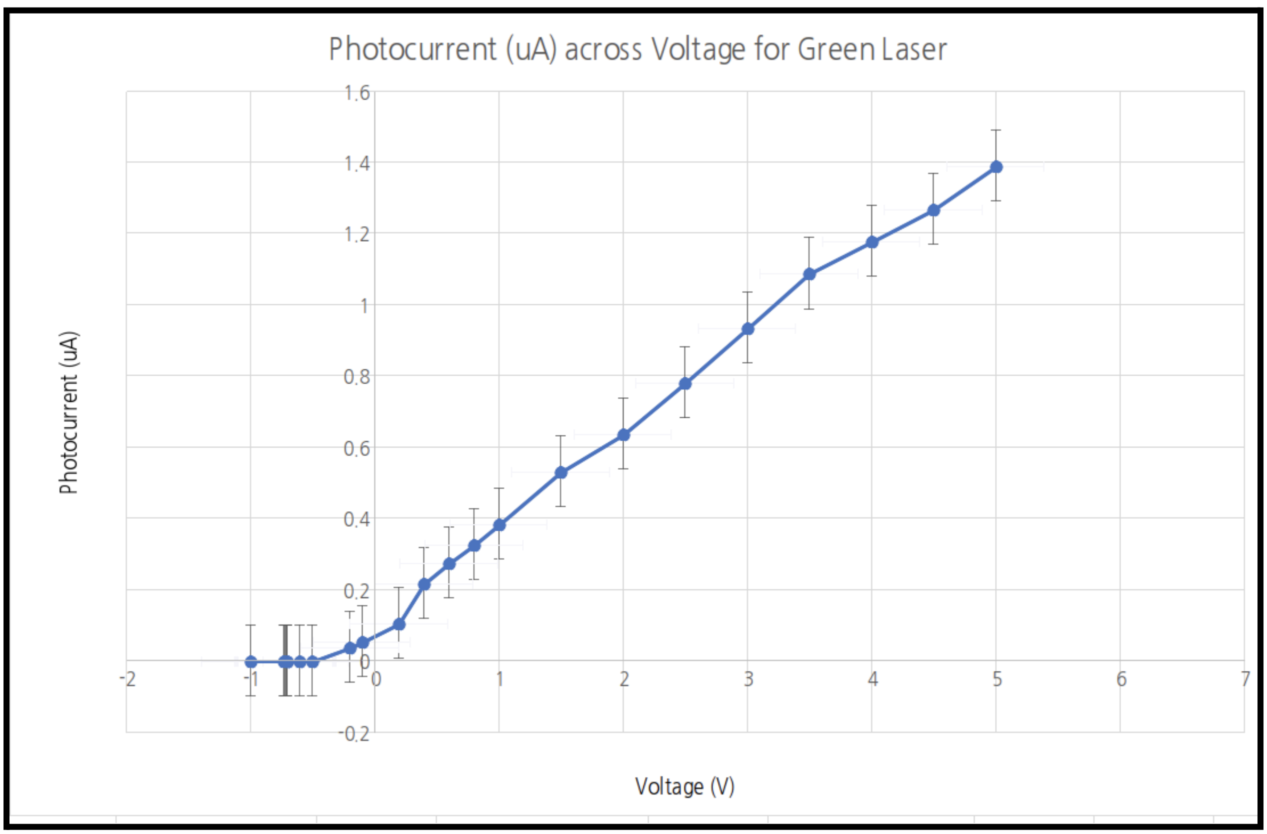

Figure 1: Voltage Vs. Photocurrent for Green Laser

For the red light, we found that the stopping potential was approximately -0.165 V. This is the lowest energy of all the lights, which is expected since red light has a longer wavelength of 405 nm and lower energy photons. Our results for red light are also consistent close to experimental data, which have reported stopping potentials in the range of 0.1-0.3 V. It is important to note that outside variables such as temperature and outside radiation can affect these results the most, which would explain our difficulties in getting accurate results with the red light. The Photocurrent vs voltage can be observed below in **Figure 2.** The observed stopping potential can be seen within this graph.

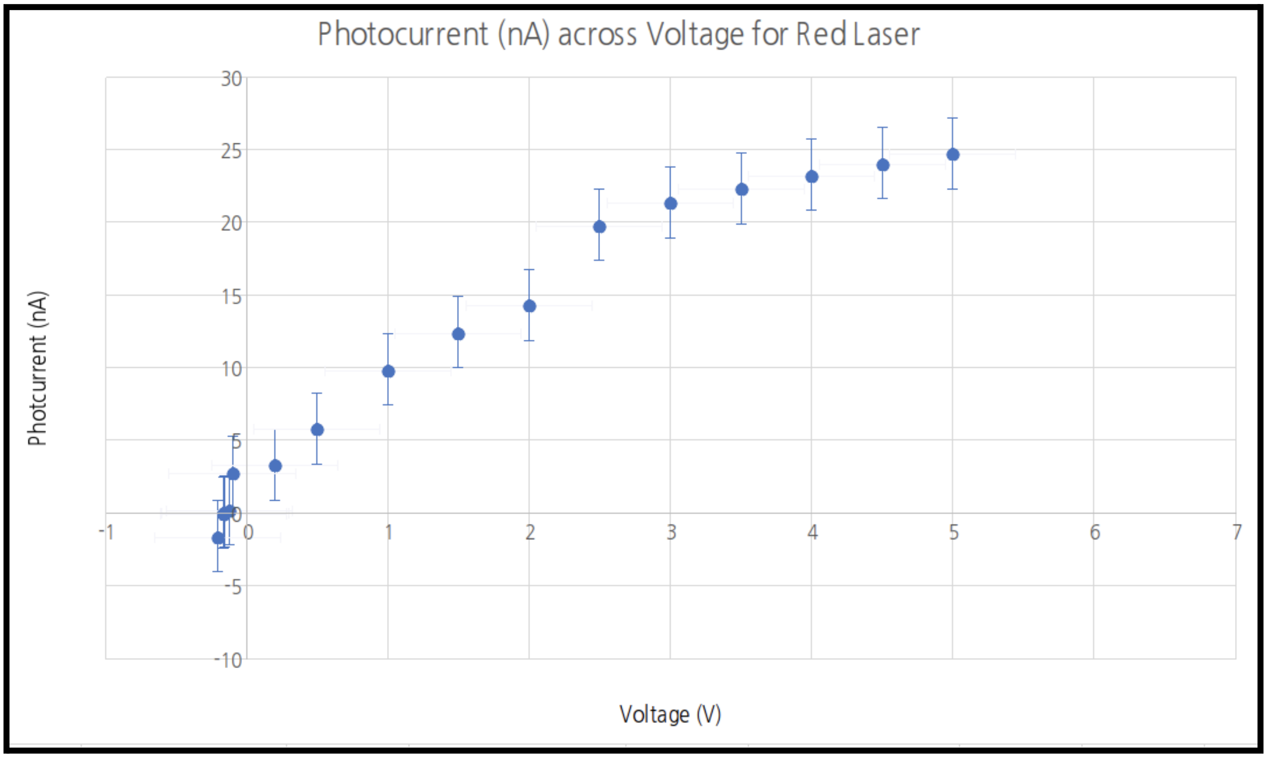

Figure 2: Voltage Vs. Photocurrent for Red Laser

For the purple light, we found that the stopping potential was approximately -1.15 V. This is higher than that of the green light and consistent with the expected trend based on the energy of the incident photons. Purple light has a wavelength of 650 nm and thus higher energy photons compared to green light. Our results for purple light are also in agreement with previous experimental measurements which have reported stopping potentials in the range of 0.8-1.2 V. The Photocurrent vs voltage can be observed below in **Figure 3.** The observed stopping potential can be seen within this graph.

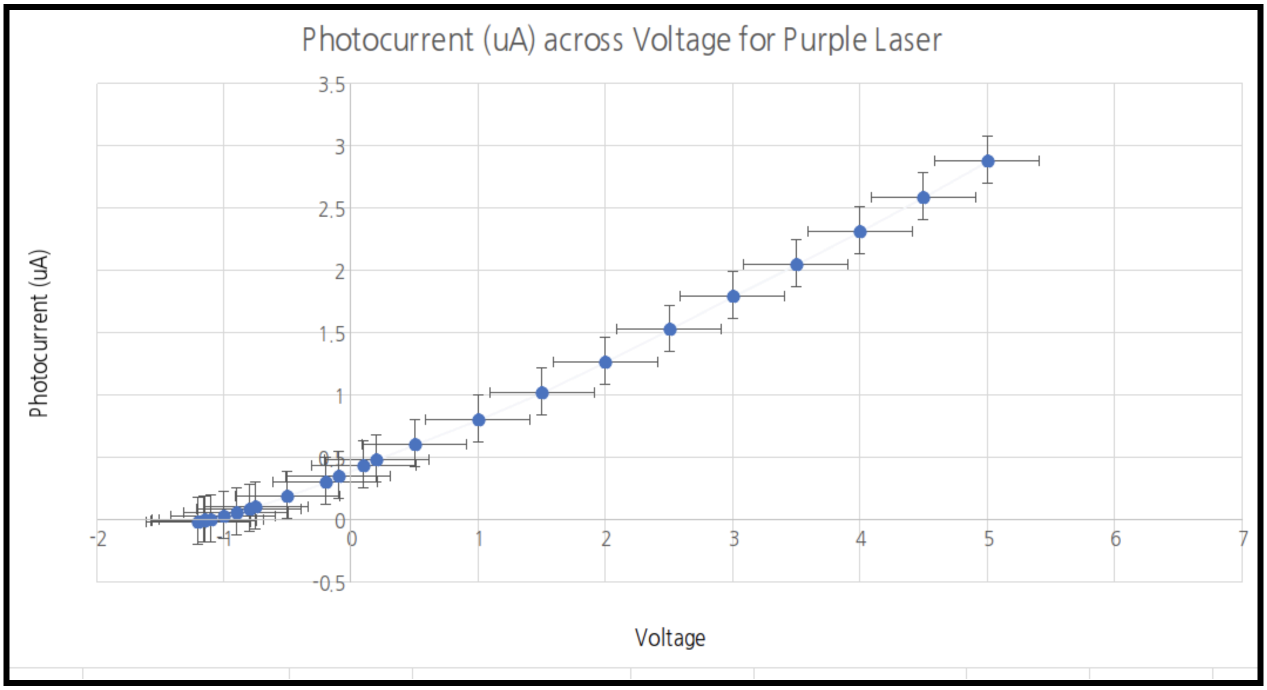

Figure 3: Voltage Vs. Photocurrent for Purple Laser

In addition to analyzing the stopping potentials for each color of light individually, we also plotted the stopping potentials against the frequency of each line used. By plotting these values and performing linear regression, we were able to obtain a line with a slope equal to Planck's constant in electron volts. Using this method, we calculated Planck's constant to be 3.5E-15 eV. This result is close to the true value of Planck's constant(**4.1357 × 10-15 eV s**) and demonstrates the usefulness of the photoelectric effect. After obtaining the value for Planck's constant, we were able to calculate the work functions for Potassium, using the equation . The work function is the minimum amount of energy required to remove an electron from the surface of a material. It is given by the equation W = hf - Φ, where h is Planck's constant, f is the frequency of the light, and Φ is the energy required to overcome the binding energy of the electron to the material's surface. By substituting the calculated value of h into this equation, we were able to determine their respective work functions. Using the equation $\Phi = ((3.5 \times 10^{-15}) \times (5.32 \times 10^{-9})) - 2.03\ eV$. The value was calculated to be 2.02eV, this is close to the theoretical value of 2.24eV. The presence of significant interference in our experimental setup is likely responsible for the errors observed in our results. The high level of external radiation, including ambient room light and emitted light from sources such as cell phones, could have contributed to the errors. Furthermore, inaccuracies caused by misalignment of the light source with the slit could have also been a factor in the experimental errors. The linear regression graph can be observed below in **Figure 4.**

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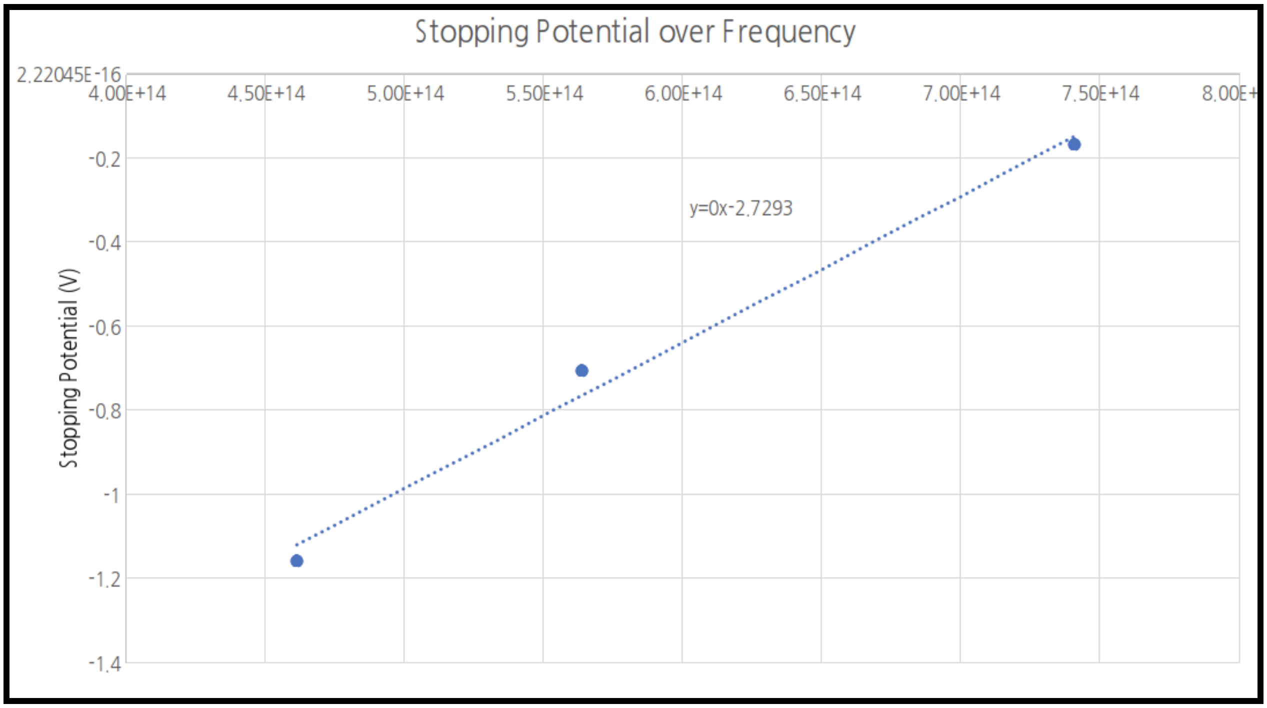

Figure 4: Stopping Potential over Frequency

Conclusion: In conclusion, this experiment aimed to investigate the photoelectric effect and its relationship with frequency and stopping potential. Our results showed that increasing the frequency of the incident light increases the photocurrent and stopping potential, indicating the direct relationship between frequency and energy of a photon. We were also able to calculate Planck's constant using linear regression on the stopping potential versus frequency graph, with a resulting value of 3.5 x 10^-15 eV. Furthermore, by using the calculated Planck's constant, we were able to determine the work function of potassium and the, which was found to be 2.02 eV. However, our results may have been affected by the interference of outside radiation and other variables in the experimental setup, which could have contributed to some errors. Overall, this experiment successfully demonstrated the photoelectric effect and its relationship with frequency, which has significant applications in various fields such as solar energy and photonics.