The non-classical effects of photoelectrons emitted from a nickle plate under electromagnetic radiation of different colors.

Thresa Kelly and Michael Murray
University of Kansas, PHSX 616 Physical Measurements
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The classical theory of electromagnetism states that light is an electromagnetic wave which can interact with electrons. It predicts that a light continuously transfers energy to a material, which can then release electrons when they accumulate enough energy. However, recent studies suggest that light is instead a packet with a quantized amount of energy. Under this model, photoelectrons could only be released from a metal if the single light quanta stores enough energy. To investigate this controversy, I measure the current across a photodiode for variable colors and intensities of light from a mercury (Hg) bulb. I find that the breaking potential energy has a linear relationship with the wavelength of the incident light [Note:: will show this next time I take data –>] and is uncharged by the intensity of incident light. This disproves the prediction of the classical theory.

I. INTRODUCTION

[NOTE:: controversy of classical/Newtonian electromagnetism. This is before particle photons! early days of quantization]

[Note::

1. *1856 James Clerk Maxwell - predicted electromagnetic waves. light was EM wave.*
2. *1901 Max Plank - theory of radiation. discrete energy levels. Absorption/emission are jumps b/t energy levels (particle behavior). First quantization! controversial.*
3. *1902 Phillip Lenard - stopping potential. energy of emitted electrons did not depend on intensity, but did depend of frequency (wave behavior). Interesting! not predicted by classical interpretation.*

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In this research, I investigate how the number of photoelectrons freed from a metal plate under incident light change with respect to the color and intensity of incident electromagnetic radiation. I observe how the 365, 405, 435, 546, and 577 nm emission lines from a mercury (Hg) bulb affect the current through a photodiode with an adjustable aperture and power supply.

II. METHOD

I use the SE-6609 Photoelectric Effect Apparatus by PASCO [1]. The diagram of the apparatus is shown in Figure 1. The main components of the apparatus consists of the light source enclosure, photodiode enclosure, direct current (DC) current amplifier, and DC power supply. PASCO states that the current amplifier is highly sensitive, the photodiode has low levels of dark current and anode reverse current, and the optical filters are high quality [1]. The light source is a mercury (Hg) bulb, which has emission lines at 365, 405, 435, 546, and 577 nm. Each of these emission lines can be isolated by selecting one of the five filters to cover the photodiode aperture. The aperture size can be set to Ø2, Ø4, Ø6, and Ø8. The nickel photodiode has a spectral response range of 300-700 nm, which covers all of the Hg emission features. The photodiode tube has a minimum cathode sensitivity ≥ 1 μ m/Lm and a dark current $\leq 20 \times 10^{-13}$ A. The DC current amplifier can measure currents between $10^{-8} - 10^{-13}$ A, and the decimal precision is set using a dial; it also has a calibration knob to zero the measured current. The photodiode DC power supply can provide voltages between -4.5 to 30 V.

The apparatus allows the user to measure the number of electrons freed from nickel metal by incident electromagnetic radiation. Light enters the filtered aperture and strikes photodiode cathode. The electromagnetic radiation then transfers its energy to the nickel and frees electrons to move to the anode; this generates a current, I_{AK}, through the circuit. The electric potential energy difference across the anode, V_{AK}, determines the amount of energy required for the electrons to overcome in order to move across the diode.

III. RESULTS AND DISCUSSION

In this research, I observe the relationship between the color and intensity of electromagnetic radiation. I claim the following uncertainties: V_{AK} is ± 0.1 V, I_{AK} is $\pm(1 \times 10^{-X})$ A where X is magnitude setting on the current amplifier, and the wavelength is $\pm$ 0.5 nm.

Figure 2 shows how current-voltage response changes with the wavelength of the electromagnetic radiation. For all colors, the current begins at zero before exponentially increasing beginning at a certain voltage ($V_{AK,0}$). For positive voltages, the slope decreases until the current levels off to a constant $I_{AK,\infty}$. Each of the five voltages has a different $V_{AK,0}$ and $I_{AK,\infty}$.

To further investigate the minimum voltage response, I extract the voltage where current first has a signal-to-noise greater than 5. The result is shown in Figure 3. The breaking voltage $V_{AK,0}$ appears to have a positive correlation with wavelength. Using a linear regression fit yields the equation

$$V_{AK,0}[V] = (0.005 \pm 0.001)[nm^{-1}] \cdot \lambda[nm] \\ -(3.0 \pm 0.5)[V] \tag{1}$$

relating the stopping potential to wavelength, with intercept describing the work function.

Next, I investigate how the current threshold relates to the color of the incident light. To do this I extract the maximum current, which occurs at $I_{AK,\infty} = I_{AK}(V_{AK} = 30V)$. I plot the $I_{AK,\infty}$ as a function of wavelength in Figure 4. A linear fit does not well represent the data, as the χ^2 is very large. It is highly unlikely that the magnitude of the current relates to the color of electromagnetic radiation. The differences in current are more likely due to the intensity of the emission line from the Hg bulb.

IV. CONCLUSION

[Note:: talk about classical vs quantum physics prediction here].

The goal of this research was to determine how the color and intensity of electromagnetic radiation affects the number of electrons freed from a nickle plate under the incident light. To investigate these effects, I use an apparatus that shines a mercury (Hg) bulb through one of five wavelength filters–365, 405, 435, 546, and 577 nm, each corresponding to an Hg emission line–and an adjustable aperture into a photodiode. I then measure the

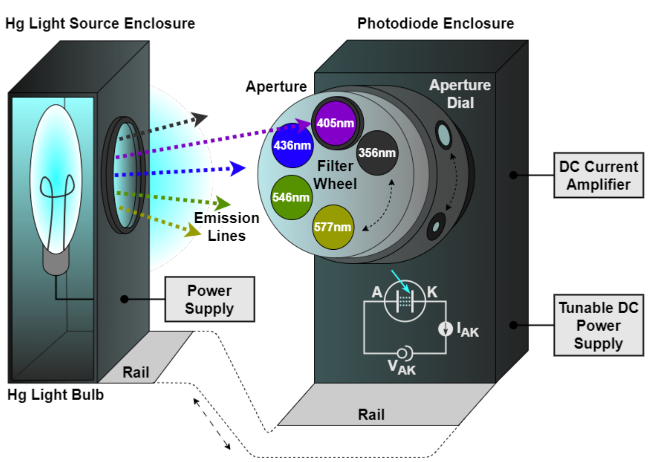

FIG. 1. Photoelectric effect apparatus [1]. The apparatus consists of two enclosures, one for the mercury (Hg) light source (left) and the other for the photodiode (right). The Hg bulb is controlled by a power supply. Light from the bulb is directed toward the photodiode by passing through a hole in the Hg light source enclosure and entering the filtered aperture of the photodiode enclosure. The filter and aperture can be changed by turning the filter wheel and aperture dial, respectively. An external device measures the DC current of the photodiode and controls the photodiode's DC power supply.

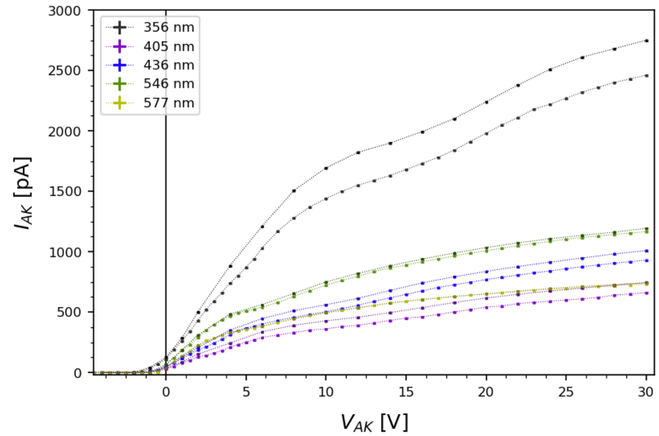

FIG. 2. DC current across the photodiode I_{AK} for a DC power supply V_{AK} for five different colors of light. The aperture is set to Ø2. Data for each 365, 405, 435, 546, and 577 nm wavelength filter is colored black, purple, blue, green, and yellow respectively. The second trial data set is slightly darker than the first trial. Each wavelength has a different minimum voltage and maximum current.

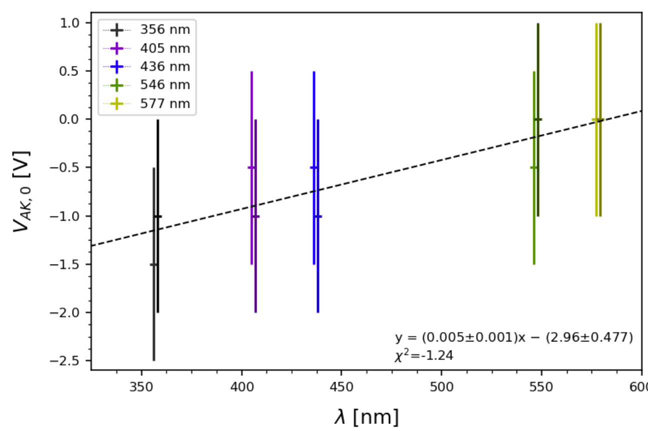

FIG. 3. Breaking voltage across the photodiode ($V_{AK,0}$) for the five wavelength (λ) filters. The second trial is colored darker and manually slightly shifted to the right compared to the first trial. The $V_{AK,0}$ appears to have a positive linear correlation to wavelength.

current of electrons scattered off of the nickle anode for voltages between −4.5 to 30 V.

I observe that the current only begins to increase once the voltage is greater than a stopping potential, $V_{AK,0}$. This potential energy difference is unique to each colored filter and has a strong positive correlation with wavelength. After overcoming this threshold, the current quickly increases with voltage before dropping off to some constant current $I_{AK,\infty}$. This maximum current is not related to the wavelength of light. The differences in magnitude are more likely due to the intensity of the emission lines from the Hg bulb.

[Note:: talk about how these results disprove classical physics. Wikipedia: "The experimental results disagree

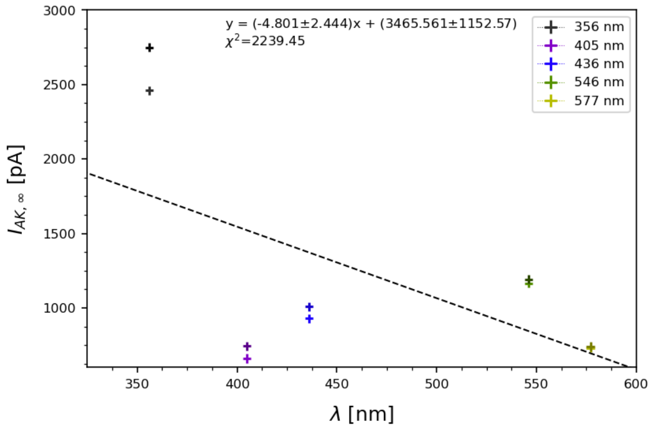

FIG. 4. Maximum current across the photodiode ($I_{AK,\infty}$) for the five wavelength (λ) filters. The second trial data is colored darker than the first trial. Current and wavelength do not have a linear correlation, shown by the very large χ^2.

with classical electromagnetism, which predicts that continuous light waves transfer energy to electrons, which would then be emitted when they accumulate enough energy. An alteration in the intensity of light would theoretically change the kinetic energy of the emitted electrons, with sufficiently dim light resulting in a delayed emission. The experimental results instead show that electrons are dislodged only when the light exceeds a certain frequency—regardless of the light's intensity or duration of exposure. Because a low-frequency beam at a high intensity does not build up the energy required to produce photoelectrons, as would be the case if light's energy accumulated over time from a continuous wave, Albert Einstein proposed that a beam of light is not a wave propagating through space, but a swarm of discrete energy packets, known as photons—term coined by Gilbert N. Lewis in 1926."]

[1] PASCO, *Photoelectric Effect Apparatus: Model No. SE-6609* (PASCO, 2023).