The Photoelectric Effect

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Abstract

The photon theory of light states that the maximum kinetic energy of photoelectrons depends purely on the frequency of the incident light, and is independent of the intensity. By testing the photoelectric effect it is evident that light acts as a particle rather than a wave. In this experiment, light from a Mercury Vapor Light Source was cast over the slit of a Pasco Scientific h/e apparatus to calculate the density of electrons collecting on a plate for varying spectrum colors. The electron buildup on the plate created an electric field that was found by attaching a voltmeter to the apparatus. The voltages made it evident that the stopping voltage (i.e. max kinetic energy of photoelectrons) does not depend on the intensity of the light. By adjusting the h/e Apparatus carefully between the three different orders of the Mercury Vapor Light and analyzing the cutoff frequency, work function and Planck's constant, it was determined that different wavelengths of light have their own particular potential differences.

I. INTRODUCTION

There were two separate sections to the experiment: the first portion proved that the alteration of light intensity does not change the potential difference between the two plates. The second portion of the experiment proves that different wavelengths have their own particular potential difference.

A Mercury lamp is a gas discharge lamp that uses an electric current through vaporized mercury to produce light. When cast onto a diffraction grating, the Mercury lamp creates a line spectrum. Each line has a known frequency and by using a lens assembly to magnify the spectral lines onto a photodetector, the stopping voltage for each frequency of light can be measured. The Kinetic Energy can be determined by measuring the minimum reverse potential needed to stop the photoelectrons and reduce the photoelectric current to zero. Relating kinetic energy to stopping potential gives us the following equation,

$$KE_{max} = Ve \tag{1}$$

where V is the voltage and e is the charge of an electron. Therefore, using Einstein's equations,

$$hv = Ve + W_0 \tag{2}$$

Eq. (3) shows how to calculate V by rearranging Eq. (2),

$$V = (h/e)v - (W_0/e) \tag{3}$$

which is the same as Eq. (4),

$$K.E. = hf - \phi \tag{4}$$

By plotting the stopping voltage (V) as a function of frequency (v) for different frequencies of light, it is possible to determine the value of Planck's constant (h), the work function (ϕ)

and the cutoff frequency (f). Figure (2) visually depicts how each of these values can be accounted for via the plot.

To find the cutoff frequency we must utilize the kinetic energy equation. Since the kinetic energy is zero at the cutoff function, by setting the equation equal to zero and solving for f using the values of h and ϕ the frequency can be calculated. This is shown in Eq. (5),

$$f = \phi/h \tag{5}$$

II. APPARATUS

The experimental setup shown in Figure (3) was used for both part I and II of the photoelectric experiment. The image shows a PASCO Scientific h/e Apparatus and a Mercury Vapor Light Source. Light from the Mercury Vapor Light Source was cast into the slit of the white reflective photodiode mask that protrudes from the h/e Apparatus. The lens protruding from the Mercury Vapor Light Source was used to adjust the sharpness of the images of the aperture centered on the hole in the photodiode mask. Furthermore, Figure (4) shows the names of all the separate parts of the apparatus.

III. EXPERIMENT: THE WAVE MODEL OF LIGHT VS. THE QUANTUM MODEL

It is well known through the photon theory of light that the maximum kinetic energy, KE_{max}, of photoelectrons depends only on the frequency of the incident light, and is independent of the intensity. Therefore the greater the frequency of the light, the higher its energy. In contrast, the classical wave model of light says that KE_{max} depends on light intensity. In other words, the brighter the light, the greater its energy.

This experiment investigated both of these theories. The first portion used two spectral lines from a mercury light source to investigate the maximum energy of the photoelectrons as a function of the intensity. The second part of the experiment used different spectral lines to investigate the maximum energy of the photoelectrons as a function of the frequency of the light.

The table in Figure (5) shows the expected frequencies and wavelengths for the different colors of the spectrum. The table in Figure (6) shows the values that were obtained for different transmissions of the colors of the spectrum during the experiment. From this table it is evident that each color of light has a unique stopping potential.

IV. EXPERIMENT: THE RELATIONSHIP BETWEEN ENERGY, WAVELENGTH AND FREQUENCY

According to the quantum model of light, the energy of light is directly proportional to its frequency. Thus, the greater the frequency, the higher energy it has. Through this experiment, the constant of proportionality, otherwise known as Planck's constant, was determined. Different spectral lines were selected from mercury and used to investigate the maximum energy of the photoelectrons as a function of the wavelength and frequency of the light. The table in Figure (7) shows the experimental values of frequency and stopping voltage for the colors of the spectrum. From this data, the values were used to create a graph of stopping voltage as a function of frequency Figure (1),

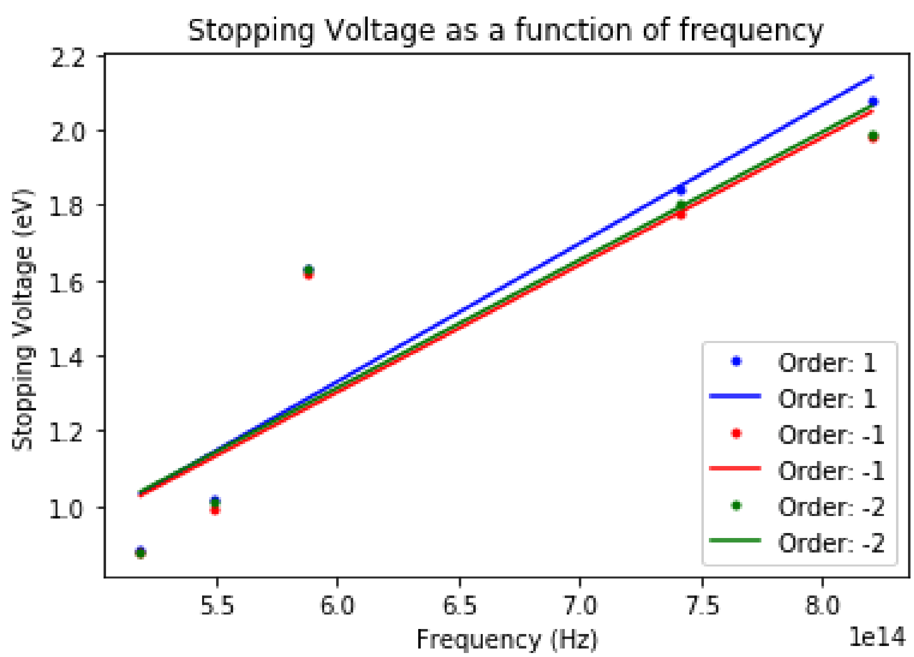

FIG. 1. Stopping Voltage as a function of frequency.

The slope of this line is the value for Planck's constants and the y-intercept is the the work function value for the different orders. The values were as follows:

order 1: $h = 3.675e - 15eV * s$ and $\phi = -0.874eV$

order -1: $h = 3.386e - 15eV * s$ and $\phi = -0.729eV$

order -2: $h = 3.401e - 15eV * s$ and $\phi = -0.726eV$

Average: $h = 3.487e - 15eV * s$ and $\phi = -0.776eV$

When using comparing the average Planck's constant value to the known value, $h = 4.136e - 15eV * s$, there is only a of 15.7 percent error! Using Eq. (5), the average cutoff frequency for the three orders is $f = 2.222e + 14$ Hz.

V. CONCLUSION

This experiment investigated stopping voltage (i.e. max kinetic energy of photoelectrons) and its dependency on the intensity of the light. By adjusting the h/e Apparatus carefully between the three different orders of the Mercury Vapor Light and analyzing the cutoff frequency, work function and Planck's constant, it was determined that different wavelengths of light have their own particular potential difference. In the first experiment, it was found that the stopping voltage is not dependent on the intensity (percent transmission) of the light and that the approximate charge provides the intensity of light. Furthermore, the approximate charge depends on the intensity of light because less light is emitted. Overall, experiment one is not consistent with the wave model because as the intensity changes, the stopping voltage does not! Therefore this represents the particle model of light. For the second experiment, Planck's constant was derived from the slope of stopping potential as a function of frequency. The value found from this experiment was 3.487e-15 and the accepted value is 4.135e-15 which yields a 15.7 percent error.

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FIGURES

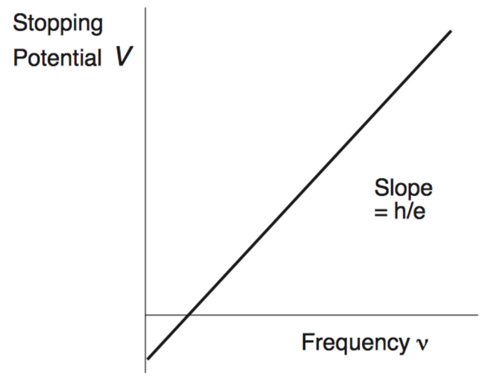

FIG. 2. Stopping Voltage as a function of frequency.

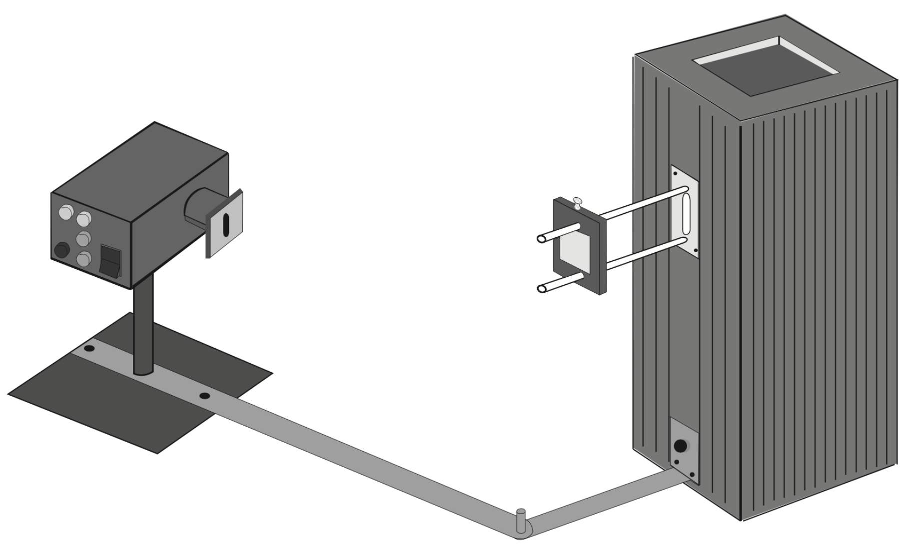

FIG. 3. The h/e Apparatus Shown With the Accessory Kit and Mercury Vapor Light Source.

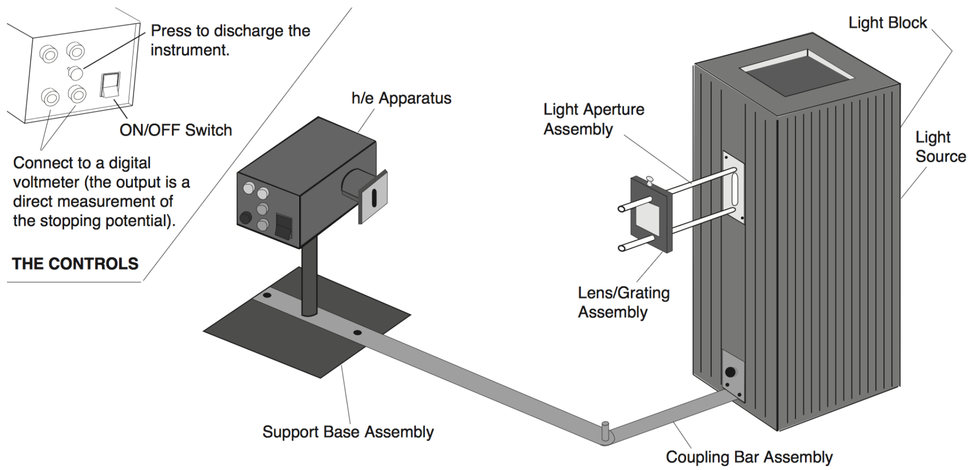

FIG. 4. Equipment Setup Using a Mercury Vapor Light Source and the h/e Apparatus.

Color	Frequency (Hz)	Wavelength (nm)
Yellow	5.18672E+14	578
Green	5.48996E+14	546.074
Blue	6.87858E+14	435.835
Violet	7.40858E+14	404.656
Ultraviolet	8.20264E+14	365.483

FIG. 5. Stopping Voltage as a function of frequency.

Color	%Transmission	Stopping Potential (V)
Color #1:Yellow	100	0.873
	80	0.865
	60	0.824
	40	0.881
	20	0.862
Color #2: Green	%Transmission	Stopping Potential (V)
	100	1.017
	80	1.018
	60	1.05
	40	1.009
	20	0.99
Color #3: Blue	%Transmission	Stopping Potential (V)
	100	1.67
	80	1.631
	60	1.631
	40	1.629
	20	1.622
Color #4: Violet 1	%Transmission	Stopping Potential (V)
	100	1.841
	80	1.839
	60	1.838
	40	1.834
	20	1.822

FIG. 6. Stopping Voltages for 5 frequencies of light.

light color	Frequency	Stopping Voltage (V)		
		1	2	3
	a	order of 1	order of -1	order of -2
Yellow	*5.18672E+14*	8.80E-01	8.77E-01	8.79E-01
Green	*5.48996E+14*	1.02E+00	9.90E-01	1.01E+00
Blue	*5.87858E+14*	1.63E+00	1.62E+00	1.63E+00
Violet 1	*7.40858E+14*	1.84E+00	1.78E+00	1.80E+00
Violet 2	*8.20264E+14*	2.08E+00	1.98E+00	1.99E+00

FIG. 7. Experimental results for Stopping voltages and Frequencies for colors of the spectrum.