

Photoelectric Effect

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Abstract

*The photoelectric effect can be useful in obtaining the ratio for the very small values of Planck's constant, h , and the charge of an electron, e . Using sodium and mercury, a light will produce ejected electrons via the photoelectric effect. By using a voltage to stop the moving electrons, the ratio h/e can be calculated. Using our best data, we found this value to be $(3.7380 \pm .023)^{-15} (V / Hz)$. This value has a 9.62% error from the accepted value of $4.136 * 10^{-15}$.*

I. INTRODUCTION

THE motivation for this lab was to use the effects of the photoelectric effect to obtain a value for the ratio between Planck's constant and the charge of an electron, $\frac{h}{e}$. The ratio can help lead to the calculation for the charge of an electron in another experiment. Then, the actual work function of the metal can be determined as well.

kinetic energy, as described by

$$\frac{1}{2}m_e v^2 = hf - W_0 \quad (2)$$

. Since electrons have charge e , the force required to stop a moving electron is eV_s . The voltage in this equation is known as the stopping voltage. Now, the stopping equation can be written using equation 2,

$$V_s = \frac{h}{e}f - \frac{W_0}{e} \quad (3)$$

II. THEORY

The photoelectric effect explains that when light above a certain frequency hits a metal, electrons will be ejected. This required frequency is known as the threshold frequency and gives support to the understanding that light energy is quantized, as expressed by

$$E = hf \quad (1)$$

. The threshold frequency is determined by the particular metal's work function, W_0 . Therefore, if the quantized energy of the light is enough to overcome the work function, electrons are ejected with the left over energy as

. For the photoelectric effect to be useful in this case, the wavelength of the light being used must be known. Using a transmissive grating, the light is separated by wavelength, where d is the distance from the grating, θ is the angle from the normal line of the grating, m is the order number that takes positive integer values, and λ is the wavelength of the light,

$$d \sin \theta = m\lambda \quad (4)$$

. Now, each wavelength can be nearly isolated in experiment.

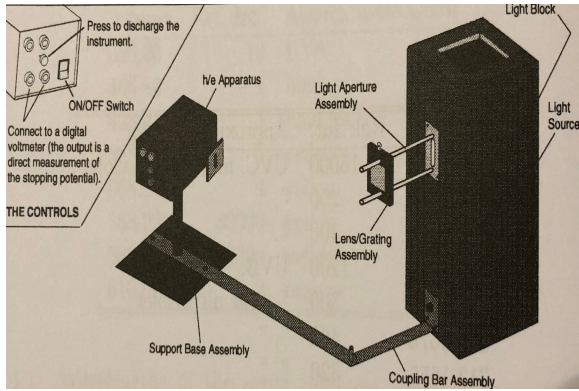


Figure 1: Fig. 1: The light block shines a light through the lens and is diffracted based on its wavelength. The h/e apparatus/photodiode can swivel to match the angle of the diffracted light.

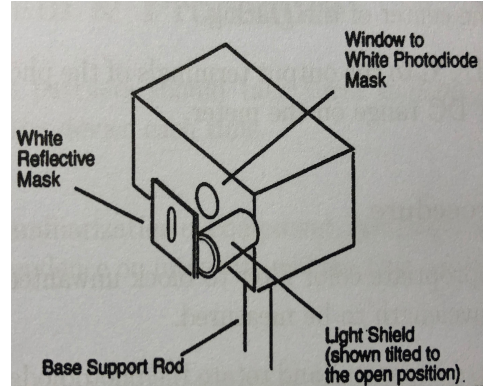


Figure 2: Fig. 2: The photodiode's components. It is created to limit ambient light and focus on a small slit of light.

III. EXPERIMENTAL ARRANGEMENT AND PROCEDURE

The experiment was conducted using the following equipment.

- 2 PASCO light sources: sodium and mercury vapor
- 1 h/e device: photodiode, and op-amp
- 1 lens with grating (6000 lines/cm) and mount
- 1 digital voltmeter
- 1 neutral (grey) filter (relative intensities of 0, 20, 40, 60, 100)
- various color filters

The light source was turned on for 5 minutes to warm up before operating. Then, the lens grating was attached to the light source. The photodiode was turned on with batteries and set up on a support base. The support base is attached to the light source via a coupling bar. After this, the assembly resembled Fig. (1).

The photodiode has a slit surrounded by white reflective mask to capture a small segment of light. Additionally, a light shield must be rotated behind the reflective mask to further stop ambient light. The photodiode is illustrated in Fig. (2).

The measurements were taken using a voltmeter to record the stopping voltage. The photodiode was screwed in tightly to the support

base so that it's only motion could occur via the coupling bar.

IV. DATA, ANALYSIS, AND RESULTS

First, the stopping voltage was measured for the sodium emission lines. The voltage was recorded for first and second order emission lines. For 4 measurements a yellow a filter was used to block other wavelengths and for the other 4, the filter was not used. The standard deviation was then calculated using

$$s = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (x_i - \bar{x})^2} \quad (5)$$

where,

$$\bar{x} = \frac{\sum w_i x_i}{\sum w_i} \quad (6)$$

and

$$w_i = \frac{1}{(\delta x_i)^2} \quad (7)$$

The best value for the stopping voltage with a filter for sodium that contributed to our h/e value was 0.2575 with a standard deviation of 0.052. After comparing with other lab teams, we determined the the voltmeter's uncertainty to be around .003V. This raises the uncertainty to $0.052 + .003 = 0.055$.

Next, the dependence of the final stopping potential on the intensity was measured using a filter that had subsections of 20% to 100%

Table 1: The V_s values in Volts for the first and second order emission lines of sodium with the filter at various transparency percentages.

	First Order V_s	Second Order V_s
20%	0.1760 ± 0.001	0.0450 ± 0.001
40%	0.2720 ± 0.001	0.1050 ± 0.001
60%	0.3142 ± 0.001	0.1260 ± 0.002
80%	0.3360 ± 0.002	0.1460 ± 0.002
100%	0.4010 ± 0.002	0.1560 ± 0.001

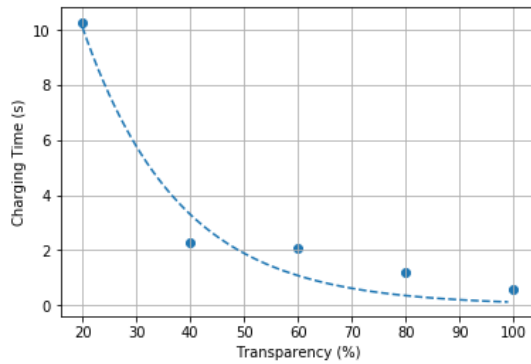


Figure 3: A plot showing the exponential decay of charging time as transparency increases. Line of best fit uses model Ae^{Bx} . Error bars are too small to display (all 0.01s)

transparency. The results are shown in Table (1). Additionally, the time it takes for the voltmeter to measure 90% of the already measured final value was recorded for each transparency filter. These values can be seen in Figure (3). More wavelengths were tested using the mercury emission lines. Instead of one wavelength, mercury was able to provide 5 different wavelengths. The wavelengths were 365.0158 for the UV line, 404.6565 for the violet line, 435.8335 for the blue line, 579.067 for the yellow line, and 546.075 for the green line. These wavelengths were given in the lab manual.

15 measurements were taken, 3 measurements for each wavelength. Once taken, the wavelengths were converted to frequency via $f = c/\lambda$. Then, linear regression was used to create a line of best fit. With V_s as the y values and frequency as the x values, the line represented Equation (3). However, us-

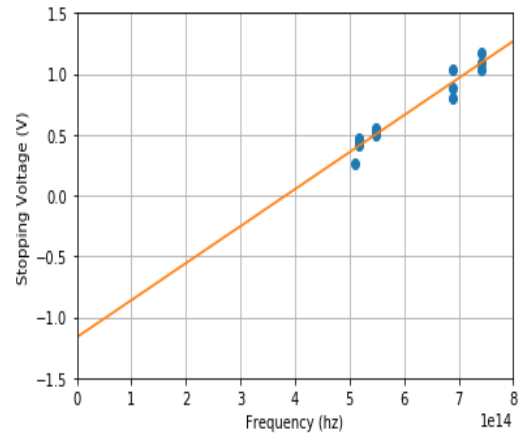


Figure 4: A graph of the stopping voltage with respect to the frequency of the emission lines of both mercury and sodium. The error bars are too small to display.

ing the each mercury data point and the best sodium data point, the line equation was $V_s = ((2.32 \pm .011) * 10^{-15})f - (0.745 \pm 0.003)$.

After taking out 3 outliers, which were all the UV ray measurements, the equation for the line became $V_s = ((3.0422 \pm .010)^{-15}f - (1.165 \pm 0.002)$. This suggests the h/e value is closer to $\frac{h}{e} = (3.0422 \pm .010)^{-15}$. The line of best fit can be seen, along with the data points, in Figure (4). The normalized χ^2 value of the line is 632.09 which is extremely high. Even when the slope and intercept are adjusted to minimize the χ^2 value, it remains the same.

Taking out even more outliers, all 3 violet measurements and two blue measurements, the remaining 8 data points led to a value of $V_s = ((3.7380 \pm .023)^{-15}f - (1.531 \pm 0.009)$. This line can be seen in Figure (5). The χ^2 value of this line becomes 203.37 which is still incredibly high. This suggests that either the measurements were poorly taken or the linear line is a bad function to represent the data. However, it is known that this data should be well represented by a linear line. Therefore, the data is inaccurate. This could be due to a faulty light source, as all of our voltage readings are lower than common values from the other teams. We know it is not the photodiode because we switched it out with a teams whose

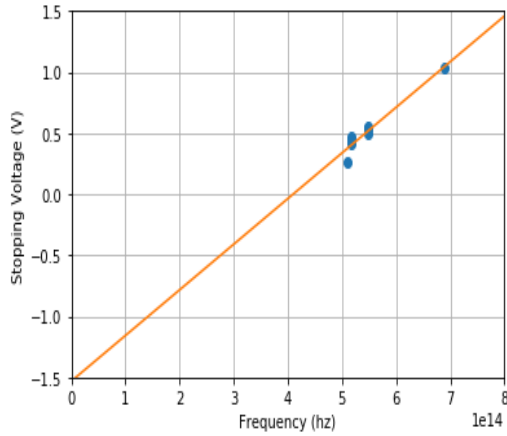


Figure 5: Similar to Figure (4) but with 4 less data points to get a closer value of h/e to the accepted value.

diode produced high voltage values.

V. CONCLUSION

The accepted value for h/e is 4.136×10^{-15} . Without taking out the outliers, our value of $(2.32 \pm .011) \times 10^{-15}$ has a 43.8% error. However, after taking out 3 outliers, the value of $(3.0422 \pm .009) \times 10^{-15}$ improved to 26.5% error. After taking out 7 outliers total, the value of $(3.7380 \pm .023) \times 10^{-15}$ improved the percent error even further to 9.62% error. Our expected h/e value therefore becomes

$$\frac{h}{e} = (3.7380 \pm .023) \times 10^{-15}$$

Since our photodiode was reading lower voltage numbers, especially for the high frequency emission lines, than the average lab group in the class, if the light source was the problem, a proper light source would have increased the voltage readings and therefore increased the predicted h/e value. This would make it closer to the accepted value.

With the h/e value, in future experiments the ratio e/m can be found. Together, the h/e ratio and e/m ratio can be used to calculate e . The ratios are very useful in determining e because even though e is such a small value and hard to measure alone, the ratios are not.

The ratios are larger and therefore easier to measure.

The experiment can be improved by setting the station up in a completely dark room with no ambient light. Additionally, the angle of each emission line can be calculated from Equation (4) and then setting the photodiode to match that angle. This would allow for the measurement of more wavelengths as they are not visible to the eye, but their angles of diffraction is known and can be calculated based on their wavelengths. These wavelengths are found in the lab manual. Lastly, the experiment can be tested using multiple sets of equipment, that way the equipment with the best data sets can be chosen. This would help eliminate uncertainty due to the equipment.

REFERENCES

[Professor Wang, 2018] Physics 18L Lab Manual.