Observation of the Photoelectric Effect

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Abstract

In this lab, we replicated Einstein's photoelectric effect experience using a PASCO *h/e* apparatus that measured the stopping potential V_0 of first-order spectral light generated by a mercury light source and flashed onto cathodes contained within a vacuum tube. Light flashed onto the cathode would cause the emission of photoelectrons and accumulate charge on the nickel anode. The *h/e* ratio and work function ϕ was found using the plot of stopping potential vs. frequency in part 1. Part 2 of the lab measured stopping potential vs. relative optical intensity using a variable transmission filter. Experimental findings showed that as light transmission increased, so did the stopping potential. The experimental *h/e* value was found and compared to the accepted *h/e* ratio of $4.1356 * 10^{-15}$ J*s/C. Results came within 3 standard errors and any uncertainties were likely due to room lighting skewing results or incomplete discharge of the *h/e* apparatus when taking measurements.

Introduction

The photoelectric effect is a physical phenomenon that describes the emission of electrons when light shines on a metal [1]. Observation of the photoelectric effect began with German physicist Heinrich Hertz in 1887, when he first noticed the metal producing a spark when certain frequencies of illumination occurred on a metallic surface. It was later J.J. Thomson who discovered that these “sparks” were electrons that were excited by light being emitted from the metal surface [1].

Resulting from his experimental observation, physicist Philipp Lenard discovered that the emission of light-excited electrons from a metallic surface is dependent on the frequency of the light rather than on the intensity of the illumination. Einstein then proposed in 1905 that light behaved as a particle. It was theorized that light consisted of photons, then described as discrete quanta, in which the energy of these photons was equal to the frequency f of the light multiplied by Planck’s constant, $h = 6.62607 \times 10^{-34}$ J*s. The energy of a photon is mathematically displayed as hf.

The relation between the kinetic energy of a photoelectron, an emitted electron, is described as:

$$K = hf - \phi$$

Where K is the kinetic energy of the photoelectric, hf is the Planck’s energy quantization of the blackbody spectrum, and ϕ is the work function of the metallic surface. When $hf \geq \phi$ photoelectrons are emitted.

Ultimately, 19th century physicists wanted to use classical mechanics to describe light. This eventually led to our more modern concept of light known as electromagnetic radiation that exhibits both wave and particle characteristics [1]. The concept of electromagnetic radiation includes not only visible light frequencies, but also ranges describes radio, microwave, infrared, ultraviolet, x-rays, and gamma rays.

Experimental Procedure

This lab made use of a PASCO *h/e* measurement apparatus containing vacuum tube with the cathode and a nickel anode [2]. A mercury light source was also used during this experiment consisting of a mercury bulb contained by a mercury light source housing.

This experiment was performed using a mercury light source to illuminate the cathode of a vacuum tube. Once the light is illuminated onto the cathode, spectral lines appear. The photoelectrons that are emitted from the cathode once light is illuminated onto its surface then collect on the anode causing an electrical current that can be measured using a voltmeter connected to the h/e apparatus. The *h/e* apparatus and mercury light source are arranged at an angle as shown in figure 1.

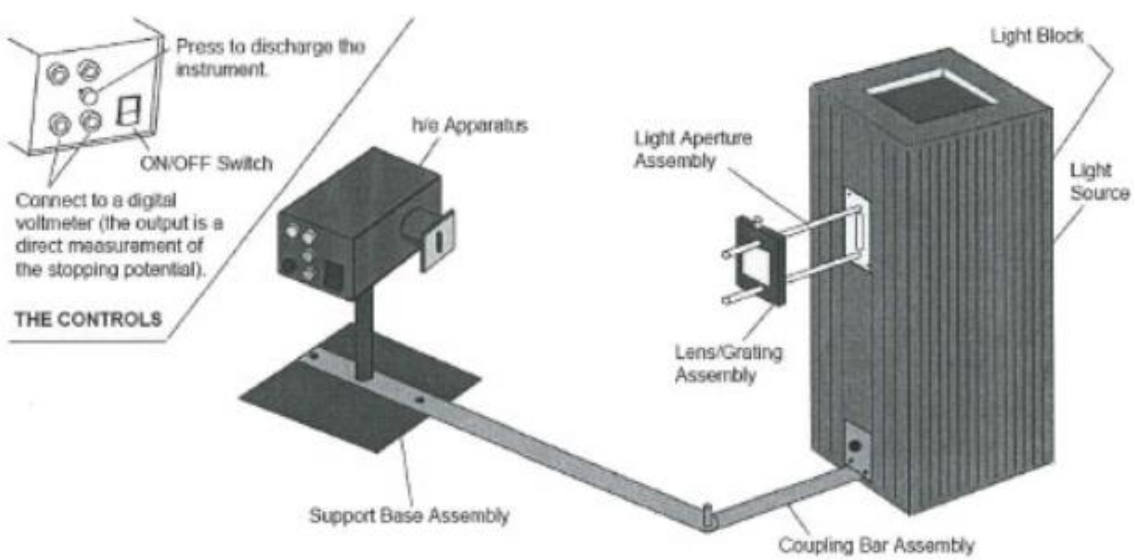

Fig. 1. Experimental Setup (from laboratory handout)

Once the experimental setup is arranged accordingly, and the light shield of the *h/e* apparatus is rolled out of the way, the mercury light source must be turned on. The *h/e* apparatus contains a white reflective mask. When the mercury light source is turned on and positioned correctly, the five spectral lines will appear on this reflective mask. Only the first-order spectral lines are used for this experiment since they are the most prominent lines. The light shield is rolled away then placed back in between each spectral line measurement. Also, between each voltage measurement for each spectral line, the *h/e* apparatus must be discharged by pressing the ZERO button on the side panel to improve the accuracy of the output voltage measurement.

The stopping potential V_0 is first measured for each of the spectral lines that appear within the first-order spectrum (the brightest lines). The stopping potential is determined from the following equation:

$$V_0 = \frac{h}{e} f - \frac{\Phi}{e}$$

The stopping potential equation is later rearranged to determine the experimental *h/e* value. The known value for *h/e* is 4.1356 * 10^{15} J*s/C.

When measuring the green and yellow lines, the green- and yellow-colored filters are placed on the *h/e* measurement apparatus. These are used to filter out extra light in the room and prevent it from contaminating results. For the blue, violet, and UV lights, a colored filter is not used. This is because the frequency of the ambient room light is within range of green and yellow light, so it is not necessary to use a color filter for blue, violet or UV lights.

Before plotting, the wavelength must be converted to frequency using the following equation:

$$f = \frac{v}{\lambda}$$

The stopping potentials will be graphed for each frequency and given a linear fit. Using this graph, the experimental *h/e* value can be determined along with ϕ, the work function.

A second set of data is collected, the stopping potential V_0 as a function of the relative optical intensity. In this part of the lab, a single first-order spectral line is used for measurement and a variable transmission filter is placed over the reflective mask of the *h/e* apparatus. The stopping potential is recorded for 20%, 40%, 60%, 80%, and 100% transmission.

Results

The lab data are shown in table 1 and the plot is shown in figure 2. Specifically, the plot of the stopping potential V_0 vs. frequency *f*. The accepted mean value for *h/e* is $4.1356 * 10^{-15}$ J*s/C and the experimental *h/e* value gathered from part 1 of this experiment was $3.7913 * 10^{-15}$ +/- $1.75 * 10^{-16}$ J*s/C so the experimental and the known value were in close agreement.

V0	wl	frequency
0.714	5.79066e-07	5.17717e+14
0.806	5.46074e-07	5.48996e+14
1.42	4.35833e-07	6.87861e+14
1.577	4.04656e-07	7.40858e+14
1.828	3.65015e-07	8.21315e+14

Table 1. Stopping potential data collected for part 1

The stopping potential is plotted as a function of frequency and given a linear fit as shown in figure 2. The relationship between stopping potential and frequency as shown by this plot is that as the frequency increases, so does the stopping potential. Frequency and wavelength are inversely proportional to each other. Hence, higher wavelengths have lower frequencies and vice versa. So, a lower frequency light like yellow or green colored light would have a higher stopping potential than higher frequency lights such as blue, violet, and ultraviolet light.

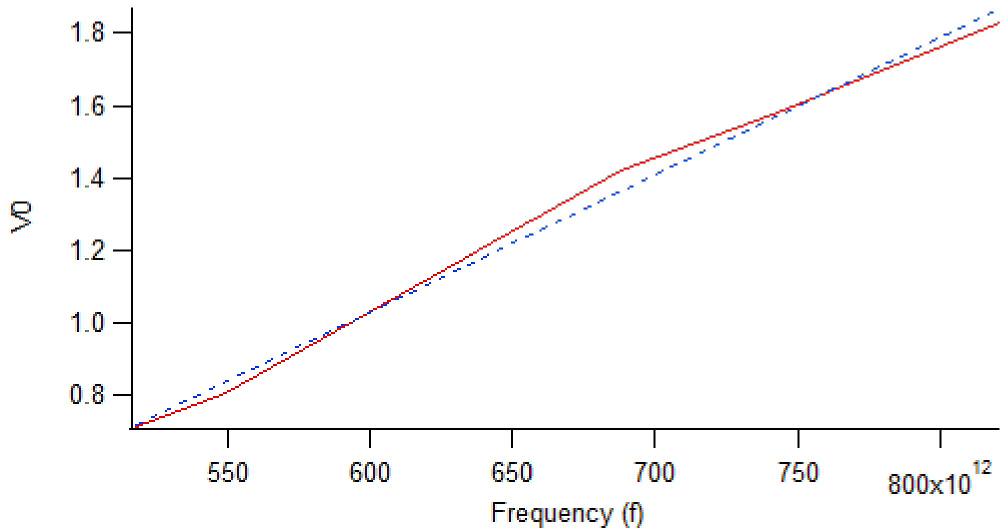

Fig. 2. Stopping potential vs. Frequency

The second part of the lab required the use of a variable transmission filter placed over the white reflective mask panel of the *h/e* apparatus and the use of a single first-order spectral light. For this part of the experiment, the blue spectral light was used. Table 2 shows the data collected for this part of the experiment.

V0t	transmission
1.124	20
1.196	40
1.242	60
1.243	80
1.294	100

Table 2. Stopping potential and relative optical intensity data in part 2

It was hypothesized that as light transmission increased, so would the stopping potential. This relationship is reasonable because if more light reaches the cathode and electrons are excited by light, electrons will gain more kinetic energy. A greater kinetic energy will take a higher stopping potential for the electrons to stop moving throughout the electric field. This hypothesis was experimentally tested by varying the light transmission levels and recording the stopping potential using the *h/e* apparatus connected to a voltmeter. Figure 3 shows a plot of the stopping potentials vs the transmission levels. As hypothesized, as the transmission level of the light increases, so does the stopping potential.

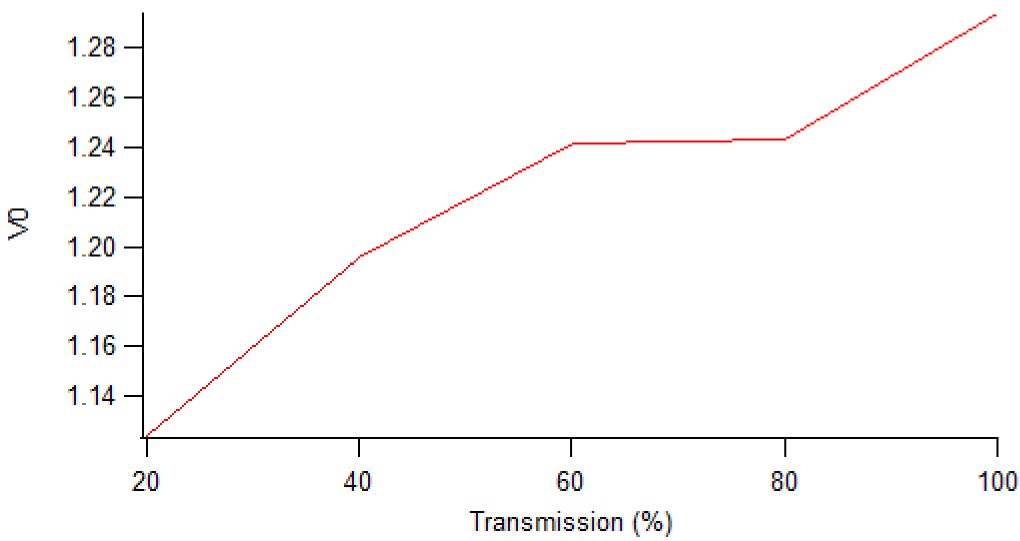

Fig. 3. Stopping potential vs. Relative optical intensity

Conclusions

For this experiment, the results were statistically significant. Any uncertainties are likely to have resulted from human error and instrumentation errors. Possible sources of uncertainty that occurred in determining the *h/e* value likely resulted from ambient lighting in the room slightly skewing results and accumulated charge on the anode in which the *h/e* apparatus may have not been fully discharged.

Though 19th century observations of the photoelectric effect were unable to establish whether light was a particle or a wave, the significant findings that resulted from these experiments consisted of the concept that light shined on a metal surface can cause the emittance of electrons and electric conductivity, and that to increase this current the transmission of the light must be increased. Also resulting from observations of the photoelectric effect was the concept that higher frequencies of light will excite more kinetic energy in electrons.

In our observation of the photoelectric effect, the data yielded a similar experimental *h/e* value to the accepted *h/e* value. As previously noted, the known *h/e* value is $4.1356 * 10^{-15}$ J*s/C and the experimental *h/e* value was found to be was $3.7913 * 10^{-15}$ +/- $1.75 * 10^{-16}$ J*s/C. These values are in close agreement and are therefore statistically significant.

References

[1] Khan Academy. (n.d.). *Photoelectric effect (article) | photons*. Khan Academy. Retrieved November 8, 2021, from https://www.khanacademy.org/science/physics/quantum-physics/photons/a/photoelectric-effect.

[2] *Photoelectric Effect System • SE-6609*. PASCO scientific. (n.d.). Retrieved November 8, 2021, from https://www.pasco.com/products/lab-apparatus/fundamental-constants/se-6609#desc-panel.

[3] *Mercury Light Source • Se-6608*. PASCO scientific. (n.d.). Retrieved November 8, 2021, from https://www.pasco.com/products/lab-apparatus/light-and-optics/light-sources-and-lasers/se-6608#desc-panel.