Photoelectric effect — h/e

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Date: 04/16/21

I. Introduction

This lab will study the photoelectric effect and measure the ratio of Planck's constant h to the electron charge e by measuring h/e. The accepted value of this ratio is 4.1357×10^{-15} Joule/Amp.

This effect happens when light striking a material causes electrons to be ejected. Each quantum of light can liberate one electron from a surface. The electron's kinetic energy (KE) will equal the energy of the light quantum (L_q) minus the binding energy to the material (BE), or,

$$KE = L_q - BE \tag{1}$$

The kinetic energy is proportional to the electric potential required to stop the electrons, where the electron's charge is the proportionality constant. The energy of the light quantum is proportional to its frequency, where the proportionality constant is Planck;s constant. Thus measuring the stopping voltage at several frequencies gives the ratio of these two proportionality constants: h/e.

II. Layout and equipment

We will be taking measurements using the PASCO AP-9368. Below is an itemized list of all of the equipment we will be using in this experiment.

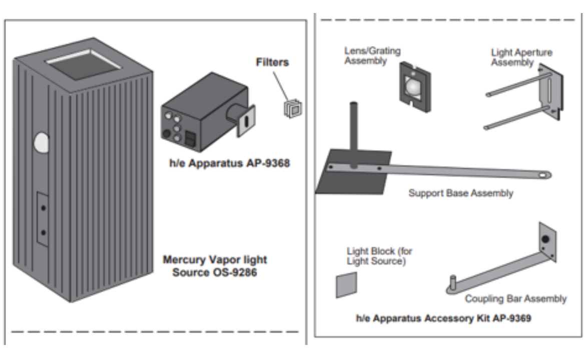

Fig. 1: h/e Equipment identification, courtesy of PASCO Scientific.

The setup for the equipment in the experiment can be seen below.

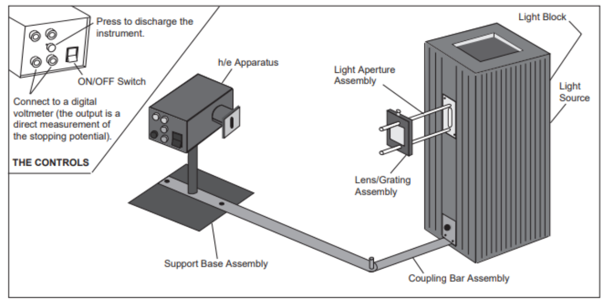

Fig. 2: Equipment setup using a Mercury Vapor Light Source and the h/e apparatus, courtesy of PASCO Scientific.

The apparatus includes the PASCO AP-9368 with the Mercury lamp (black box on the right), the photo diode (the h/e apparatus on the left), a digital voltmeter that will be attached to the h/e apparatus to take our measurements, and three filters. Two of which are colored (green and yellow respectively) and the final filter is a variable transmission filter that has values ranging from 100% to 20%.

III. Procedure

A. *Experiment 1*

To begin the first experiment we must first turn on our mercury lamp. It may take several minutes for the lamp to warm up and put out enough light to do the experiment. We can then turn on our h/e apparatus and adjust the position of the detector so that the light output from the lamp aligns onto that of the slit for our detector.

To finish our setup, we must connect the digital voltmeter to the output terminals of our h/e apparatus (seen in the top left corner of Figure 2). Once complete, adjust the h/e apparatus so that only one of the spectral colors falls upon the opening of the mask of the photo diode. It is important to note that if the green or yellow spectral lines are chosen, we must place the corresponding colored filter over the white reflective mask on the h/e apparatus.

Now, place the variable transmission filter in front of the white reflective mask (and over the colored filter if it is used) so that the light passes through the section marked 100% and reaches the photo diode. It is important to check at this point that the light does in fact reach the detector by sliding the black cylinder on the h/e apparatus out of the way (located behind the white reflective mask). This will allow us to look into the apparatus to ensure that our light does, in fact, land on the detector.

Once done, we must slide the cylinder back into place and record the voltage reading on our digital voltmeter. To record our data, we must also press the instrument discharge button, release it, and observe approximately how much time is required to return to the recorded voltage.

Moving on, we can adjust the variable transmission filter so that the next section is directly in front of the incoming light and record the new digital voltmeter reading. Once again, pressing the discharge button and measuring the time delay for the voltmeter to return to our original voltage. We must repeat this until we have tested all five sections on the filter for our desired color, and then again repeat the procedure using a second color from the spectrum.

B. Experiment 2

Now, removing the variable transmission filter entirely from our h/e apparatus, we must measure the stopping potential, with our voltmeter, for each of the six colors. We must also make sure to use the yellow and green colored filters on the reflective mask of the h/e apparatus when we measure the yellow and green spectral lines.

IV. Data/Analysis

A. Experiment 1

The colors we chose to survey for the fist experiment were Red and Blue. Below is a plot showing our recorded data of each colors stopping potential vs intensity.

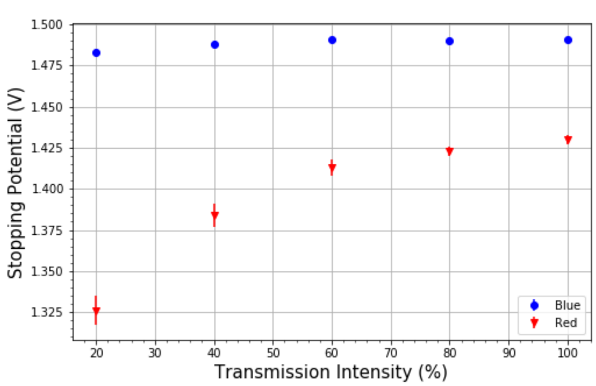

Fig. 3: Red and Blue Stopping Potential vs. Intensity.

It is noted that while the Blue spectra holds the relationship with Intensity while expected, Red's relationship is more dramatic. While both colors show a decrease in stopping potential as the light intensity decreases, Blue's decreases is more gradual while Red's decrease is more dramatic.

B. Experiment 2

For the second experiment, we surveyed every color from Red to Ultra Violet and plotted their stopping potential as a function of their frequency using the values from the table shown below.

Color	Wavelength (nm)	Frequency (THz)
Red	625.000	480.000
Yellow	578.000	518.672
Green	546.074	548.996
Blue	435.835	687.858
Violet	404.656	740.858
Ultraviolet	365.483	820.264

Our colors as a function of stopping potential are plotted below along with their Best Fit lines.

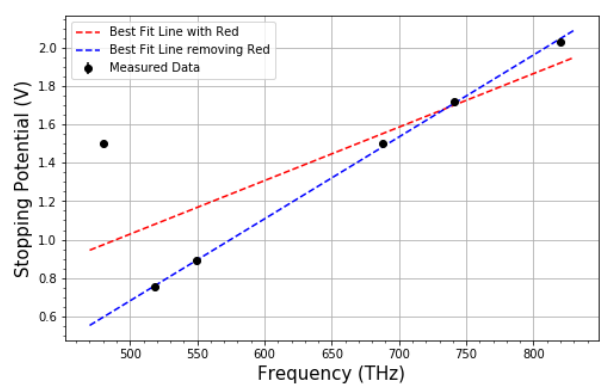

Fig. 4: Our colors Stopping Potential vs. Frequency. We plotted two Best fit lines, one including all of our data points (shown in Red) and another removing the color Red, our outlier color (Shown in Blue).

As seen in our data, our measured Stopping potential for Red does not follow the same trend as the rest of the colors. Because of this, we decided to plot two Best-Fit lines, one including Red, and another removing it.

The residuals for both of these sets of data are seen in the page below.

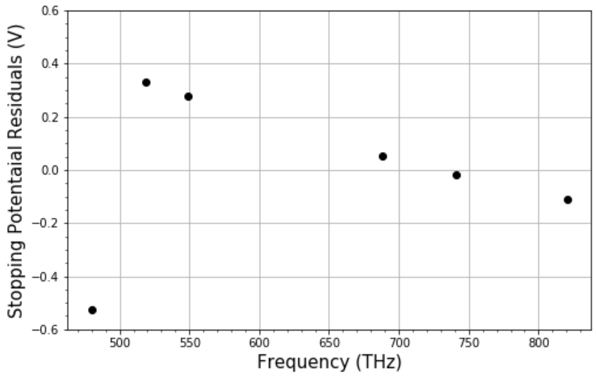

Fig. 5: Our Residuals plotted including Red in our data set.

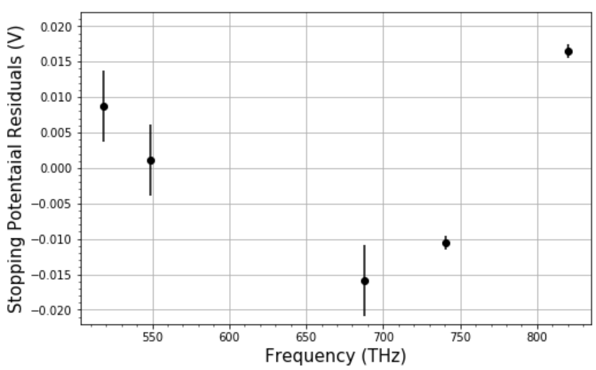

Fig. 6: Our Residuals plotted removing Red from our data set.

Because the color Red is such an extreme outlier seen in both figures 4 and 5, we decided to remove the color from our data when calculating the h/e value.

We were able to find h/e by measuring the slope of our blue best fit line (seen in figure 4) and converting that measurement from V/THz to J/A. Our measured h/e value is:

$$h/e = 4.27020(9) \times 10^{-15} \text{ J/A} \tag{2}$$

Which is off the known value of h/e only 3.252% above the accepted value (h/e = 4.1357 $\times 10^{-15}$ J/A) which is well within our uncertainty.

For fun, we also decided to calculate what our h/e value would be if we included the color Red in our data set. We measured an h/e value of $2.788354(12) \times 10^{-15}$ J/A which is a whopping 32.578% below what the accepted value of h/e is, well outside our uncertainty.

V. Conclusion

Overall, we measured the h/e value to be $4.27020(9) \times 10^{-15}$ J/A. We were able to determine that a majority of the uncertainty that plagued this value stemmed from the photons of our Mercury Vapor lamp not entering our h/e apparatus at a steady current. Furthermore, the trend line for our best-fit line without Red makes sense, as a higher frequency and shorter wavelength results in an increased energy, which is then displayed as our Stopping Potential (V) which is shown well (after removing Red) in figure 4.

We must note that we encounter an unusual result when measuring the stopping potential (V) of the Red spectrum. In figure 4, it is obvious that Red is an outlier from the rest of our data. However, we are also keen to note that this result also affected the first experiment. Not only is the stopping potential of Red positioned much higher than what our best fit line suggests (somewhere around 0.6 - 0.5 V), Red also suffers severely from that of the change in Intensity.

We believe the error that occurred when we measured our Red stopping potential stemmed from us not using a filter for it, much like how we used one for the Green and Yellow spectrum. Also, while not recorded in our data, it was observed that the time delay for Red to return back to its original stopping potential in the first experiment was much higher than that for Blue. Finally, Red has a much lower frequency and wider wavelength than that of the other colors, possibly suggesting that this color has more difficulty when passing through a filter. This could explain why the change in Stopping Potential as a function of Transmission Intensity is more dramatic with Red than it is with Blue as shown in figure 3.