ENPHYS253
Lab 4: h/e and the Photoelectric Effect

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1 Introduction

In 1921, Albert Einstein won the Nobel prize in Physics for his work in describing the photoelectric effect [1] as it was significant in paving the way of modern day physics. Einstein's work was built on the efforts of Max Planck, who determined that the energy of a photon was proportional to its frequency. However, physics as it were known at the time predicted that the energy of light was proportional to its intensity. By using the photoelectric effect, Einstein was able to show that the older models of light were incorrect and provided validity to the newer field of quantum mechanics.

Photoelectric emission occurs when light hits a material that causes an electric current. Einstein said that energy of a photoelectron was equal to the energy of a photon by the equation:

$$E = KE_{\text{max}} + W_0 = h\upsilon \tag{1}$$

where KE_{max} is the kinetic energy of an electron, W_0 is the work function (the minimum energy to separate an electron from a material), h is Planck's constant and υ is the frequency of light. It is the purpose of this experiment to show that the energy of a photon is independent of the intensity of light by measuring the time it takes for beam of light to reach its stopping potential but that the energy of a photon is dependent on its frequency by measuring Einstein's linear relationship between stopping potential, frequency and Planck's constant.

2 Results and Analysis

The stopping potential data from table 1 and table 2 were plotted into figure 1. Since the data exponentially decays, equation 4 was used to create a linear relationship between transmission percentage and time. This data was plotted onto figure 2, with the randomly distributed residual plots on figures 3 and 4 indicating a good linear fit for the data. The linear model supports the quantum model prediction that increased intensity would increase the photoelectric current. The data in figure 2 shows that the greater intensity, the less time it takes to reach the stopping potential. The quantum model predicts that the energy of a photoelectron is independent of the intensity of light, which is shown in table 1 and 2 by the fact that the stopping potential values stay constant within error.

The frequency and stopping potential values from table 3 were plotted against each other onto 5. Using a linear regression with equation 2 and the accepted value of e=$1.45 \pm 0.02\mathrm{J\,C^{-1}}$, the value of h/e was determined as $(4.20 \pm 0.03) * 10^{-15}\mathrm{J\,s\,C^{-1}}$, h as $(6.73 \pm 0.04) * 10^{-34}\mathrm{J\,s}$, W_0/e as $1.45 \pm 0.02\mathrm{J\,C^{-1}}$ and W_0 as 2.32 ± 0.02J. The value of measured value of h has a percentage difference of 1.6% from the accepted value of $6.626 * 10^{-34}\mathrm{J\,s}$. The results from figure 5 support the quantum model that a higher frequency results in higher energy photoelectrons.

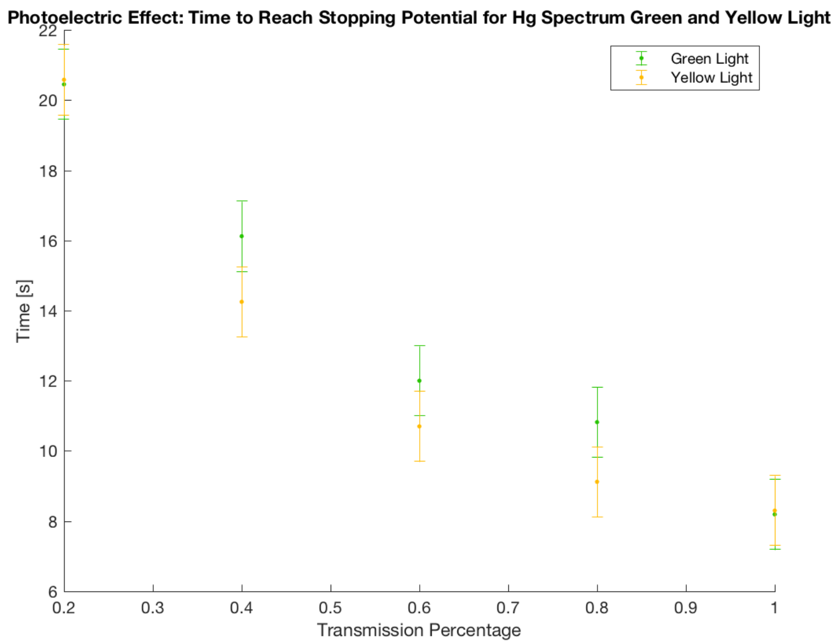

Figure 1: Measured time to Reach Photoelectric Stopping Potential for Hg Spectrum Green with frequency $5.49 * 10^{14}$ and Yellow light with frequency $5.19 * 10^{14}$ Note the exponential decay. points.

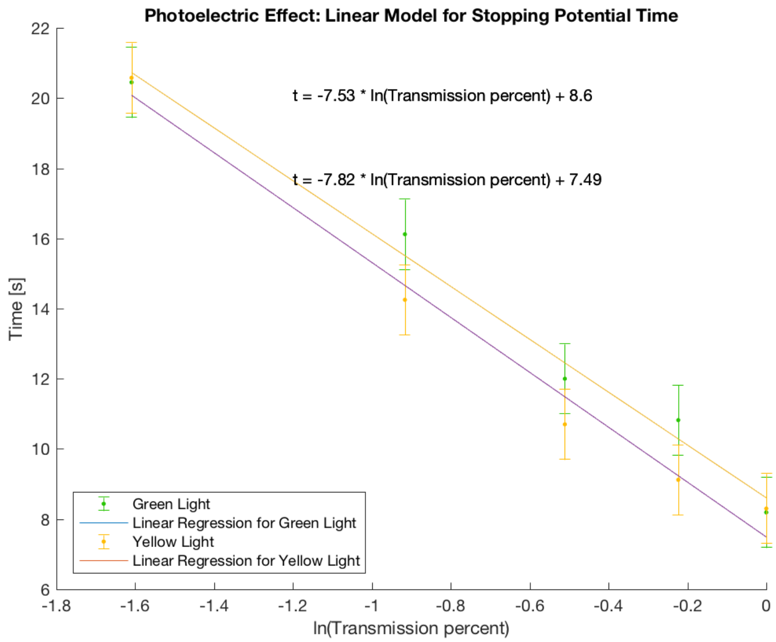

Figure 2: Linear Model for the Photoelectric Stopping Potential for Hg Spectrum Green with frequency $5.49 * 10^{14}$ and Yellow light with frequency $5.19 * 10^{14}$

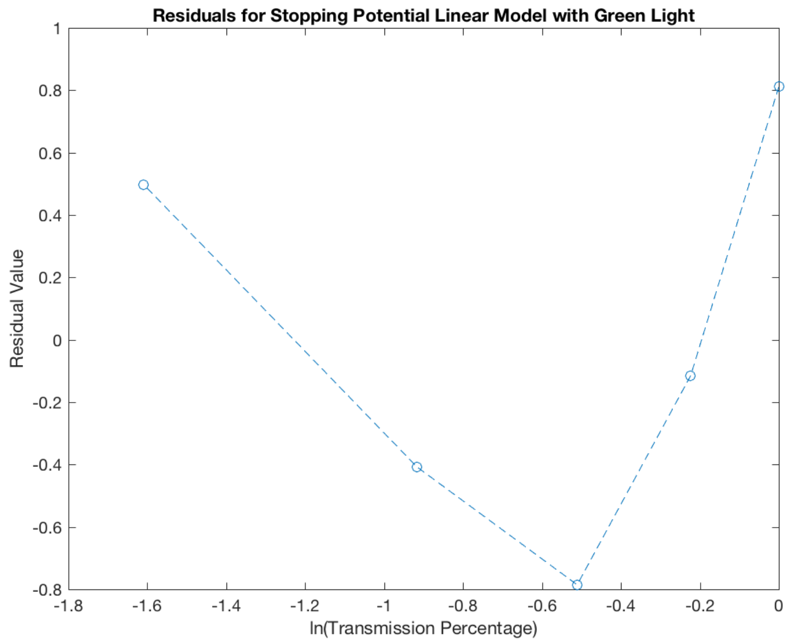

Figure 3: Plot of residuals for green light data from 2. Note the randomness of the data.

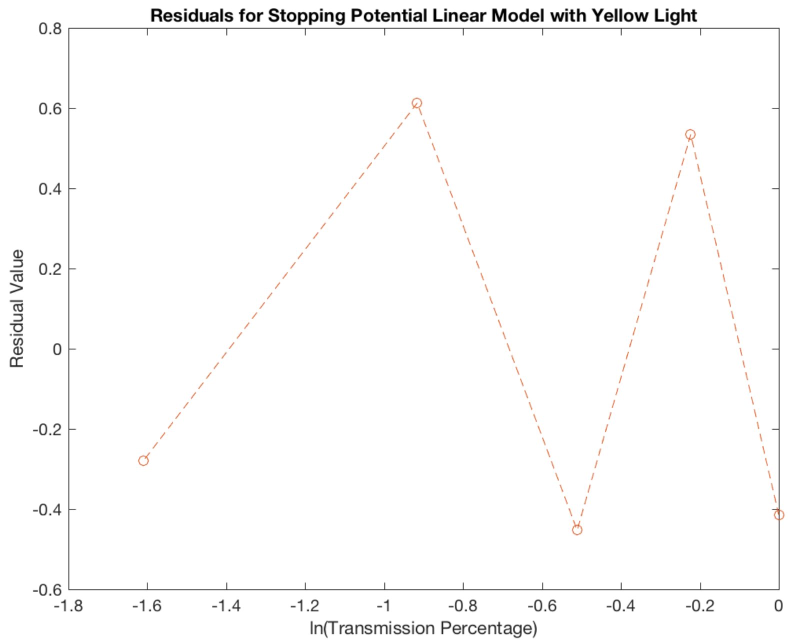

Figure 4: Plot of residuals for yellow light data from 2. Note the randomness of the data

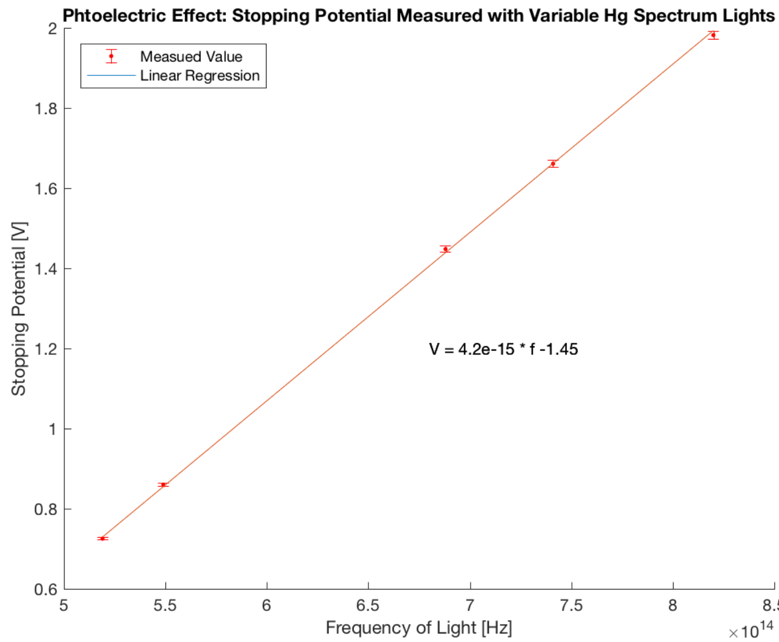

Figure 5: Photoelectric Effect: Stopping Potential Measured with Variable Hg Spectrum Lights

3 Appendix

3.1 Equation List

h is Planck's constant which has an accepted value of $6.626 * 10^{-34}\mathrm{J\,s}$ [2], υ is frequency, KE_{max} is the maximum kinetic energy of the emitted photoelectrons, W_0 is the work function, V is is the stopping potential in Volts, e is the charge of an electron with an accepted value of $1.602{*}10^{-19}\mathrm{C}$ [3], p_{trans} is the transmission percentage and t is the time to reach stopping potential.

$$V = (h/e)\upsilon - (W_0/e) \tag{2}$$

$$KE_{\mathrm{max}} = Ve \tag{3}$$

$$t = A\ln(p_{trans}) + t_{100\%} \tag{4}$$

3.2 Raw Data

Table 1: Photoelectric Stopping Potential Time and Voltage for Hg Spectrum Green light with frequency $5.49 * 10^{14}\mathrm{Hz}$

Transmission Percent	Stopping Potential [V] +/- 0.0042 [V]	Time to Recharge [s] +/- 1 s
100	0.857	8.19
80	0.855	10.82
60	0.855	12
40	0.854	16.12
20	0.851	20.45

Table 2: Photoelectric Stopping Potential Time and Voltage for Hg Spectrum Yellow Light, with frequency $5.19 * 10^{14}\mathrm{Hz}$

Transmission Percent	Stopping Potential [V] +/- 0.0036 [V]	Time to Recharge [s] +/- 1 s
100	0.721	8.3
80	0.720	9.12
60	0.720	10.7
40	0.719	14.25
20	0.716	20.58

Table 3: Photoelectric Stopping Potential Time for Various Hg Spectrum Lights

Light Colour	Frequency * 10^{14}[Hz]	Stopping Potential [V]	Error in Stopping Potential [V]
Yellow	5.19	0.725	0.0036
Green	5.49	0.860	0.0043
Blue	6.88	1.448	0.0072
Violet One	7.41	1.661	0.0083
Violet Two	8.2	1.982	0.0099

3.3 Sample Calculations using Linear Regression Data from 2

$h = h/e*e = (4.20\pm0.03)*10^{-15}\,\mathrm{J\,s\,C^{-1}}*1.602*10^{-19}\mathrm{C}= (6.73\pm0.04)*10^{-34}\,\mathrm{J\,s}$
$W_0 = W_0/e*e = 1.45 \pm 0.02\mathrm{J\,C^{-1}}*1.602*10^{-19}\mathrm{C}= 2.32 \pm 0.02\mathrm{J}$

References

[1] Nobel Media AB, "The nobel prize in physics 1921," 2017.

[2] The NIST Reference on Constants, Units and Uncertainties, "Planck's constant."

[3] The NIST Reference on Constants, Units and Uncertainties, "Elementary charge."