McGill Physical Journal

# An Illuminating Exploration of LEDs and Their Governing Physical Theory

Evan Henderson, Monte Mahlum

McGill University Department of Physics

Febraury 16th, 2022

**Abstract**

The purpose of this experiment was to test the hypothesis that the light given off by an LED is due to an excited electron returning to the n-type semiconductor from the p-type semiconductor. This was done indirectly by testing a prediction following from this hypothesis which states that the relation between turn-on energy, and the frequency of an LED obey the equation $E = h\nu$. By fitting data from multiple LEDs, two experimental values for Planck's Constant were found one from no resistance in the circuit and the second with a 467 $\Omega$ resistor. These values were found to be $(3.43 \pm 0.02) \times 10^{-15} eVs$ and $(3.49 \pm 0.02) \times 10^{-15} eVs$ respectively. Neither of these values are in agreement with the accepted value of Planck's Constant $(4.135667696... \times 10^{-15} eVs$ [1]). This finding does not support the prediction that was made by the hypothesis.

# 1 Introduction

LEDs may be pretty to look at, but they also have useful scientific applications. The purpose of this experiment was to analyze the inner physics of the common LED and to test the hypothesis that the light given off by an LED is due to an excited electron returning to the n-type semiconductor from the p-type semiconductor. These Semiconductors allow electrons to move between them, but there is a small energy difference that must be overcome, unlike a pure conductor. The electron is able to return to its unexcited state as the electric field created by the semiconductor is overcome by the voltage potential applied across the two semiconductors. As the electron becomes no longer excited, it emits a photon of a wavelength that can be measured. This relation between applied voltage and emitted wavelength of light is hypothesized to be

$$e\Delta V = hf, \tag{1}$$

where e is the charge of a single electron, V is the potential difference, h is Planck's constant, and f is the frequency of the emitted light. A goal of this experiment is to experimentally determine Planck's constant using LED emission wavelength and its corresponding turn-on voltage. In doing so, the hypothesis that the energy difference between the n and p-type semiconductors obeys equation 1 will be tested. This relationship can also be written with wavelength ($\lambda$) and the speed of light, c = 299792458 m/s ( [2]) instead of frequency:

$$e\Delta V\frac{\lambda}{c} = h. \tag{2}$$

# 2 Materials

Breadboard, DC Voltage Supply, Voltmeter, Digital Spectrometer, StellarNet GREEN-Wave Digital Spectrometer, Resistors, Assortment of LED's (Red, Purple, Orange, Yellow, Yellow-Green, Green, Blue, Ultraviolet, Warm-White, White,)

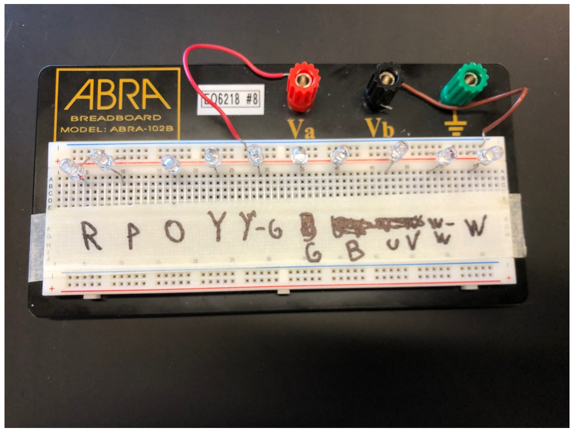



Figure 1: Breadboard Setup

# 3 Methodology

## 3.1 Determining Turn-on Voltage

1. LEDs assembled in breadboard as shown in figure 1.
2. The DC Voltage Supply was connect across the Red LED.
3. Voltage was increased fairly quickly until LED was observed to turn on.
4. Voltage was decreased slowly until LED was observed to no long be on.
5. Voltage was increased slowly until LED was observed to turn on.
6. Turn-on voltage was measured.
7. Steps 2-6 were repeated for each colour of LED.
8. Steps 2-7 were repeated with a resistor ($467\Omega$) in series with each LED.

## 3.2 Measuring LED Emission Wavelength

1. The DC Voltage Supply was connected across the Red LED and resistor ($467\Omega$).
2. With Voltage at 0V, the Digital Spectrometer was zeroed while being pointed at the off LED.
3. Voltage was increased until LED shined brightly.
4. Snapshot of Digital Spectrometer was recorded, such that prominent wavelength emissions could be determined.
5. Steps 1-4 were repeated for each colour of LED.

# 4 Results

The turn-on voltage of different coloured LEDs were measured to test the prediction of the hypothesis that the energy and frequency relation obeyed equation 1. The data was fitted to equation 1 in order to calculate a value for Planck's Constant. These fits can be found in figures 2, and 3 and final values are presented in Table 1.

Figure 2: Turn-On Voltage of Different LEDs With No Resistance

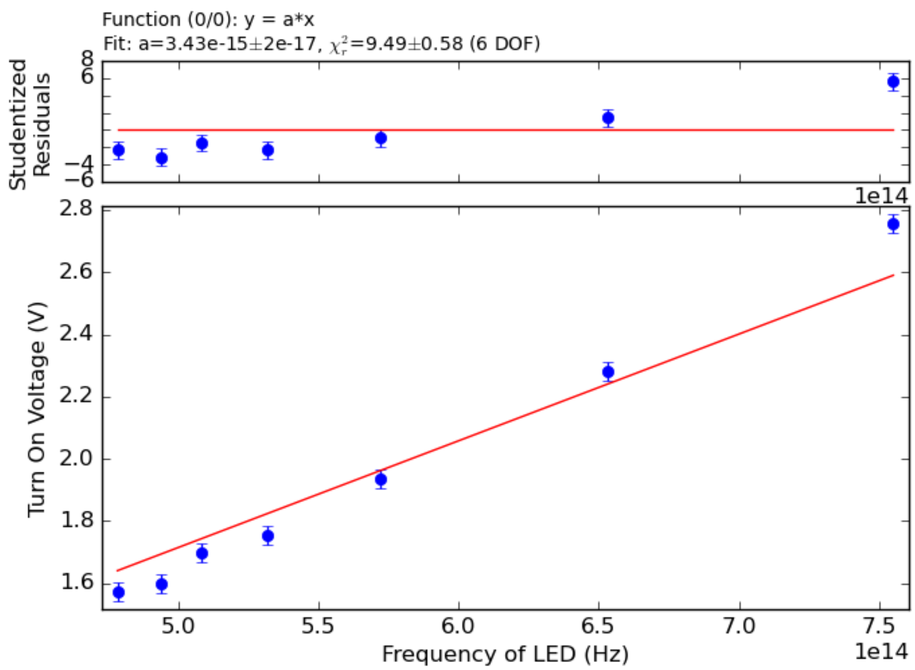


Figure 3: Turn-On Voltage of Different LEDs With 467 Ohm Resistance

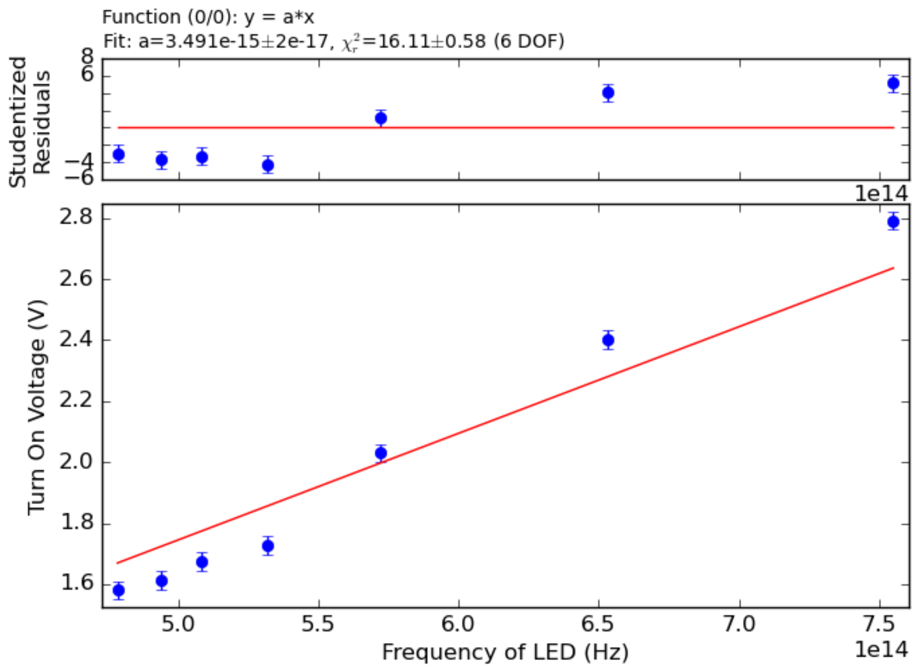



Table 1: Results From Fitting $V = \frac{h}{e}\nu$ to Experimental Data of Turn on Voltage Versus Frequency of LED Light

| Resistance | $h$ $(eVs \times 10^{-15})$ | $\sigma_h$ $(\pm eVs \times 10^{-15})$ |
|---|---|---|
| None | 3.43 | 0.02 |
| 467 Ohm | 3.49 | 0.02 |
| Literature Value | 4.14 [1] | |

# 5 Discussion

As seen in Table 1, this experiment found Planck's Constant to be $(3.43 \pm 0.02) \times 10^{-15} eVs$ in the case with no resisitor and $(3.49 \pm 0.02) \times 10^{-15} eVs$ in the case with a 467 $\Omega$ resistor. This value is in poor agreement with the literature value of plank's constant ($4.14 \times 10^{-15} eVs$ [1]).

Error analysis by means of the residual plots and $\chi^2$ values demonstrates that error on turn-on voltage was likely underestimated in this lab. Error was estimated by the variation in voltage observed during steps 3-5 in *Methodology 3.1 Determining Turn-on Voltage*. However it was difficult to determine precisely when the LED turned on. This is because the initial luminosity was very faint and the experiment was performed in a bright room.

Both measurements of Planck's constant are significantly lower than the literature value, suggesting that even with greater uncertainties, they may not agree. This is evidence against the prediction made by the hypothesis that the relationship between turn-on voltage and frequency of LEDs obeys equation 1. Since the experimental value for Planck's constant is below expected ones, this suggests that turn-on voltage may have been underestimated. Turn-on voltage was measured at the first sign of light emitted by the LED, even if minute. By the hypothesis, this corresponds to limited number of excited electrons obtaining enough energy to cause an emission, while the rest are still below the turn-on threshold. If the hypothesis is correct, a greater threshold of luminosity should have be taken as the indication for turn-on voltage. What exactly this threshold luminosity should be set as, is unknown and this should be investigated in future experiments. Alternatively, a less likely cause for this error is that the frequency may have been overestimated, however the uncertainty on the digital spectrometer was negligible relative to the voltmeter and LED.

Lastly it should be noted that while data was collected on ten different colours of LEDs, only seven were used in the data analysis of this lab. Some LEDs (namely Purple, Warm-White, and White) emit more than one wavelength of light. This makes it much more difficult to determine the relation between frequency and turn-on voltage with multiple contributing emission wavelengths.

# 6 Conclusions

The results of this experiment suggest a strong relationship between the emission frequency of an LED and the LED's turn-on voltage. However, both of the experimentally determined values of Planck's constant ($(3.43 \pm 0.02) \times 10^{-15} eVs$ and $(3.49 \pm 0.02) \times 10^{-15} eVs$) were not in agreement with its theoretical value ($4.135667696... \times 10^{-15} eVs$), meaning that the hypothesized model can not be support by this experiment. Future researchers should strive to reduce systematic error by performing the experiment in a dark room, and more rigorously defining the luminosity at which the LED may be considered "on". Alternatively there might be some unconsidered physical factor not accounted for in the proposed model that is skewing the determined value of Planck's constant.

# References

[1] National Institute of Standards and Technology. Kilogram: Mass and Planck's Constant. Created May 14, 2018, Updated June 2, 2021. https://www.nist.gov/si-redefinition/kilogram-mass-and-plancks-constant 1, 4

[2] What is the speed of light?. Vicky Stein. SPACE.com. January 2022. Accessed February 2022. https://www.space.com/15830-light-speed.html 1

# A First Appendix: Author Contribution Statements

Monte Mahlum

M.M contributed by taking raw data, analyzing this data via Data Analysis prompts, answering lab questions, writing the Lab Report, and completing the assignment.

Evan Henderson

E.H contributed by taking raw data, analyzing this data via Data Analysis prompts, answering lab questions, writing the Lab Report, and completing the assignment.

# B Second Appendix: Lab Book

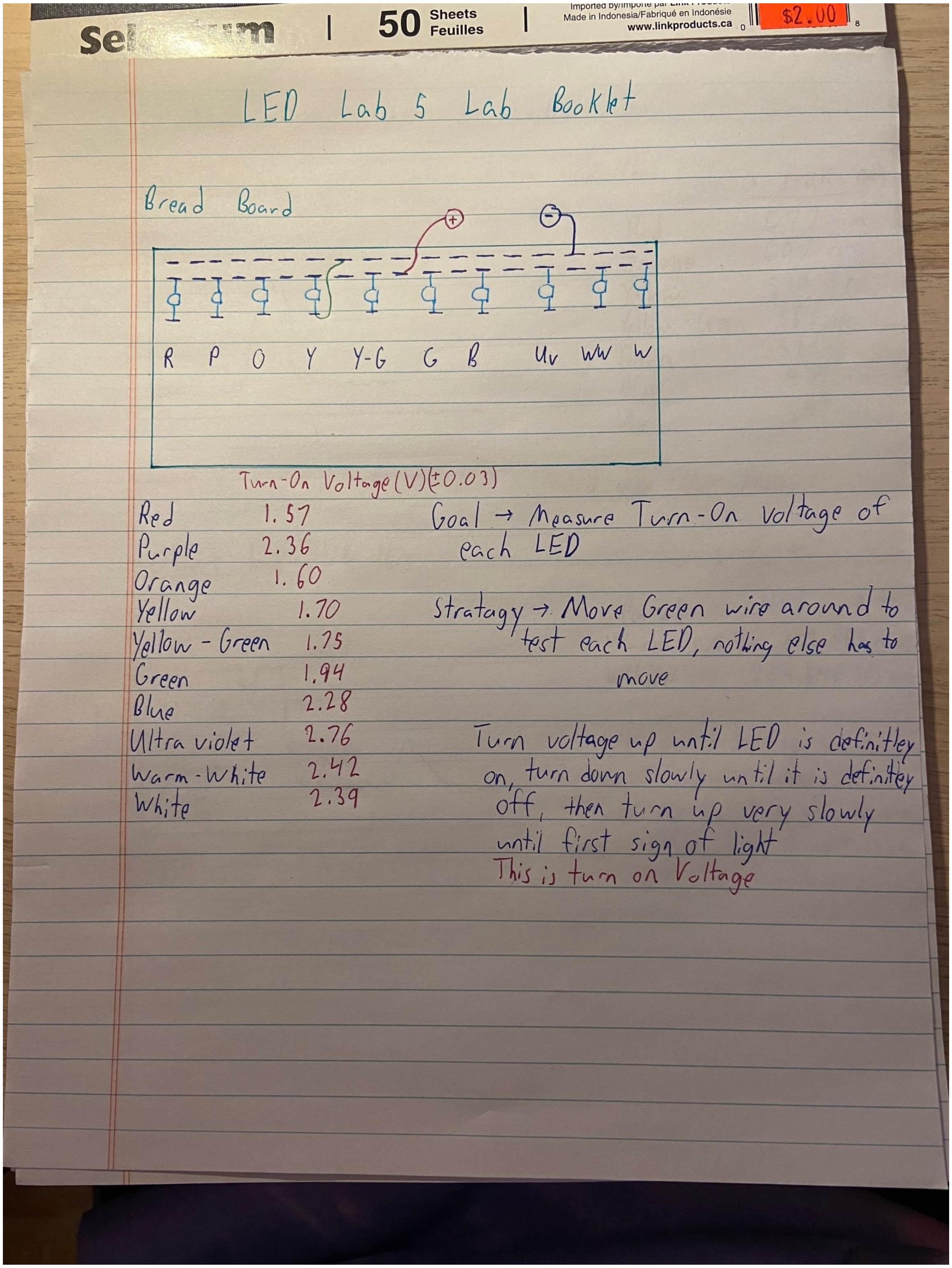
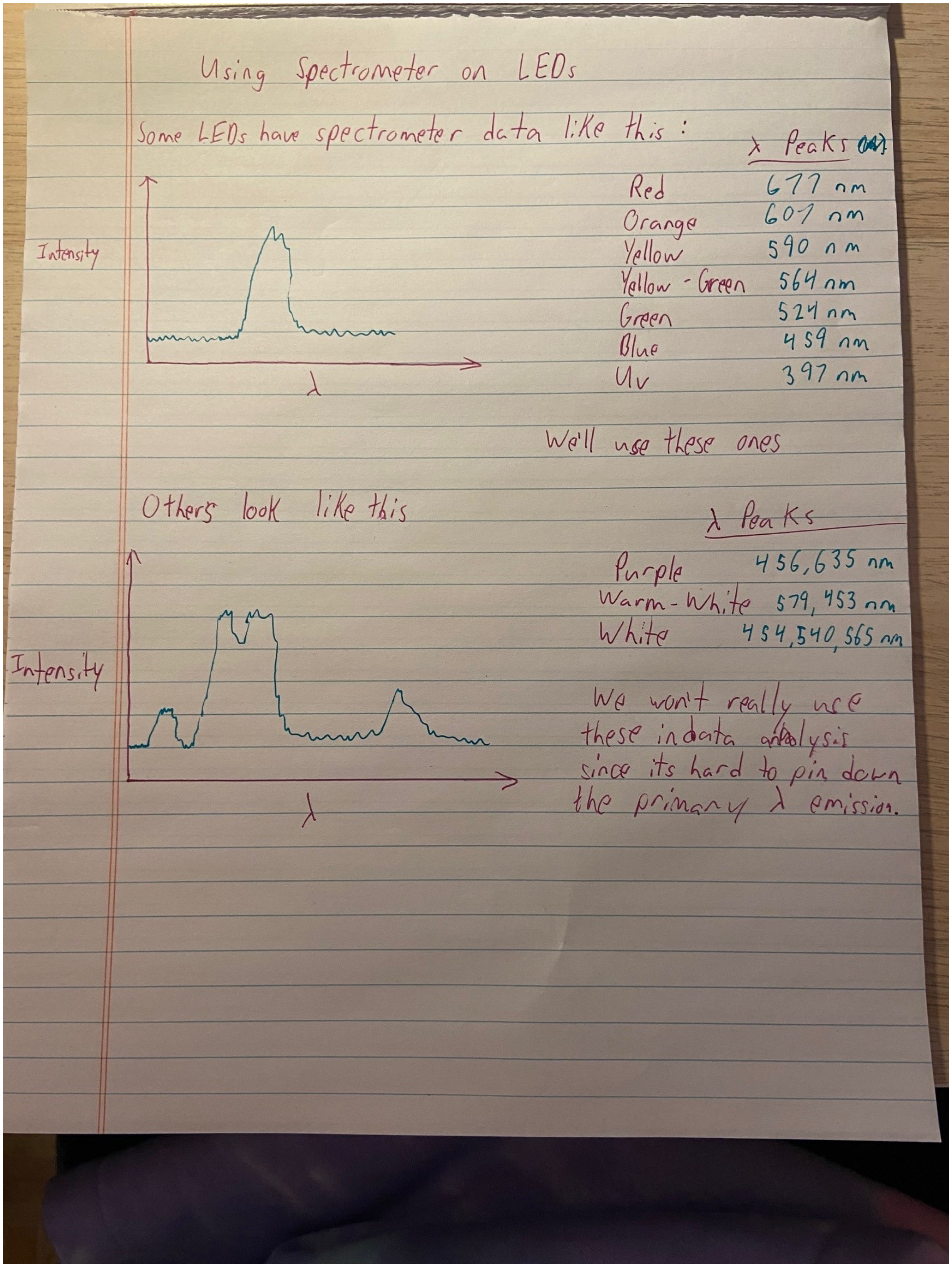



Figure 4: Lab Book page one



Using Spectrometer on LEDs

Some LEDs have spectrometer data like this :

Intensity

λ

| | λ Peaks |
|---|---|
| Red | 677 nm |
| Orange | 607 nm |
| Yellow | 590 nm |
| Yellow - Green | 564 nm |
| Green | 524 nm |
| Blue | 459 nm |
| Uv | 397 nm |

We'll use these ones

Others look like this

Intensity

λ

| | λ Peaks |
|---|---|
| Purple | 456,635 nm |
| Warm-White | 579, 453 nm |
| White | 454,540,565 nm |

We won't really use these in data analysis since its hard to pin down the primary λ emission.

Figure 5: Lab Book page two