Measuring Planck's Constant

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1 Project Summary

I propose to measure Planck's Constant using Light Emitting Diodes (LEDs). LEDs are circuit elements that emit photons upon a threshold energy. A plot of activation energy versus the frequency of emitted light should yield a straight line with a slope not different from Planck's Constant. Knowledge of Planck's constant will be useful for understanding the nature of energy in light, describing energy levels of the atom, and understanding many other physical observations.

Contents

2 Project Description

2.1 Background Information

The accepted relationship between the wavelength, λ, and the frequency, ν, is as follows: (where c is the speed of light)

$$\nu = \frac{c}{\lambda} \tag{1}$$

Planck's constant plays a central role in quantum mechanics, describing how subatomic particles interact with each other.

Planck's constant, h, is the proportionality constant which relates a photon's energy E to its frequency ν (and subsequently wavelength λ, as described in Planck (1901):

$$E_{\text{photon}} = h\nu = \frac{hc}{\lambda}. \tag{2}$$

As of right now it is unknown what causes the quantization of light, or whether light is quantized at all. We only know how very strange it is.

2.2 Experiment Design

Planck's constant, h, cannot be directly measured like the temperature of coffee can. Both the energy, E, and the frequency ν of a photon must be measured first, and h is derived as the proportionality constant between these two properties. The easiest way to measure E and ν is with Light Emitting Diodes (LEDs). LEDs are diodes, which due to an embedded semiconductor chip allow electrons to flow from its n-side to its p-side-but not vice versa. The reason behind this phenomena is the large drop in energy an electron experiences when traveling from the p-side to the n-side. As we might fall from a cliff and release our potential energy due to gravity in the form of kinetic energy, the electrons release their potential in the form of photons. By nature, LEDs only emit one wavelength because of the unique band gap of the semiconductor.(Turton, 2000)

This is incredibly useful because the discrete wavelength emitted by the diode can be measured with a spectrograph.(Butler and Laqua, 1995)

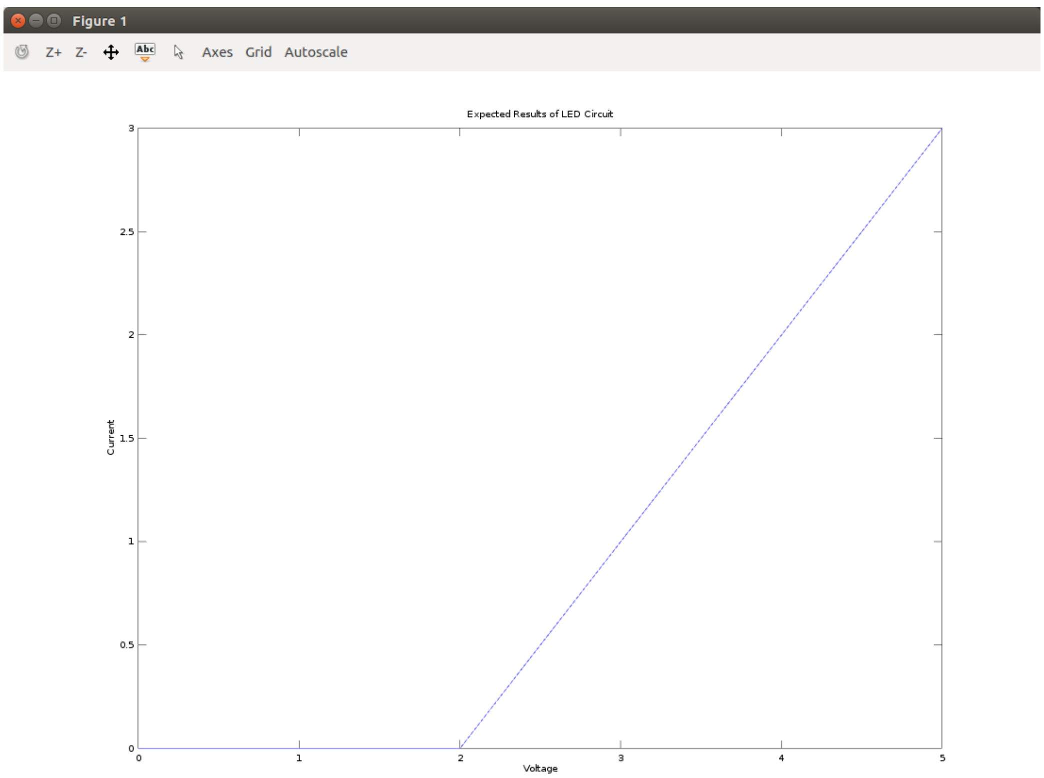

Figure 1: This is a graph of voltage vs. current for any given arbitrary LED. Where the function is zero, the activation energy of the LED (the smallest quantized energy of the photon for the given band gap) has not yet been reached, therefore current has not been allowed to flow through the circuit and there is not a linear relationship between i and V.

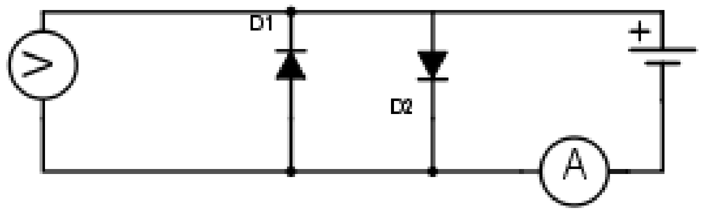

Figure 2: The nature of the diode is to allow current to flow in only one direction. Therefore by having to LEDs in opposing orientations, only one LED will be powered at any given potential. Therefore, by controlling the power supply we are able to collect data for two LEDs in a sitting. This is done by wiring two power supplies to the circuit. One will be wired inversely of the other, and only one shall be active at any given moment. This will essentially treat the circuit as though it were a single loop with a single LED.

Using equation 1, the frequency can easily be derived. Our theory predicts that the photon has a discrete energy proportional to the wavelength which the LED emits. To measure the energy, the nature of an LED must again be considered. If our theory proves true, there must be some quantity of energy at which the diode begins to emit photons. The band gap of the semiconductor determines the wavelength of the photon, therefore even if more than that predicted discrete energy value is introduced into the system, the energy of each individual photon will stay the same. As energy only affects intensity, the discrete energy of a photon emitted by an LED is the minimum energy to emit a photon.

An eye cannot be used to find the minimum energy to power an LED. Instead a familiar equation can be used:

$$V = iR \tag{3}$$

Where V is voltage, i is current, and R is resistance.(Millikan and Bishop, 1917) In order to complete a circuit current must flow. For current to flow through a diode a minimum energy must be reached to 'push the electron of the cliff.' Therefore if by measuring current and voltage in the circuit containing the LED, we obtain a graph like 1.

After the activation energy as reference in 1 is obtained, we are able to graph the respective frequencies of our LEDs vs their activation energies, and the slope is h.(Nieves et al., 1997)

LabView will be used to control the variable power supply, ammeter, and voltmeter. The power supply will vary its voltage from 0V to 85% of maximum capacity of the LED. While the power supply varies its voltage, the voltmeter and ammeter will record the instantaneous current and voltage. The information collected will be immediately sent to Plotly, which is a cloud data storage service.

Six LED frequencies will be tested. As shown in figure 2, two LEDs will be able to be tested without having to manually switch frequencies. This will allow two frequencies to be tested a night.

2.3 Possible problems

LabView When working with software or a language in a new way, complications are inevitable. However, LabView is a proprietary software with ample support and recent stable releases. Additionally I have extensive programming experience, have worked with LabView previously, and possess the *expert* skill of searching the internet for solutions (or as the youths' call it, 'Googling'). My prerequisites shall greatly lower the learning curve, and I have allotted an extra week of leeway to successfully deploy the required code.

Experiment Execution There is a chance that while the experiment is executing itself autonomously that it will fail for a number of reasons. Reasons for failure may include but are not limited to LEDs burning out, computer failure, human tampering (ie janitors), and unforeseen bugs in the code. These failures are very difficult to avoid, however precautions will be made. To avoid burning out LEDs the highest power provided to the diodes will never exceed 85% of their specifications. A sign will be put up to prevent unwanted interference from anyone who stumbles upon the experiment. However, if Windows spontaneously decides to update, someone disregards the cautionary sign, or if the code crashes on its 1000th loop, little can be done to prevent such events.

To save time in the case of the experiment inevitably going awry, I will post the data to Plotly as it is recorded. Plotly autonomously uploads data to its cloud server, which is accessible from anywhere with an internet connection. With Plotly, I will be able to check the progress of the experiment while not presently in the lab to catch any mishaps within the experiment.

2.4 Broader Impact

The confirmation of Planck's Constant would give us yet another constraint on which to base our theories of infinitesimally small particles. Hopefully this will lead to the validation of Einstein's hypothesis that light itself is quantized.(Compton, 1927) Planck's constant also implies that there is a finite minimum energy a photon of a certain frequency may possess.

In scientific applications beyond physics, Planck's Constant would allow us to create a qualitative model of the atom. By measuring the frequency of photons emitted by an atom we can derive the energy, and perhaps find different energy levels within an atom.(Bohr, 1913)

Even greater than its theoretical applications, is the paradigm shift it would induce. The existence of Planck's Constant implies that the macroscopic objects we interact with in everyday life are in fact composed of an tiny quantized particles. Who knows how such a discovery would shift science as we know it?

3 Time Line

I will begin by ensuring all of the equipment is functioning properly. By March 20th I will have tested and debugged code, established communication to equipment operated by LabView, and ensured that all physical components of the experiment are mechanically operational. Additionally, after the conclusion that each component of the experiment is functional is reached, I will have performed several mock runs of the experiment to confirm the data produced is not erroneous.

By March 27th I will have completed the data collection by running experiment as described in experimental design. The factor which will determine the stopping point of data collection is the quality of the data and the coherantness of the patterns the data produces. No less than two

Table 1 Experiment Timeline

3/20	Calibration and Setup Completed
3/27	Data Collection Completed
4/03	Data Interpretation and Numerical Analysis Completed
4/10	Error and Uncertainty Analysis Completed
5/09	Final Report and Presentation Completed

significant figures of experimental precision is acceptable in measuring the activation energy of the LEDs.

By April 3rd the data collected will be plotted and analyzed using Matlab to create lines of best fit where seen necessary and manipulated to derive Planck's Constant. The data shall also be compared to a numerical analysis performed using the current theoretical knowledge of light.

By April 10th the uncertainty of the data will be calculated and abnormalities in the data will be judged to determine whether they are an experimental error By May 9th I will have turned in my Final Report and have presented in Physics Seminar.The proposed timeline is available in Table 1.

4 Facilities, Equipment and Other Resources

To complete this experiment successfully, I will need certain pieces of equipment, many of which are already present in the lab.

- **Two Variable Power Supplies** with the capability to be programmed by LabView. Already owned.
- **Two Multimeters (Voltage and Current)** with the capability to be programmed by Labview. Already owned.

- **Breadboard** Already owned.
- **Banana Plugs and Wires** Already owned.
- **Assorted LEDs** with wavelengths corresponding to infrared, red, yellow, green, blue and ultraviolet light. The total cost of this is $5.34 from the supplier RadioShack.

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