Faculty of Science
Department of Physics
Laboratory Report Cover Page

Course Number	PCS224
Course Title	Physics: Solid State Physics
Semester/Year	Fall Semester 2023
Instructor	Carina Rebello
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Lab/Tutorial Report No.	Lab Experiment #4

Report Title	Lab 4 - LED Characterization

Section No.	03
Group No.	39
Submission Date	Nov. 8 11:30 pm
Due Date	Nov. 8 3:00 pm

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Appendices

Introduction

The objective of this lab is to determine the turn on voltage of each LED color and Panck's constant. Using the provided code and equipment, we can measure the current and voltage of each LED; we can determine the gap energy *Vs* to solve for h Planck's constant.

Theory

Light emitting diodes (LEDs) are semiconductor light sources which contain the P-N junction. Unlike a regular semiconductor, applying a sufficient amount of voltage in the forward bias direction allows electrons and holes to recombine, therefore releasing energy in the form of light. The voltage at where the LED turns on is known as the threshold voltage or "turn on" voltage which we will be observing in this lab. Below is a graph of many LEDs and their current vs voltage in a forward bias.

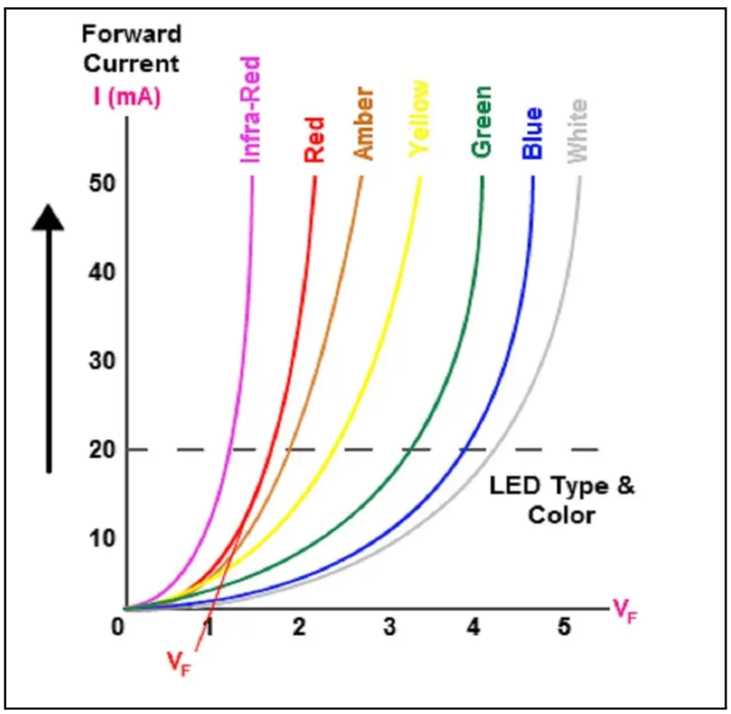


Figure 1.0: LED current vs voltage

In this experiment, we will determine the threshold voltage of each LED and derive Planck's constant by using the following measurements and given information.

- Measured Current
- Measured Voltage
- Wavelength of each LED colour

The equations needed to derive Plank's constant can be seen by the following below:

$Eg = hf$

$eV_s = \frac{hc}{\lambda}$ ← Equation (1) Solving for Planck's constant V_s vs $\frac{hc}{\lambda}$ graph

$x = \frac{V_s(y-b)}{ln(I)}$ ←Equation (2) Solving for threshold voltage

$f = \lambda/c$ ⟵Equation (3) Solving for frequency of each LED

To calculate Planck's constant we will need to find where the threshold voltage started. Using equation 2, we can find where the x-intercept is by plugging in 1mA for y and using the inverse slope and y-intercept to solve for x. To graph the threshold voltage vs frequency, we must solve for frequency first. Using equation (3) and the provided values of wavelengths, we can find the frequency of each colour. Graphing the voltage on the y-axis and frequency on the x-axis, we get a slope of $\frac{vc}{\lambda}$. We can solve for Planck's constant by using equation (1). When isolating h by multiplying the slope by *e*, the calculator should give us the estimated value of Planck's constant.

Procedure

The experiment began with the initialization of the computer and the launch of the Arduino Integrated Development Environment (IDE). A code was provided that required correction, likely to ensure its proper functionality. Subsequently, the corrected code was uploaded to an Arduino board connected to a breadboard. The LED from the equipment box was then carefully placed onto the breadboard, where it pulsated intermittently, gradually increasing in brightness until fully illuminated. To manage this process, an 'exit(0)' statement was implemented within the code, ensuring the LED turned off after completing the pulsing sequence. This sequence was designed to measure both the voltage and current of the LED. Recorded data, encompassing the values of both voltage and current, were meticulously logged into a Google Sheets document. This procedure was repeated for various LED lights, presumably to gather a comparative analysis of different LEDs under the same conditions. The systematic approach aimed to not only fix the code but also to measure and record the performance of different LED lights for a comprehensive analysis of their electrical characteristics.

Results and Calculations

Blue LED	
voltage (V)	current (mA)
1.03 ± 0.005 V	0.4 ± 0.05 mA
1.24 ± 0.005 V	1.1 ± 0.05 mA
1.28 ± 0.005 V	3.1 ± 0.05 mA
1.41 ± 0.005 V	6.2 ± 0.05 mA
1.44 ± 0.005 V	9.8 ± 0.05 mA
1.65 ± 0.005 V	10.4 ± 0.05 mA
1.69 ± 0.005 V	11.6 ± 0.05 mA
1.78 ± 0.005 V	12.3 ± 0.05 mA
1.84 ± 0.005 V	14 ± 0.05 mA
1.94 ± 0.005 V	15.1 ± 0.05 mA
1.98 ± 0.005 V	15.6 ± 0.05 mA
2.04 ± 0.005 V	16.6 ± 0.05 mA
2.16 ± 0.005 V	17.7 ± 0.05 mA
2.22 ± 0.005 V	19.5 ± 0.05 mA
2.27 ± 0.005 V	20.5 ± 0.05 mA
2.31 ± 0.005 V	21.4 ± 0.05 mA
2.39 ± 0.005 V	22.4 ± 0.05 mA
1.1 ± 0.005 V	51.5 ± 0.05 mA
1.18 ± 0.005 V	53.3 ± 0.05 mA
1.24 ± 0.005 V	54.6 ± 0.05 mA
1.29 ± 0.005 V	56.4 ± 0.05 mA
1.4 ± 0.005 V	58 ± 0.05 mA
1.49 ± 0.005 V	59.4 ± 0.05 mA
1.59 ± 0.005 V	64.1 ± 0.05 mA
1.7 ± 0.005 V	62.3 ± 0.05 mA
1.82 ± 0.005 V	63.6 ± 0.05 mA
1.86 ± 0.005 V	65.4 ± 0.05 mA
1.88 ± 0.005 V	66.8 ± 0.05 mA
1.97 ± 0.005 V	66.8 ± 0.05 mA
2.05 ± 0.005 V	66.9 ± 0.05 mA

Table 1.0 Voltage and Current for Blue LED

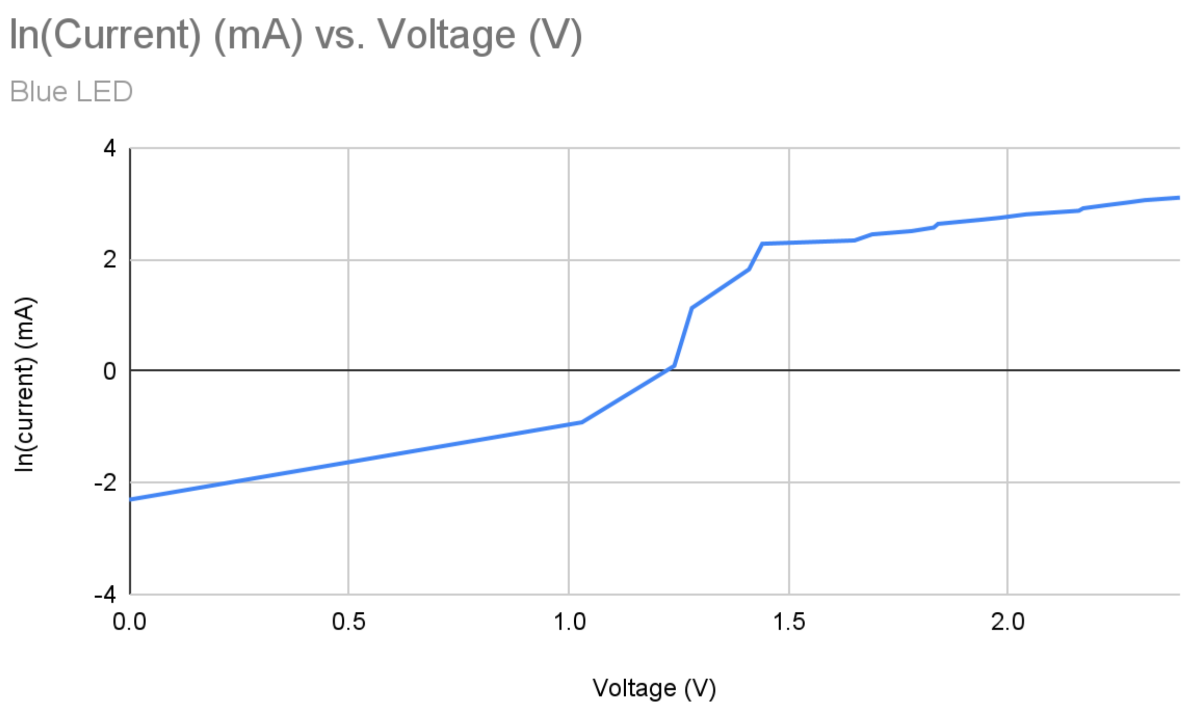


Figure 2.0 Graph of Natural Log of Current (mA) vs. Voltage (V) for Blue LED

Red LED	
voltage (V)	current (mA)
1.03 ± 0.005 V	0.2 ± 0.05 mA
1.29 ± 0.005 V	0.5 ± 0.05 mA
1.5 ± 0.005 V	0.7 ± 0.05 mA
1.68 ± 0.005 V	1.4 ± 0.05 mA
1.76 ± 0.005 V	1.8 ± 0.05 mA
1.82 ± 0.005 V	2.3 ± 0.05 mA
1.96 ± 0.005 V	3.2 ± 0.05 mA
2.08 ± 0.005 V	3.7 ± 0.05 mA
2.16 ± 0.005 V	4.6 ± 0.05 mA
2.42 ± 0.005 V	5.9 ± 0.05 mA
2.48 ± 0.005 V	6.7 ± 0.05 mA
2.66 ± 0.005 V	7.3 ± 0.05 mA
2.8 ± 0.005 V	7.7 ± 0.05 mA

Table 2.0 Voltage and Current for Red LED

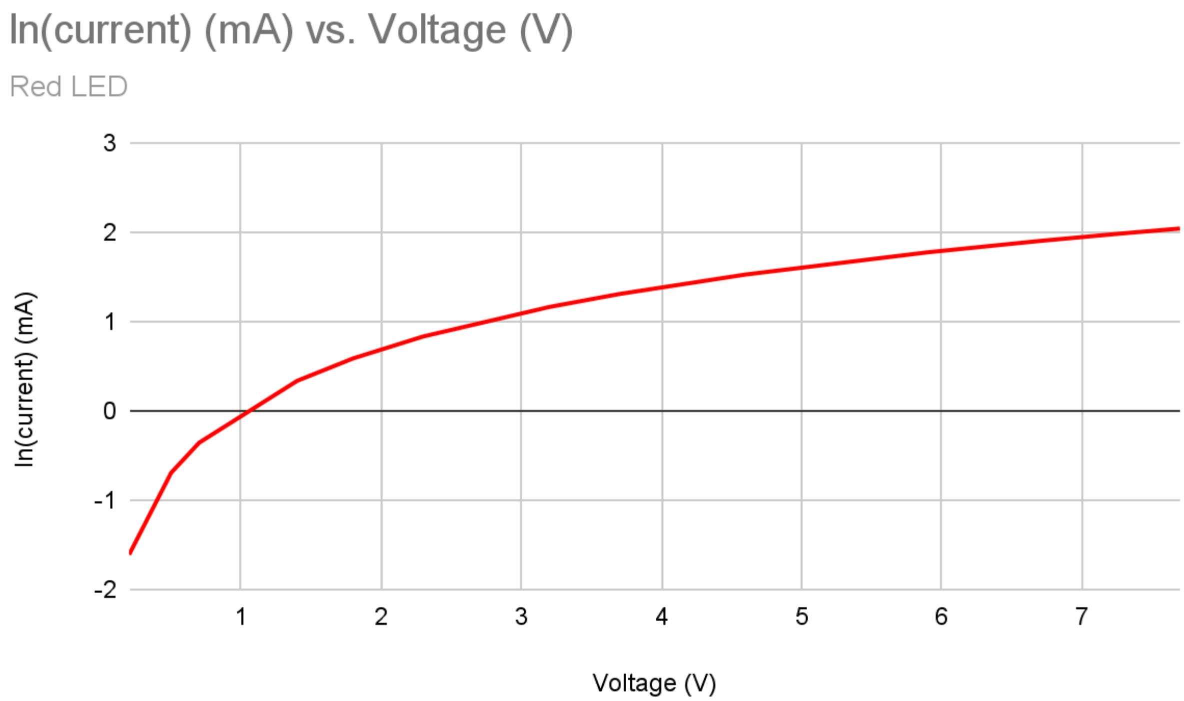


Figure 3.0 Graph of Natural Log of Current (mA) vs. Voltage (V) for Red LED

Green LED	
voltage (V)	current (mA)
1.03 ± 0.005 V	0.2 ± 0.05 mA
1.06 ± 0.005 V	0.3 ± 0.05 mA
1.08 ± 0.005 V	2 ± 0.05 mA
1.14 ± 0.005 V	6.4 ± 0.05 mA
1.21 ± 0.005 V	10.9 ± 0.05 mA
1.25 ± 0.005 V	12.2 ± 0.05 mA
1.31 ± 0.005 V	15 ± 0.05 mA
1.36 ± 0.005 V	21 ± 0.05 mA
1.39 ± 0.005 V	24.9 ± 0.05 mA
1.45 ± 0.005 V	29.4 ± 0.05 mA
1.49 ± 0.005 V	34.1 ± 0.05 mA
1.53 ± 0.005 V	40.6 ± 0.05 mA
1.54 ± 0.005 V	43.5 ± 0.05 mA
1.57 ± 0.005 V	49.6 ± 0.05 mA
1.58 ± 0.005 V	54.9 ± 0.05 mA
1.64 ± 0.005 V	61 ± 0.05 mA
1.69 ± 0.005 V	67.8 ± 0.05 mA
1.73 ± 0.005 V	73 ± 0.05 mA
1.74 ± 0.005 V	79.2 ± 0.05 mA
1.75 ± 0.005 V	86 ± 0.05 mA

Table 3.0 Voltage and Current for Green LED

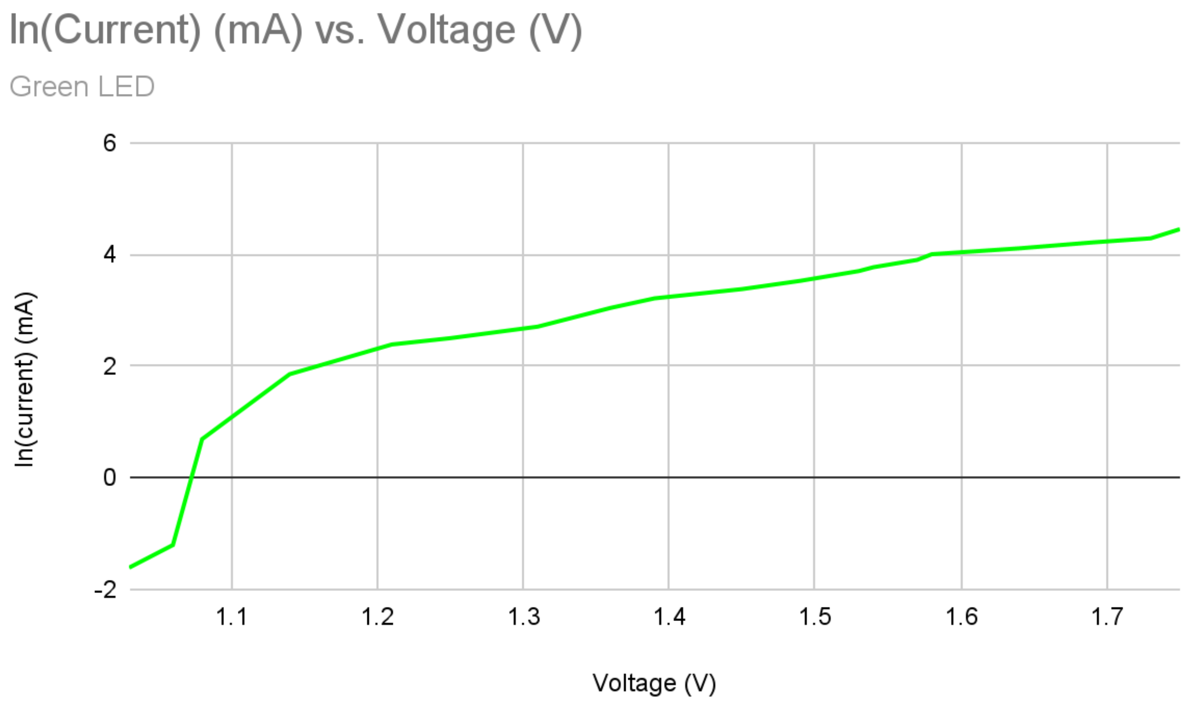


Figure 4.0 Graph of Natural Log of Current (mA) vs. Voltage (V) for Green LED

Yellow LED	
voltage (V)	current (mA)
1.03 ± 0.005 V	0.2 ± 0.05 mA
1.07 ± 0.005 V	1.5 ± 0.05 mA
1.16 ± 0.005 V	3.5 ± 0.05 mA
1.22 ± 0.005 V	10.1 ± 0.05 mA
1.26 ± 0.005 V	15.1 ± 0.05 mA
1.28 ± 0.005 V	18.8 ± 0.05 mA
1.31 ± 0.005 V	20.3 ± 0.05 mA
1.32 ± 0.005 V	22.3 ± 0.05 mA
1.35 ± 0.005 V	26.9 ± 0.05 mA
1.36 ± 0.005 V	29.2 ± 0.05 mA
1.37 ± 0.005 V	31.4 ± 0.05 mA
1.38 ± 0.005 V	34 ± 0.05 mA
1.4 ± 0.005 V	38.8 ± 0.05 mA
1.41 ± 0.005 V	42 ± 0.05 mA
1.42 ± 0.005 V	44.5 ± 0.05 mA
1.45 ± 0.005 V	48 ± 0.05 mA
1.49 ± 0.005 V	53 ± 0.05 mA
1.52 ± 0.005 V	55.9 ± 0.05 mA
1.53 ± 0.005 V	58.9 ± 0.05 mA
1.55 ± 0.005 V	62 ± 0.05 mA
1.57 ± 0.005 V	65 ± 0.05 mA
1.59 ± 0.005 V	68.3 ± 0.05 mA
1.64 ± 0.005 V	71.9 ± 0.05 mA
1.66 ± 0.005 V	74.4 ± 0.05 mA
1.69 ± 0.005 V	75.9 ± 0.05 mA
1.76 ± 0.005 V	81.7 ± 0.05 mA
1.78 ± 0.005 V	84.2 ± 0.05 mA
1.81 ± 0.005 V	87.9 ± 0.05 mA
1.82 ± 0.005 V	90.8 ± 0.05 mA
1.84 ± 0.005 V	94.3 ± 0.05 mA

Table 4.0 Voltage and Current for Yellow LED

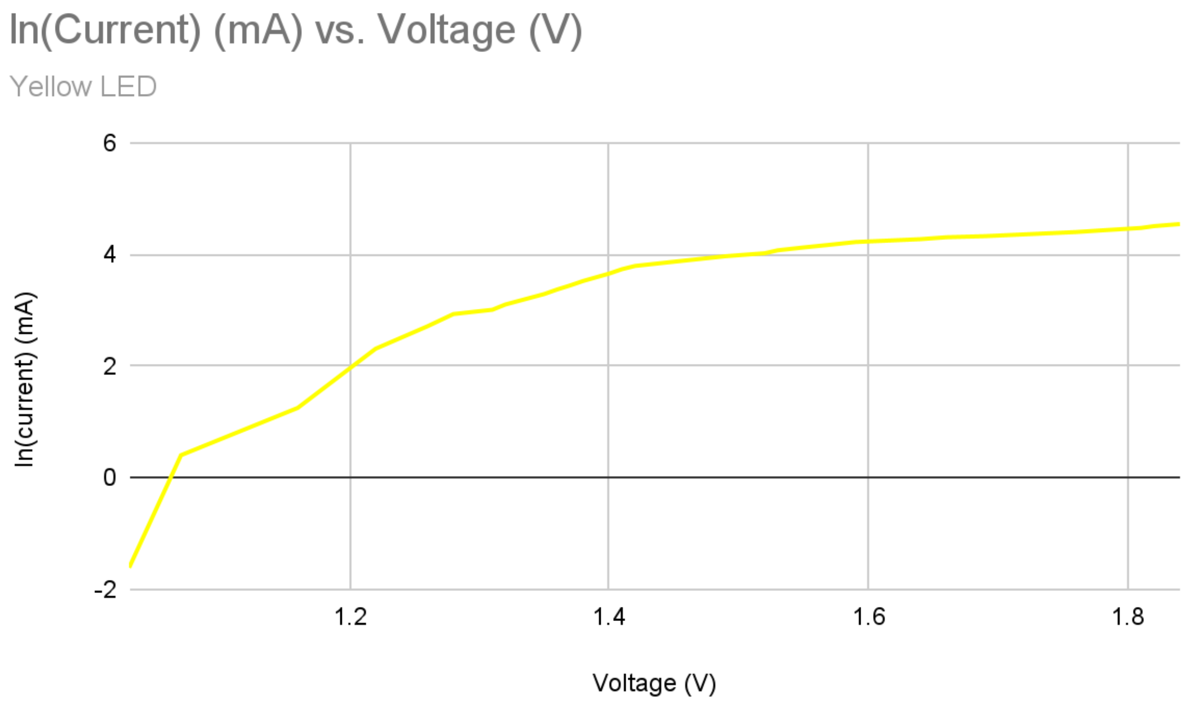


Figure 5.0 Graph of Natural Log of Current (mA) vs. Voltage (V) for Yellow LED

Purple LED	
voltage (V)	current (mA)
1.03 ± 0.005 V	0.2 ± 0.05 mA
1.08 ± 0.005 V	0.6 ± 0.05 mA
1.69 ± 0.005 V	0.7 ± 0.05 mA
2.02 ± 0.005 V	1.6 ± 0.05 mA
1.5 ± 0.005 V	2.9 ± 0.05 mA
1.37 ± 0.005 V	5 ± 0.05 mA
1.76 ± 0.005 V	7.4 ± 0.05 mA
1.91 ± 0.005 V	8.5 ± 0.05 mA
1.99 ± 0.005 V	10.2 ± 0.05 mA
2.06 ± 0.005 V	14.2 ± 0.05 mA
2.18 ± 0.005 V	17.4 ± 0.05 mA
2.24 ± 0.005 V	20.8 ± 0.05 mA
2.34 ± 0.005 V	23.1 ± 0.05 mA
2.38 ± 0.005 V	25.2 ± 0.05 mA
2.44 ± 0.005 V	27.3 ± 0.05 mA
1.17 ± 0.005 V	56 ± 0.05 mA
1.27 ± 0.005 V	58.9 ± 0.05 mA
1.34 ± 0.005 V	61.2 ± 0.05 mA
1.39 ± 0.005 V	64 ± 0.05 mA
1.51 ± 0.005 V	66.5 ± 0.05 mA
1.57 ± 0.005 V	68.9 ± 0.05 mA
1.71 ± 0.005 V	70.7 ± 0.05 mA
1.78 ± 0.005 V	73.1 ± 0.05 mA
1.91 ± 0.005 V	75.7 ± 0.05 mA
1.99 ± 0.005 V	79 ± 0.05 mA
2.16 ± 0.005 V	81.3 ± 0.05 mA
2.24 ± 0.005 V	84.2 ± 0.05 mA
2.32 ± 0.005 V	87.4 ± 0.05 mA
2.41 ± 0.005 V	89.9 ± 0.05 mA
2.49 ± 0.005 V	92.7 ± 0.05 mA
2.6 ± 0.005 V	96 ± 0.05 mA

Table 5.0 Voltage and Current for Purple LED

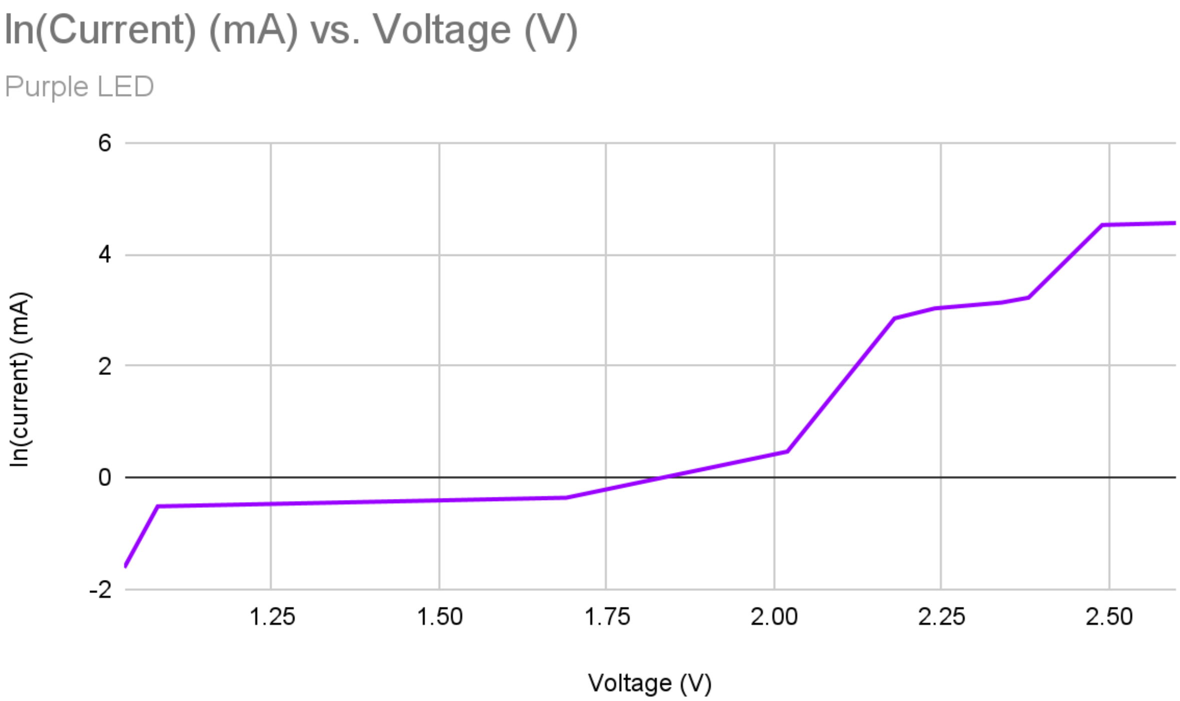
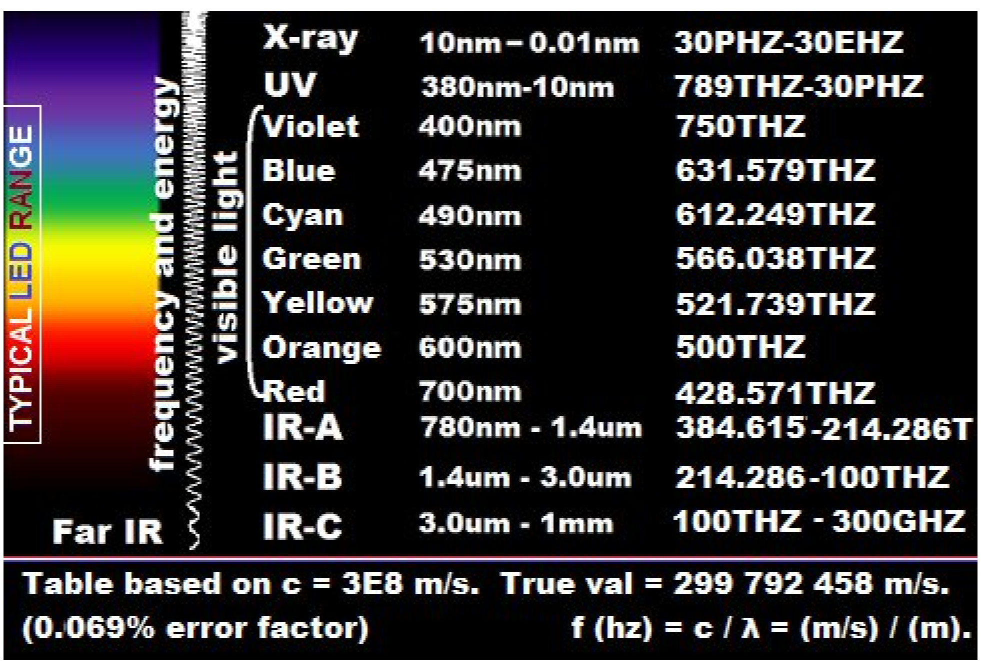


Figure 6.0 Graph of Natural Log of Current (mA) vs. Voltage (V) for Purple LED



X-ray	10nm – 0.01nm	30PHZ-30EHZ
UV	380nm-10nm	789THZ-30PHZ
Violet	400nm	750THZ
Blue	475nm	631.579THZ
Cyan	490nm	612.249THZ
Green	530nm	566.038THZ
Yellow	575nm	521.739THZ
Orange	600nm	500THZ
Red	700nm	428.571THZ
IR-A	780nm - 1.4um	384.615-214.286T
IR-B	1.4um - 3.0um	214.286-100THZ
IR-C	3.0um - 1mm	100THZ - 300GHZ

Table based on c = 3E8 m/s. True val = 299 792 458 m/s.
(0.069% error factor) f (hz) = c / λ = (m/s) / (m).

Figure 7.0 Wavelengths for Different Colour LEDs

Colour	Wavelength (nm) (From Figure 7.0)	Threshold Voltage (V) (From x-intercept of current/voltage graph)	Frequency (Hz) (c/λ)
Blue	475 ± 0.5 nm	1.24 ± 0.005 V	6.32×10^{14} s^{-1}
Red	700 ± 0.5 nm	1.01 ± 0.005 V	5.43×10^{14} s^{-1}
Green	530 ± 0.5 nm	1.06 ± 0.005 V	5.66×10^{14} s^{-1}
Yellow	575 ± 0.5 nm	1.04 ± 0.005 V	5.22×10^{14} s^{-1}
Purple	400 ± 0.5 nm	1.82 ± 0.005 V	7.50×10^{14} s^{-1}

Table 6.0 Wavelength, Threshold Voltage, and Frequency of Different Colour LEDs

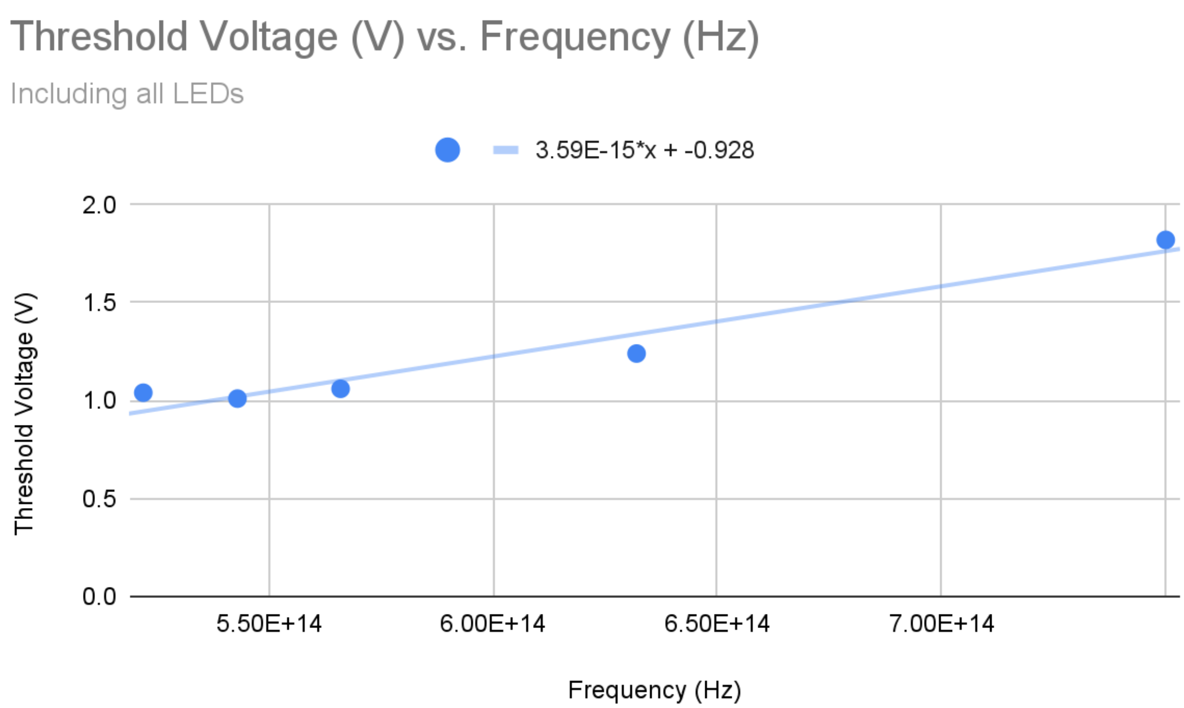


Figure 8.0 Graph of Threshold Voltage and Frequency for Different Colour LEDs

$$h = e\frac{V_t}{\nu} = (1.602 \times 10^{-19} C)(3.59 \times 10^{-15}) = 5.75 \times 10^{-34} \frac{J}{Hz}$$

$$\%\, error\, of\, h = \left|\frac{measured - accepted}{accepted}\right| \times 100 = \left|\frac{5.75\times10^{-34} - 6.63\times10^{-34}}{6.63\times10^{-34}}\right| \times 100 = 13\%$$

Discussion

1. The threshold voltage is the voltage required for forward conduction to occur. For LEDs, it is the voltage required to turn on the LED. When the threshold voltage is reached, hole and electron pairs are created to release energy in the form of light. For this lab, it can be referred to as the turn-on voltage.
2. Changing the transistor would result in a reverse bias.
3. We use a break in the for loop so the loop stops when a certain condition is met. If we were to allow the LED to surpass 5V, this would lead to a short circuit and the LED would burn out.
4. Code is provided below:

```
#include <Wire.h>

#include <SPI.h>

#include <Adafruit_MCP4725.h> // DAC library

#include <Adafruit_INA219.h> // INA219 current sensor library


// Declare a current sensor object.

Adafruit_INA219 ina219; // Commands like ina219.getCurrent_mA() will read the current.


// Declare our voltage supply objects.

Adafruit_MCP4725 dac_LEDsupply;

#define DAC_RESOLUTION (9) // Set this value to 9, 8, 7, 6 or 5 to adjust the
resolution.


// Declare some useful variables.

float voltageAcrossLED;

float currentAcrossLED;


void setup(void) {

Serial.begin(9600); // Initiates serial communication, so we can send our data to

// our computer. This is where the the baud rating is set.

// Initialize the INA219 sensor (current sensor).

ina219.begin();

// Initialize our DAC breakout board.

dac_LEDsupply.begin(0x62); // 0x62 sets the hex address of dac
```

```
// so the arduino addresses the correct DAC.

}


void loop() {


for( int i= 0; i < 4096; i += 10){

dac_LEDsupply.setVoltage(i, false); //sets the output voltage to 0V and

voltageAcrossLED = ina219.getBusVoltage_V(); //Take a voltage reading

Serial.print(voltageAcrossLED); //Print the voltage readingå

Serial.print(" "); //Add a space between the voltage reading and the next reading
taken

currentAcrossLED = ina219.getCurrent_mA();

Serial.print(currentAcrossLED);

Serial.println(" ");

dac_LEDsupply.setVoltage(0, false); //sets the output voltage to 5V.

delay(30);

if(currentAcrossLED>100){

i = 4096;

}

}

}
```

Conclusions

In this experiment, we observed how the current across an LED changes when the voltage across it increases and how that relates to its brightness for 5 different coloured LEDs. We also found the threshold voltage for each LED using the relationship between the natural log of current and the applied voltage. Using the relationship between the threshold voltage and calculated frequency, we succeeded in finding planck’s constant with a sufficient percent error. Discrepancies could have been caused by faulty electronic equipment or missing data points.

References

W. Moebs, S. J. Ling, and J. Sanny, "university physics volume 1," *OpenStax*, 19-Sep-2016. [Online]. Available: https://openstax.org/books/university-physics-volume-1. [Accessed: 04-Nov-2022].

https://www.quora.com/What-is-the-wavelength-of-light-emitted-by-LED