Calculating Planck's Constant

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Abstract

This project aims to calculate Planck's constant (h) by performing a multi-slit diffraction experiment. This constant appears in the ratio of the energy of a photon to its frequency as well as the momentum of a wave matter multiplied by its wavelength and many other relations. About the experiment, it has been designed to be constructed with LEDs with various colors and DC circuits, including an Ardunio [1]. LEDs with multiple colors will allow to repeat the experiment several times and calculate Planck's constant for different wavelengths. The precision between the values of h will determine the accuracy of the project.

I Introduction

The motivation behind the need for such a constant is the inconsistency between existing theoretical frameworks and empirical observations concerning black-body radiation.

The first trial came from Wilhelm Wien, which is now known as Wien's law [2]. Wien considered an adiabatic expansion of a cavity containing waves of light in thermal equilibrium. Using Doppler's principle, he showed that, under slow expansion or contraction, the energy of light reflecting off the walls changes in the same way as the frequency. This approach worked well in short wavelengths and high temperatures, but it fell short when extended to longer wavelengths.

Then Lord Rayleigh and Sir James Jean came up with the Rayleigh-Jeans law based on classical physical arguments, relying upon the equipartition theorem [3]. It provided theoretical insights into longer wavelengths but proved inadequate when applied to shorter wavelengths.

While Max Planck had been working on this problem for quite some time, he took a very unusual approach out of desperation. He assumed that the energy levels of light should be quantized, not continuous.

Planck's solution required introducing an additional variable denoted as "h", which he thought was a math trick and was expecting to disappear at some point. However, after he derived an expression for black-body radiation, subsequently recognized as Planck's law, the constant did not disappear, and beyond that, it was realized that it successfully matched the experimental data for the entire wavelength and temperature values [4].

His assertion that energy existed in discrete units challenged classical notions of continuity. Still, eventually, this approach shifted the perspective on energy, matter, and behavior of fundamental particles and laid the foundation for quantum mechanics.

Additionally, this constant and its background idea extends its origins in theoretical physics and has already entered our daily lives long before. One of the most common usage areas of the Planck constant is in semiconductor technology, particularly in the design and refinement of semiconductor devices like computer chips. These chips are the backbone of modern electronics, powering a wide array of devices, from smartphones to supercomputers. LEDs are also its products, which are frequently used in screen technology, household lighting, traffic signals, and as well as this project. Unlike the traditional ampules, they do not consume most of their energy to heat and contribute to the energy economy.

II Theory & Mathematics

I Wavelength Calculation

When light waves pass through a very thin slit, they begin to propagate circularly since the slit behaves as though the slit is a point source[5, p. 114,115,116][6, p. 444,445,448]. In double or multi-slit experiments, these circular waves create an interference pattern on the surface they fall onto [5, p. 114,115,121].

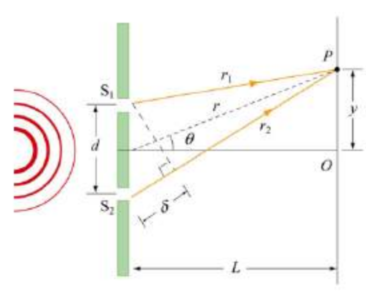

Figure 1: [7, p. 14-5]

From the cosines theorem with given variables in Fig. 1 [7, p. 14-5], one can produce following two formulas:

$$r_1{}^2 = r^2 + \frac{d}{2}^2 - 2\frac{d}{2}r\cos{(\frac{\pi}{2} - \theta)}[7, p.\ 14-5] \quad (1)$$

which is also

$$r_1{}^2 = r^2 + \frac{d}{2}^2 - dr\sin{(\theta)}[7, p.\ 14-5] \quad (2)$$

$$r_2{}^2 = r^2 + \frac{d}{2}^2 - 2\frac{d}{2}r\cos{(\frac{\pi}{2} + \theta)}[7, p.\ 14-5] \quad (3)$$

which is also

$$r_2{}^2 = r^2 + \frac{d}{2}^2 + dr\sin{(\theta)}[7, p.\ 14-5] \quad (4)$$

When Eq. 2 is subtracted from Eq. 4 [7, p. 14-6], remaining formula is following:

$$r_2{}^2 - r_1{}^2 = 2dr\sin{(\theta)}[7, p.\ 14-6] \quad (5)$$

In Figure 1, when d is taken remarkably smaller then L [8][7, p. 14-6], r_1 and r_2 can be considered as if they are parallel, and their sum is equal to 2r: $r_1 + r_2 = 2r$ [7, p. 14-6]. Then, following simplification can be done:

$$(r_2 + r_1)(r_2 - r_1) = 2dr\sin{(\theta)}[7, p.\ 14-6] \quad (6)$$

$$2r(r_2 - r_1) = 2dr\sin{(\theta)} \quad (7)$$

and the remaining formula becomes

$$r_2 - r_1 = d\sin{(\theta)} \quad (8)$$

In addition, when r_1 and r_2 accepted as they are parallel [7, p. 14-6], the distance indicated with δ becomes the difference between r_1 and r_2.

$$\delta = d\sin{(\theta)}[7, p.\ 14-6] \quad (9)$$

Considering the two alongside slits of the grating, the light fringes occur just like in the Fig. 2.

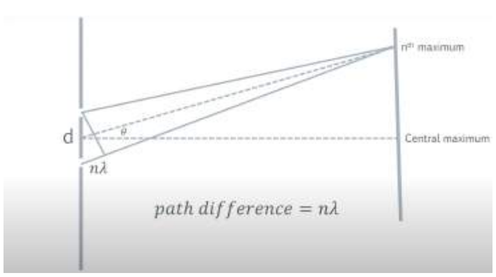

Figure 2: [9]

As it is seen (after applying an approximation since d is so tiny compared to the distance between the slits and wall) from the similarity between triangles, the angle between d and the line perpendicular to the longer line that goes to nth maximum from the bottom slit is the same with the angle theta as shown in the Fig. 3. Hence, it is seen that δ is proportional with nλ.

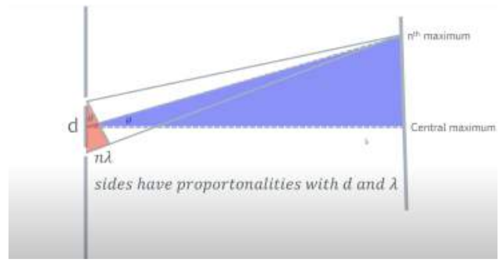

Figure 3: [9]

Therefore, there is a proportionality between d and λ as well. With this information, one can quickly achieve the equation.

$$d\sin\theta = n\lambda \quad (10)$$

Hence, the wavelength of the light waves can be found using this pattern obtained from a light source passing through a diffraction grating. Diffraction patterns also have some dark points. However, for this experiment, since the wavelength will be measured, the "constructive interference" pattern is needed, which can be determined by the light lines on the screen on which the pattern appears [7, p. 14-6]. The formula above gives information about these light ones, also called the maxima. For constructive pattern, here, "n" takes only zero and other integer values [7, p. 14-6]. The sign is determined based on the brightest point in the center, depending on whether the point interested is in the +x or -x direction [10]. After assigning specific values for d, θ, and n, this formula will be used to find the wavelength of the light source.

This formula was derived using double slit experiment. However, it can also be used for diffraction grating as if it will be done in this project [8].

Einstein came up with the idea that the light is transported via particles called photons, and these photons have the energies proportional to their frequency [5, p. 251,][11, p. 8]:

$$E = hf \ \ [4] \quad (11)$$

Frequency of a photon can also be given with the formula below:

$$f = c/\lambda \quad (12)$$

Therefore, through the relations above, the energy of a photon can be obtained:

$$E = hc/\lambda \quad (13)$$

II Knee Voltage Calculation

The knee voltages of each red, green, and blue LED will be calculated through a multimeter to determine the specific energies required to light the LED by using the equality

$$E = eV \tag{14}$$

where e is the electric charge of a single electron (basically, calculating eV).

In future trials, a more complicated setup containing a circuit with a digital-to-analog converter and a programming part with a graphing interface just like in the [12] will be used for both higher amounts of data and more precise knee voltage values through the machinery.

III Planck Constant Calculation

Through equating the two energy equalities above, we conclude with

$$h = eV\lambda/c \tag{15}$$

IV Error Estimation

There are three main reasons for minor errors:

1. Location of the Light Source: Since the angle of light coming out of the box is affected by the position of the LED, any deviation in the placement of the LED will affect the diffraction pattern so the measurement.

2. Blurry Diffraction Pattern: Either reflecting the light that just passed through the diffraction grating to a wall or a telephone camera, the image comes out blurry and may affect the wavelength measurement's precision.

3. External and Internal Factors in Knee Voltage Calculation: After working the LED for a time, it starts to heat up, and it may affect both the brightness of the LED and its resistance. Also, due to the charge accumulation of the oscilloscope probes, there might be errors in the knee voltage measurement again (in future trials).

Regarding the error percentage, by denoting the measured h as h', V as V', and λ as λ', one can derive

$$error\,\%\,in\,h = (\frac{h'}{h} - 1) \cdot 100 \tag{16}$$

$$error\,\%\,in\,h = (\frac{V'}{V}\frac{\lambda'}{\lambda} - 1) \cdot 100 \tag{17}$$

III Equipments

1. Arduino UNO R3
2. TSL2561 Brightness Sensor
3. A digital multimeter
4. A variable voltage power-supply source
5. A breadboard and jumper wires
6. LED with colors red (620-637 nm), green (503-539 nm) blue (449-473 nm) and white (mixture of the frequencies 465 THz, 525 THz and 635 THz) [13]
7. A diffraction grating ($\Lambda = 1\ \mu$m)
8. A resistor (varies from 220Ω to 3.3KΩ)
9. A spectrometer or wavelength meter (to measure the wavelength of the LEDs)
10. White cardboard
11. A Ruler
12. Pencil
13. Duct tape
14. Cardboard

Arduino UNO is chosen for its usage ease and as well as multimeter since we do not have oscilloscope probs currently. The reason of using red, green and blue colors is mainly because of their availability as well as for the diffraction grating we have.

IV Methodology

The methodology has been prepared based on [1].

About the methodology, the approach of this project involves using light-emitting diodes (LEDs) to study the relationship between the frequency of emitted light and the electrical energy supplied. By examining the voltage at which LEDs start to emit light and the characteristics of the light itself, the principles of physics can be employed to deduce the value of Planck's constant [14]. The methodology integrates practical electronics using easily accessible components like LEDs, a power supply, resistors, and measurement tools like multimeters and Arduino-based sensors.

I Light Source

LEDs connected to a breadboard will be used to obtain a light source to utilize the voltage-current and color relationships occurring on them. The energy of the band gap determines the color of the LED light. Let V be the minimum voltage at which an LED starts shining. Then, the electron's energy is E = eV when the electron recombines with the hole. Then, it emits a photon of energy E = hf [14]. If we equate them, we get eV = hf. Therefore, if we know the frequency f and the knee voltage V, we can calculate Planck's constant. Four LEDs will be used for the accuracy.

II Proper Distance Determination (d)

For the wavelengths, length measurements will be held on the pattern reflected on the screen. Schematically, it can be said that the separation between x_1 and x_2 in Fig. 4 will be used for that purpose. However, since the setup is pretty small, the separation x_1 - x_2 would better be large enough for an easier measurement. Since this separation depends on the angle and the value of d, firstly, these values should be calculated.

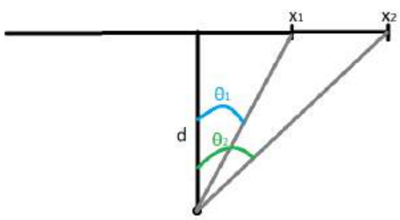

Figure 4: A Basic Diffraction Diagram

Using trigonometric relations one can basically say that

$$x_1 = d \cdot \tan\theta_1 \tag{18}$$

and similarly

$$x_2 = d \cdot \tan\theta_2 \tag{19}$$

We got the value of $\theta = \theta_2$ - θ_1 for a particular wavelength using the Eq. 20

$$|n \cdot \sin\theta| = |-m \cdot \frac{\lambda}{\Lambda}| [15, slide\ 20] \tag{20}$$

This equation is called "grating equation for planar diffraction" [15, slide 7]. In the equation, n is the "refractive index", θ is the angle given in Fig. 4 for a particular order m, λ is the wavelength for a particular color in m^{th} order spectrum, and lastly Λ is the "period" of the diffraction grating [15, slide 6].

This equation is derived using the "phase matching condition" [15, slide 5]:

$$k_x(m) = k_{x,inc} - mK_x [15, slide\ 5] \tag{21}$$

Following figures are also giving an idea of what Eq. 21 refers to :

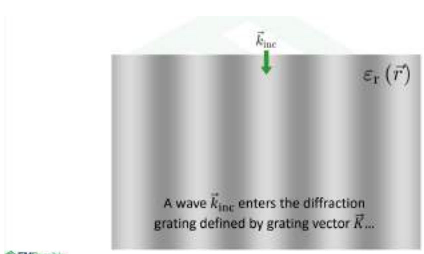

Figure 5: [16, slide 9]

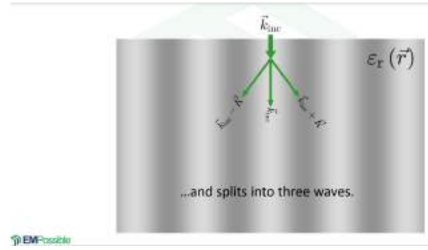

Figure 6: [16, slide 10]

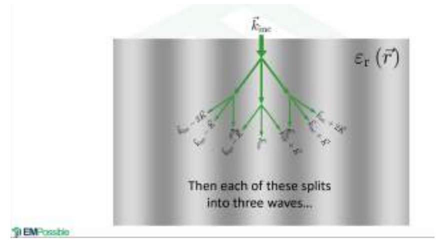

Figure 7: [16, slide 11]

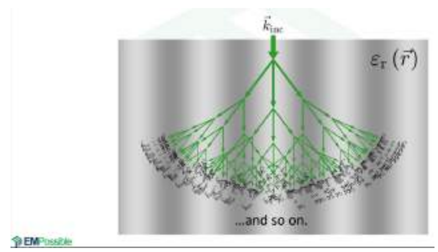

Figure 8: [16, slide 13]

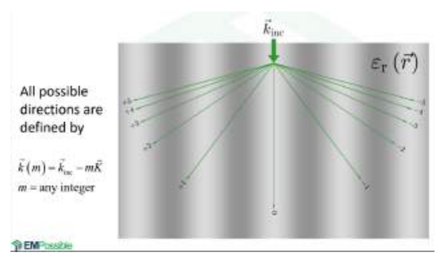

Figure 9: [16, slide 15]

In the Eq. 21, k's are "propagation vector"s for the light rays and K is the "grating vector" [17].

$$|\vec{K}| = \frac{2\pi}{\Lambda} [17] \tag{22}$$

$$|\vec{k}| = \frac{2\pi}{\lambda} [17] \tag{23}$$

Taking angles and reflective indexes into account, Eq. 21 can be rewritten as:

$$k_0 n_{avg} \sin[\theta(m)] = k_0 n_{inc} \sin\theta_{inc} - mK_x [15, slide\ 5] \tag{24}$$

$$n_{avg} \sin[\theta(m)] = n_{inc} \sin\theta_{inc} - m\frac{K_x}{k_0} [15, slide\ 5] \tag{25}$$

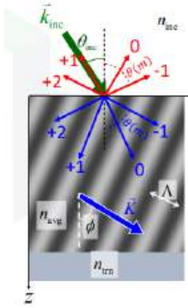

Figure 10: [15, slide 5]

Since $k_0 = \frac{2\pi}{\lambda_0}$ and $K_x = \frac{2\pi}{\Lambda_x}$[15, slide 5], formula becomes

$$n_{avg} \sin[\theta(m)] = n_{inc} \sin\theta_{inc} - m\frac{\lambda_0}{\Lambda_x}[15, slide\ 5] \quad (26)$$

When the incident ray comes perpendicularly to the grating, θ_{inc} will be zero [15, slide 5]; therefore $\sin\theta_{inc}$ will also be zero. Then, the final version of the formula can be written as

$$n_{avg} \sin[\theta(m)] = -m\frac{K_x}{k_0}[15, slide\ 20] \quad (27)$$

In this experiment, the light ray coming from the LED will tried to be fallen perpendicularly to the diffraction grating. Therefore, Formula 27 is valid for the experiment.

In the Eq. 27, n and m were taken as 1 and 1, as the angle for one of the first order spectrum were tried to be calculated. (At 20°C and under 101.325kPa pressure, air's reflective index(n) is ≈ 1.0002718 [18]. Therefore, in this experiment, it is taken as 1.) For calculating the diffraction period, the formula

$$\Lambda = 1/1000[lines/mm][19] \quad (28)$$

should be applied for our diffraction grating [19]. However, since the wavelength is given in terms of nm, it should be converted Λ from mm to nm [19], then the result will be $\Lambda = 1000nm$. The λ expresses wavelength of the light with particular color in given spectrum with order m. For the example plot given in Fig. 23, the value of 760 nm was used.

III Knee Voltage Calculation (V_k)

A DC-regulated power supply will be used to obtain the voltage and current of the LED. To not give too much power to the LED and blow it up, a 1K resistor will be used. After building the circuit and providing enough current and voltage, the voltage and current between two ends of the LED will be measured using a DC multimeter. After obtaining the current (I) and voltage (V) data, the graph of I vs V will be extrapolated to find the knee voltage.

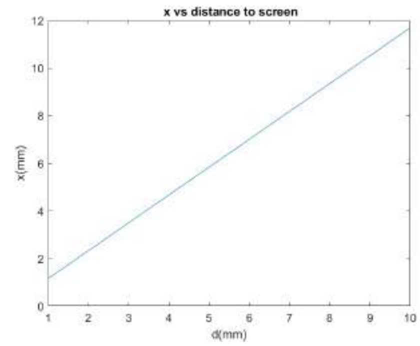

Figure 11: x vs distance to screen (d)

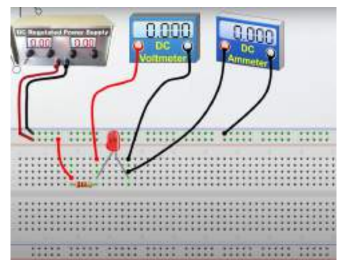

Figure 12: LED circuit [20]

IV Wavelength Calculation (λ)

In this part, diffraction grading will interfere with light to produce the final pattern. By calculating the distance between the diffraction grading and the screen and also the distance between the central maxima (m=0) and another maxima (m=1), the sinus of the angle between the direction of the initial light waves and scattered wave can be found to pluck it into the grating equation (Eq. 10) to find the wavelength where d is the distance between each slit of the diffraction grading.

V Planck's Constant Calculation (h)

After calculating the wavelength (λ) and the knee voltage (V), Planck's constant will be calculated for each LED experiment.

VI Error Calculation

Calculated Planck's constants will be compared with the theoretical value of Planck's constant which is $6.62607015 \cdot 10^{-34} JHz^{-1}$ [21]. And the percentage error will be calculated using formula below [22]:

$$\%Error = \frac{Experimental\,Value - Actual\,Value}{Actual\,Value} \cdot 100 \quad (29)$$

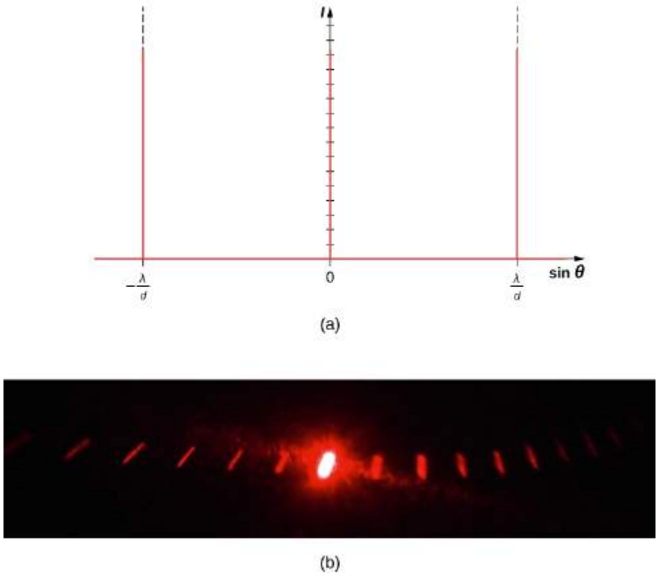

Figure 13: "(a) Intensity of light transmitted through a large number of slits. When N approaches infinity, only the principal maxima remain as very bright and very narrow lines. (b) A laser beam passed through a diffraction grating. (credit b: modification of work by Sebastian Stapelberg)" *figure and explanation were taken from the website [23]

V Contingency Plan

In case of any high error, there is a plan to build a sensor circuit using Arduino R3, and a TSL2561 Brightness Sensor (Fig. 14). Using an Arduino-based circuit, the wavelength of the light will be determined after this process. The frequency will be calculated by simply taking the reciprocal of the wavelength.

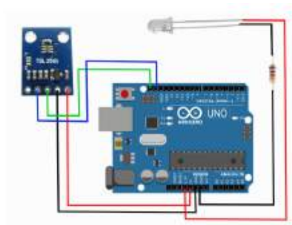

Figure 14: Sensor circuit to measure the wavelength [14]

VI Experiment & Results

I 1st Trial

On the first trial of the experiment, an Arduino circuit was built to light the LED. Constructing the circuit, depending on the measurement, white LED or a colored LED, a resistor and Arduino UNO R3 were connected to breadboard with jumper wires.

For the observation of the pattern, white LED were connected. Then, a cardboard box were taken and a slit with few millimeters width was opened on one of its surfaces. The circuit was placed inside the box. Then, The light coming out of the slit passed from the diffraction grating. Unfortunately, the amount of light was not sufficient to create a pattern on a surface. However, when a phone was placed in front of the grating, photo of the the pattern which appeared directly on the surface of the grating was taken, and so that it was managed to catch the diffraction pattern (Fig. 15).

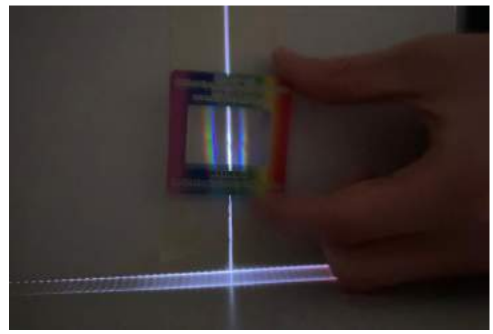

Figure 15: Photo of the diffraction pattern seen on the grating's surface itself (LED as a light source)

Figure 16: Photo of the diffraction pattern seen on the grating's surface itself (Phone flash as a light source)

Beside the white LEDs, phone's flash was also tried as a light source, and diffraction pattern could be seen more clearly because it was propagating more light. However, the light of the flash was more orangish. Thus, it had not been certain that it would give a pattern as LED light gives, but indeed a more clear pattern was observed (Fig. 16).

On the other hand, it was decided that using phone was not the option because, in later trials, if a phone would be used, then it would be very difficult to measure the energy of the light since phone will not be able to be connected to multimeter. Moreover, in any case, amount of light it propagates still will be not sufficient to create a pattern on a surface.

During the observations, how the distances between the grating and wall, and grating and the slit would have liked to be examined, too. Therefore, the location of the phone and the grating were being adjusted. Normally, the distance between the grating and the slit should not have influenced the width and separation of the spectra. Nevertheless, when the experiment with the photos was held, while the distance between the grating and the slit affected the pattern, the distance between the camera and the grating did not. This was not expected considering the theory.

II 2nd Trial

A white LED light bulb from PHYS 102 lab was used a light source. However, no pattern was observed on the wall. Light bulb was tried twice when it was inside the box and when it is outside, but it did not changed the result. Then, the white led was used again. This time more voltage was managed to be supplied to the LED, and finally a pattern on the wall was observed . A distance between the diffraction grating and the wall was changed, and this time observations were consistent with the theory. When the distance between the grating and wall increased, the width of the spectra, and also the separation distance between the spectra increased.

Figure 17: Photo of the diffraction pattern seen on the wall (LED as a light source)

In addition to the wavelength observation, a rough knee voltage calculation is also made. The main aim was just to determine the knee voltage instead of taking a series of measurements—these knee voltages are in Table 1 in the blue-colored cells.

III 3rd Trial

To be able to find the wavelengths of the lights, the two spectra seen in the Fig. 19 was used. For the measurement, pictures of the diffraction pattern seen on the grating's surface were used as if Figures 15 and 16. This time LED, slit, diffraction grating and the phone were tried to be aligned. Additionally, a mm scale added on the grating's surface. Otherwise it would not be possible to measure the distances properly using the image of the pattern since it would be difficult to take account how zooming affects the dimensions.

Figure 18: Setup for Wavelength Measurement

Figure 19: Photo of the diffraction pattern seen on the diffraction grating with the distance 1 cm between the slit and the diffraction grating (LED as a light source)

Figure 20: Photo of the diffraction pattern seen on the diffraction grating with the distance 2 cm between the slit and the diffraction grating (LED as a light source)

Figure 21: Photo of the diffraction pattern seen on the diffraction grating with the distance 3 cm between the slit and the diffraction grating (LED as a light source)

However, considering the wavelength observation in Fig. 22, although the precision of the first wavelength measurement, Fig. 19, is satisfactory, the error rate significantly increases, Fig. 20 & 21, when the diffraction grating is put further away. Since those two measurements' percentages are not in the range for acceptance for such a precise observation, only the values of the first measurement are considered. The possible reasons for the phenomena will be examined.

Lastly, the Knee Voltage measurements were completely done. A particular voltage applied to the LEDs. Then until the first light trace appeared on the LED, the value was increased gradually. This particular voltage at which LED started to glow was accepted as the Knee Voltage. Besides the knee voltages marked with blue, other voltage measurements recorded in Table 1.

Colours/Distance (slit-diffraction grating)	1 cm	2 cm	3 cm
Blue	458 nm (θ=27.2)	407 nm (θ=24)	326 nm (θ=19)
Green	541 nm (θ=32.7)	500 nm (θ=29.9)	392 nm (θ=23.1)
Red	650 nm (θ=40.5)	586 nm (θ=35.8)	457 nm (θ=27.1)
Error percentages (according to the av values of the corresponding colour)	-0.65% 3.84% 3.42%	-11.71% -4.03% -6.76%	-29.28% -24.76% -27.29%

Figure 22: Wavelength Measurements

Table 1: Voltage Measurements

Red LED		Blue LED		Green LED	
Applied V	Measured V	Applied V	Measured V	Applied V	Measured V
1.6	1.68	2.35	2.36	1.74	1.80
1.7	1.8	2.40	2.41	1.76	1.88
1.8	1.88	2.50	2.51	1.80	1.88
1.9	1.96	2.60	2.59	1.89	1.96
2.0	2.00	2.70	2.66	2.00	2.04
2.1	2.08	2.80	2.73	2.10	2.08
2.2	2.12	2.80	2.78	2.20	2.12
2.3	2.20	3.00	2.83	2.30	2.16
2.4	2.24	3.10	2.88	2.40	2.20
2.5	2.28	3.20	2.92	2.50	2.24
2.6	2.32	3.30	2.97	2.60	2.24
2.7	2.35	3.51	2.85	1.80	1.79
2.8	2.40	3.6	2.91	1.90	1.89
2.9	2.40	2.38	2.39	2.00	1.94
3.0	2.44	2.50	2.50	2.10	1.98
3.1	2.48	2.59	2.56	2.20	2.01
3.2	2.48	2.70	2.62	2.30	2.03
3.3	2.52	2.79	2.65	2.40	2.04
3.4	2.54	2.89	2.68	2.50	2.05
3.5	2.56	3.30	2.72	2.60	2.06
3.6	2.56	3.2	2.80	2.70	2.07
3.7	2.68	3.39	2.82	2.80	2.06
3.8	3.76	3.49	2.86	2.90	2.07
3.9	3.84	3.59	2.88	3.00	2.07
4.0	3.96	3.70	2.93	3.10	2.08
4.1	4.04	3.80	2.97	3.20	2.09
4.2	4.08	3.91	3.25	3.30	2.09
		4	3.27	3.40	2.09
				3.50	2.08
				3.60	2.07

During the Knee Voltage measurements of the blue and green LEDs, when the values marked with red in Table 1 were reached, an anomaly was realized. It was expected that the measured values would have increased with increasing applied voltage. On the other hand, approximately at the red marked points the values started decreasing. Then, to check whether there was a problem with the setup or it was normal for voltages to start decreasing at a particular point, the applied values were decreased again, and measurement were repeated. In these second trials done for blue and green LEDs, inconsistency of the measured values decreasing with increasing voltage were solved. These second measurements were significant to detect the problem with the setup. (The order of the measurements starting from the red marked point might not be in a given order as written in table 1.) For now, an hypothesis possibly explaining why the problem may have occurred at red marked points might be that changing voltage values were adversely affecting the LEDs lifetime; therefore, circuit might have behaved unexpectedly. In addition, changing voltage values, and high voltage values might have damaged other circuit elements, too. For the same reasons, second measurements may not be reliable since the LEDs had already been damaged. That is why it would be better if the experiment would be done using a special device next time as it will be stated in next section "Future Work".

IV Calculation of Planck Constant

According to the blue marked values in the Table 1 and the left column of the Fig. 17, here are the calculated h values for red, green and blue LED

1. Red: $\lambda = 650$ nm, $V_k = 1.68$ V, h = $5.824 \cdot 10^{-34}$, error% = -12.1%
2. Green: $\lambda = 541$ nm, $V_k = 1.8$ V, h = $5.194 \cdot 10^{-34}$, error% = -21.6%
3. Blue: $\lambda = 458$ nm, $V_k = 2.36$ V, h = $5.765 \cdot 10^{-34}$, error% = -12.9%

VII Future Work

As seen in the Calculation of Planck Constant values above, especially the green LED measurement has significant amount of error. Since the first wavelength measurements have low percentage errors and more reliable than the knee voltage measurements, future work will more focused on the voltage measurements.

Regarding this situation, as stated in the Knee Voltage Calculation subsection, in future trials, a more complicated setup containing a circuit with a digital-to-analog converter and a programming part with a graphing interface just like in the [12] will be used for both higher amounts of data and more precise knee voltage values through the machinery.

About the wavelength measurements, it is found that low distance between the slit and the diffraction grating gives better results. Using this fact and also for higher precision, narrowing the slit will be the future work for wavelength observations.

VIII Gantt Chart

See Figure 23.

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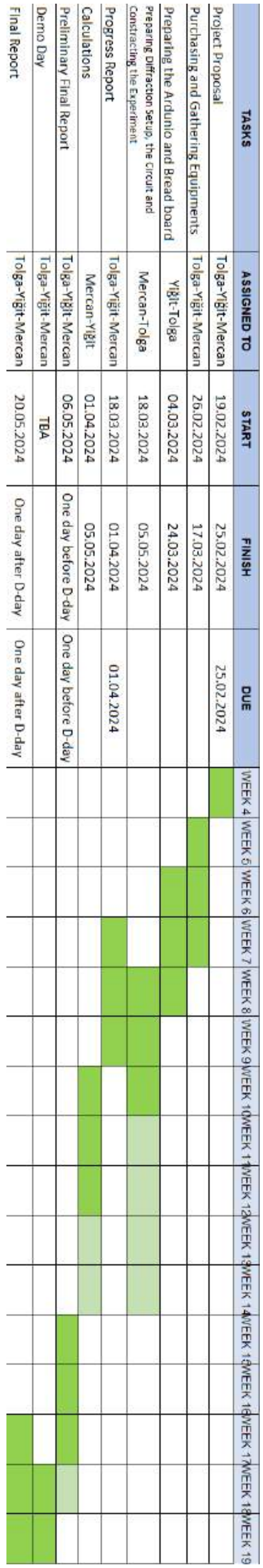

TASKS	ASSIGNED TO	START	FINISH	DUE	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 12	WEEK 13	WEEK 14	WEEK 15	WEEK 16	WEEK 17	WEEK 18	WEEK 19
Project Proposal	Tolga-Yiğit-Mercan	19.02.2024	25.02.2024	25.02.2024																
Purchasing and Gathering Equipments	Tolga-Yiğit-Mercan	26.02.2024	17.03.2024																	
Preparing the Ardunio and Bread board	Yiğit-Tolga	04.03.2024	24.03.2024																	
Preparing Diffraction Setup, the Circuit and Constracting the Experiment	Mercan-Tolga	18.03.2024	05.05.2024																	
Progress Report	Tolga-Yiğit-Mercan	18.03.2024	01.04.2024	01.04.2024																
Calculations	Mercan-Yiğit	01.04.2024	05.05.2024																	
Preliminary Final Report	Tolga-Yiğit-Mercan	06.05.2024	One day before D-day	One day before D-day																
Demo Day	Tolga-Yiğit-Mercan	TBA																		
Final Report	Tolga-Yiğit-Mercan	20.05.2024	One day after D-day	One day after D-day																

Figure 23: Gantt Chart