JURNAL INOVASI DAN PEMBELAJARAN FISIKA
JIPF-UNSRI
ejournal.unsri.ac.id/index.php/JIPF
Program Studi Pendidikan Fisika
FKIP Universitas Sriwijaya
Jalan Raya Palembang-Prabumulih
KM 32 Ogan Ilir
jipf@fkip.unsri.ac.id
p-ISSN 2355-7109 e-ISSN 2657-0971

A LOW-COST DIFFRACTION-BASED LIGHT WAVELENGTH MEASUREMENT FOR CLASSROOM PURPOSES

E C Prima[1]*, A Z Y Muntaz[1], F Muslihah[1], G S A Muharam[1], L A Kurniawan[1], M F Ulfi[1], W T Saputra[1]

[1]Department of Science Education, Faculty of Mathematics and Science Education, Universitas Pendidikan Indonesia, Bandung 40154, Indonesia

*ekacahyaprima@upi.edu

Abstract

As requested by science education curricula, students are challenged to analyze light properties through optical instruments. However, the light is an electromagnetic wave, and it is very short and not easy to be measured using conventional instruments like a vernier caliper. The research aims to measure light wavelength by analyzing the light diffraction phenomenon for classroom purposes. The method applied Huygens's diffraction principle. The parameters used for the independent variable are the types of lasers and the gap between the laser and screens. Next, the dependent variables are the diffraction angle, wavelength (λ), and the gap between diffraction spots. We used diffraction slits (2,500 and 7,500 lines per inch) as control variables. Three laser beams passing through the various slits can be seen and further evaluated to estimate the wavelength. The result shows that the lasers with different wavelengths (665.45, 544.35, 416.20 nm) have been demonstrated successfully with percent errors of 2.32-2.76% and percent differences of 2.29-2.73%. We have concluded that this low-cost experiment can be implemented in school.

Keywords: Laser beam; Slit; Light diffraction; Wavelength; Huygen's principle

Abstrak

Sebagaimana terdapat dalam kurikulum pendidikan ipa, siswa perlu dilatih untuk mampu menganalisis karakteristik cahaya melalui instrumen optik. Namun demikian, cahaya merupakan sebuah gelombang elektromagnetik yang memiliki panjang gelombang sangat pendek dan tidak mudah untuk diukur menggunakan alat instrumen sederhana seperti jangka sorong. Penelitian ini bertujuan untuk mengukur panjang gelombang cahaya dengan menganalisis fenomena difraksi gelombang untuk tujuan pembelajaran. Metode yang digunakan yaitu prinsip difraksi Huygen. Parameter independen yang digunakan meliputi tiga laser dan jarak antara laser dengan layar. Parameter dependen yang digunakan yaitu sudut difraksi, panjang gelombang, dan jarak antara 2 kisi difraksi. Kami menggunakan slit difraksi (2,500 dan 7,500 kisi per inci) sebagai variabel kontrol. Tiga berkas sinar laser akan melewati kisi tersebut untuk diamati lebih lanjut dievaluasi untuk mengestimasi panjang gelombang. Sebagai hasilnya, terlihat bahwa laser dengan berbagai panjang gelombang (665.45, 544.35, dan 416.20 nm) telah berhasil terukur dengan persen *error* 2.32-2.76% dan persen perbedaan 2.29-2.73%. Kami menyimpulkan bahwa eksperimen murah ini dapat diimplementasikan di sekolah.

Kata kunci: Berkas sinar laser, Kisi, Difraksi cahaya, Panjang gelombang, Prinsip Huygen

Cara Menulis Sitasi: E C Prima, A Z Y Muntaz, F Muslihah, G S A Muharam, L A Kurniawan, M F Ulfi, W T Saputra. (2023). A Low-Cost Diffraction-based Light Wavelength Measurement for Classroom Purposes. *Jurnal Inovasi dan Pembelajaran Fisika*, *10* (1), 57-62.

INTRODUCTION

Science education curricula in Indonesia has been being improved continously with introducing freedom to learn curriculum. However, the latest survey shows that the students must be challenged to improve their 21st century skills. Braaten and Sheth (2017) assumes that learning science managed by teachers cannot meet expectations due to less practical skills. The same thought was also expressed by Fitri (2021) that errors during experiment and the limitations of practical tools make the teaching and learning process not run optimally, causing a lack of understanding in students' minds. Proven by a report released by the OECD Organisation for Economic (2013) states that the 2018 Program for International Student Assessment (PISA) Survey was conducted to measure achievement in mathematics, reading, and science performance in students aged 15 years in the survey participating countries. Indonesia occupies a lower position than other countries and is also in the lowest position when compared to countries in Southeast Asia, especially Indonesia's scientific performance ability score of 396, which is in the lower rank of 71 out of 79 countries (OECD., 2018). In most cases, teaching science in Indonesia is primarily done in the classroom using only accompanying books, and students are less involved in actual activities. If we want the achievement of learning objectives and a deep understanding of students, the students must be involved in the learning process (Dwiyanti, Setiabudi, & Prima, 2021; Hamdani, Prima, Agustin, Feranie, & Sugiana, 2022; Kamdi, Rochintaniawati, & Prima, 2022).

Science learning cannot be done by rote memorization or passively listening to the teacher explain concepts. However, students themselves must learn through experimentation, observation, and active experimentation, which will eventually form creativity and awareness to maintain and improve natural phenomena that occur further to shape scientific attitudes (Suryawati & Osman, 2017). Marton (1988) stated that descriptions of what students learn are as important as descriptions of how they learn. This should be defined recursively in that both have structural (how) and referential (what) aspects. Prima, Utari, Chandra, Hasanah, and Rusdiana (2018) declares that changing conceptions of the values and purposes of science teaching have tended toward an increasing emphasis on laboratory work. The nature of the scientific enterprise is found in the methods by which problems are attacked. The same thought had been proposed by Prosser and Millar (1989) that learning in a discipline such as physics involves more than changing conceptions. In this work, the work will further discuss the importance of practical work to make a meaningful learning. The experiment developed was focused on Grade 8 junior high school.

Science learning in grade 8 junior high school has core competencies and basic competencies in the curriculum which contains material about light, waves, and vibrations along with their experiments as tabulated in Table 1.

Table 1. Core competence and basic competencies in grade 8 Junior high school

CORE COMPETENCE 3 (COGNITIVE)	**CORE COMPETENCE 4 (PSYCHOMOTOR)**
3. Understanding knowledge (factual, conceptual, and procedural) based on curiosity about science,	4. Trying, processing, and serving in the concrete realm (using, parsing, composing, modifying, and creating) and abstract realm (writing, reading, counting, drawing,

CORE COMPETENCE 3 (COGNITIVE)	CORE COMPETENCE 4 (PSYCHOMOTOR)
technology, art, culture-related phenomena, and eyesight event.	and composing) according to what was learned in schools and other sources same in point of view/theory.
BASIC COMPETENCIES	**BASIC COMPETENCIES**
3.11 Analyzing the concepts of vibration, waves, and sound in everyday life, including the human hearing system and the sonar system in animals	4.11 Presenting experimental results on vibrations, waves, and sound Analyzing the properties of light, the formation of shadows on flat and curved planes, and their application to explain the process of human vision, insect eyes, and the working principle of optical instruments.
3.12 Analyzing the properties of light, the formation of shadows on the plane flat and curved and its application to explain human vision process insects, and the working principle of optical instruments.	4.12 Presenting experimental results about shadow formation on mirrors and lenses.

Based on Table 1, it appears to be a set of competencies and basic competencies related to cognitive and psychomotor skills. Core Competence 3 related to cognitive skills and includes the ability to understand knowledge based on curiosity about science, technology, art, culture-related phenomena, and eyesight event. Moreover, Core Competence 4 related to psychomotor skills and includes the ability to try, process, and serve in the concrete realm (using, parsing, composing, modifying, and creating) and abstract realm (writing, reading, counting, drawing, and composing) according to what was learned in schools and other sources, with the same point of view/theory.

These basic competences are described more detail by Basic Competencies 3.11 and 3.12 which are about the ability to analyze the concepts of vibration, waves, sound, and properties of light, including the human hearing system and the sonar system in animals, and the formation of shadows on flat and curved planes, and their application to explain the process of human vision, insect eyes, and the working principle of optical instruments. Furthermore, Basic Competencies 4.11 and 4.12 are related to the ability to present experimental results on vibrations, waves, sound, and shadow formation on mirrors and lenses. Overall, it appears that these competencies are related to the ability to understand and apply scientific principles and concepts in practical ways.

Seeing this condition, we took the initiative to develop a practical work that can help teachers in school identify the measurement of diffraction of light. This experiment focused on a low-cost diffraction-based light wavelength measurement for school purposes as our effort in science education to provide solutions related to problems regarding the practical material related to diffraction. Consequently, learning activities are not only based on theory and formulas but an experiment can be carried out for students to understand the light diffraction process better using light wavelengths measured using manageable equipment.

Previous works have studied diffraction phenomena. Born and Wolf (2013) released a seventh edition book of the principles of optics electromagnetic theory of propagation interference and diffraction of light. Fakhruddin (2006) investigated the thermal expansion using single-slit diffraction state that a screen will display a diffraction pattern as a result of a laser beam passing through a narrow slit. As the metal strip is heated, it expands, widening the slit and altering the diffraction pattern. Logiurato, Gratton, and Oss (2020) conducted new experiments on diffraction discussed the diffraction pattern from two-dimensional gratings and introduced the laue diffraction by crystals. This paper contributes to developing a simple optical diffraction experiment to measure the wavelength of light for classroom purpose. It is observed to act as a reflective lattice phase for incident light, producing theoretically diffracted light as it passes through a narrow and equal double slit called the diffraction slit. In particular, we also show the relationship between surface wave intensity and amplitude (height).

METHOD

Principle of diffraction

There is a principle that is consistent with diffraction called Huygens' principle (Baker & Copson, 2003). Huygens' principle states that *every point on a wavefront can be considered a source of tiny wavelets that spread out in the forward direction at the speed of the wave itself. The new wavefront is the envelope of all the wavelets, the tangent to all of them.* Huygens' principle is particularly useful for analyzing what happens when waves run into an obstacle and the wavefronts are partially interrupted. Huygens' principle predicts that waves bend in behind an obstacle, as shown in Figure 1.

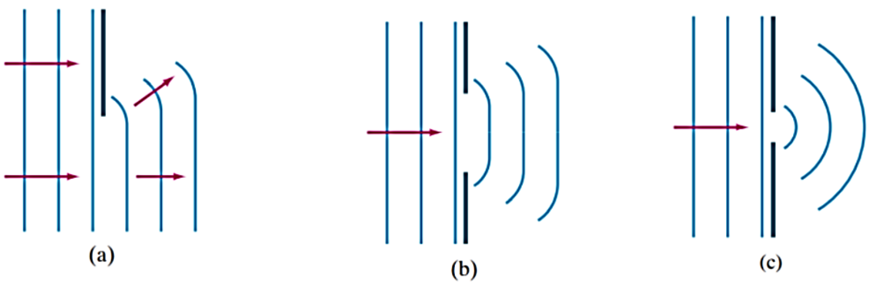


Figure. 1. Huygen's principle is consistent with diffraction (a) around the edge of an obstacle, (b) through a large hole, and (c) through a small hole whose size is on the order of the wavelength of the wave

The bending of waves behind obstacles into the "shadow region" is known as diffraction. Since diffraction occurs for waves, but not for particles, it can serve as one means for distinguishing the nature of light. In Figure 1, we should note that diffraction is most prominent when the size of the opening is on the order of the wavelength of the wave. if the opening is much larger than the wavelength, diffraction may go unnoticed.

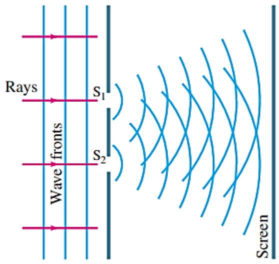


Figure. 2. Plane waves (parallel flat wavefronts) fall on two slits. if the light is a wave, light passing through one of two slits should interfere with light passing through the other slit

Figure 2 shows diffraction caused by the waves leaving the two small slits. The plane waves (parallel flat wavefronts) fall on two slits. If the light is a wave, light passing through one of two slits should interfere with light passing through the other slit. To understand how an interference pattern is produced on the screen, we can see Figure 3.

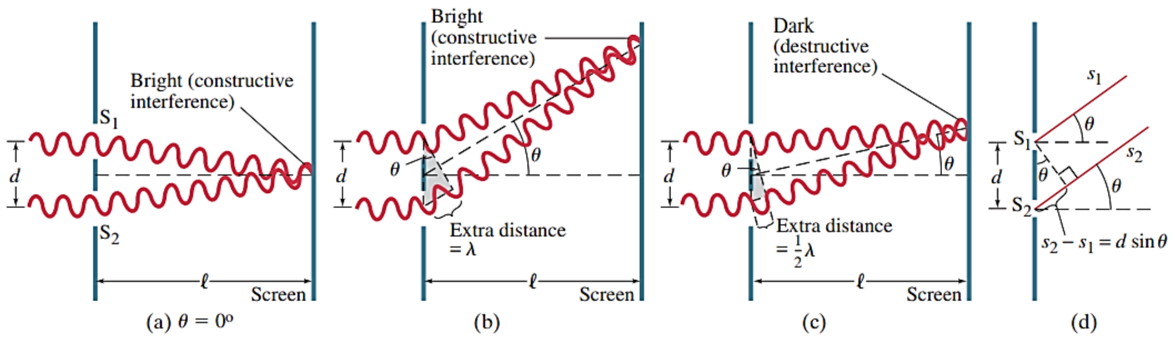


Figure. 3. How the wave theory explains the pattern of lines seen in the double-slit experiment. (a) at the center of the screen, (b) and (c) at a certain angle, and (d) a more detailed diagram showing the geometry for parts (b) and (c)

Waves of wavelength λ are shown entering the slits S1 and S2, which are a distance d apart. The waves spread out in all directions after passing through the slits, but it can be shown from three different angles as shown in Fig. 3. To determine exactly where the bright lines fall, note that Fig. 3 is somewhat exaggerated; in real situations, the distance d between the slits is very small compared to the distance l to the screen. The rays from each slit for each case will therefore be essentially parallel, and θ is the angle they make with the horizontal as shown in Fig. 3. (d). From the shaded right triangles shown n figure 3.2 and 3.3, it shows that the extra distance traveled by the lower ray is d sin θ. Constructive interference will occur and a bright fringe will appear on the screen, when the path difference, d sin θ, equals a whole number of wavelengths (Eq. 1)

$$d \sin\theta = n\lambda \qquad n = 0, 1, 2, \ldots, \tag{1}$$

The value of n is called the order of the interference fringe and d is the distance between the slides or the slit constant with Equation 2.

$$d = \frac{1}{N} \tag{2}$$

Where *N* is the number of slits per unit length.

The wave may also result in a diffraction pattern. It is due to the interference of waves diffracted around the outer edge of the disk and resulting in the group of fringes. To see how a diffraction pattern arises, we can analyze from Figure 4 how monochromatic light passes through a narrow slit. We assume that parallel rays (plane waves of light pass straight through a slit of width *d* to a viewing screen very far away. As we know from Huygens' principle that waves passing through slit spread out in all directions.

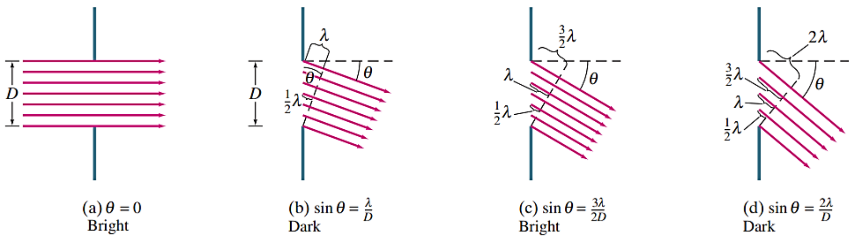


Figure. 4. Analysis of diffraction pattern formed by light passing through a narrow slit of width *D*.

The angle θ at which this takes place can be seen in Fig. 4. (b) to occur when $\lambda = D \sin\theta$ so it resulted in Eq. 3.

$$\sin\theta = \frac{\lambda}{D} \tag{3}$$

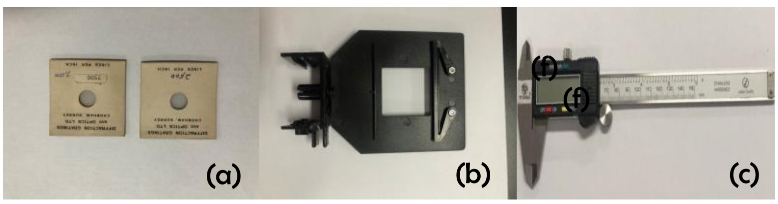
The light intensity is a maximum at θ = 0 and decreases to a minimum (intensity = zero) at the angle θ given by Fig. 4. (a). If we consider the larger θ, it will show also a minimum zero intensity in the diffraction pattern in Eq. 4

$$d \sin\theta = n\lambda; \qquad n = \pm 1, \pm 2, \pm 3, ... \tag{4}$$

but not at *n* = o where there is the strongest maximum. Between the minima, smaller intensity maxima occur at approximately (not exactly) *n* = 3/2, 5/2, …. Note that *d* is a single slit width, whereas *d* is the distance between two slits.

Materials

This research needs several materials and equipment which are a sliding rail, a slit holder, a sliding screen, two kinds of diffraction grating with 7500 lines/inch and 2500 lines/inch, a digital vernier caliper, 3 kinds of laser green, red, and blue colored. These materials are shown in Figure. 5 up to Figure. 12.



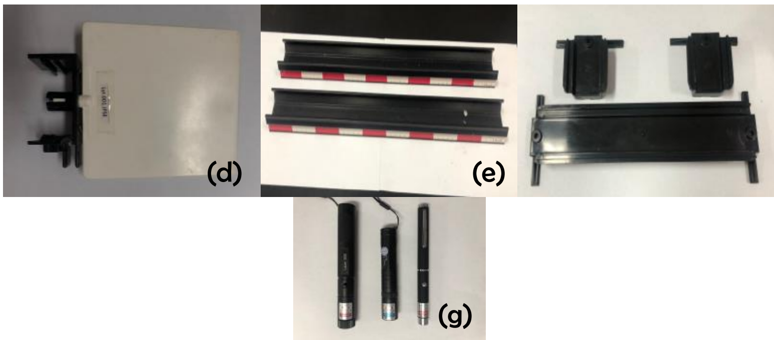


Figure. 5. The listed equipment for this experiment: (a) two kinds of diffraction grating, (b) slit holder, (c) digital vernier caliper, (d) screen, (e) sliding rail, (f) rail base, (g) three kinds of laser that used

On the top end of each laser, there are description labels that mention the industrial wavelength of each laser. Cautions and manufacturing countries are also mentioned on the labels.

Figure. 6. Description label for each laser (405, 532, 650 nm)

Red laser industrial wavelength is 650 nm±10, blue laser industrial wavelength is 405 nm±10, and green laser industrial wavelength is 532 nm±10.

Variables

This experiment contains 3 kinds of variables which are independent, dependent, and controlled. Those variables are detailed in Table 2.

Table. 2. Experiment parameter

Parameter	Details
Independent	Kinds of laser and the distance between the laser and the screen
Dependent	Lambda (λ), angle, and the distance between diffraction points
Control	Kinds of diffraction slit (2500 lines/inch and 7500 lines/inch)

Procedures

Figure 4 shows how the experiment sets based on the theory of diffraction and relates also to the theory of Pythagoras. Lasers emit the light and pass through the diffraction slit which makes the light diffracted into several directions. The length of the central light is represented by an "a" which is as long as the distance in the sliding rail between the diffraction slit and the screen. The length of the 1st diffraction is represented by "c" which is measured by the theory of Pythagoras through Eq. 5.

$$c = \sqrt{a^2 + b^2} \tag{5}$$

The letter "b" is representative of the distance between central light and the 1st diffraction.

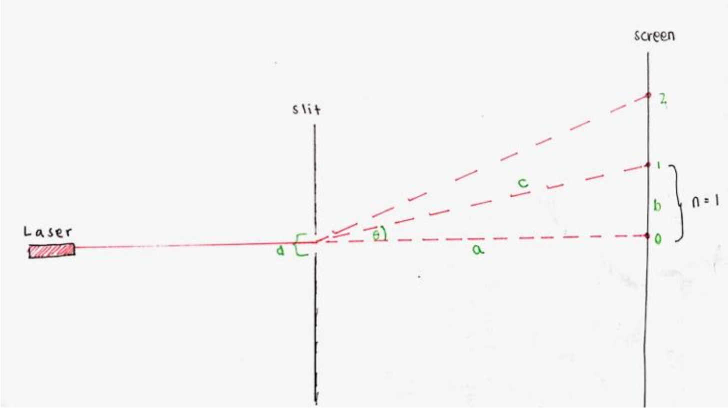


Figure. 7. Experiment setting scheme

In the laboratory, the a is referred to the point in the sliding rail between the diffraction slit holder and the screen, the b is referred to the distance between the center of one point of diffraction to another which is measured by the digital vernier caliper. The laboratory setting of this experiment can be seen in Figure 14

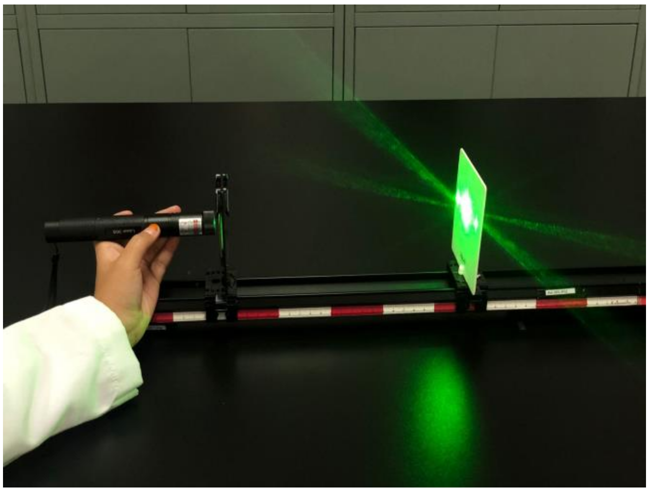


Figure. 8. Laboratory setting

This setting is arranged according to some steps. First, sliding rails are arranged, then the screen and the slit holder are put on each end of the rail. A diffraction slit of 2500 lines/inch is installed on the slit holder. The screen is adjusted until the pointer shows 50 cm. The red laser is turned on and placed behind the diffraction slit at the point where the light exactly penetrates the diffraction slit, the laser is kept stable when penetrating the diffraction slit. The diffraction points that appear on the screen are measured by using a digital vernier caliper from the center of the point to another center of the diffraction point. The steps are repeated but use another laser until 3 kinds of data from 3 kinds of laser are obtained. For the 7500 lines/inch slit diffraction the steps are the same, but the screen is adjusted until the pointer shows 30 cm.

Analysis Method

The main maximum diffraction pattern on the slit is represented by the formula in Eq.(6) and Eq. (7).

$$d \sin\theta = n\lambda \qquad (6)$$

$$\text{where the } d = \frac{1}{N} \quad (7)$$

From the theory of Pythagoras and referring to Figure.4, the sin θ is determined using the Eq. 8

$$Sin\ \theta = \frac{b}{c} \text{ where } c = \sqrt{a^2 + b^2} \text{ hence the } Sin\ \theta = \frac{b}{\sqrt{a^2+b^2}} \quad (8)$$

From Eq. (6), the λ is determined using the formula

$$\lambda = \frac{d\ sin\ \theta}{n} \quad (9)$$

and substitute the Eq. 7. and the value of $n = 1$ based on Figure.4, hence the equation will be

$$\lambda = \frac{sin\ \theta}{N} \quad (10)$$

The value of Sin θ in Eq.8 is substituted in Eq.9, hence the equation will be

$$\lambda = \frac{\mathrm{b}}{N\sqrt{a^2+b^2}} \quad \text{in the unit of cm} \quad (11)$$

The λ is measured in the unit of nm, hence the Eq.11 multiplied by 10^7.

Analyzing Experimental Error and Uncertainty

Percent Error

The accepted or "true" value of such quantity found in textbooks or this study found in the description label of the laser is the most accurate value (usually rounded off to a certain number of significant digits) obtained through sophisticated experiments or mathematical methods. The absolute difference between the experimental value E and the accepted value A, written E-A, is the positive difference in the values. For a set of measurements, E is taken as the average value of the experimental measurements. When an accepted value of a physical quantity is known, the percent error is calculated for a comparison of an experimental value with the accepted value. Percent error is given by the ratio of the absolute difference between E and A over A and expressed as a percent.

$$Percent\ error = \frac{|E-A|}{A}\ x\ 100\% \quad (12)$$

Percent Difference

It is sometimes instructive to compare the result of two measurements when there's a known or accepted value. The comparison is expressed as a percent difference, which is the ratio of the absolute difference between the experimental values E_2 and E_1, and the average or mean value of the two results expressed as a percent.

$$Percent\ difference = \frac{|E2-E1|}{\frac{(E2+E1)}{2}}\ x\ 100\% \quad (13)$$

In many instances, there will be more than two measurement values. When there are three or more measurements, the percent difference is found by dividing the absolute value of the difference of the extreme values (that is, the values with the greatest difference) by the average or mean values of all the measurements.

RESULT AND DISCUSSION

Table 3. shows that this study uses two slits with different N values (number of slits per unit length), there are slits with 2500 lines/inch and 7500 lines/inch. The unit is converted to lines/cm to make it compatible with further calculations. This study used three different color lasers, namely red, green and blue. The value of a is the distance between the coming of light and the screen. The value of b is the distance of the white point or zero point to point one as the result of diffraction and it is measured using a digital vernier caliper. The value of c is the value obtained through the formula, Pythagoras.

Table 3. Measurement of a, b and c values

N (lines/Inch)	N (lines/cm)	Color	a (cm)	b (cm)	c (cm)
2500	984	Red	50.0±0.05	3.292±0.0005	50.1
7500	2953	Red	30.0±0.05	5.993±0.0005	30.6
2500	984	Green	50.0±0.05	2.638±0.0005	50.1
7500	2953	Green	30.0±0.05	4.971±0.0005	30.4
2500	984	Blue	50.0±0.05	2.007±0.0005	50.0
7500	2953	Blue	30.0±0.05	3.786±0.0005	30.2

The table provides measurements of 'a', 'b', and 'c' values for different combinations of line densities (in lines/inch and lines/cm) and colors of laser light (red, green, and blue). The 'a' value represents the distance between the source of the light (presumably a laser) and the screen on which the diffraction pattern is observed. The 'b' value represents the distance from the central maximum of the diffraction pattern to the first minimum on either side, which is a measure of the size of the diffraction pattern. The 'c' value is the distance between the two slits that are used to create the diffraction pattern. This value is calculated using the Pythagorean theorem, which suggests that it represents the hypotenuse of a right triangle formed by the distance between the two slits and the distance between the screen and the slits. The line densities are given in both lines/inch and lines/cm units to facilitate comparisons across different measurement systems. Overall, it appears that this study aims to investigate how different line densities and colors of laser light impact the diffraction and interference patterns that are formed. The measurements provided in the table will be used to gain insights into the properties of diffraction and interference of light under different conditions. The detailed analysis from Table 3 is tabulated in Table 4.

Table 4. shows the results of the calculation of the λ from the measurement by using Eq. 11. The average of lambda measured for the red laser is 665.45 nm, green laser is 544.35 nm, and for the

blue laser is 416.20 nm. The lambda standard from the industry for the red laser is 650±10, the green laser is 532±10, and the blue laser is 405±10. The percent difference for each laser is calculated by using Eq. 13 and the results are 2.35% for the red laser, 2.29% for the green laser, and 2.75% for the blue laser. Furthermore, The percent error for each laser is calculated by using Eq. 12 and resulted in 2.38% for the red laser, 2.32% for the green laser, and 2.76% for the blue laser. The accuracy is from 100% - percent errors.

Table 4. Result results of the calculation of the λ, percent difference, and percent errors

N (lines/Inch)	N (lines/cm)	Color	λ (nm)	measured	λ standard	Percent Difference (%)	Percent Errors (%)
2500	984	Red	667.6	665.45	650±10	2.35	2.38
7500	2953	Red	663.3				
2500	984	Green	534.9	544.35	532±10	2.29	2.32
7500	2953	Green	553.8				
2500	984	Blue	407.8	416.20	405±10	2.73	2.76
7500	2953	Blue	424.6				

Table 4 provides the results of calculations for the wavelength (λ) of the laser light used in the experiment, as well as the percent difference and percent error between the measured values and the standard values. For each combination of line density and color, there are two measurements given for λ: the measured value and the standard value with a tolerance of ±10 nm. The percent difference between the measured and standard values is also calculated, which represents the relative difference between the two values. Additionally, the percent error is calculated, which represents the difference between the measured value and the standard value as a percentage of the standard value.

Based on the table, it appears that the red laser light had a measured wavelength of 667.6 nm for the 2500 lines/inch and 984 lines/cm combination, with a standard value of 650 nm ±10 nm. The percent difference between the measured and standard values is 2.35%, and the percent error is 2.38%. Similarly, for the green laser light, the measured wavelength was 534.9 nm for the 2500 lines/inch and 984 lines/cm combination, with a standard value of 532 nm ±10 nm. The percent difference between the measured and standard values is 2.29%, and the percent error is 2.32%. For the blue laser light, the measured wavelength was 407.8 nm for the 2500 lines/inch and 984 lines/cm combination, with a standard value of 405 nm ±10 nm. The percent difference between the measured and standard values is 2.73%, and the percent error is 2.76%.

It is worth noting that there are missing values for the 7500 lines/inch and 2953 lines/cm combinations, which suggests that measurements were not taken for those combinations. Overall, the results suggest that the measured values for the wavelength of the laser light are relatively close to the standard values, with percent differences and errors in the range of 2-3%. This provides evidence that the experiment was conducted carefully and accurately.

Based on the data obtained, the experimental tools used have the following scheme.

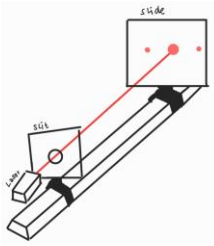


Figure. 9. The installation of the sliding rail as a base, the diffraction slit, and the screen are arranged in 50 cm and 30 cm arranged.

The independent variables used are the type of color in the laser, namely red, green, and blue colors; then the value of a is the distance between the coming of light and the screen. The dependent variable is the value of c. The value of b is the distance of the white point or zero point to point one as the result of diffraction. And the value of c is the value obtained through the formula, Pythagoras. The Pythagorean scheme formed is as follows.

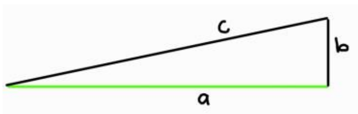


Fig. 10. The imaginer line for the

The formula of the formed Pythagoras: $c = \sqrt{a^2 + b^2}$ (14)

The light diffraction board located near the flashlight, has two values, namely the A board with a value of 2500 and the B board with a value of 7500 with the N unit owned, namely lines/inch. Both values need to be converted into units of meters or centimeters so that it is easier to calculate the output, namely wavelengths with units of nanometers (nm). The results obtained are boarding A worth 984.252 lines/cm and boarding B worth 2952.756 lines/cm.

The Laser Beam light Through the Slit

The three laser beam lights that pass the different slits will pass the slit and produce the grating. The grating result is in Tables 3 and 4. The way to calculate each slit is to determine the distance of the piece of the grating by using digital vernier calipers. The reason behind it is the grating of the light has a small number and also the number of different orientations is also small. Then, the Debye-Scherrer method is important for this experiment. The Debye-Scherrer method has the equation to determine the particle size.

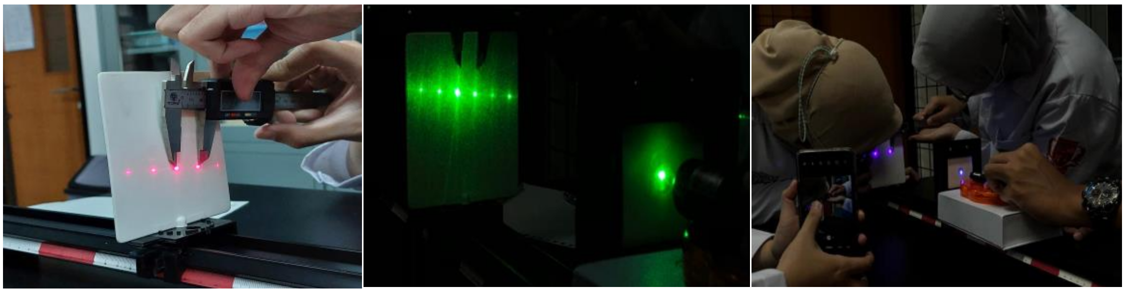
$$d = \frac{K\lambda}{\beta \cos \theta} \quad (15)$$

The K is the Scherrer constant the Full width at half maximum (FWHM) of the peak is the Bragg angle and the wavelength of the employed X-ray beam (1.54,184).

The wavelength that applied the principle of Hyugen was also used for this project, the proof is the project has the maximum laser beam diffraction. The Huygens principle could determine the angle by:

$$d \cos \alpha = m\lambda ; \qquad m = \pm 1, \pm 2, \pm 3, \ldots \tag{16}$$

$$\alpha = \cos^{-1} (m\lambda / d) \tag{17}$$



(a) (b) (c)

Figure. 11. The grating of three kinds of laser: (a) red laser, (b) green laser, (c) blue laser.

The Inverse Square Law

The rate of reduction is proportional to the square of the distance between the emitter and the receiver as light intensity drops with the distance from the source to the receiving surface (sink). We refer to this as the Inverse Square Law. The measured light intensity is inversely proportional to the square of the distance to the source of electromagnetic radiation, according to the inverse square law.

$$I = \frac{S}{4\pi r^2} \tag{18}$$

Diffraction Slit of the Light

Case this experiment has the same procedure as Young's experiment and the thing difference is on the slit. The experiment used two different diffraction slits. There are 7500 lines/inch and 2500 lines/inch by three different colors of monochromatic light. Observe the interference fringes and use the formula to find the wavelength of the light experimentally.

$$\lambda = \frac{dy}{L} \tag{19}$$

d = the distance d between (the centers) of the slits.

y = the distance between the centers of the central bright fringe and the next one.

L = the distance between the slits and the screen.

The infrared wavelength can be determined using the diffraction grating equation $d \sin a = n\lambda$. where d is the lattice spacing, atomic number, and λ is the wavelength. Since the angle a is small, we can write $\sin a \approx \tan a$ = S/L as follows:

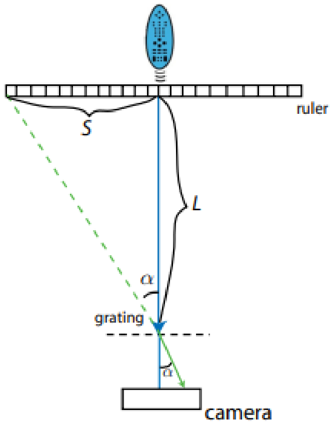


Figure. 12. The geometry setup

Finding a wavelength through the principle of light diffraction

Based on the result, the principle of light diffraction was used to determine the wavelength. The low-cost apparatuses support the experiment and the main apparatus is a diffraction single-slit. The light through the diffraction slit will diffract the light and make some diffraction resulting in the slides 50 cm and 30 cm in front of the slit. It makes the pattern of the brightest spot slide and it is measured from the brightest spot into the next spot.

The previous experiment was performed by the students in Maine High School. They used laser light to pass the slit and show it onto the paper at some distance and they marked it as the bright point. The conclusion of this experiment is to use the formula below to find the wavelength of the laser. The b means the distance between bright spots, d is slit separation and also L is the distance between the slit and the slide. They assume from the equation the $a >> d$

$$\lambda = \frac{bd}{a} \tag{20}$$

there is a relation between *d* and L. Which is in the distance L we can determine the value of *d*. It occurs in our experiments when we change the length of L, the bright spot 1 can occur in the slide.

Based on the factory information the laser's wavelength is approximately similar to the results of the experiments. The difference is 1-5 cm. It means there's an error occurring in the experiment. The project assumes that the error is human error, it occurs especially when we measure the length of a bright spot. The measurement should be from the center point of the bright spot until one other bright spot. Maybe there is a slight wobble from the hand allowing human error to occur. The experiment can measure the percentage of error by:

$$\text{Percentage error }\% = \frac{|\text{Measured value} - \text{True value}|}{|\text{True value}|} \text{ x } 100\% \tag{21}$$

CONCLUSION

Diffraction-based light wavelength measurement has been tested successfully with the simple material. The main materials are a diffraction slit (7500 lines/inch and 2500 lines/inch) and three lasers with red, green, and blue. The results for percent error in this experiment are 2.38% for the red laser with a 2.35% of percent difference, 2.32% for the red laser with a 2.29% of percent difference, and 2.76% for the blue laser with a 2.73% percent difference. This measurement has an accuracy of 97.6% for the red laser, 97.7% for the green laser, and 97.2% for the blue laser. This measuring method can be implemented by the students and the teachers for science learning with the low-cost diffraction-based light wavelength measurement without hesitation and with high validity. In the experience of this project, there are some difficulties to be faced. There are measuring the grating should be appropriate to measure the validity of the laser beam. Moreover, the distance between the slit and slide should be placed appropriately. If it is not stable, the diffracted ray will be difficult to measure.

ACKNOWLEDGMENT

This work was supported by Program Penelitian Unggulan (Grant No. 557/UN40.LP/PT.01.03/2023), Universitas Pendidikan Indonesia, 2023.

REFERENCES

Baker, B. B., & Copson, E. T. (2003). *The mathematical theory of Huygens' principle* (Vol. 329): American Mathematical Soc.

Born, M., & Wolf, E. (2013). *Principles of optics: electromagnetic theory of propagation, interference and diffraction of light*: Elsevier.

Braaten, M., & Sheth, M. (2017). Tensions teaching science for equity: Lessons learned from the case of Ms. Dawson. *Science Education, 101*(1), 134-164.

Dwiyanti, U., Setiabudi, A., & Prima, E. C. (2021). Investigation on Teachers' Perception of Augmented Reality as Interactive Media for Science Learning. *Jurnal Pendidikan MIPA, 22*(2), 245-255.

Fakhruddin, H. (2006). Quantitative investigation of thermal expansion using single-slit diffraction. *The Physics Teacher, 44*(2), 82-84.

Fitri, S. F. N. (2021). Problematika Kualitas Pendidikan di Indonesia. *Jurnal Pendidikan Tambusai, 5*(1), 1617-1620.

Hamdani, S. A., Prima, E. C., Agustin, R. R., Feranie, S., & Sugiana, A. (2022). Development of Android-based Interactive Multimedia to Enhance Critical Thinking Skills in Learning Matters. *Journal of Science Learning, 5*(1), 103-114.

Kamdi, N., Rochintaniawati, D., & Prima, E. C. (2022). Efektivitas Web Based Inquiry Learning pada Materi Pencemaran Lingkungan dalam Konteks ESD (Education Sustainable Development) untuk Meningkatkan Kemampuan Berinkuiri dan Kepedulian Lingkungan Siswa SMP Kelas VII. *PENDIPA Journal of Science Education, 6*(3), 733-738.

Logiurato, F., Gratton, L., & Oss, S. (2020). Optical Simulation of Laue Crystal Diffraction with New Experiments on Diffraction. *The Physics Teacher, 58*(2), 130-132.

Marton, F. (1988). Describing and improving learning *Learning strategies and learning styles* (pp. 53-82): Springer.

OECD., K. (2018). *OECD science, technology and innovation Outlook 2018*: OECD Publishing Paris.

Organisation for Economic, C. D., and PISA. (2013). *Excellence Through Equity: Giving Every Student the Chance to Succeed*. Paris: OECD Publishing.

Prima, E. C., Utari, S., Chandra, D. T., Hasanah, L., & Rusdiana, D. (2018). Heat and temperature experiment designs to support students' conception on nature of science. *JOTSE: Journal of technology and science education, 8*(4), 453-472.

Prosser, M., & Millar, R. (1989). The "how" and "what" of learning physics. *European journal of Psychology of Education, 4*(4), 513-528.

Suryawati, E., & Osman, K. (2017). Contextual learning: Innovative approach towards the development of students' scientific attitude and natural science performance. *Eurasia Journal of Mathematics, Science and Technology Education, 14*(1), 61-76.