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Distribution of the Fraunhofer Diffraction Intensity by a Rectangular Slit Using a Razor Blade

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Abstract: This research was conducted by making a rectangular slit using a razor blade as a narrow gap in the Fraunhofer diffraction experiment. The intensity distribution measurement on the resulting diffraction pattern uses a voltage divider circuit. This circuit takes advantage of the nature of the LDR, which changes resistance when exposed to light. Experiments show that a diffraction pattern screen when a 560 nm coherent light passes through a narrow rectangular slit made of razor cut. We measured the narrow gap using a tracker application with the resulting gap size (0.3564 x 0.4677) mm. The ratio of the intensity distribution of the x-axis bright pattern on the Fraunhofer diffraction by a rectangular slit with slit size height x width = (0.4677 x 0.3564) mm from $\beta = -5\pi$ to 5π (maximum 4, maximum 3, maximum 2, maximum 1, central maximum, maximum 1, maximum 2, maximum 3, maximum 4) is 0.000873; 0.000763; 0.005395; 0.020583; 1; 0.039658; 0.008088; 0.002554; 0.001218. The ratio of the intensity distribution of the y-axis bright pattern on the Fraunhofer diffraction by a rectangular slit with slit size height x width = (0.4677 x 0.3564) mm from $\gamma = -5\pi$ to 5π (maximum 4, maximum 3, maximum 2, maximum 1, central maximum, maximum 1, maximum 2, maximum 3, maximum 4) is 0.001890; 0.001469; 0.002447; 0.040516; 1; 0.037141; 0.006482; 0.001690; 0.000440. This study indicates that diffraction experiments and the measurement of the diffraction pattern's intensity can be carried out with simple materials and equipment and can be used in the correct experiment.

Keywords: Diffraction; Fraunhofer; Rectangular slit; Razor blade; a voltage divider circuit

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Introduction

The diffraction event is defined as the wave propagation event when the wave passes through a narrow slit. The gaps used in the experiment can be in the form of upload slits or multiple slits called lattices, namely solid barriers the line where if light passes through, it will be deflected and then creates a regular pattern of light and dark spots (Aviani & Erjavec, 2011; Coffey et al., 2010; Jetty et al., 2012). The intensity distribution on the screen is known as the diffraction pattern (Ghatak, 2010). Diffraction topic is a general topic studied by students in physics class (Kazanskiy, 2012; Moxnes and Osgood, 2018). Diffraction events are easily shown to students through experiments, but there is a need for a narrow slit as a barrier to visualize the diffraction pattern.

Many researchers have developed grids for diffraction experiments using natural resources such as banana stalks, onion skins, fish fins, butterfly wings, and plastic bags (Aji et al., 2017, 2019; England et al., 2014; Groff, 2012; Monsoriu et al., 2011; Parker and Martini, 2014). In addition, diffraction experiments can be carried out with sophisticated digital devices (Paixão et al., 2021; Piunno, 2017). Making narrow slit is quite tricky because it requires making tiny dimensions. However, we can make this narrow gap using the available resources around us. In this study, the res The researchers created

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a narrow rectangular slit using a razor blade in this studyap can be made by combining the positions of the razor blade pieces.

Diffraction experiments don't just use properties that are already available. Several studies were conducted by combining or manipulating objects to see the diffraction patterns that occur. The researcher can propose a scheme for producing structures with the designed diffraction. Experimental results with waveguides can be compared with predictions made by paired modes (Eisenberg et al., 2000). The Fraunhofer diffraction pattern can be observed with fractal lattices, which produce a similar diffraction pattern on its own, which can be evaluated analytically (Monsoriu et al. 2011). Another study carried out simulations of the diffraction of waves through slits using an excel spreadsheet that could visualize the effect of different parameter variations such as several gaps, light wavelength, gap width, and gap separation on the Fraunhofer diffraction pattern (Singh et al., 2018).

This study aims to create a narrow rectangular slit using a razor blade for the Fraunhofer diffraction experiment. In this study, the process of measuring the distribution of intensity on the Fraunhofer diffraction was carried out using a simple voltage divider circuit. This study's results can be used as an alternative for educators in teaching quadrilateral slit diffraction using relatively simple materials. Narrow gaps using a razor cut are very easy for lecturers, teachers, and students to make at school and home. The little rectangular gap created is shown in Figure 1. Measurement of the slit width was carried out using a tracker application. By using Tracker, users can track an object's position, velocity, and accelerations (Brown et al., 2011). The slit distance is investigated by spectral analysis with Tracker can be more precise (Pratidhina et al., 2020). Educators and scientist use Tracker to teach and study various topics such as vector object falling in liquid and air (Sirisathitkul et al. 2013), projectile motion (Yusuf, 2016), mechanical energy (Bryan, 2010), damped harmonic oscillation (Poonyawatpornkul & Wattanakasiwich, 2013), torsion (Eadkhong et al., 2012), and impulse (Ayop, 2017).

Figure 1. A narrow rectangular gap using a razor blade

The Fraunhofer diffraction patterns are quite intricate so that several Fraunhofer diffraction patterns for circular slits are simulated by modifying the Bessel function (Yanuarief, 2016). In this study, the observation of the Fraunhofer diffraction pattern was carried out in a rectangular slit. The circuit used to see the intensity distribution in the diffraction experiment uses a voltage divider circuit. This sequence can determine the ratio of the intensity in the maximum to minimum to the central maximum. The voltage divider circuit is shown in Figure 2.

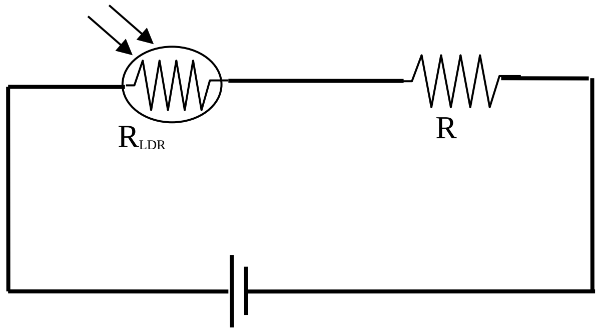

Figure 2. Voltage divider circuit chart

Method

A narrow rectangular slit is created by combining the blade cut position into a tiny slit, as shown in figure 1. A rectangular slit is placed at a great distance from the screen, called Fraunhofer diffraction (Ghatak, 2010). The intensity distribution equation for the Fraunhofer diffraction

$$I(P) = I_0 \frac{\sin^2 \gamma}{\gamma^2} \frac{\sin^2 \beta}{\beta^2} \quad (1)$$

Intensity distribution ratio for Fraunhofer diffraction

$$\frac{I(P)}{I_0} = \frac{\sin^2 \gamma}{\gamma^2} \frac{\sin^2 \beta}{\beta^2} \quad (2)$$

with $\beta = \frac{\pi b x}{\lambda z}$ and $\gamma = \frac{\pi a y}{\lambda z}$

Observation of the intensity of the diffraction pattern utilizes the LDR resistance in the voltage divider circuit. The amount of LDR resistance varies depending on the intensity of light received by the LDR surface. The amount of resistance is inversely proportional to the intensity received. When the intensity received is large, the LDR resistance becomes small. To facilitate observation, a voltage divider circuit is used; as shown in Figure 2, the ratio of the change in intensity received uses the voltage on resistor ratio (R).

Based on the initial understanding of intensity, namely the broad unity power formulated in equation 3.

$$I = \frac{P}{A} = \frac{\frac{V^2}{R}}{A} \quad (3)$$

The ratio of the intensity distribution received by the LDR is proportional to the square of the stress ratio on R shown in equation 4.

$$\frac{I(P)}{I_0} \approx \left(\frac{V(P)}{V_0}\right)^2 \quad (4)$$

Based on the above comparisons, the Fraunhofer diffraction intensity ratio can be formulated in equation 5.

$$\left(\frac{V(P)}{V_0}\right)^2 = \frac{\sin^2\gamma}{\gamma^2}\frac{\sin^2\beta}{\beta^2} \quad (5)$$

Method of Observation

Observation of the rectangular slit diffraction pattern is carried out by determining the intensity distribution that is formed. LDR is installed by displaying a small position (as shown in figure 3) so that the received light intensity focuses on a certain point.

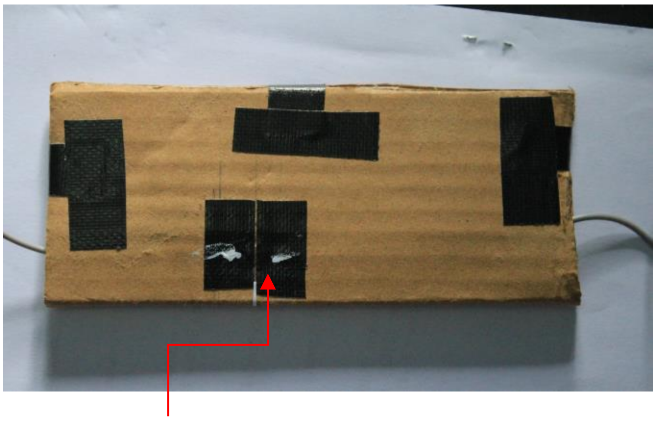

Figure 3. LDR hole position for intensity observation

Observations are made by turning off all lighting in the room except to see the voltage value shown on the multimeter. The next step is turning on the laser and shining it at the center of the slit until a clear diffraction pattern is formed, as shown in Figure 4.

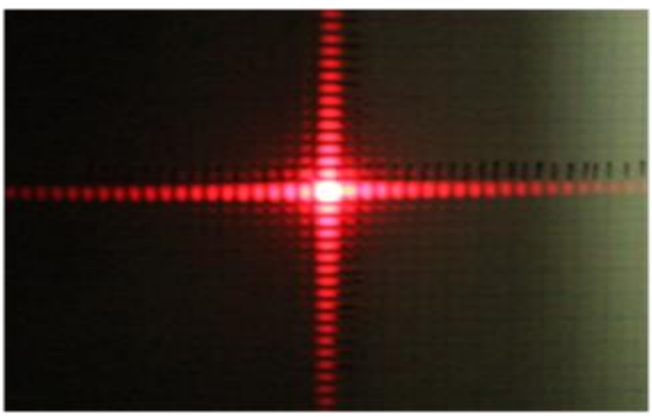

Figure 4. Fraunhofer diffraction pattern by a rectangular slit

The voltage divider circuit is used to see the intensity distribution by directing the LDR to the center maximum. The central maximum determines the center point as the coordinate center (0.00) and observes the measured voltage R on the multimeter. The LDR resistance is directed at another point to be measured, and the measured voltage on the multimeter is observed. In addition to measuring the LDR voltage, a distance to the center maximum is measured by highlighting the point using a flashlight.

Result and Discussion

Diffraction can be defined as the bending of light when it passes through a barrier or narrow gap. Diffraction is an explanation from Huygens that cannot be separated from the interference because the resulting patterns result from interference from light waves to produce minimum patterns and maximum patterns. The resulting minimum patterns are destructive interference, while the observed maximum patterns are constructive interference. The diffraction experiment carried out is the Fraunhofer diffraction, which is the distance from the gap to the far screen so that the beam is parallel to the main axis.

The Fraunhofer diffraction experiment by a rectangular slit requires a slit of small size for diffraction to occur. Therefore, the first thing to do in this lab is to make a rectangular slit using a razor blade. The measurement of the slit was done by photographing the slit holes and then entering them in the tracker program so that the width (b) and height (a) slit sizes were (0.3564 x 0.4677) mm.

The laser beam shone on the center of the rectangular slit produces a diffraction pattern, as shown in Figure 4. It is then assumed that the diffraction position pattern along the horizontal line is the x-axis. The diffraction position pattern with the vertical line's direction is the y-axis, and the maximum intensity is the z-axis. The gap to the screen (z) is made quite far to facilitate the intensity distribution measurement, which is about 5 meters. The intensity of the diffraction of light when the distance z is made, the farther away is getting smaller. A sufficiently large resistor value is used to increase the measuring device's sensitivity, namely 19.4 kΩ. Measurement of intensity at a particular position uses an LDR, which is closed on the sides. The LDR surface used to receive light is small, this is done to measure the point's position. The LDR resistance will change according to the intensity it receives, so to measure the light intensity a voltage divider circuit is used. The decrease in measured light intensity is proportional to the square drop in voltage across the resistor. The observations made in this experiment are the measuring point's position and the voltage on the resistor. Measurements were made only up to the minimum 5 pattern because the intensity meter circuit's sensitivity was insufficient so it was not sensitive enough to measure smaller voltages.

The diffraction pattern occurs in the horizontal (x-axis) and vertical (y-axis) direction. Still, measurements are made in the x-axis direction with a constant y-axis position and measurements on the y-axis with a stable x-axis position. The data obtained are of two types: the intensity ratio data in the x-axis direction and the intensity ratio data in the y-axis direction. The diffraction pattern measurement is done by measuring the intensity on the horizontal axis and diffraction pattern's vertical axis. When observing the diffraction pattern on the x-axis, we think of the diffraction pattern on the vertical line (y-axis) as a constant whose position value is close to zero, so based on the trigonometric limit's identity function, such as equation 6.

$$\frac{\sin^2\gamma}{\gamma^2}=\left(\frac{\sin\gamma}{\gamma}\right)^2=(1)^2=1 \quad (6)$$

The equation for the intensity ratio on the horizontal line becomes equation 7.

$$\left(\frac{V(P)}{V_0}\right)^2=\frac{\sin^2\beta}{\beta^2} \quad (7)$$

where b = slit width (mm), x = distance of the observed point to the center maximum (cm), λ = laser wavelength (nm), z = slit distance to screen (cm).

When observing the diffraction pattern on the y-axis, we think of the diffraction pattern on the horizontal line (x-axis) as a constant whose position value is close to zero, so it is adjusted to the identity of the trigonometric limit function in equation 8.

$$\frac{\sin^2\beta}{\beta^2}=\left(\frac{\sin\beta}{\beta}\right)^2=(1)^2=1 \quad (8)$$

The equation for the intensity ratio on the vertical line becomes equation 9.

$$\left(\frac{V(P)}{V_0}\right)^2=\frac{\sin^2\gamma}{\gamma^2} \quad (9)$$

with $\gamma=\pi ay/\lambda z$, a = slit height (mm), y = distance of the observed point to the center maximum (cm), λ = laser wavelength (nm), z = gap to screen distance (cm).

The intensity measurement results on the diffraction pattern are compared with the central maximum pattern's intensity values. The results of the voltage measurement of the voltage divider resistor in the horizontal position (x-axis) are shown in table 1. The measurement of the voltage across the voltage divider circuit in the vertical position (y-axis) is shown in Table 2.

Table 1. The results of measuring the intensity ratio in the horizontal position (x axis)

Position x (cm)	Voltage R (volt)	Voltage ratio (V/V0)	$(V/V0)^2$	Note
-4.30	0.009	0.002	0.000004	Min 5
-4.10	0.138	0.030	0.000873	Max 4
-3.60	0.009	0.002	0.000004	Min 4
-3.00	0.129	0.028	0.000763	Max 3
-2.80	0.007	0.001	0.000002	Min 3
-2.20	0.343	0.073	0.005395	Max 2
-1.60	0.020	0.004	0.000018	Min 2
-1.30	0.670	0.143	0.020583	Max 1
-0.90	0.047	0.010	0.000101	Min 1
0.00	4.670	1.000	1.000000	Central Max
0.80	0.261	0.056	0.003124	Min 1
1.30	0.930	0.199	0.039658	Max 1
1.80	0.016	0.003	0.000012	Min 2
2.30	0.420	0.090	0.008088	Max 2
2.70	0.007	0.001	0.000002	Min 3
3.30	0.236	0.051	0.002554	Max 3
3.60	0.009	0.002	0.000004	Min 4
4.00	0.163	0.035	0.001218	Max 4
4.40	0.009	0.002	0.000004	Min 5

Table 1 is the measurement data on the x-axis. Measurement of diffraction patterns to a minimum 5. The distribution of intensity on the x-axis is related to the value β. The minimum 5 pattern is the 5 orders, so the value β = 5π and β =(πbx)/(λz). Based on these two equations, the data is entered (b = 0.3564 mm) and the x = 4.3 cm value is obtained. In theory, the minimum x-axis value = -4.3 cm, and the maximum x-axis value = 4.3 cm. Observation data shows that the minimum x-axis value = -4.3 cm and the maximum x-axis value = 4.4 cm. This value is considered to be close to the theoretical value so that the maximum distance observed to the minimum pattern of the 5th is quite valid. The minimum position based on observations by the eye, whose position may shift due to the observation parallax error, is the minimum position.

Table 2 is the measurement data on the y-axis. Measurement of diffraction patterns to a minimum of 5. The intensity distribution on the y-axis is related to the value γ. The 5th minimum pattern is the 5th order, so the value γ = 5π and γ= (πay)/(λz). Based on these two equations, the data were entered (a = 0.4677 mm), and the y = 3.5 cm was obtained. In theory, the minimum y-axis value = -3.5 cm and the maximum y-axis value = 3.5 cm. Observation data shows that the minimum y-axis value = -3.5 cm and the maximum y-axis value = 3.5 cm. This value is considered to be close to the theoretical value so that the maximum distance observed to the minimum pattern of the 5th is quite valid. Based on the above calculations, it can be concluded that the larger the width of the grid, the smaller the nth and minimum distance to the maximum center.

Table 2. The results of measuring the intensity ratio in the vertical position (y-axis)

position y (cm)	voltage R (volt)	Voltage ratio (V/V0)	$(V/V0)^2$	Note
-3.40	0.034	0.007	0.000053	Min 5
-3.00	0.203	0.043	0.001890	Max 4
-2.60	0.037	0.008	0.000063	Min 4
-2.30	0.179	0.038	0.001469	Max 3
-1.90	0.012	0.003	0.000007	Min 3
-1.60	0.231	0.049	0.002447	Max 2
-1.30	0.039	0.008	0.000070	Min 2
-1.00	0.940	0.201	0.040516	Max 1
-0.70	0.061	0.013	0.000171	Min 1
0.00	4.670	1.000	1.000000	Central Max
0.70	0.162	0.035	0.001203	Min 1
1.00	0.900	0.193	0.037141	Max 1
1.40	0.039	0.008	0.000070	Min 2
1.70	0.376	0.081	0.006482	Max 2
2.00	0.042	0.009	0.000081	Min 3
2.40	0.192	0.041	0.001690	Max 3
2.70	0.017	0.004	0.000013	Min 4
3.00	0.098	0.021	0.000440	Max 4
3.40	0.008	0.002	0.000003	Min 5

Based on the intensity ratio equation in Table 1 and Table 2, the data is used to graph the relationship between β (x axis) or γ (y axis) to the intensity ratio (z axis). Graph of the relationship between β and the intensity ratio $(V / V0)^2$ is shown in Figure 5. In contrast, the graph of the relationship between γ and the intensity ratio $(V/V0)^2$ is shown in figure 6.

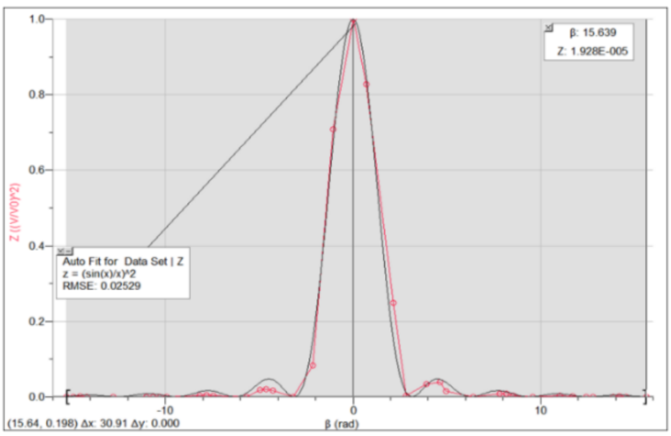

Figure 5. Graph of the relationship between β and the intensity ratio $(V/V0)^2$

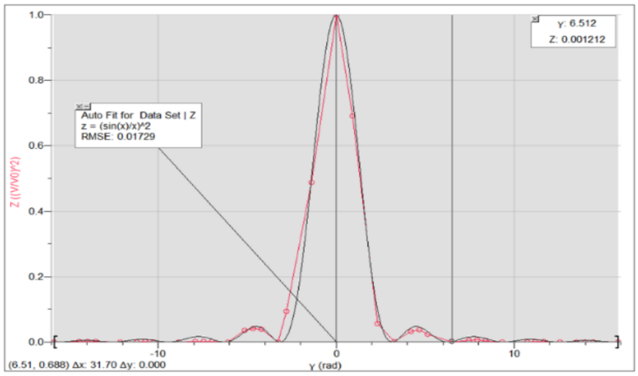

Figure 6. Graph of the relationship between γ and the intensity ratio $(V/V0)^2$

Based on the graphs in Figure 5 and Figure 6, the intensity ratio value between experiment and theory can be found based on graphic fitting.

The ratio between the experimental value and the theory value will determine the Chi square value as follows.

$$\chi^2 = \frac{\sum_{n=1}^{N}\left(z_{experiment} - z_{teory}\right)^2}{N} = \frac{0.0183915859}{39} = 0.0004715791$$

The above results show the difference between the intensity comparison data from the experimental results and the theory.

The ratio between the experimental value and the theoretical value will determine the Chi square value, which indicates the difference between practical and theoretical values. The results of the Chi square value are stated as follows.

$$\chi^2 = \frac{\sum_{n=1}^{N}\left(z_{experiment} - z_{teory}\right)^2}{N} = \frac{0.012004089}{39} = 0.000307797$$

The intensity distribution on the x-axis is affected by value β. To determine the intensity distribution pattern graphically, it graphically graphs of the relationship between β and the intensity ratio. The relationship graph β and the intensity ratio $(V/V0)^2$ can be seen in Figure 4. The experimental graph is compared with the theoretical graph to determine the theoretical data's deviation value by looking for the chi square value. The theoretical graph uses the intensity distribution ratio formula, namely, $y = \sin^2\beta/\beta^2$. The chi square value is determined by comparing experimental data's z position value and the value of the theory z position at point β according to existing practice data. The chi squared value results for relationship data β and the intensity ratio $(V/V0)^2$ is 0.0004715791. Based on the theoretical graph and the experimental graph, it can be seen immediately that the value of the experimental graph is not much different from the theoretical graph.

The intensity distribution on the y-axis is influenced by value γ to determine the intensity distribution pattern graphically. It graphically graphs the relationship between γ and the intensity ratio. Relationship graph γ and the intensity ratio $(V/V0)^2$ can be seen in Figure 4. The chi square value results for relationship data γ and the intensity ratio $(V/V0)^2$ is 0.000307797. The chi square value of the y-axis data is smaller when compared to the x-axis data. This shows that the intensity distribution value on the y-axis is more accurate than the measure on the x-axis.

The intensity distribution pattern on the x-axis is stated as follows.

$$\frac{d\left(\frac{V}{V_0}\right)^2}{d\beta} = \frac{d\left(\frac{\sin^2\beta}{\beta}\right)}{d\beta}$$

$$= \frac{2\sin\beta\cos\beta}{\beta^2} - \frac{2\sin^2\beta}{\beta^3}$$

$$= \sin\beta\,(\beta - \tan\beta) = 0$$

$$\sin\beta = 0 \text{ dan } \tan\beta = \beta$$

$$\sin\beta = 0 \Rightarrow \text{minimum}$$

$$\tan\beta = \beta \Rightarrow \text{maximum}$$

By using the graph method, the roots of tan β = β from -5π to 5π is β = {-4.47π; -3.47π; -2.46π; -1.43π; 0; 1.43π; 2.46π; 3.47π; 4.47π}. The intensity distribution pattern on the y-axis uses the same analogy as the x-axis so that the roots of tan γ = γ from -5π to 5π is γ = {-4.47π; -3.47π; -2.46π; -1.43π; 0; 1.43π; 2.46π; 3.47π; 4.47π}. The intensity at the minimum pattern is theoretically zero. In the experiment, the intensity ratio in the minimum pattern is not equal to zero but the value is very small. This happens because at that point the LDR surface still receives light from the maximum pattern around it.

Table 3. Comparison of the intensity distribution in the maximum theoretical and experimental patterns

axis	Maximum to-	Intensity Ratio Theory (I_{teory})	Experiment Intensity Ratio ($I_{experiment}$)	Percentage of Experiments to Theory (%)
X (from left to right)	4	0.005024	0.000873	17.40
	3	0.008340	0.000763	9.10
	2	0.016480	0.005395	32.70
	1	0.047190	0.020583	43.60
	1	0.047190	0.039658	84.00
	2	0.016480	0.008088	49.10
	3	0.008340	0.002554	30.60
	4	0.005024	0.001218	24.20
Y (from the bottom up)	4	0.005024	0.001890	37.60
	3	0.008340	0.001469	17.60
	2	0.016480	0.002447	14.80
	1	0.047190	0.040516	85.90
	1	0.047190	0.037141	78.70
	2	0.016480	0.006482	39.30
	3	0.008340	0.001690	20.30
	4	0.005024	0.000440	8.80

The intensity value in the maximum pattern can be calculated using the equation $\sin^2\beta/\beta^2$ so that the difference between the theoretical and experimental intensity ratios can be seen in table 3. The greater the percentage ratio between the experimental value and the theoretical value, the closer the experimental data will be to the theoretical value. The experimental intensity ratio value is different from the theoretical intensity ratio value based on the calculation percentage. The practical intensity ratio value is smaller than the theory. It is because the theoretical intensity distribution is used at the point which is a form of case simplification by assuming γ is constant. Simultaneously, the experimental data is the intensity on the line so that the intensity is lower.

This experiment shows that experimental activities in learning, especially on diffraction material, can be carried out using simple materials. The tools and materials used allow students to duplicate them and learn concepts through experimentation with fun. The experimental results show that theory and practice do not show many different results, even though the equipment used is quite simple. It is also in line with Maretta, (2016) research that integrating science and local wisdom is effective after an open inquiry given

Conclusion

Light diffraction events, especially Fraunhofer diffraction, can be carried out by students using narrow slits made by themselves and simple measuring instruments. The slit width is inversely proportional to the width of the diffraction pattern. The bigger the gap width, the smaller the maximum nth and minimum nth distance from the maximum center, and vice versa. The intensity ratio in the minimum pattern is small but not equal to zero. This is because the LDR surface as the intensity receiver still gets light from the maximum pattern around the measured minimum pattern.

The ratio of the intensity distribution of the x-axis maximum pattern on the Fraunhofer diffraction by a rectangular slit with slit size height x width = (0.4677 x 0.3564) mm from $\beta = -5\pi$ to 5π (maximum 4; maximum 3; maximum 2; maximum 1; central maximum; maximum 1; maximum 2; maximum 3; maximum 4) are 0.000873; 0.000763; 0.005395; 0.020583; 1; 0.039658; 0.008088; 0.002554; 0.001218. The ratio of the intensity distribution of the y-axis maximum pattern on the Fraunhofer diffraction by a rectangular slit with slit size height x width = (0.4677 x 0.3564) mm from $\gamma = -5\pi$ to 5π (maximum 4; maximum 3; maximum 2; maximum 1; central maximum; maximum 1; maximum 2; maximum 3; maximum 4) are 0.001890; 0.001469; 0.002447; 0.040516; 1; 0.037141; 0.006482; 0.001690; 0.000440.

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