

MODULE 15

DIFFRACTION

1. EXPERIMENTAL AIM

- 1.1. To understand the formation of diffraction pattern.
- 1.2. To understand the factor of width and number of slits to the diffraction pattern.
- 1.3. To understand the light intensity pattern produced from diffraction.
- 1.4. To compare light intensity patterns produced by diffraction to the patterns produced by interference.

2. EXPERIMENTAL APPARATUS



Figure 15.1. Tools and materials of module 15.

- 2.1. LabQuest Stream Interface
- 2.2. Logger Pro application
- 2.3. Red laser (635.5 ± 5) nm and its stand
- 2.4. Light sensor
- 2.5. Set of single, double, and multiple slits and its stands.
- 2.6. Ruler
- 2.7. Rail
- 2.8. Flashlight

3. BASIC THEORY

In classical physics, waves and particles are considered to be different. Superposition is a unique characteristic of wave, which is not observable in particles. Superposition occurs when two waves are

intersecting. This superposition is the base for interference and diffraction patterns, which is produced as a wave packet passes through a narrow slit. The interference pattern consists of minimas and maximas which periodicity depends on the separation distance of the slits. Maximas are the result of constructive superposition, whilst the minimas are the result of destructive superposition. The interference pattern will also then be affected by the diffraction pattern, which occurs due to the narrow slit opening.

Diffraction patterns caused by a single slit was explained by Christian Huygens. According to Huygens, each part of the slit is functioning as a new wave source so that light from a particular point on the slit may interfere with light packets from another part of the slit.

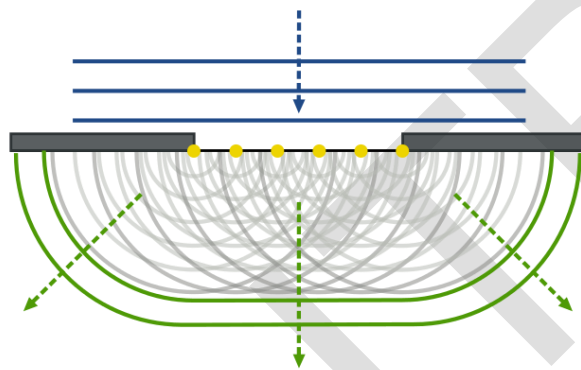


Figure 15.2. Huygens Principle.

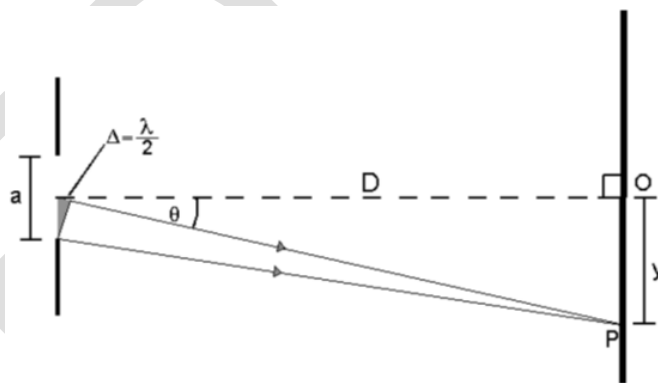


Figure 15.3. A scheme for single slit diffraction.

Figure 15.3 shows a light wave of length λ was diffracted by a narrow slit of width w . The interference of wave sources from a slit produced a maxima-minima pattern on the screen. The diffracted light intensity in respect to the angle wave propagation angle to the screen satisfies the following equation:

$$I \propto \left(\frac{\sin \Phi}{\Phi} \right)^2 \quad (15.1)$$

in which

$$\Phi = \frac{\pi w \sin \theta}{\lambda} \quad (15.2)$$

where w is the width of slit, θ is the angle of wave propagation behind the slit, and λ is the light wavelength. The condition for a minima is:

$$\sin \Phi = 0 \quad (15.3)$$

which will occur when the sine is zero, so that:

$$\Phi = 0, \pi, 2\pi, 3\pi, \dots \quad (15.4)$$

By equation (15.2), we obtain the condition for $\sin \Phi = 0$:

$$\frac{\pi w \sin \theta}{\lambda} = 0, \pi, 2\pi, 3\pi, \dots \quad (15.5)$$

or

$$\sin \theta = 0, \frac{\lambda}{w}, \frac{2\lambda}{w}, \frac{3\lambda}{w}, \dots \quad (15.6)$$

However, as $\sin \theta = 0$ is the condition for the center main maxima, the minimas may only occur on:

$$\sin \theta = \frac{\lambda}{w}, \frac{2\lambda}{w}, \frac{3\lambda}{w}, \dots \quad (15.7)$$

In which the width of the main maxima is equal to the distance of the two first minimas. These first minimas occur on the angle θ which satisfies:

$$\sin \theta = \frac{\lambda}{w} \quad (15.8)$$

For a very small θ , it is possible to approximate $\theta \approx \sin \theta$, so that the angle in which the main minima occurs satisfies:

$$\theta \approx \frac{\lambda}{w} \quad (15.9)$$

which suggests the width of the first maxima (in angle unit) is:

$$2\theta \approx \frac{2\lambda}{w} \quad (15.10)$$

Suppose the slit to screen distance is D , so that the width of the main maxima in length unit is:

$$\Delta y = D \cdot 2\theta = \frac{2\lambda D}{w} \quad (15.11)$$

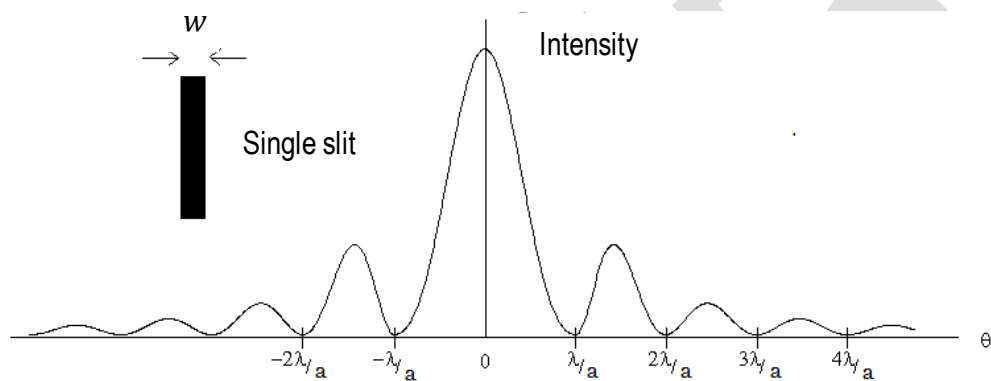


Figure 15.4. Single slit diffraction pattern.

According to Figure 15.4, equation (15.11) may be developed further to obtain:

$$n\lambda = \frac{w\Delta y}{D} \quad (15.12)$$

where n is the order of the minima produced (1, 2, 3, ...).

4. EXPERIMENTAL PROCEDURE

4.1. Apparatus Set-up

1. Assemble the apparatus as given in Figure 15.5. (Please consult with your assistant).

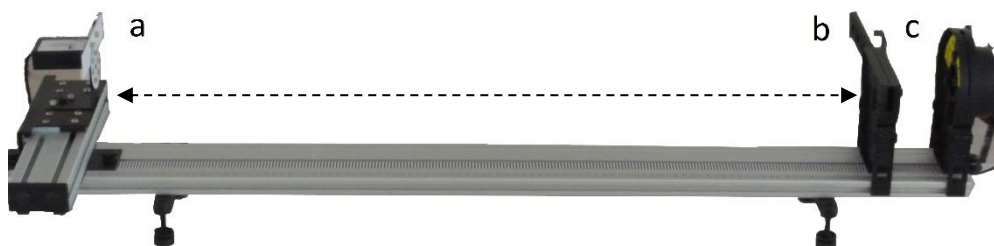


Figure 15.5. Apparatus scheme. (a) Light sensor, (b) Set of slits, (c) Laser.

2. Please ensure the side of the slit which contains informations regarding the shape and width of the slit is facing the laser.
3. Set the distance between the light sensor to the slits set to $L = 90$ cm and the distance between the slits set to the laser is $b-c = 10$ cm.
4. Connect the light sensor to the PC, then connect it to the voltage source.

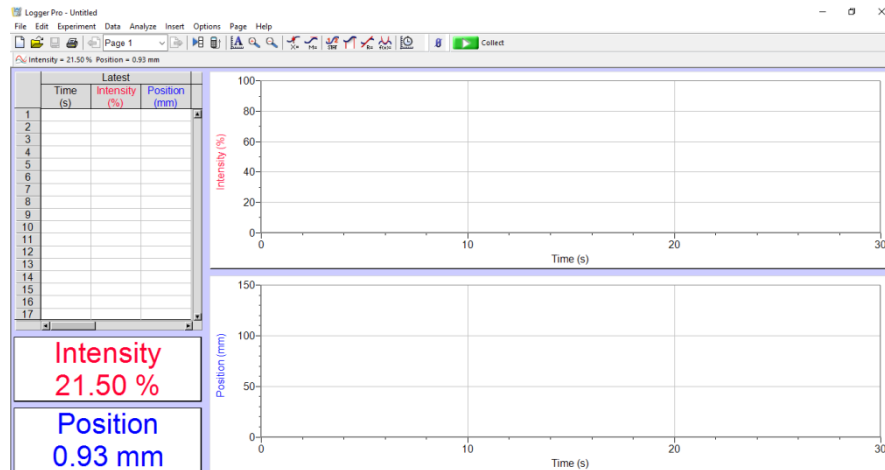


Figure 15.6. Logger Pro interface.

5. Connect the laser to the voltage source. Please keep the laser turned off before the data collection begins.
6. Set the slit optic by swiping it so that it shows a single slit of 0.08 mm in width.
7. Turn on the laser, set the vertical and horizontal position of the laser accordingly so that the packets passes through the slit and the result is visible on the light sensor board as given in Figure 15.7. This is a procedure to adjust the positioning of the laser.

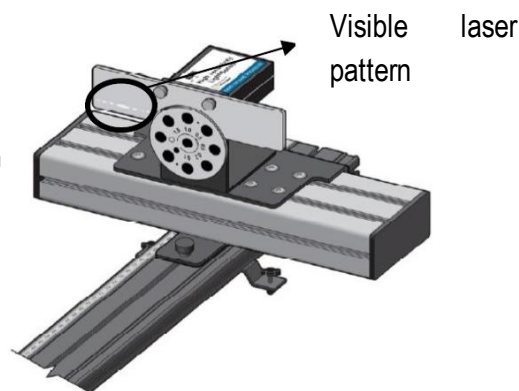






Figure 15.7. The position of laser wave packet visible after the adjustment.

4.2. Single Slit Diffraction

1. Use a single slit of width 0.08 mm.
2. Turn on the laser.
3. Calibrate the laser position.

4. Note the distance between the sensor and the slit (L), width of slit (w), and the laser wavelength (λ).
5. Set the sensitivity of the sensor to $1 \mu\text{W}$ and the sensor opening to 0.5 mm .
6. Slide the sensor to the rightmost end.
7. Press the  (Zero) button on the Logger Pro panel to reset the reading of both sensors (light and position) to zero.
8. Record the data by clicking the button  (Collect). Then, slide the sensor slowly for 20-30 seconds so that an intensity curve appeared on the monitor. Save the data,
9. Should the data did not appear, do an autoscaling by pressing the button  (Autoscale graph) on the panel.
10. Repeat step 8 by sliding the sensor to the opposite direction.
11. Repeat steps 1-9 by using a different slit width.

4.3. Comparing the Diffraction Pattern and the Double Slit Interference Pattern

1. Use a single slit of width 0.08 mm .
2. Turn on the laser.
3. Reset the laser position by clicking the button  (Zero) on the Logger Pro panel.
4. Observe and draw the pattern produced.
5. Measure the distance between the center maxima to the midpoint of the first minima.
6. Measure the distance between the center maxima to the midpoint of the second minima.
7. Measure the width of the center maxima.
8. Repeat steps 2-7 by using a single slit of different width.
9. Repeat steps 2-7 by using a double slit of width 0.08 mm and interslit distance of 0.25 mm .
10. Repeat steps 2-7 by using a double slit of width 0.08 mm and another interslit distance.

5. ANALYSIS

- 5.1. According to the data obtained in 4.2.4, calculate theoretically by using equation (15.12), the distance for the first, second, and third minima from a 0.08 mm slit.
- 5.2. Observe the intensity vs position curve obtained. Zoom in the graph on the necessary position. Use Examine tool in Analysis Menu, then position the cursor to a part of the curve corresponding to the center maxima. Note this position.
- 5.3. Determine the midpoint of the first three minima from each of the two sides of the center maxima. Position the cursor on the lowest intensities. Note these positions.
- 5.4. Determine the distance of y_n , which is the distance between the center maxima to the first, second, and third minima.
- 5.5. Compare the observed results in part 4.3. In the use of single slit, what is the effect of the slit width to the pattern produced?
- 5.6. Compare the observed results in part 4.3. In the use of double slit, what is the effect of the slit width and interslit distance to the pattern produced?
- 5.7. According to the experiment 4.3, how is the width of center maxima from all types of slits used?
- 5.8. Tabulate the data obtained from 5.1 - 5.3 and 7 in the following table:

Pattern Order	Distance to the left side minima (mm)	Distance to the right side minima (mm)	Average distance (mm)	Theoretical distance (mm)	Error(%)
n=1					
n=2					
n=3					

- 5.9. Measure the peak intensity of the center maxima and the first two maxima on each side. If the baseline of the graph is not at zero, make a new calculation by correcting the positions first.
- 5.10. Theoretically, the intensities of the first and second maximas are $I_1 = 0.045 I_0$ and $I_2 = 0.016 I_0$. Tabulate the data obtained from 5.9 in the table below.

Pattern Order	Intensity (%)	Relative intensity to I_0 (%)	Theoretical relative intensity (%)	Error (%)
n=0		-	-	-
n=1				
n=2				

- 5.11. Repeat the steps for each variation of slits.
- 5.12. Explain the shape of intensity curves produced by each type of slit. How is the effect of the slit size to the curve shape?

6. REFERENCES

- Abdullah, Mikrajuddin. (2007) : Fisika Dasar II, Penerbit ITB.
- Dukerich, Larry. (2012) : *Advanced Physics with Vernier - Beyond Mechanics*, Vernier Software and Technology.
- Halliday, David; Resnick, Robert; and Walker, Jearl. (2008) : *Fundamental of Physics (Extended)*, 8th Edition, John Wiley & Sons, xx – xx.
- Tjia, May On. (1994) : *Gelombang*, Dabara Publishers, 195 – 197.