

PHY 222 Lab 11 Interference and Diffraction Patterns

Investigating interference and diffraction of light waves

April 17, 2015

Print Your Name

Print Your Partners' Names

Instructions

Before lab, read the *Introduction*. Then answer the Pre-Lab Questions on the last page of this handout. Hand in your answers as you enter the general physics lab.

You will return this handout to the instructor at the end of the lab period.

Table of Contents

- 0. Introduction 1
- 1. Activity #1: A Diffraction demonstration. 7
- 2. Activity #2: Getting familiar with the equipment and the initial setup. 7
- 3. Activity #3: Double-slit interference pattern. 9
- 4. Activity #4: Single-slit diffraction pattern 11
- 5. Activity #5: Exploring other types of diffraction patterns 12
- 6. When you are done... 14

0. Introduction

Abstract: A quick introduction to diffraction phenomena exhibited by electromagnetic waves.

Diffraction is one of the most important phenomenon exhibited by waves that clearly distinguish them from particles. When a plane wave encounters a barrier with a narrow opening, it bends and spreads out as a circular wave as it passes through the opening (Figure 1a). On the other hand a parallel beam of particles while passing through a narrow opening do not spread out (Figure 1b).

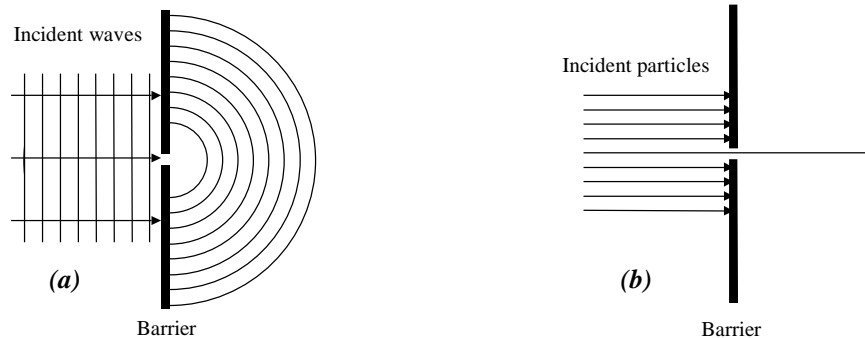


Figure 1 Comparison of waves and particles passing through a narrow opening in a barrier. (a) The waves after passing through the opening act as though the opening were a point source emitting circular waves. (b) Particles are restricted to a narrow region after passing the opening.

Since diffraction is a phenomenon unique to waves, it is exhibited by all types of waves – sound waves, waves on water, electromagnetic waves, etc. In this lab you will observe and investigate interference and diffraction patterns that result from the diffraction of visible light. Visible light, as you may recall, is a particular type of electromagnetic wave.

We begin by defining a few terms that frequently arise while studying diffraction-related phenomena.

Monochromatic beam of light: A *monochromatic beam of light* is a beam of light of a single wavelength (or color).

Coherent sources (or waves): Two or more sources are called *coherent sources* if the waves that leave the two sources bear a definite relationship to each other. If the two waves do not bear a definite relationship to each other then they are said to be incoherent. Figure 2 is a sketch of two coherent sources while Figure 3 is a sketch of two incoherent sources.

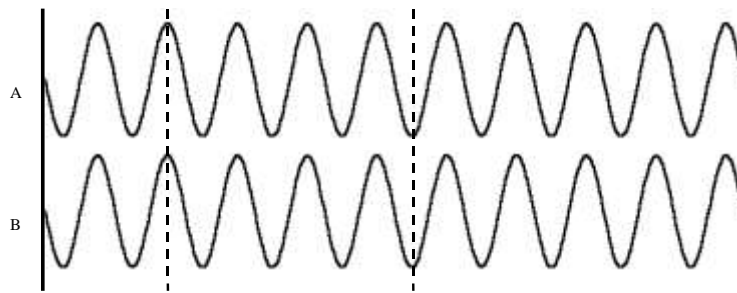


Figure 2 The figure shows waves emitted by two sources A & B. The crests of waves emitted by source A always corresponds to the crests of the waves emitted by source B and similarly for the troughs. The two waves are said to be exactly in phase.

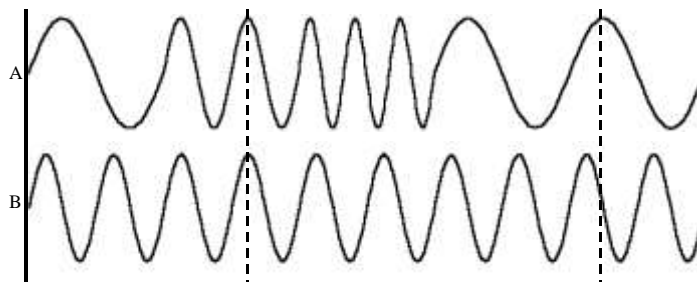


Figure 3 Sources A & B are incoherent sources because there is no fixed relationship exists between the crests and troughs of the waves emitted by the two sources.

Waves exactly in phase and exactly out of phase: Two coherent waves are said to be *exactly in phase* if a crest(trough) of one wave exactly coincides with the crest(trough) of the other wave. The two waves shown in Figure 2 are exactly in phase with respect to each other. Two waves are said to be *exactly out of phase* if a crest(trough) of one wave exactly coincides with the trough(crest) of the other wave.

Constructive and destructive interference: When two waves having the same amplitude and wavelength and exactly in phase with respect to each other interfere with one another the amplitude of the resulting wave is twice the amplitude of the individual waves and the two waves are said to undergo *constructive interference*. Similarly, when two waves with the same amplitude and wavelength and exactly out of phase with respect to each other interfere with one

another the amplitude of the resulting wave is zero and the two waves are said to undergo *destructive interference*.

0.1 *Double-slit interference pattern*. Consider a parallel, monochromatic beam of light (for example light from a laser beam) incident on a barrier that consists of two closely spaced narrow slits S_1 and S_2 . The narrow slits split the incident beam into two coherent beams of light. After passing through the slits the two beams spread out due to diffraction and hence interfere with one another (Figure 4a). If this transmitted light is made to fall on a screen some distance away one observes an interference pattern of bright and dark fringes on the screen (depicted in Figure 4b and Figure 4c). The bright fringes correspond to regions where the light intensity is a maximum (brightest) and the dark fringes correspond to regions where the intensity is a minimum.

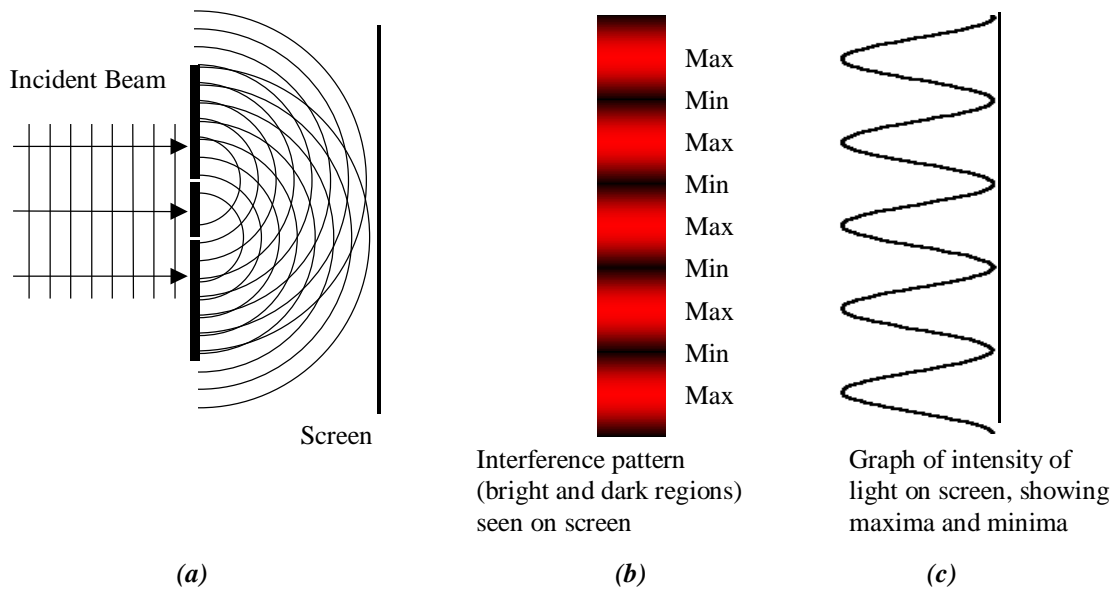


Figure 4 (a) The experimental setup to observe a double-slit interference pattern, (b) The interference pattern observed on the screen showing the bright and dark fringes, and (c) a sketch of the intensity maxima and minima.

How is this interference pattern produced? Let us try and understand the bright fringe located at the center of the screen between the two slits.

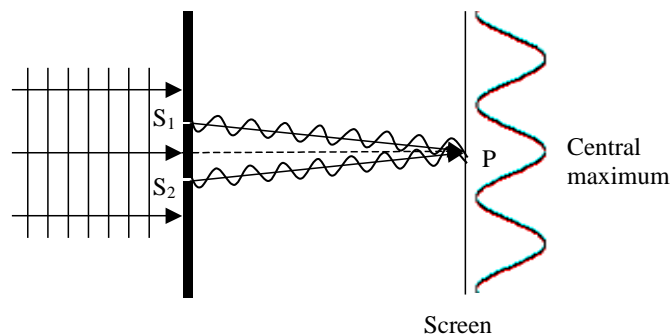


Figure 5 The waves reaching the point P at the center of the screen are exactly in phase since they travel equal distances

Figure 5 shows the waves reaching the point P from the slits S_1 and S_2 . The waves emerging from the slits S_1 and S_2 are *exactly in phase*. Since they travel the same distance to reach the point P they are in phase at the point P. In other words a crest of one wave arrives at the same time as a crest from the other wave. The two waves therefore interfere constructively at the point P and hence there is a bright fringe (or a maximum) at the center of the screen.

To explain how the other bright fringes seen on either side of the central maximum are produced refer to Figure 6. Let λ be the wavelength of the incident light. Let d be the distance between the two slits and L be the distance from the slits to the screen. Suppose the point P_1 corresponds to the position of the first maximum above the central bright fringe.

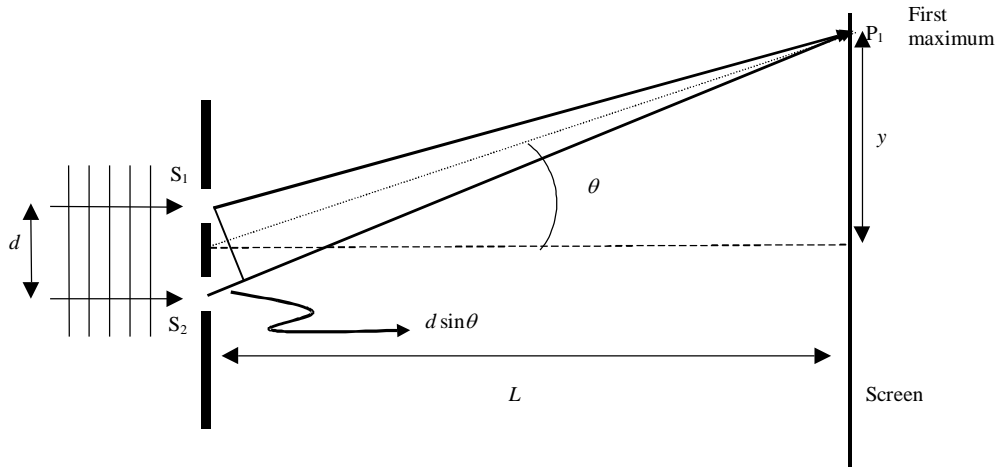


Figure 6 The wave reaching point P_1 from slit S_2 must travel an extra distance $d \sin \theta$.

From Figure 6 it is clear that the line from S_2 is greater than the line from S_1 which means that the wave from S_2 travels an extra distance to reach point P_1 . If we assume that the slit-to-screen length L is much greater than the slit separation d ($L \gg d$) then the lines from the two slits to the point P_1 are approximately parallel and the excess distance traveled by the wave from S_2 or the path difference is approximately $d \sin \theta$.

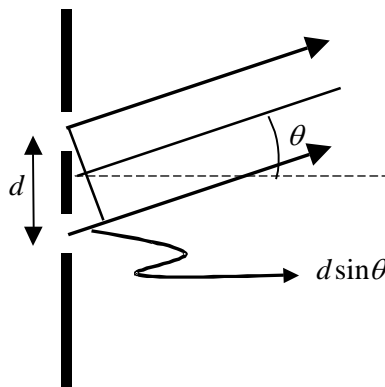


Figure 7 The path difference is approximately $d \sin \theta$ if the two waves are parallel to each other.

Since the two waves interfere constructively at point P_1 , the two waves reaching point P_1 must be exactly in phase and hence the path difference must be equal to one wavelength. i.e.,

$$d \sin \theta = \lambda \tag{1}$$

Equation (1) is also responsible for the presence of the first bright fringe below the central maximum. In general, for all points on the screen where the path difference is some integer multiple of the wavelength the two waves from the slits S_1 and S_2 arrive in phase and bright fringes are observed. Thus the condition for producing bright fringes is

$$d \sin \theta = \lambda, 2\lambda, 3\lambda, 4\lambda, \dots \quad (2)$$

Similarly, dark fringes are produced on the screen if the two waves arriving on the screen from slits S_1 and S_2 are exactly out of phase. This happens if the path difference between the two waves is an odd integer multiple of half-wavelengths. i.e.,

$$d \sin \theta = \frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}, \frac{7\lambda}{2}, \dots \quad (3)$$

If y is the distance of a given bright or dark fringe from the central maximum on the screen (Figure 7) then

$$\tan \theta = \frac{y}{L} \quad (4)$$

Our assumption $L \gg d$ implies that the angle θ is very small and hence

$$\sin \theta \approx \tan \theta = \frac{y}{L} \quad (5)$$

Equations (2), (3) and (5) imply that the interference maxima (bright fringes) are located at

$$y = 0, \lambda \frac{L}{d}, 2\lambda \frac{L}{d}, 3\lambda \frac{L}{d}, 4\lambda \frac{L}{d}, \dots, \quad (6)$$

on the screen, while the interference minima (dark fringes) are located at

$$y = \lambda \frac{L}{2d}, 3\lambda \frac{L}{2d}, 5\lambda \frac{L}{2d}, 7\lambda \frac{L}{2d}, \dots \quad (7)$$

on the screen. Thus, the distance between adjacent maxima or adjacent minima on the screen is

$$\Delta y = \lambda \frac{L}{d} \quad (8)$$

Equation (8) suggests that the interference maxima and minima are evenly spaced and if one were to plot Δy versus L/d for various slit separations d , the graph is a straight line with slope equal to the wavelength of the incident light.

0.2 Diffraction pattern from a single-slit: Consider a beam of light incident on a barrier consisting of a single slit of width a . If the light passing through the slit is made to fall on a screen a distance L away from the slit, one observes a diffraction pattern of alternating dark and bright fringes on the screen (Figure 8).

The diffraction pattern produced on the screen can be explained by assuming that each point on the wave passing through the slit acts as a source of circular waves and emits light in the forward direction. These waves interfere with one another resulting in the dark and bright fringes observed on the screen.

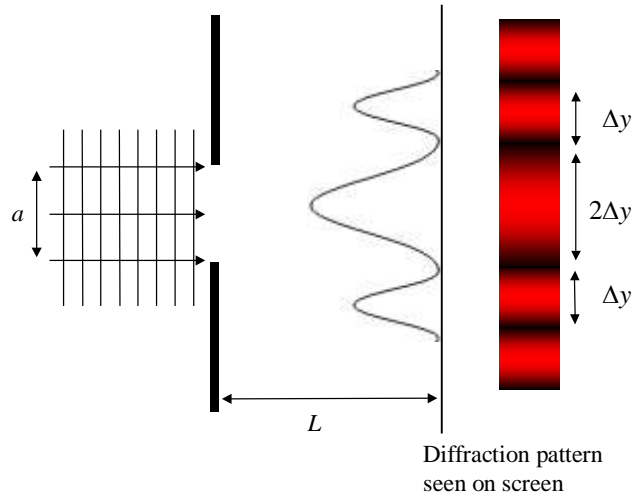


Figure 8 Single-slit diffraction pattern

An argument not unlike the one presented while discussing the double-slit interference pattern shows that the spacing between the dark fringes on the screen is given by

$$\Delta y = \lambda \frac{L}{a}, \quad (9)$$

except that the dark fringes on either side of the central maximum are a distance $2\Delta y$ apart (refer to Figure 8). Notice the central maximum in a single-slit diffraction pattern has a width $2\Delta y$.

In the case when the slit is very narrow, $\lambda \gg a$, the separation of the fringes is very large. A point-like slit corresponds to $a \rightarrow 0$. In that case, $\Delta y \rightarrow \infty$. Thus, the central maximum becomes infinitely broad. This is the case of circular wave depicted in Figure 4a.

It is also interesting to consider the slit which is very broad, $\lambda \ll a$. In the limit of very broad slit, $a \rightarrow \infty$, the separation between fringes becomes infinitely small, and $\Delta y \rightarrow 0$. In other words, all fringes appear at the same place, or simply all light is incident at the center of the screen. But this is how particles move! No light was deflected. When all obstacles are large compared to the wavelength, the light travels along the straight lines. This is the case of so called **geometrical optics**. In case the light interacts with objects of dimensions comparable to the wavelength we talk about **wave optics**.

Equipment: Computer with LoggerPro and/or Excel
Laser (PASCO OS-8528 Diode Laser)
PASCO OS-8529 Slit Accessories (Multiple Slit Set and Single Slit Set)
Optics bench
Wood board, about 30 cm by 30 cm in size and about 1 to 2 cm thick
Sheet of white paper mounted on the wood board, to make a viewing screen
Ruler, metric with length 30 cm (about 1 foot in the English system)
Meter stick with length 2.0 m
Desk lamp
Flashlight
Ripple tank, one for entire lab, used as a demonstration
Desk lamp positioned to illuminate the lab's networked printer

1. Activity #1: A Diffraction demonstration.

1.1 The lab instructor will demonstrate the phenomenon of diffraction by showing you the diffraction of water waves when passing through a small aperture in a ripple tank.

2. Activity #2: Getting familiar with the equipment and the initial setup.

2.1 *Getting familiar with the equipment:* At your table you will see a laser beam mounted on an optics bench, a pair of slit accessories and a wooden board clamped firmly on one end of the table that will act as a screen.

2.2 Ensure that the optics bench is perpendicular to the wood board.

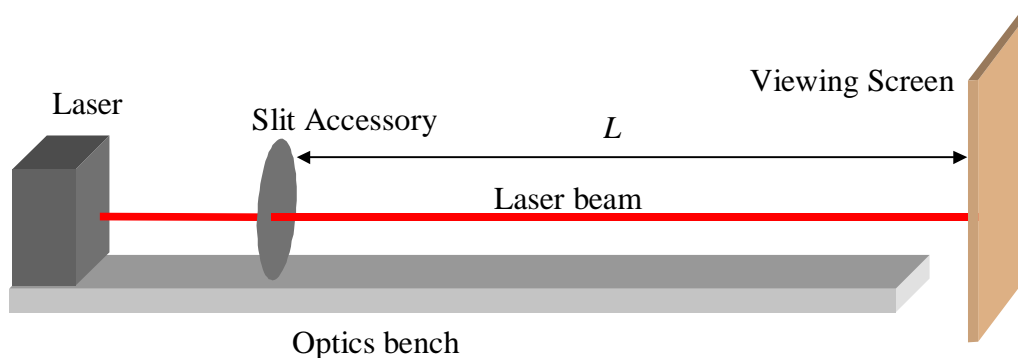


Figure 9 Experimental setup. The optics bench must be perpendicular to the wood board that acts as the screen.

2.3 *Slit Accessories:* On your table you will find a pair of slit accessories – two plastic circular disks with apertures mounted on metal frames.

2.3.1 One of them is the MULTIPLE SLIT SET which consists of various types of double-slits and the other is the SINGLE SLIT SET which consists of various single-slits and dotted apertures.

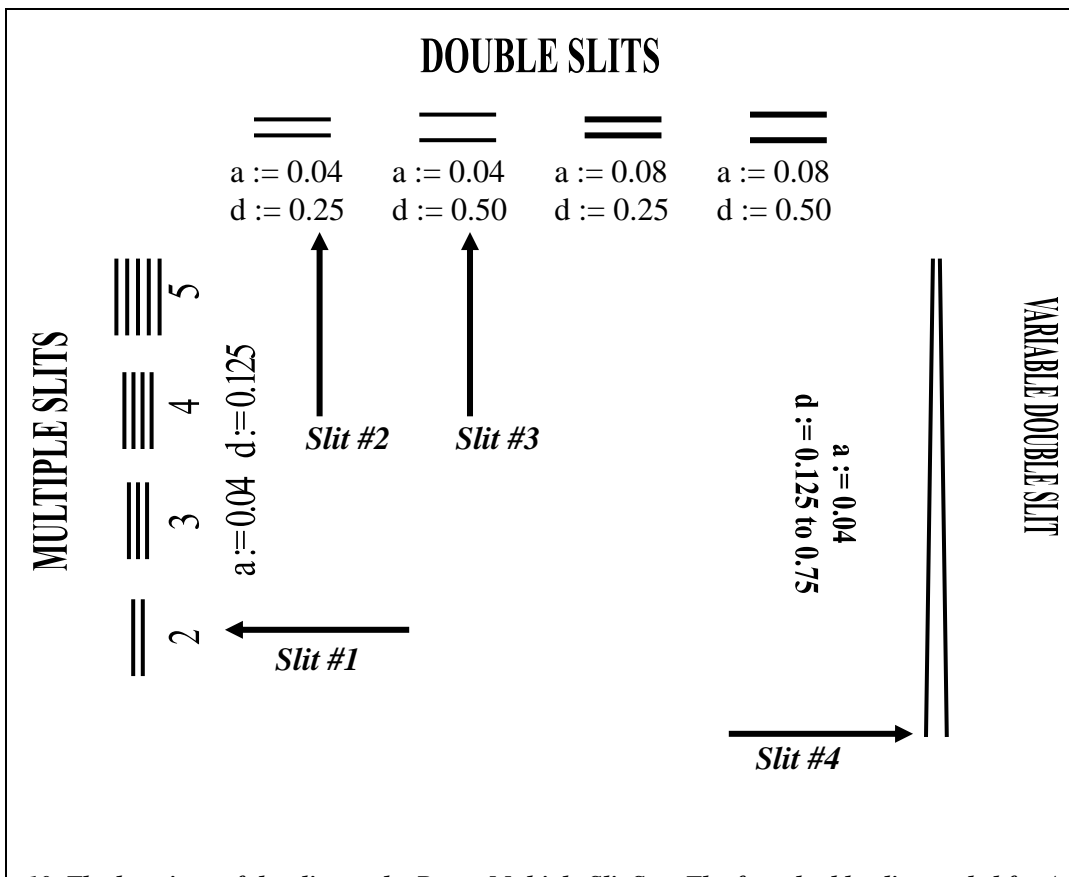


Figure 10 The locations of the slits on the Pasco Multiple Slit Set. The four double-slits needed for Activities #2 and #3 are marked Slit #1, Slit #2, Slit #3, and Slit #4. The values of a and d are in millimeters.

2.4 Look carefully at all the slits that you see on the MULTIPLE SLIT SET. It contains slits classified as DOUBLE SLITS, a VARIABLE DOUBLE SLIT, COMPARISONS and MULTIPLE SLITS.

2.4.1 Each double-slit on the MULTIPLE SLIT SET is characterized by two numbers - a and d . The number a represents the width of each slit (slit width) while the number d is the distance between the two slits (slit separation).

2.4.2 All distances mentioned on the both slit accessories are measured in millimeters.

2.5 Identify the following four double-slits on the MULTIPLE SLIT SET. Referring to Figure 10, on page 8, may be helpful.

2.5.1 In the slits under MULTIPLE SLITS identify the only *double-slit* (it has a 2 written below it). This double slit has dimensions

$$a = 0.04 \text{ mm}, d = 0.125 \text{ mm.} \quad (\text{Slit \#1})$$

2.5.2 In the slits under DOUBLE SLITS identify the *double-slits* with dimensions

$$a = 0.04 \text{ mm}, d = 0.25 \text{ mm} \quad (\text{Slit \#2})$$

$$a = 0.04 \text{ mm}, d = 0.5 \text{ mm} \quad (\text{Slit \#3})$$

2.5.3 The fourth double-slit is actually the end of the VARIABLE DOUBLE SLIT with the largest slit separation. This corresponds to a double-slit with dimensions

$$a = 0.04 \text{ mm}, d = 0.75 \text{ mm.} \quad (\text{Slit \#4})$$

2.6 Now look carefully at the apertures on the SINGLE SLIT SET. All the single-slits that you see on this set are characterized by the number a . This corresponds to the width of the single slit. Under PATTERNS identify the apertures titled SQUARES, HEXES AND DOTS. These are square, hexagonal and circular apertures filled uniformly with small dark dots.

2.7 *The laser beam*

AVOID LOOKING DIRECTLY INTO THE LASER BEAM OR THE REFLECTION OF THE BEAM FROM A MIRROR OR METAL SURFACE.

2.7.1 Place the laser at the end of the optics bench furthest from the wood board.

2.7.2 Switch the laser ON and you should see a bright red spot on the wooden board.

3. Activity #3: Double-slit interference pattern.

Abstract: Determining the wavelength of the laser beam from the double-slit interference pattern.

3.1 Make sure the laser is switched ON.

3.2 Place the MULTIPLE SLIT SET on the optics bench about 10 cm - 15 cm (100 mm – 150 mm) in front of the laser beam with the dark plastic surface facing the laser beam.

3.3 Arrange the equipment so that the distance L between the MULTIPLE SLIT SET and the wood board is **exactly 1.5 m**. You must maintain this distance unchanged for the entire lab.

3.4 Ensure that the laser beam is approximately horizontal. Your lab instructor will provide you with appropriate instructions for this adjustment.

3.5 Rotate the circular plastic disk so that the laser beam passes through the double-slit with $a = 0.04 \text{ mm}$ and $d = 0.125 \text{ mm}$.

3.6 If your arrangement is correct, you will observe an interference pattern on the wood board. The interference pattern consists of closely spaced bright and dark fringes. You may have to get close to the wood board to see this pattern.

3.7 Tape a sheet of white paper to the wood board, so that the entire interference pattern falls on the sheet.

3.8 Notice that the bright and dark fringes in the interference pattern are evenly spaced.

3.9 You need to determine the average distance between adjacent dark fringes. Here is one method of doing this accurately:

3.9.1 Use a pencil to mark out the position of several (10 to 12, if possible) dark fringes on the sheet of paper by making a thin vertical line at the center of each dark spot.

3.9.2 Remove the sheet of paper and measure the distance from the first mark to the last mark with a ruler.

3.9.3 Count the number of bright fringes enclosed by the first and last marks on the sheet of paper.

Interference and Diffraction

3.9.4 Divide the total distance measured in step 3.9.2 by the total number of bright fringes counted in step 3.9.3. This is the average distance Δy between adjacent dark fringes.

3.9.5 Record your measurements in Table 1.

3.10 Repeat steps 3.6-3.9 for the double-slit with $a = 0.04$ mm and $d = 0.25$ mm.

3.11 Repeat steps 3.6-3.9 for the double-slit with $a = 0.04$ mm and $d = 0.5$ mm.

3.12 Repeat steps 3.6-3.9 for the double-slit with $a = 0.04$ mm and $d = 0.75$ mm. This double-slit corresponds to the end of the VARIABLE DOUBLE SLIT with the largest slit separation.

Dimensions of the double-slit (mm)	Distance measured in step 3.9.2 (mm)	Total number of fringes counted in step 3.9.4	Average Δy (mm)
$a = 0.04 ; d = 0.125$			
$a = 0.04 ; d = 0.25$			
$a = 0.04 ; d = 0.5$			
$a = 0.04 ; d = 0.75$			

Table 1: Calculating the average distance between dark fringes.

3.13 Switch the computer ON, and run LoggerPro or Microsoft Excel.

3.14 Prepare a spreadsheet similar to Table 2. Enter all distances in meters.

Name:	...	
	...	
	...	
$L=$	1.5	m
Slit width		
d	L/d	Δy
(m)		(m)
0.000125
0.00025
0.0005
0.00075

Table 2 Sample LoggerPro spreadsheet

3.15 Create a **Scatter Plot** of Δy versus L/d using LoggerPro or Excel.

3.16 Fit the data to a straight line with the **Analyze -> Linear fit** option.

3.16.1 Set the intercept to zero and display the equation on the plot.

3.16.2 Format the equation so that the slope is displayed in scientific notation to two decimal places.

3.17 **Record** the slope of the straight line fit. The slope corresponds to the wavelength of the laser beam.

$$\lambda = \text{_____ m}$$

3.18 The range within which the wavelength of the laser beam must lie is mentioned on one of the sides of the laser casing (Note: $1 \text{ nm} = 10^{-9} \text{ m}$).

3.19 Check whether the wavelength determined lies within this range. If not, bring it to the attention of your lab instructor.

3.20 Print copies of the spreadsheet and the graph for you and your partners.

3.21 Quit LoggerPro.

4. Activity #4: Single-slit diffraction pattern

4.1 Replace the MULTIPLE SLIT SET with the SINGLE SLIT SET.

4.2 Set the distance from the slit to the screen to be **exactly** 1.5 m.

4.3 Pass the laser beam through the single slit with slit width $a = 0.16 \text{ mm}$. You should observe a diffraction pattern on the wood board.

4.4 Determine the average spacing Δy between the dark fringes. Recall that in a single-slit diffraction pattern the width of the central maximum is **twice the width of the other maxima**. You must take this into account when calculating Δy . Refer to Figure 8.

4.5 **Record** the average spacing here: $\Delta y = \text{_____ mm}$.

Q 1 Use equation (9) – and note Figure 8, the wavelength recorded in 3.17, and the average spacing between the dark fringes recorded in 4.5 to determine the width of your single-slit. Show your calculation.

$$\text{Width}_{\text{measured}} = \text{_____ mm}$$

Q 2 Compare the value that you have calculated with the actual value ($\text{Width}_{\text{actual}} = 0.16 \text{ mm}$) by calculating the percent discrepancy. Show your calculation.

$$\text{Discrepancy} = \frac{\text{Width}_{\text{measured}} - \text{Width}_{\text{actual}}}{\text{Width}_{\text{actual}}} \times 100\%$$

4.6 Discuss your answers to *Q 1* and *Q 2* with your instructor. **Instructor's initials** _____

5. Activity #5: Exploring other types of diffraction patterns

Abstract: Investigating diffraction patterns obtained by passing a laser beam through apertures of various shapes.

5.1 In order to clearly see the patterns in this activity, ***you must display them on a white screen and the lamp at your workstation must be turned off.***

5.2 In this activity you will pass the laser beam through the apertures SQUARES, HEXES and DOTS found under PATTERNS on the SINGLE SLIT SET. These apertures have the shape of a square (4 sides), hexagon (6 sides) and circle respectively and are uniformly filled with dark dots. See Figure 11 for a magnified view of these apertures and the patterns.

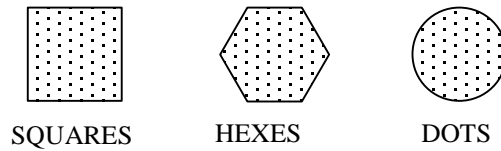


Figure 11 A magnified view of the patterns inside the various apertures.

5.3 With the laser beam switched ON rotate the SINGLE SLIT SET so that the beam passes through the aperture SQUARES. Carefully look at the diffraction pattern produced on the screen.

5.4 Replace the aperture SQUARES by HEXES and again observe the diffraction pattern produced on the screen.

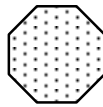


Figure 12 An octagonal aperture filled with dark dots

5.5 Now suppose an octagonal (8-sided polygon) aperture uniformly filled with dots is placed in front of the laser beam (the SINGLE SLIT SET does not have such an aperture)

Q 3 What diffraction pattern would the octagonal aperture produce on the screen? Sketch the diffraction pattern in the space below and give reasons.

5.6 Replace the aperture HEXES by the aperture DOTS. Observe that the diffraction pattern produced on the screen is made of alternating bright and dark circular bands.

Q 4 One can think of a circle as an N-sided polygon where N is a very very large number. This is because as the number of sides of a polygon increases the shape of the polygon starts resembling that of a circle. In the light of this fact and your answer to Q 2 explain why the

diffraction pattern produced by the aperture DOTS is made of alternating bright and dark circular bands.

Hint: First determine the diffraction pattern produced by an N -sided polygon. Then figure out what would happen to the diffraction pattern if the number of sides N becomes very large.

5.7 Show your response to the instructor. The instructor's initial go here: _____

6. Determine the diameter of your hair (if time permits)

Abstract: Investigating diffraction patterns obtained by passing a laser around an obstacle.

6.1 The method described in the previous activity can be used to measure diameter of a thin wire or a hair.

Cut a small piece of your own hair. Mount it on the optical bench using Scotch tape. The laser beam should pass through the straight segment of the hair. Ask the instructor for help if you need suggestions how to accomplish this.

6.2 Measure the diameter (width) of the hair from the diffraction pattern the same way as in the previous experiment. Show your work below:

Interference and Diffraction

When you are done...

6.1 Switch the laser OFF.

6.2 Quit LoggerPro if you haven't done so yet.

6.3 Hand in this handout with all questions answered along with the printouts from Activity 3.

Pre-Lab Questions

Print Your Name

Read the *Introduction* to this handout, and answer the following questions before you come to General Physics Lab. Write your answers directly on this page. When you enter the lab, tear off this page and hand it in.

1. What happens to a light wave when it encounters a barrier with a narrow opening?
2. Does an ordinary light bulb emit monochromatic light? Explain.
3. Sketch two coherent sources that are exactly out of phase.
4. Why is there a bright fringe at the center of the screen in a double-slit interference experiment? That is, why is there constructive interference at the center point?
5. A laser beam of wavelength 650×10^{-9} meter is incident on a double-slit with a slit separation of 0.125 mm. An interference pattern is produced on a screen a distance 1.5 m away from the slits. At what distances above the central maxima are the next two bright fringes observed? Show your calculation.

Interference and Diffraction

6. A laser beam of wavelength 650×10^{-9} meter is incident on a double-slit with a slit separation of 0.125 mm. An interference pattern is produced a distance 1.5 m away from the slits. What is the distance between adjacent dark fringes? Show your calculation.
7. A laser beam of wavelength 650×10^{-9} meter is incident on a single slit of width 0.16 mm. An diffraction pattern is produced a distance 1.5 m away from the slit. What is the width of the central maximum? That is, what is the distance between the dark fringes on either side of the central maximum. Show your calculation.

8. In the diagram to the right, Δy is the spacing between dark fringes. Explain why the total distance between the two dark fringes indicated by arrows is $4\Delta y$ instead of $3\Delta y$.

