Experiment
20
Diffraction

INTRODUCTION

As long ago as the 17^{th} century, there were two competing models to describe the nature of light. Isaac Newton believed that light was composed of particles, whereas Christopher Huygens viewed light as a series of waves. Because Newton was unable to observe the diffraction of light, he concluded that it could not be wave-like. Thomas Young's double-slit experiment in the early 19^{th} century provided convincing evidence that supported the wave model of light. This is the second of two experiments in which you will examine the related phenomena of diffraction and interference.

OBJECTIVES

In this experiment, you will

- Compare and contrast features of the patterns produced on a screen when light from a laser passes through either one or two slits.
- Discern which features of the pattern arise from the interaction of the light with the single slit and which arise from the double slits.
- Use the principle of superposition to explain how waves from two sources could interfere constructively or destructively.
- Use Huygen's Principle to construct a diagrammatic explanation of how path length differences for waves originating at different points in the slit give rise to the dark fringes in a diffraction pattern.
- From experimental parameters, predict the locations of dark fringes in the pattern.
- Collect intensity *vs.* position data to test your predictions.

MATERIALS

Vernier data-collection interface
Logger *Pro* or LabQuest App
Vernier Diffraction Apparatus
ruler
Vernier Optics Expansion Kit
Vernier Dynamics Track
Green Diffraction Laser (optional)

PRE-LAB INVESTIGATION

Direct exposure on the eye by a beam of laser light should always be avoided with any laser, no matter how low the power. If you performed Experiment 19, your instructor may have you skip the pre-lab investigation and Part 1 of this experiment.

1. Attach the laser at one end of the track so that it faces down the length of the track. Connect the power supply. Leave the laser off until all parts are in place to avoid accidental reflections.

2. Set the diffraction slit assembly to a single slit of width, $a = 0.08$ mm. Attach the assembly to the track, with the silver reflective side of the glass plates facing the laser. Position it about 10 cm from the laser assembly.

3. Attach the High Sensitivity Light Sensor and the Linear Position Sensor to the other end of the track, with the light sensor facing the slits.

4. Turn on the laser. Adjust the horizontal laser position to achieve maximum brightness of the pattern. Adjust the vertical laser position to center the pattern vertically on the entrance aperture of the light sensor. Use this procedure every time you change the slits.

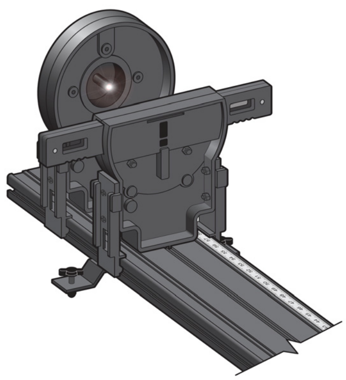

Figure 1 Laser and slit assembly

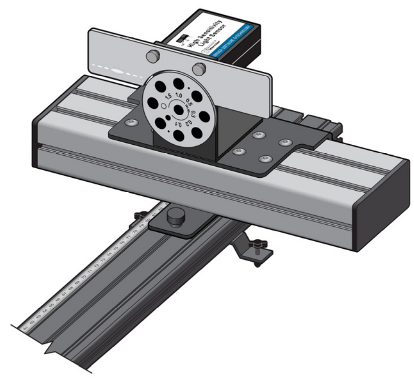

Figure 2 Light sensor assembly

5. Slide the light sensor assembly so that the pattern from the beam falls on the screen to one side or the other of the aperture disk (see Figure 2). Observe features of the pattern and record your observations in your lab notebook.

6. Now, set the slit assembly to a double slit in which the slit width, a = 0.08 mm and the slit separation, d = 0.25 mm. Align the laser as you did in Step 4.

7. View the pattern that forms as the laser beam passes through the double slit. Record your observations in your lab notebook, then turn off the laser.

Discuss what features the patterns have in common and the ways they appear to differ. You may find it helpful to repeat your observations of the single slit and double slit patterns.

Study the similar behavior of water waves using a simulation that can be found at the PhET web site: http://phet.colorado.edu/en/simulation/wave-interference. The simulation allows you to examine the patterns resulting when water waves from a dripping faucet pass through one or two slits in a barrier.

PART 1 SINGLE AND DOUBLE SLIT PATTERNS–A CLOSER LOOK

PROCEDURE

1. Return to the diffraction apparatus. Examine the pattern obtained when the laser shines through the single slit with a = 0.08 mm. Using a ruler, measure the distance between the midpoint of the central bright region and the midpoint of the first dark fringe. Repeat this measurement for the second dark fringe. Then, measure the width of the central bright region from dark fringe center to dark fringe center.

2. Now, take a closer look at the pattern obtained when the laser shines on the double slit used in the Pre-Lab Investigation (a = 0.08 mm, d = 0.25 mm). Using a ruler, measure the distance

between the middle of the central bright region and the location where the alternating bright and dark fringes seem to disappear. Then, measure the width of the central bright region.

EVALUATION OF DATA

1. Compare your measurements for the single- and double-slit patterns. What feature of the pattern appears to arise from the single slit? What feature appears to arise from the double slit? Compare your findings with those of other groups.
2. Consider what feature of the single-slit pattern would change if you changed the slit width. Test your prediction.
3. Consider what feature of the double-slit pattern would change if you used the same slit width but changed the separation between the slits. Test your prediction.

PART 2 DIFFRACTION AND THE SINGLE SLIT PATTERN

In a typical discussion of how waves from multiple slits produce an interference pattern, the slits are treated as point sources of light. To understand how light passing through a *single* slit can undergo interference, review text or web resources regarding Huygens' principle as it relates to diffraction. Imagine that each point along the wave front in a slit acts as if it were a separate source of "wavelets" that can interfere with one another (see Figure 3).

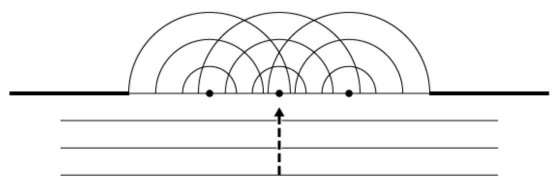

Figure 3 Huygens' principle

To understand why dark fringes occur in the pattern, consider how the path length difference of waves from two sources within the slit can result in destructive interference when the waves reach the screen. The small angle approximation allows you to substitute y/D for $\sin\theta$ in your calculation of the distance between the middle of the central bright region and the dark fringes to either side (see Figure 4).

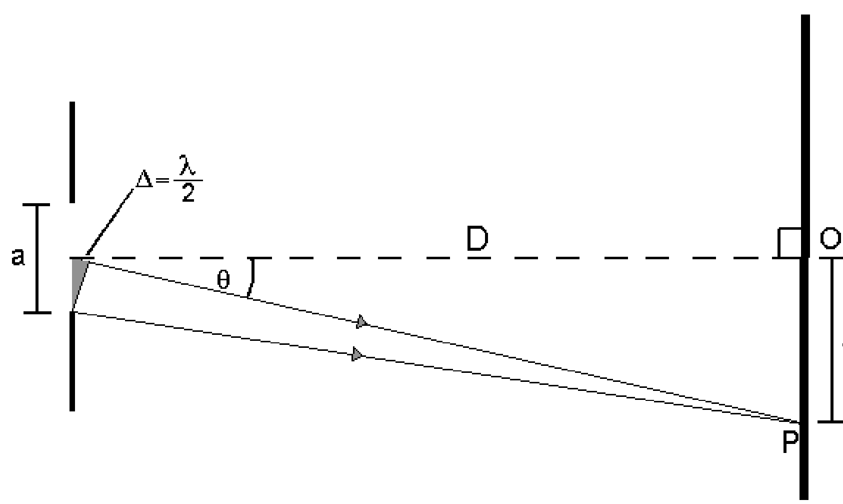

Figure 4 Diffraction geometry

PROCEDURE

1. Connect the High Sensitivity Light Sensor and the Linear Position Sensor to the interface and start the data-collection program.

2. Choose the same single slit (a = 0.08 mm) that you used in Part 1. Adjust the alignment of the laser on the slit as you did in the Pre-Lab Investigation.

3. Record the distance, D, from the slit assembly to the light sensor. Record the slit width, a, and the wavelength, λ, of the laser.

4. The optimal combination of light sensor sensitivity and sensor aperture depends on the type of laser and the slit configuration. It allows an intensity reading that reveals the detail necessary for you to make your measurements. For the red laser and a slit width of 0.08 mm, we suggest setting the sensitivity to 1 μW and using an aperture of 0.5 mm.

5. Move the sensor assembly all the way to the right as viewed from the laser. Zero both sensors.

6. Start data collection, and then move the sensor assembly stage toward the other side of the rail on which it is mounted. Take at least 20 seconds to execute the motion, slowing when the sensor is traversing the brightest portions of the pattern. Stop collecting data when the stage reaches the end stop. Test that you moved the stage sufficiently smoothly by storing the run and collecting another run, moving the stage in the opposite direction.[1] The trace of the second run should overlay that of the first.

7. Repeat Steps 6 and 7 with a different slit width. You may find it necessary to change the aperture to obtain sufficient detail to complete your evaluation of data. When you are finished collecting data, save your experiment file and turn off the laser.

EVALUATION OF DATA

1. From the values of D, a and λ, calculate the theoretical distance y_n, from the central maximum to the middle of each of the first three dark fringes to either side for the first slit you used.

2. Zoom in on the portion of the graph that shows the most useful information. Choose the Examine tool from the Analysis menu and move the cursor to your best estimate of the position of the peak corresponding to the central maximum. Due to reflection off the front surface of the glass in the slit assembly, the intensity may dip sharply at this point (see Figure 5). Record this position in your lab notebook.

[1] If you are using LabPro, do not move the stage between runs or the second run will be shifted horizontally.

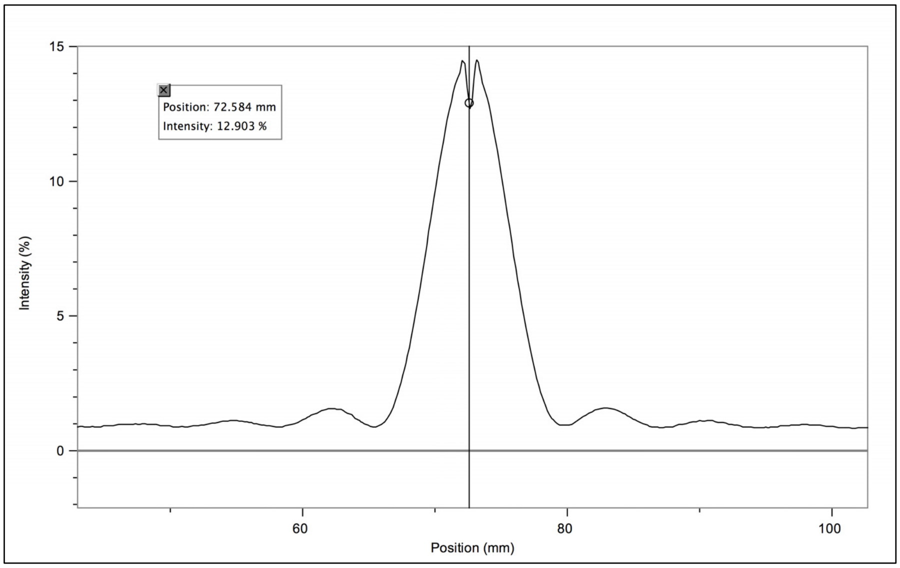

Figure 5 Drop in intensity at central maximum

3. Determine the locations of the middle of the first three dark fringes to either side of the peak. To do so, position the cursor where you think the intensity has reached a minimum value, then use the arrow keys on the keyboard (in Logger *Pro*) or on LabQuest (in LabQuest App) to move the cursor to either side and note how the intensity changes. Record the locations of the minima in your notebook.

4. Determine the distance, y_n, from the central maximum to the middle of the first three dark fringes on either side. If the distances are not the same on either side, decide how to report the best value for y_n.

5. Determine the percent difference between the theoretical and experimental values of these distances.

6. Now measure the peak intensity of the central maximum and first two bright fringes to either side. If the baseline of your intensity *vs*. position graph is not zero, create a new calculated column that adjusts the intensities. Because of the abrupt drop in intensity at the peak, you will have to estimate its value. Record the intensity values in your notebook.

7. The theoretical intensities of the bright fringe to either side of the central maximum are given by $I_1 = 0.045\,I_0$ and $I_2 = 0.016\,I_0$. How do your experimental values compare?

8. Predict how the distances of the dark fringes from the central maximum for the second slit width you used will compare to those of the first, then repeat Steps 1–6.

EXTENSION

1. How does the distance from the central maximum to the first dark fringe vary with slit width? If the slit were ten times wider, what would you expect to see on the screen? What model of light would best explain your observations?

2. Suppose you shone a green laser (λ = 532 nm) on the single slit you used in your first trial. What effect would this have on the distance from the central maximum to the dark fringes? Use a geometric rather than an algebraic explanation for your answer.

3. Suppose you were able to narrow the slit width to the point that it was less than the wavelength of the light you shone on it. Would you see dark fringes in the pattern on the screen? Explain.