Experiment 112-6

Diffraction and Interference

Introduction

Single Slit Diffraction: When light passes through a narrow slit, a diffraction pattern consisting of a series of dark and light bands, or fringes, is observed. As you can see in Figure 6.1, the pattern is most intense at the central maximum. The condition for the n^{th} *minimum of intensity due to diffraction* is given by the equation

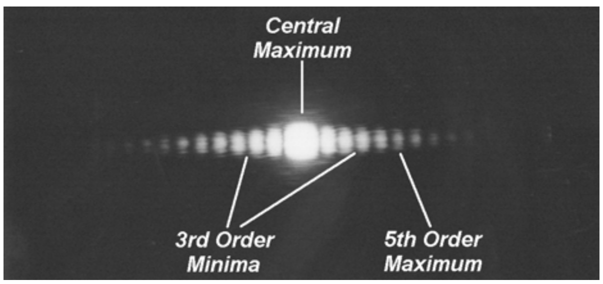

Figure 6.1 Single Slit Diffraction Pattern

$$n\lambda = w\sin\theta\,, \qquad (6.1)$$

where θ is the angular displacement of the minimum from the location of the central maximum, w is the width of the slit, and λ is the wavelength of the incident light. The integer n denotes the *order* of the minimum; that is, $n = 1$ denotes the first order, $n = 2$ the second order, and so on. Note also that the bright fringes, or maxima, occur midway between the minima. Their intensity is considerably less than that of the central maximum.

Double Slit Diffraction and Interference: When light passes through two narrow slits separated by a distance d, a combined diffraction and interference pattern like the one illustrated in Figure 6.2 is usually observed. The locations of the more widely separated diffraction minima are determined by the width of the slits, and are given by equation (6.1). The condition for the m^{th} *maximum due to interference* is given by the equation

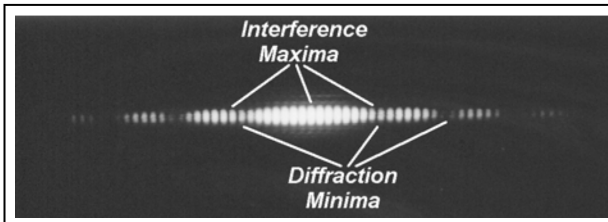

Figure 6.2 Double Slit Diffraction & Interference Pattern

$$m\lambda = d\sin\theta\,, \qquad (6.2)$$

where θ is the angular displacement of the maximum from the location of the central maximum, d is the center-to-center separation of the slits, and m is the *order* of the maximum. Dark fringes, or minima, occur midway between the maxima.

Combined diffraction and interference patterns like the one illustrated in Figure 6.2 are only observable for reasonable combinations of slit width and slit separation. If the slits are too narrow the diffraction minima will be so widely separated as to be unobservable. On the other hand, if the slit separation is too wide, the interference maxima will be so closely packed as to be indistinguishable.

Circular Diffraction: When light passes through a circular aperture, a diffraction pattern like the one illustrated in Figure 6.3 is observed. The location of a maximum or a minimum of intensity is given by

$$k\lambda = a\sin\theta , \qquad (6.3)$$

where a is the diameter of the aperture and the value of k depends upon which dark or light ring is observed. Values of k for the first five dark and the first five bright rings are given in the table below. As an example, the criterion for the formation of the third dark ring is given by $3.24\lambda = a\sin\theta$.

Ring number	k (dark rings)	k (bright rings)
1	1.22	1.64
2	2.23	2.69
3	3.24	3.72
4	4.24	4.72
5	5.24	5.72

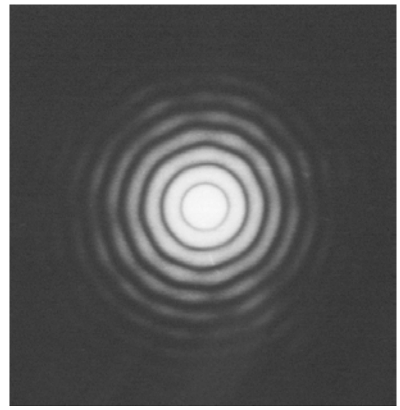

Figure 6.3 Circular Diffraction

Purpose

The purpose of the experiment is to use diffraction and interference patterns to determine (1) the width of a single slit, (2a) the width of the individual slits making up a double slit, (2b) the distance between the two slits, and (3) the diameter of a circular pinhole.

IMPORTANT SAFETY NOTES!

Although the lasers used in this laboratory are of low power, they still produce a very intense beam and must be treated with respect. The beam is not of sufficient intensity to cause skin burns but it can cause serious eye damage. ***Protection from possible eye damage is the responsibility of each and every student in the laboratory.*** The following guidelines should be applied.

(a) NEVER LOOK DIRECTLY INTO THE LASER BEAM!
(b) Do not pick up or otherwise make large adjustments in the position of the laser while it is turned on.
(c) Do not allow the beam to cross an aisle where people may be walking or to cross from one side of the bench to the other where someone may be seated.
(d) Watch for beams reflecting off glass or other shiny surfaces. They can be as dangerous as the main beam.
(e) The lasers are normally be placed on the laboratory benches at approximately eye level for any persons seated in the chairs. Because of this, be careful that your laser does not shine across the bench to the other side. Also, be sure to place the large wooden box across the bench at its midpoint so that the beam cannot travel the entire length of the bench.

PROCEDURE

1. Single Slit Diffraction

The laser should be mounted on a rod and lab stand assembly and placed at the end of the lab bench. Mount the slide on a laboratory stand using a stem-mounted spring clip holder and a right angle clamp to hold and position it about a centimetre in front of the laser.

Tape a 40 cm strip of paper tape horizontally at the same height as the laser to the wooden screen placed about half way down the lab bench. Measure the distance D between the slit and the screen.

Qualitatively observe the effect of slit width on the diffraction pattern displayed on the screen by shining the laser through each of the slits.

Shine the laser through the second narrowest of the single slits and adjust its position of to optimize the diffraction pattern both for symmetry and intensity of illumination. Mark the location of the central maximum (CM) and of every diffraction maximum observable on both sides out to $n = 20$.

Remove the paper tape from the screen. Label the CM and number the diffraction minima. Measure the distance s_n between six pairs (same value of n) of diffraction minima on opposite sides of the CM.

Record your data in a table similar to the one below and calculate the average value of the slit width as well as the standard error in the mean.

n	$s_n \left(\times 10^{-3}\text{ m}\right)$	θ_n (rad)	$w_n \left(\times 10^{-3}\text{ m}\right)$
3			
6			
9			
12			
15			
18			

Calculate the angle that each of the minima make with respect to the central maximum from $\theta_n = s_n/2D$. This is an excellent approximation for $\sin\theta$ at the small angles found here. Use Equation (6.1) to calculate the width of the slit for each n, then do a statistical analysis to get the mean and standard error estimate. The manufacturer lists the wavelength of the laser light as 632.8 nm.

Make a sandwich of the diffusing screen and the slide with the slits. Illuminate the slide from the diffusing screen side and use the measuring microscope to check the width of the slit. Compare the directly measured value to the one derived from the diffraction pattern.

How does the error introduced by the small angle approximation compare to the standard error in the mean? How would the observed diffraction pattern have changed (a) if a wider (or a narrower) slit had been used or (b) if light of a larger (or smaller) wavelength had been used?

2. Double Slit Diffraction and Interference

The apparatus should be set up the same way as it was for the diffraction pattern. In this case, however, shine the laser through the middle pair of slits on the glass slide. (The double slits are on one side of the slide; the single slits are on the other.) Measure the distance from the central maximum to several of the diffraction minima on each side of the central maximum. These widely spaced minima will be more than a centimetre apart.

Next, measure the distance from the central maximum to several of the maxima due to interference on either side of the central maximum. These closely spaced maxima should be less than half centimetre apart.

Use the data from the minima due to diffraction in Equation (6.1) to calculate the width of the slits. Find the average value along with the standard error in the mean.

Use the data from the maxima due to interference in Equation (6.2) to calculate the (center to center) separation between the slits. Find the average value along with the standard error in the mean. Tabulate the data in two separate tables similar to the one in Part 1.

Use a measuring microscope to measure the slits' widths and their center-to-center separation. (Measure the distance from left edge to left edge and from right edge to right edge. The average of these distances is equal to the centre-to-centre separation.) Compare these measured values to those you found from the diffraction and interference patterns. Which values are the more accurate? Explain.

How would the interference pattern have changed (a) if a more widely (or a more narrowly) spaced double slit had been used or (b) if light of a larger (or smaller) wavelength had been used?

3. Pinhole Diffraction

Set up the apparatus in the same way as you did in Part 1 using a pinhole instead of the slit. Mount the pinhole using the large spring clip from the apparatus drawer. Slide the 'double finger' of the three-pronged burette clamp into the end of the clip and use it to mount the pinhole on the lab stand. The adjustment screw on the burette clamp should enable you to position the pinhole precisely to obtain a good diffraction pattern.

Use the 'telescope' to measure the distance from the center of the pattern to as many of the maxima and minima that your can see on each side of the central maximum.

Use these data in Equation (6.3) to calculate the diameter of the pinhole. Find the average value along with the standard error in the mean. Compare the value you found for the pinhole aperture with the value marked on the pinhole mount. Does your result agree with this value within experimental error?

How would the diffraction pattern have changed (a) if a pinhole of larger (or smaller) aperture had been used or (b) if light of a larger (or smaller) wavelength had been used?