Interference and Diffraction: Patterns from Slits

In this laboratory we will study the interference and diffraction patterns that occur with two or more slits. This study is complicated by the fact that the interference effects and the diffraction effects are super-imposed on the same intensity pattern. Part of the purpose of the laboratory is to help you make careful distinction between these two effects and to learn to recognize their features. The double slit experiment was very important in the development of the wave theory of light because it gave the first technique for determining the wavelength of light. In this lab you will also determine the wavelength of a Helium-Neon Laser.

First consider a double slit with slit separation d and slit width D. The interference pattern caused by waves which have traveled through different slits causes *bright* fringes to appear on the screen at angles given by

$$d \sin\theta = m\lambda \qquad m = 0, 1, 2, 3, \ldots \tag{1}$$

where m is the order number of the bright fringe, and θ is the angle between the central axis and the interference maximum.

Super-imposed on this pattern is the diffraction pattern which can be thought of as interference among waves that have traveled through different parts of a single slit. The diffraction pattern from each slit is identical, and they overlap exactly to a very good approximation. In this case, the angular position of the dark fringes is given by

$$D \sin\theta = m\lambda \qquad m = 1, 2, 3, \ldots \tag{2}$$

where m is the order number of the dark fringe, and θ is the angle between the central axis and the diffraction minima. Note that there is no zero order dark fringe.

An example of such an interference/diffraction pattern for double slits is shown in Figure A. The corresponding diffraction and 'pure' interference patterns are shown in Figures B and C, respectively. Note that the pattern in Figure A is a product of the intensity patterns shown in Figures B and C. It turns out that the number of interference fringes within the central diffraction peak depends on the ratio d/D. In using the laser be careful not to shine the laser in your own eye, or the eyes of any of your classmates. Although these lasers are not powerful enough to damage your eyes, it is an unpleasant experience to look directly into one. Be especially careful of stray reflections.

Figure A

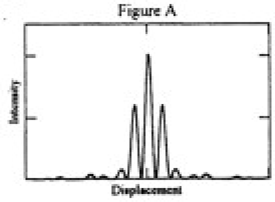


Figure B

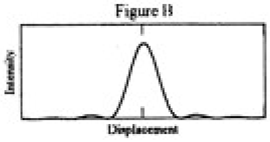
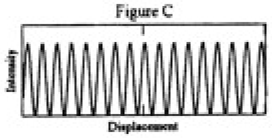
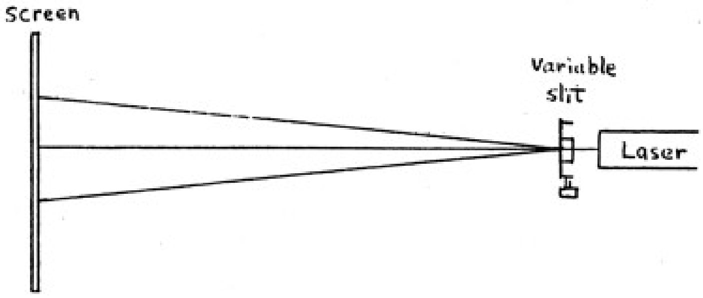


Figure C



PROCEDURE

1. First we will view the diffraction pattern from a single variable slit.
   (a) Set up the laser on the optical bench so that the light travels through the single variable slit hits the screen as shown below. Rotate the slit so that it is in the vertical direction.



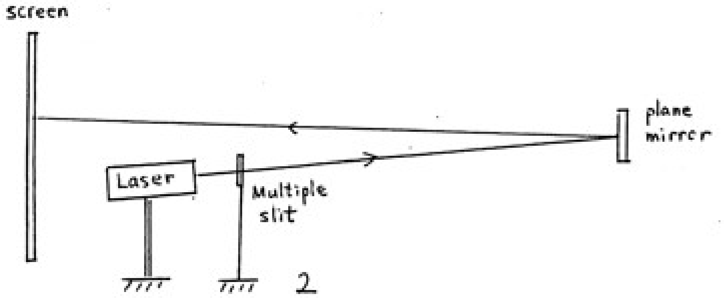
   (b) *Gradually* open and close the slit several times, being careful that the laser light travels through the center of the slit at all times. As you make the slit narrower, you may need to reposition the slit to maximize the transmitted light. Note carefully how the pattern changes as the slit goes from wide open to very narrow but not quite closed.

   (c) Answer the following two questions for part (1) in your lab notebook;

      i. How does the diffraction pattern you see change as the slit width increases?

      ii. How does the width of the central maximum compare with the other higher order maxima?

2. Now replace the single variable slit by the multiple slit. Reposition the laser and add the plane mirror (horizontally) so that after going through the slide the laser light reflects off the mirror and on to the screen as shown below. This set-up will allow the interference/diffraction pattern to expand more before hitting the screen, making the measurements more accurate. We first concentrate on the interference pattern.



   (a) Position the slide so that the laser light goes through the double slit and adjust for maximum transmission and clarity.

   (b) The most obvious features of this pattern are the equally spaced bright and dark interference fringes. If you look closely, you will see that these interference fringes vary in intensity because there is a diffraction pattern superimposed on the interference pattern. There may even be some missing bright fringes for the interference pattern if they happen to fall on the diffraction minima.

   (c) Study this pattern carefully with your lab partners and discuss the various features. Make sure that you can distinguish between the two patterns, and point out the location of any missing fringes.

   (d) Locate the central interference bright fringe ($m = 0$) and locate two corresponding bright fringes on either side of the central maximum which are as far out as you can see clearly (the farther out they are, the more accurate your measurements will be). By counting outward from the center, determine the order number of these fringes. Be sure to take into account any missing fringes. Record this number.

   (e) Measure the distance from the center of the central maximum, to the center of each of the maxima located in part (d). One way to do this is to lightly mark the positions of the maxima with a pencil, then place the screen flat on the table to measure the distances. Average these two numbers and use the fact that

$$\tan\theta = y_m/L$$

   where L is the distance that the laser travels from the double slit to the screen, to find θ for these fringes. Record all these measurements.

   (f) Using the value of d marked on your slide and the value of θ just determined, calculate the wavelength of the laser in nanometers with equation (1). Note that there are 10^{-9} m/nm.

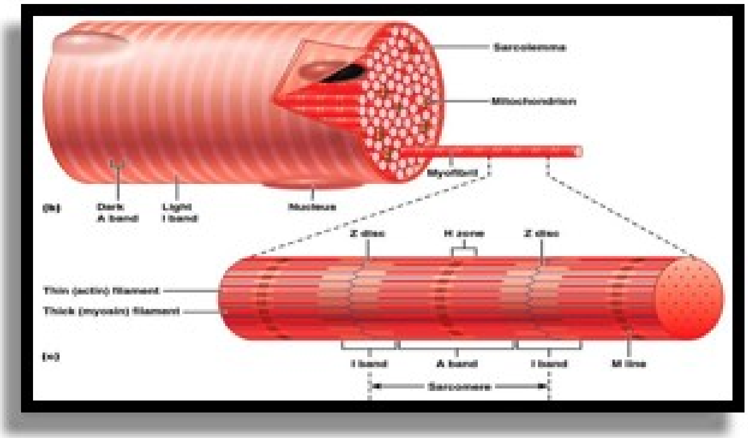
3. We now concentrate on the diffraction pattern.

   (a) Locate the positions of two corresponding diffraction minima. Choose minima that are as far from the central maximum as possible. By counting outward from the center, determine the order number of these dark fringes. Record this number.

(b) Measure the distance from the center of the central maximum, to the center of each of the two minima located in part (a). Average these two numbers and determine θ as in part (2). Record all these measurements.

(c) Using the value of D marked on your slide and the value of θ just determined, calculate the wavelength of the laser in nanometers with equation (1). Note that there are 10^{-9} m/nm. Average your results from parts (2) and (3) and compare to the known value of 632.8 nm.

4. We now will probe the structure of a biological system optically. We can do this by directing the laser beam onto a sample and observe the diffraction pattern on the screen. The sample we will use is muscle fiber from a rabbit. This fiber is a cylindrical structure which may be many centimeters long and approximately 100 microns in diameter. When suitably illuminated, it is seen to have regular striations that extend across the fibers, dividing them in sarcomere, which are stacked one atop the other. Within the fiber are many cylindrical subunits, the fibrils. These fibrils are further divided into segments by thin partitions called Z-lines or Z-discs. These run from fibril to fibril across the fiber thus dividing it into sacromeres. In our experiment, the dark Z-discs will act as parallel lines in a diffraction grating. The grating spacing is then the same length as the sarcomere length.



(a) Locate the positions of two corresponding interference maxima of order number 1, 2, or 3.

(b) Measure the distance from the center of the central maximum, to the center of each of the two maxima located in part (a). Average these two numbers and determine θ as in part (2). Record all these measurements.

(c) Using the value of λ determined above and the value of θ just determined, calculate the sarcomere length (d) with equation (1).