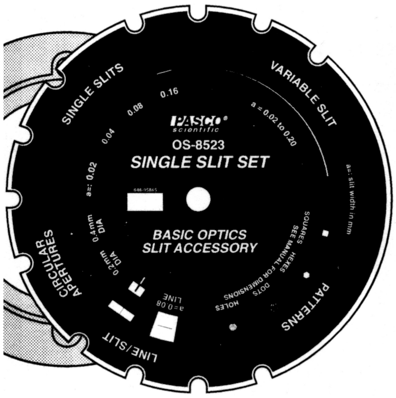
DIFFRACTION AND INTERFERENCE

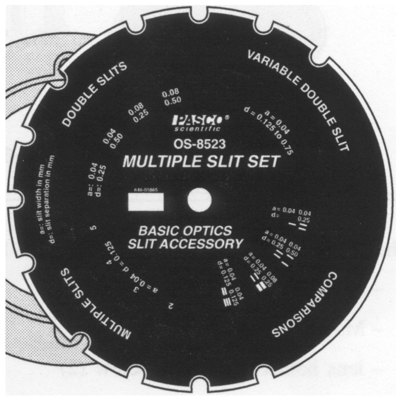
In this experiment you will demonstrate the wave nature of light by investigating how light bends around edges and how it interferes constructively and destructively. You will observe these effects in a variety of situations and use the wave theory of light to measure wavelength.

APPARATUS

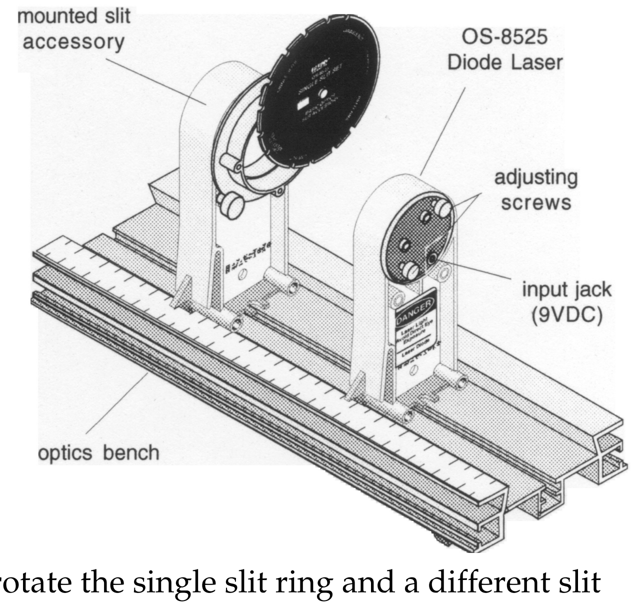
- ❑ Optical rail with cm marks
- ❑ Screen and paper at end of optical rail
- ❑ Multiple Slit pattern
- ❑ Single Slit pattern
- ❑ Laser diode source with vertical and horizontal positioning

PROCEDURE





1. Position the laser at one end of the optical rail. Place the Single slit set 5 – 10 cm in front of the laser with the text facing the laser. Squeezing the base of the holders and sliding them along or angling them allows for motion and changing of the slit disks and laser. Rotate the slit to one of the single slits so the single slit is in position to be hit by the laser.



2. Optimize the position of the laser by slowly rotating the horizontal and vertical adjustment screws on the back of the laser. When you have the laser aligned so the beam hits the single slit, optimize the alignment by looking at the pattern formed on the screen. Find the alignment with the brightest, most centrally located pattern.
3. To go to a new slit or pattern simply rotate the single slit ring and a different slit should click into the correct position. You may need to make small adjustments for the different slits and patterns.

SINGLE SLIT DIFFRACTION

1. Select the single 0.04 mm slit by rotating the single slit disk until the 0.04 mm slit is centered in the holder. Adjust the position of the beam and optimize the pattern on the screen.

2. Draw a picture of the pattern on the screen. How are you going to display the intensity of the light? (Graph, drawing, etc.)

3. Rotate the slit apparatus to the 0.02 mm slit and the 0.08 mm slit and draw those patterns.

4. Describe in clear sentences the changes in the patterns as a function of the width of the slit. Be specific.

5. In the table below, record the position of the dark regions (called orders) for the 0.04 mm and 0.08 mm single slits as measured from the central maximum. Also record the distance from the slit to the screen.

    a. Slit to Screen distance ______________________ (cm)

Slit Width (mm)	Distance from center to first order (m=1)	Distance from center to second order (m=2)
0.04		
0.08		

SINGLE SLIT DIFFRACTION -- THEORY

If light is made of particles, a beam of such particles should pass straight through a long, narrow slit and form a single spot on a screen placed beyond the slit. If it is wavelike in nature, a more complex pattern results. Light waves reaching a given point on the screen arrive from different parts of the slit. Their amplitudes add, and an interference pattern results. Consider pairs of points separated by a distance of half the slit width, such as (A,B) or (C,D) in Figure 1 below. There exists a location on the screen for which waves coming from point C are exactly half a wavelength out of phase with waves from point D. At this point on the screen the waves cancel, so no light is observed there.

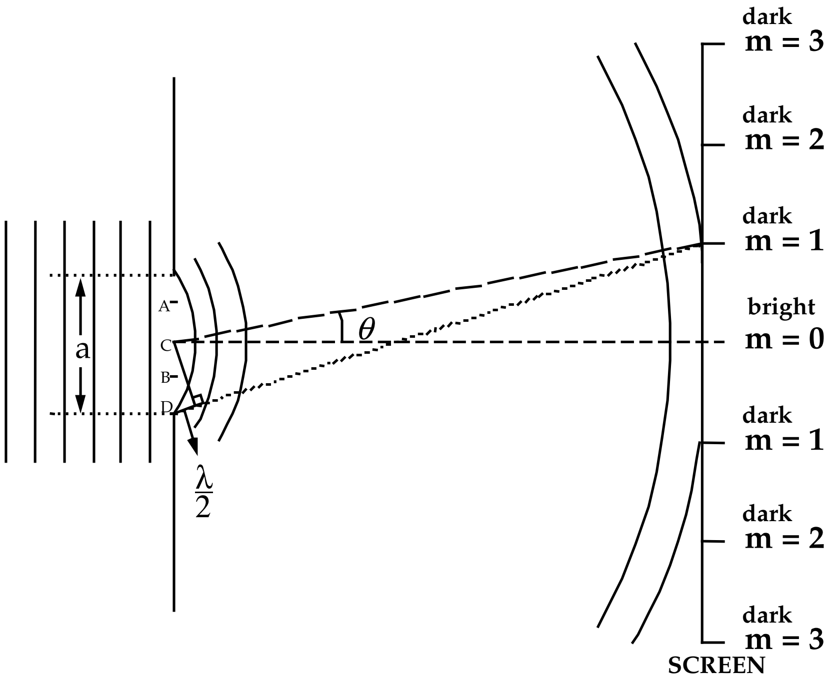


Figure 1

The situation shown (m = 1) in Figure 1 is for the first destructive minimum and occurs at two positions with angles $\sin\,\theta = \lambda / a$.

Additional *minima* occur at $\sin\ \theta = m\ \lambda / \ a$. The m = 1 minimum is the most important one. For small θ, the angle in radians is $\theta = \lambda / a$. The angle is also the ratio of the distance from the central maximum to the first minimum divided by the distance between the slit and the screen.

6. Use the two facts above to determine a formula relating L (the distance to the screen), y_1 (the distance from the central maxima to the first order minima), the slit width a and the wavelength λ:

   a. Formula: ________________________ (1)

7. Now determine the wavelength of light from the laser by applying the above formula to the data you have obtained.

   b. Wavelength of laser ______________________________

Note that the angle at which the first minimum occurs in the diffraction pattern is important because it is the limit of the angular resolution of any optical system. For a circular lens, the minimum angle between two points of light that can be resolved is θ = 1.22 λ/a, where the 1.22 factor depends on the shape of the lens and a is the diameter of the lens.

Finally, take the single slit disk into the hall by squeezing the base of the holder and lifting it off the rail. Look at the light in the hall through one of the single slits. What do you see? Now, put the slits back and take your index finger and thumb and close them just ever so slightly and look through the tiny gap at the light. Try to bounce them just off each other and see if you can see diffraction through your own fingers!!

DOUBLE SLIT INTERFERENCE:

8. Replace the single slit disk with the double slit disk. Select the double slit with 0.04 mm slit width and 0.25 mm slit separation. Adjust the position of the laser beam to optimize the pattern. Draw a picture or graph of the pattern.

9. Change to a new double slit with the same width (0.04 mm) but a different separation (0.50 mm). Make a sketch of this new pattern.

10. Change to a third double slit, one with a different width (0.08 mm) but the original separation. Make a sketch showing this pattern.

11. Describe the differences and similarities in the patterns. What part of the pattern is associated with the slit width? What part of the pattern is associated with the separation between the slits? To help answer these questions observe the pattern obtained with the variable slit, which allows you to continuously vary the separation without changing the width.

DOUBLE SLIT -- THEORY

Waves passing through each of two long, narrow slits will diffract as you have investigated above, but the waves from the two slits will also interfere with one another. Figure 2 below shows the geometry in which the path lengths between the point on the screen and each slit differ by an integral number of wavelengths. This causes constructive interference, with intensity maxima located at angles given by the equation

$$\sin\theta = \frac{m\lambda}{d}, \; m = 0, 1, 2, 3, .. \qquad (2)$$

The slits are separated by a distance d. If the distance mS (distance of maxima from $m = 0$) to the mth maximum is much smaller than the slit to screen distance L, one can also approximate: $\sin\theta = \theta = mS/L$. In this case, the maxima are equally spaced.

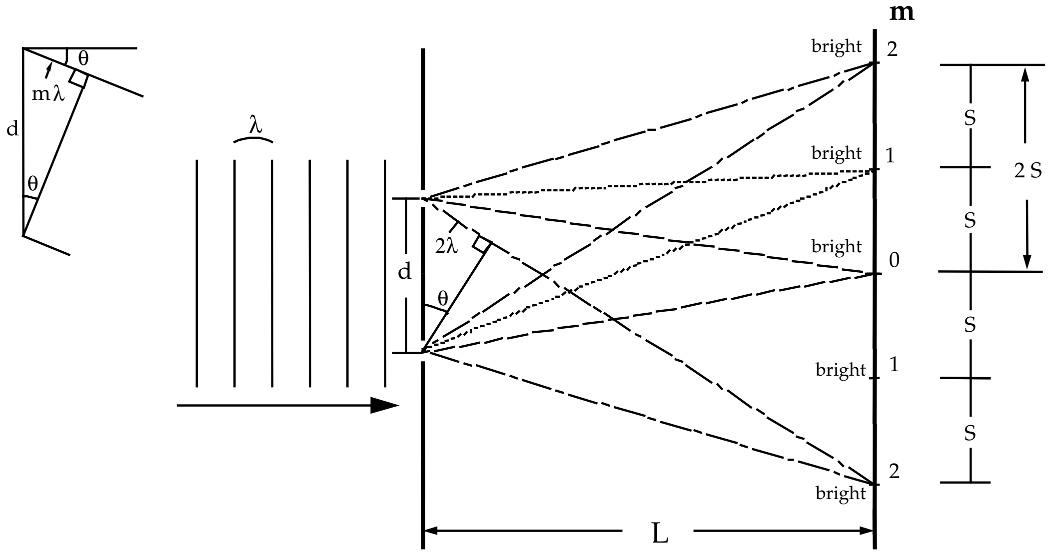


Figure 2

When the distance or path length between the spot and each slit differ by a half integral number of wavelengths the interference is completely destructive (intensity *minima*) where

$$\sin\theta = \frac{(m+\frac{1}{2})\lambda}{d}, \; m = 0, 1, 2, 3, .. \tag{3}$$

The diffraction pattern that is actually observed from the double slit is the theoretical double slit maximum pattern shown in Figure 3 -- from Equations (2) and (3) -- modulated by the single slit minimum pattern -- from Equation (1) -- shown in Figure 4. The result is shown in Figure 5. Note that some of the double-slit maxima have nearly zero intensity as they coincide with single slit minima, as shown in Figure 4. These are termed *missing orders*.

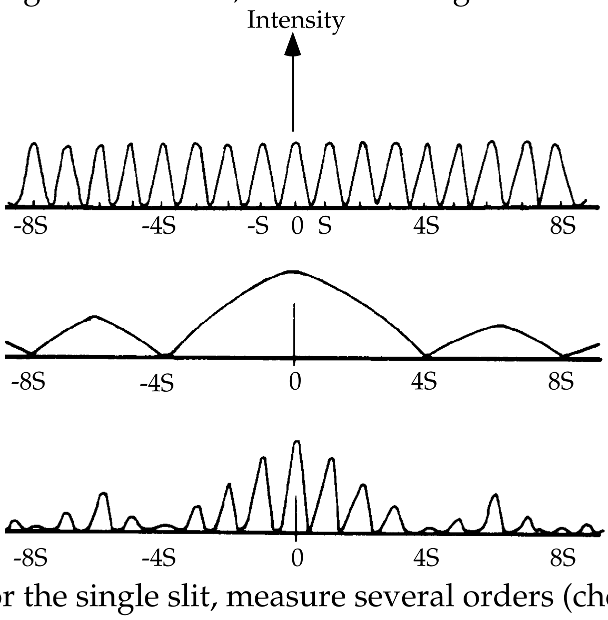


Figure 3

Figure 4

Figure 5

12. As you did for the single slit, measure several orders (choose the minima or maxima) of positions of a given double slit, and calculate the wavelength of the

light. How can you improve the accuracy of your measurement? Can you take more data from a single image and average it? Try that out:

a. Laser wavelength: ________________________________

MORE QUESTIONS

13. Look for missing orders in the double slit pattern. Use equations (1) and (2) to show that missing orders occur when d / a = 2, 3, 4... Do the missing orders (for double slits) occur where they are predicted to by theory?

14. In the experiments, the slits are long and narrow. Why is the diffraction pattern one dimensional? What happens to the pattern in the long dimension? What would you observe for a small square slit? A round pinhole? Explore with different transmission objects on the slit wheels provided. Choose 4 *different* transmission objects, draw them, and under each provide an explanation of the origin of the pattern.