

## Physics 197 Lab 8: Diffraction

### Equipment:

Item	Part #	Qty per Team	# of Teams	Total Qty Needed	Storage Location	Qty Set Out	Qty Put Back
CD and DVD set		1 set	8	8 set			
Protractor		1	8	8			
Single Slit Accessory	PASCO OS-8453	1	8	8			
Optics Bench	PASCO OS-8518	1	8	8			
Red Diode Laser and Power Cord	PASCO OS-8525A	1	8	8			
Green Nd:YAG Laser and Power Cord	PASCO OS-8458	1	8	8			
Screen	PASCO OS-8480	1	8	8			
Multiple Slit Accessory	PASCO OS-8453	1	8	8			
Meter Stick		1	8	8			

### Layouts:

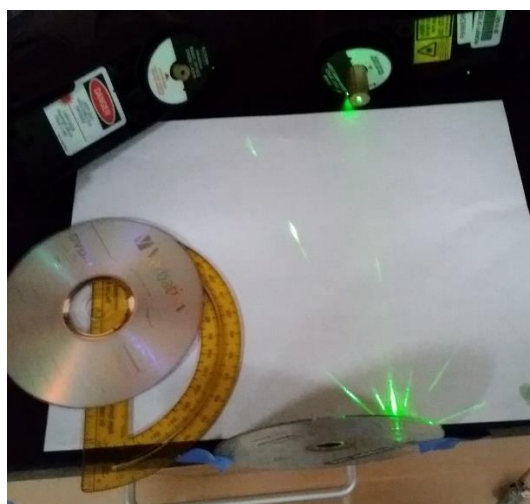


Figure 1, Experiment A, CD Diffraction



Figure 2, Experiment B, Green Laser, Multiple Slits



Figure 3, Experiment C Red Laser Single Slit



Figure 4, Interference and Diffraction 5 Slits



Figure 5, Diffraction, Single Slit



Figure 6, Diffraction Round Aperture, 0.4 mm

### Summary:

In this lab, students will investigate diffraction and interference of laser light from the grooves in a CD and DVD (acting like a diffraction grating), along with diffraction patterns of rectangular slits and circular apertures. For the CD experiment, a laser impinging on a CD will have the light diffract into multiple orders (figure 1), and students will measure the angles to determine the groove spacing in the CD. Students will then use a red and green laser to investigate and quantify diffraction patterns from slits and circular apertures, both at a screen near the apertures and on the wall across the room.

### PreLab:

The formula for the diffraction intensity from a single slit is:

$$I = I_0 \left\{ \frac{\sin \left[ \frac{\pi a (\sin \theta)}{\lambda} \right]}{\frac{\pi a (\sin \theta)}{\lambda}} \right\}^2$$

where  $a$  is the slit width,  $\theta$  is the angle off axis,  $\lambda$  is the wavelength and  $I_0$  is the peak on-axis intensity.

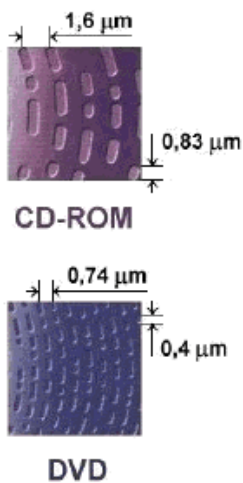
Show that the zeroes in this formula will be evenly spaced in  $\sin(\theta)$ , occurring where  $\sin(\theta) = m\lambda/a$ , with  $m = +/-1, +/-2, \dots$  but not 0.

If you make the substitution  $x = \pi a \sin(\theta)/\lambda$ , you can see that the equation simplifies to

$$I = I_0 \left\{ \frac{\sin(x)}{x} \right\}^2$$

Carefully Plot  $I/I_0$  as a function of  $x$  from  $x=0$  (where it is equal to 1) out to the second 0 where  $\sin(\theta) = 2\lambda/a$  (that is at  $x=2\pi$ ) using at least 10 evenly spaced points. You can do this by hand or using a spreadsheet or other program. This should give a sense of the height of the first bright fringe relative to the central bright fringe.

### Experiment A: CD Diffraction



A Compact Disk (CD) and a DVD store information in tiny pits arranged in circular groove patterns. When light from a laser hits these grooves it is diffracted into different orders just like in a diffraction grating. If you arrange a laser and a CD as in figure 1, so that the laser beam hits the CD side on in a region where the grooves are vertical, you should be able to see the different diffraction orders. (Center the hole in the CD at the level of the table top). Use the green laser and then the red laser to observe this pattern on a piece of paper. (The CD can be taped to the edge of the table using the blue tape, and the laser can be set on its side so it is close to the table, and aimed downwards so it just hits the CD at the level of the table). Trace the positions of the different orders, and measure the diffraction angles with a protractor. Using the formula  $d \sin(\theta) = m\lambda$  and the wavelengths printed on the lasers, calculate the spacing  $d$ . Compare the value you get with the red and green laser, and compare that to the value in the diagram to the left. Then repeat the experiment using the green laser with the DVD. (You do not need to use the red laser with the DVD). In order to improve the statistics of your data, please use multiple diffraction orders if you can see them to get an average diffraction angle for each combination of laser and CD or DVD that you test.

### Experiment B: Diffraction and Interference from Multiple Slits.

Using the green laser and the Multiple Slit Accessory set up on a rail with a screen (Figure 2), observe and record (with sketches and descriptions) what happens as you shine the laser through 2, 3, 4 and 5 slits with the same spacing. What changes? What doesn't change? Explain your results.

### Experiment C: Diffraction from a Single Slit (Red laser on screen)

(The following write-up is partially taken from the manual for the PASCO OS-8523 Slit Accessory.)

(\*\*\* Note: In the following pasted section, equations say “y” where they should really say “y” \*\*\*)

## Purpose

The purpose of this experiment is to examine the diffraction pattern formed by laser light passing through a single slit and verify that the positions of the minima in the diffraction pattern match the positions predicted by theory.

## Theory

When diffraction of light occurs as it passes through a slit, the angle to the minima in the diffraction pattern is given by

$$a \sin \theta = m\lambda \quad (m = 1, 2, 3, \dots)$$

where  $a$  is the slit width,  $\theta$  is the angle from the center of the pattern to the  $m^{\text{th}}$  minimum,  $\lambda$  is the wavelength of the light, and  $m$  is the order (1 for the first minimum, 2 for the second minimum, . . . counting from the center out). See Figure 1.1.

Since the angles are usually small, it can be assumed that

$$\sin \theta \approx \tan \theta$$

From trigonometry,

$$\tan \theta = \frac{y}{D}$$

where  $y$  is the distance on the screen from the center of the pattern to the  $m^{\text{th}}$  minimum and  $D$  is the distance from the slit to the screen as shown in Figure 1.1. The diffraction equation can thus be solved for the slit width:

$$a = \frac{m\lambda D}{y} \quad (m = 1, 2, 3, \dots)$$

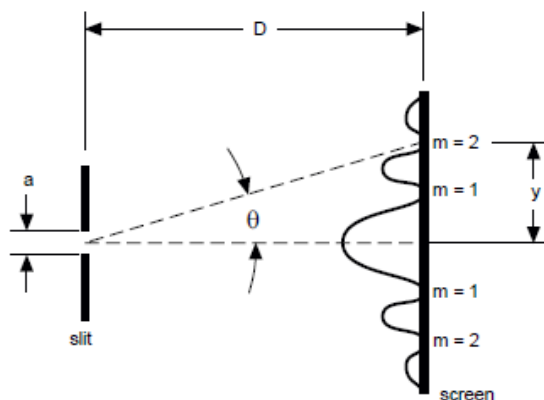


Figure 1.1: Single Slit Diffraction Pattern

## Setup

- ① Set up the red laser at one end of the optics bench and place the Single Slit Disk in its holder about 3 cm in front of the laser. See Figure 3.
- ② Cover the screen with a sheet of paper and attach it to the other end of the bench so that the paper faces the laser.
- ③ Select the 0.04 mm slit by rotating the slit disk until the 0.04 mm slit is centered in the slit holder. Adjust the position of the laser beam from left-to-right and up-and-down until the beam is centered on the slit.

## Procedure

- ① Determine the distance from the slit to the screen. Note that the slit is actually offset from the center line of the slit holder. Record the screen position, slit position, and the difference between these (the slit-to-screen distance).
- ② Turn off the room lights and mark the positions of the minima in the diffraction pattern on the screen.
- ③ Turn on the room lights and measure the distance between the first order ( $m = 1$ ) marks and record this distance. Also measure the distance between the second order ( $m = 2$ ) marks and record this distance.
- ④ Make a sketch of the diffraction pattern to scale.
- ⑤ Change the slit width to 0.02 mm and 0.08 mm and make sketches to scale of each of these diffraction patterns.

### Analysis

- ① Divide the distances between side orders by two to get the distances from the center of the pattern to the first and second order minima. Record these values of  $y$ .
- ② Using the average wavelength of the laser (650 nm for the Diode Laser), calculate the slit width twice, once using first order and once using second order. Record the results.
- ③ Calculate the percent differences between the experimental slit widths and 0.04 mm.

### Questions

- ① Does the distance between minima increase or decrease when the slit width is increased?

### Experiment D: Diffraction from a Single Slit (Green Laser on Wall).

Using the Green Laser and the 0.16 mm wide slit, create a diffraction pattern on the far wall of the lab. (Be careful to have the laser strike the wall at close to a perpendicular angle, or you will have to make a correction to your measured distances.) If it is inconvenient to use the far wall, the length of two optical rails in series should be sufficient. Make a sketch of the pattern, and measure the distance between zeroes. (Use a fairly large number of zeroes, and divide by the appropriate amount, remembering that there is no zero in the middle). Use the slit width, the distance to the wall or screen, and the formula for the spacing between zeroes to calculate the wavelength of the laser. Compare this to the wavelength written on the laser.

### Experiment E: Diffraction from a Circular Aperture.

Use the green laser, the single slit Accessory and the screen to observe the diffraction pattern (an Airy pattern) from circular apertures of diameter 0.4 mm and 0.2 mm. The angular diameter  $\theta$  of the first dark band in the pattern should be equal to  $2.44 \lambda/D$  where  $D$  is the diameter of the aperture. Calculate  $D$  based on the given laser wavelength and a measurement of  $\theta$  (remembering that for small angles the angular diameter in radians is equal to the linear diameter divided by the distance from the aperture to the screen). How does your calculation compare to the given aperture diameter? Can you improve your measurement by increasing the distance from the aperture to the observed Airy pattern (say on a far wall of the room)? Try it.