

Diffraction and Compact Discs

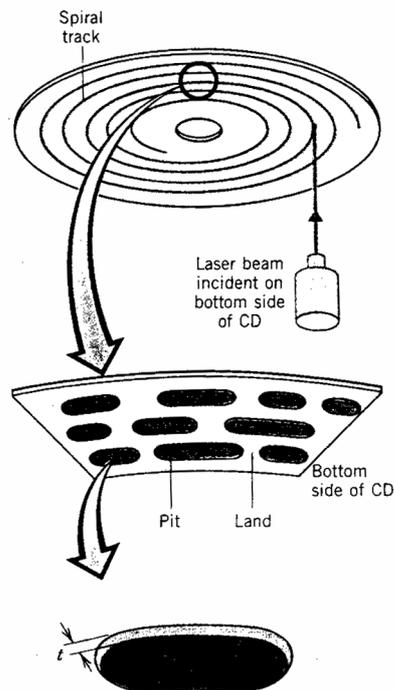
PHYS 1301
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Introduction

By now, you have some experience with the phenomenon of diffraction. In today's lab you will use diffraction to probe the structure of the bottom of a compact disc (CD). Although an understanding of how a compact disc works is certainly not necessary to understand the important physics ideas of the twentieth century, it is useful for you to understand some general features of diffraction and it is useful for you to have some understanding of how everyday devices work.

The bottom or unmarked surface of a CD has a spiral pattern of alternating raised areas and flat surfaces. See figure 1. Although it is difficult to do so with the unaided eye, if you could see the bottom surface structure of the CD, you would observe that these raised areas are shaped something like oblong mounds of carefully controlled height but of varying length. (Seen from the marked or top surface of the CD, these same mounds look like pits and in fact are usually referred to as "pits".) The CD surface *between* the pits is often referred to as "land". See figure 1. Laser light is shot at the bottom of the CD, reflected and then detected by some electronics whose detailed workings we don't need to worry about. As the CD spins, the laser light illuminates various pits and lands simultaneously. The reflected light undergoes some partial destructive interference so that the total amount of reflected light varies with time as the CD rotates. This varying amount of light is transformed by the CD player electronics into a varying sound signal that you hear as music.

The pits and lands can be thought of as functioning together as slits in a diffraction grating. When we bounce light off of the CD bottom, the sets of pits and lands will diffract the light and produce a characteristic diffraction pattern on a screen. By measuring the geometrical features of the diffraction pattern, we can then determine the average size of the pits and lands.



The bottom surface of a compact disc (CD) carries the audio information in the form of raised areas ("pits") and land along a spiral track. A CD is played by using a laser beam that strikes the bottom surface of the disc and reflects from it.

Figure 1. Basic structure of a compact disc reflecting surface.

Procedure

1. **Do not stare directly into the laser beam. Doing so will only hurt you, possibly blinding yourself.**
2. Position the mirror, mirrored surface up, about halfway between the laser stand and the bookend. The laser stand and the bookend should be separated by about 60 cm.
3. Aim the laser downwards and turn it on by connecting it to its power supply.
4. Adjust the height and orientation of the laser diode, so that when it is turned on, the light strikes the mirror and is reflected onto the graph paper held by the bookend. Measure two heights Y_1 and Y_g , the vertical distance the laser front end is *above the mirror* and the vertical distance the beam spot is on the graph paper, respectively. You will need also to measure two horizontal distances, X_1 and X_g . These are the horizontal distances between the laser head and the mirror beam spot, and between the mirror beam spot and the beam spot on the graph paper, respectively. (Diagram 2 below shows the general idea except substitute the mirror for the CD.)
5. Change the vertical height only (by, say, 10 cm or so) of the laser but still bounce the laser light off the mirror and onto the graph paper. Record the new values of Y_1 and Y_g .

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7. Now shorten the distance between the laser head and the graph paper symmetrically so that the separations x_l and x_g are each about 20 cm. Measure and record again y_l and y_g , and x_l and x_g .
8. Remove the mirror. Place the CD, marked side down, onto the table. We will call this arrangement "setup 1." Separate the laser head and the graph paper so that x_l and x_g are each about 70 cm. (Again, use the mirror beam spot on the mirror as your origin.) Adjust y_l so that the laser head is about 5 cm above the tabletop. Measure y_l . Position the CD so that the laser beam strikes the CD on a spot closer to the laser than to the graph paper. See figure 2. The laser head, CD beam spot, CD center and graph paper beam spot should all lie in a single plane. Observe the pattern of laser light on the graph paper. Measure the vertical height y_g above the CD surface of the center of the spot pattern.
9. Now position the CD so that the laser light strikes the CD near an edge, at a point halfway between the laser head and the graph paper. Call this arrangement "setup 2" and refer to figure 3 below. Observe the pattern of light on the graph paper. You should see well-separated dots of light, with one dot that is much brighter than the others. This is the so-called 0th order maximum. You will notice the 1st order maxima and possibly a 2nd order maxima as well on either side of the central maximum. Measure and record the vertical heights of these maxima above the CD surface.

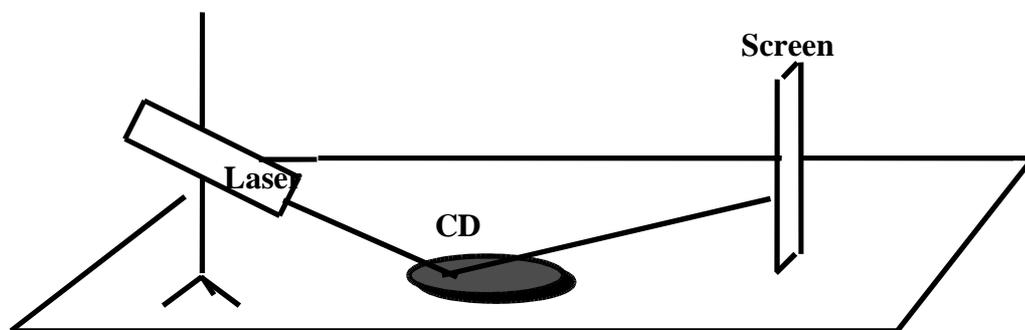


Figure 2

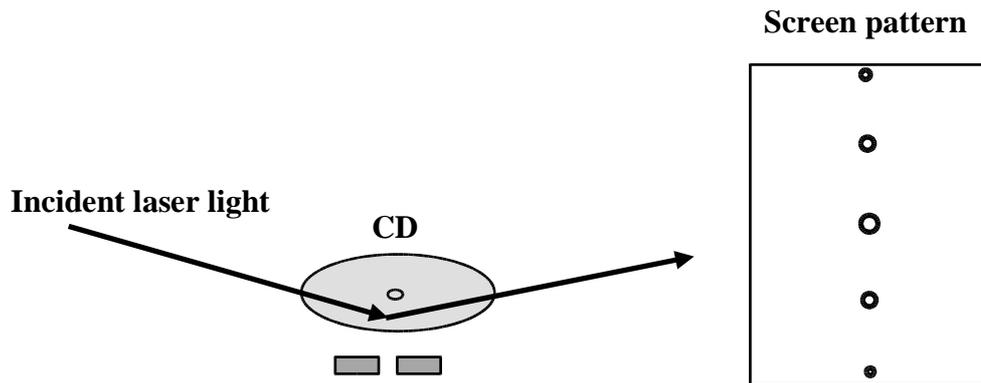


Figure 3

Analysis

Be sure to show your calculations. They can be handwritten.

1. Fill in data tables 1 and 2. Refer to figure 3 to compute the so-called incident angle θ_{inc} and the reflected angle θ_{refl} in data table 1 refer to figure 3. You will need to compute the inverse tangent for a right triangle using your measured distances found in the appropriate table.

To complete data table 3, you need to remember the simple formula for diffraction from a diffraction grating. Recall from a previous lab, $d \sin \theta = n \lambda$, where d is the spacing between slits, θ is the diffraction angle, n is an integer ($n = 0, 1, 2, 3, \dots$) that labels the so-called *order* of the bright spot, and λ is the wavelength of the light passing through the grating. Since the only unknown in this equation is the slit spacing d you can easily solve for it. Although a CD is not really a diffraction grating, after all the light bounces off of the CD, it does not pass through it, the CD acts like a diffraction grating because the reflected light undergoes constructive and destructive interference due to the special geometry of the CD's bottom surface. What made the diffraction grating produce the characteristic pattern of alternating bright and dark spots when light was passed through it was its special geometry which caused light to constructively and destructively interfere with itself. Hence, the two seemingly different objects behave in a similar pattern. The distance d you compute here is an average separation between neighboring pits in the region where the laser light strikes the CD surface.

2. Pick up the CD by the edge so that the shiny surface is facing upwards. Hold the CD so that it reflects light off of the overhead lights. Notice what you observe.

Questions

1. When you were using the mirror (data table 1), do you notice any pattern between Q_{inc} and Q_{refl} ? For example, do they seem close together in value, do they differ wildly, do they seem to have no relationship at all with each other? See if you can guess a general relationship between Q_{inc} and Q_{refl} . For example, does one angle seem always to be about the twice the value, or 1/3 the value of the other?
2. What is your value for the for the typical pit-to-pit separation d ? What do you think is the major source of error in this value? Explain.
3. How well do you think you can measure distances in this lab? 1 meter, 0.2 meters, 1 millimeter? Why is this? Do your distances in data tables 1 and 2 reflect this claimed precision?
4. What do you see on the reflective surface of the CD when you hold it up to the lights? Draw a **simple** diagram explaining what you saw. Be sure to label important features. This is also an example of diffraction although it is (a little) subtler than what you have seen before. In general, you expect diffraction to occur when the size of the geometrical structures scattering the light are about the same size as the wavelength of the light being scattered. Assuming this last statement is true (it is) and based on your measurements of the typical pit separation on a CD, what is your estimate for the wavelength λ_{vis} of visible light?
5. Succinctly state what you learned in this lab.

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Name _____ Section _____

Abstract

Calculations

DATA TABLE 1

Mirror	y_1 (m)	y_g (m)	x_1 (m)	x_g (m)	q_{inc}	q_{rfl}
Setup 1						
Setup 2						
Setup 3						

Date Table 2

CD	y_1 (m)	y_g (m)	x_1 (m)	x_g (m)	q_{inc} (deg)	q_{rfl} (deg)

DATA TABLE 3

CD						
Setup 2	y_1 (m)	y_g	x_1	x_g (m)	$\sin \theta$	d (m)
0 th order						
1 st order						
1 st order						
2 nd order						
2 nd order						

CD diagram

Answers to Questions

1.

2.

3.

4.