Diffraction and Compact Discs

PHYS 1301 F98
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Introduction

You all have some experience with the phenomenon of diffraction, even if the word is new to you. 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 familiar devices work.

A CD has a sandwich structure. The very bottom layer is made from polycarbonate plastic to provide stiffness to the CD and to provide a surface to build small aluminum structures on. These structures have a ridge-like geometry when viewed from the side and have a common height, about 110 nanometers. The width of the flat or valley separating neighboring ridges varies and ranges from about 800 nanometers to 3500 nanometers. On top of the ridge structure is lacquer to protect the ridges, more plastic and then a label to identify the CD. Figure 1 is a schematic figure of a CD when viewed on edge.

The bottom or unmarked surface of a CD has a spiral pattern of these alternating raised areas and flat surfaces. 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 ridges and valleys 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 ridges and valleys 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 ridges and valleys 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 estimate the average size of the ridges and valleys.

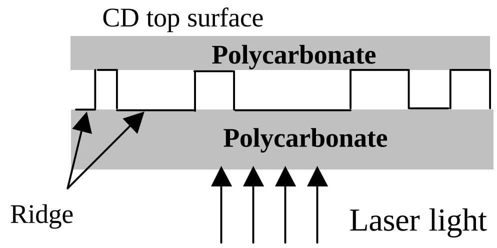

Figure 1. Basic structure of a compact disc reflecting surface.

Procedure

1. **Do not stare directly into the laser beam. Doing so will only hurt you, possibly blinding yourself.**

2. Position the mirror cube, mirrored surface up, about halfway between the laser stand and the bookend. To start, about 20 cm or so should separate the laser stand and the bookend.

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 on the graph paper held by the bookend. Measure two heights y_l 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_l 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. See figure 2 below.

5. Change the horizontal distance by 10 cm or so between the laser diode and the mirror. Move the stand with the diode, not the mirror. Position the screen so that the reflected beam spot strikes it. Record the new values of y_l and y_g.

6. Repeat step 5 two more times. Measure and record again y_l and y_g, and x_l and x_g each time. You should have measurements for 4 different mirror setups.

7. Remove the mirror. We now want to measure the diffractive properties of our CD. Tape the CD to a bookend so that it is positioned in a vertical plane. The CD's unmarked side should face outwards. Separate the laser head from the CD by about 10 cm or so and position it so that its axis is parallel to the plane of the table. Point the laser to the CD and set its height to match that of the CD center. Attach graph paper to 2 book ends and position the bookends about the laser, one on each side of the laser. Arrange matters so that the plane of the CD is parallel to the

planes of the pieces of graph paper and that both pieces of graph paper are in the same plane. You may have to slightly adjust the CD-laser separation. See figure 3 below.

8. Turn on the laser. You should see 2 bright spots on each piece of graph paper. The 4 bright spots may or may not lie in a horizontal line. Measure the distance between the laser head and the position of the two bright spots on the graph paper. The clever way to do this is to measure the distance between the two bright spots and divide by 2. (Do you see why?) Next, measure the distance between the laser head and the beam spot on the CD. You now have enough information to calculate the angular position of the maxima on the graph paper. Calculate the angular position of each of the so-called “first order” maxima and average their values. If you indeed have 4 maxima on your graph paper, repeat this procedure and measure the angular position of the “second order” maxima. Average this pair. You now have information to calculate the typical feature size of a CD.

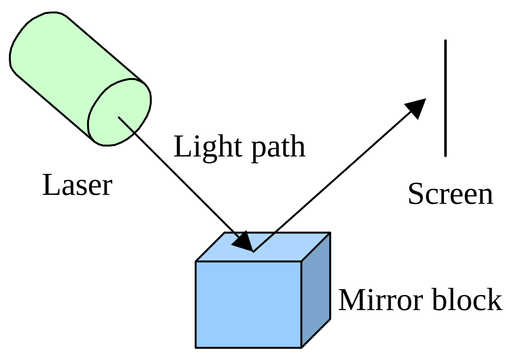

Figure 2. Setup for mirror measurements.

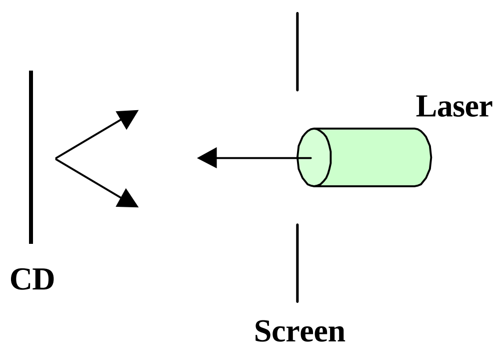

Figure 3. Setup for CD measurements.

<u>Analysis</u> (Be sure to show your calculations. Use another piece of paper.)

1. Fill in data table 1 to compute the so-called incident angle q_{inc} and the reflected

angle θ_{rfl} in data table. You will need to compute the inverse tangent for a right triangle using your measured distances found in the table.

2. Complete data table 2. 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…) which 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 is this equation is the slit spacing *d*, you can easily solve for it. Although a CD is not a diffraction grating in the strict sense of the word, the CD acts similar to 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 ridges in the region where the laser light strikes the CD surface.

CD setup 2 refers to the attempt to measure the angular position of the 2nd order maxima.

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

<u>Questions</u>

1. When you were using the mirror (data table 1), do you notice any pattern between θ_{inc} and θ_{rfl}? 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 θ_{inc} and θ_{rfl}. For example, does one angle seem always to be about the twice the value, or 1/3 the value of the other?

2. Explain how the difference between the surface of a mirror and the surface of a CD.

3. How well do you think you can measure distances in this lab? 1 meter, 0.2 meters, 1 millimeter? Do your distances in data tables 1 and 2 reflect this claimed precision?

4. What did you see on the unmarked surface of the CD when you held 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?

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Name____________________ **Section__________________**

Abstract

Calculations

DATA TABLE 1.

Mirror	y_l (m)	y_g (m)	x_l (m	x_g (m)	q_{inc} (deg)	q_{rfl} (deg)
Setup 1						
Setup 2						
Setup 3						
Setup 4						

DATA TABLE 2.

CD

Setup 1	y (m)	x_L (m)	x_R (m)

sin θ	*d* (m)

Setup 2	y (m)	x_L (m)	x_R (m)

sin θ	*d* (m)

CD diagram

Answers to Questions

Question 1.

Question 2.

Question 3.

Question 4.

Error Analysis

Describe the major sources of error in this experiment and their significance. I want more than a simple list. I need some explanation of the implications of the errors.