PhyzLab: How Groovy is Your CD?

and other puzzles of diffraction

PERIOD	1.		
	2.		
GROUP	3.		
	4.		

LASER LIGHT WARNING: Laser light can cause temporary or permanent damage to your eyes. Do not look at direct or reflected laser light. Do not shine laser light at people or animals. Laser light can be viewed safely if it is reflected from a rough surface.

• Prelab Math Exercises •

1. DETERMINE THE THICKNESS OF A SINGLE SHEET OF PAPER

Consider a single page of your physics textbook. It's pretty thin. What if someone challenged you to measure its thickness using only a common meterstick? Though it sounds impossible, you could meet the challenge. What you do is to measure the thickness of, say, a hundred sheets of paper from the book (page 1 to page 201). If you knew the thickness of 100 sheets, you could divide by 100 to get the thickness of a single sheet.

a. What's the thickness of a single sheet if 100 sheets make a stack 8.5 mm (0.0085 m) tall? Record your answer in scientific notation.

b. Suppose a 1.0 mm stack has 50 sheets. Write and evaluate ratios for the following. Include units.

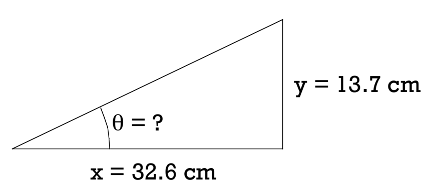
i. What is the number of sheets per millimeter?

ii. What is the number of millimeters per sheet?

iii. What is the thickness of the paper (in meters)?

2. GETTING THE ANGLE WITHOUT A PROTRACTOR

In some parts of this activity, you will need to determine an angle. A protractor will not provide an accurate measurement. A meterstick will provide the keys to the determination of the angle. Consider the right triangle shown to the right. The angle, θ, can be determined without the use of a protractor. The tangent of the angle is equal to the ratio of the length of the side opposite to the side adjacent. That is, $\tan\theta = y/x$. Use the inverse tangent (arctangent) function to determine the angle. Show full work.



• Purpose •

The following activities will allow you to measure the effects of diffraction, use these measurements to determine the groove spacing on a compact disc, and determine the wavelength of a "mystery laser."

• Apparatus •

____ diffraction grating (slide-mounted: don't touch the film)
____ diode laser pointer
____ compact disc
____ 2 metersticks
____ posterboard screen (or manila folder or equivalent)
____ a variety of support rods and clamps
____ medium and large binder clips to support gratings, CDs
____ access to different laser, DVD's and/or different gratings

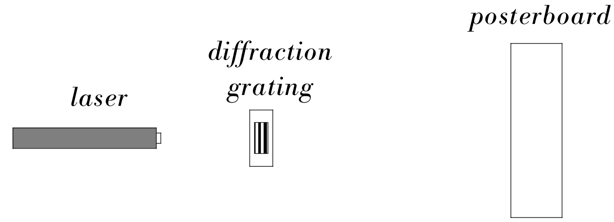
diffraction grating HANDLE BY EDGES ONLY!

compact disc

• Procedure •

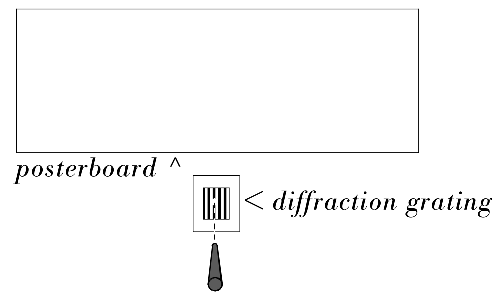
1. THE "GRATEST" SHOW ON EARTH: AN INVESTIGATION OF THE DIFFRACTION GRATING

a. Hand-hold the apparatus as shown to the right. Align the grating **vertically**.



b. Activate the laser, point it at the diffraction film and observe the pattern.

c. Draw and describe the pattern on the screen shown in the diagram below.

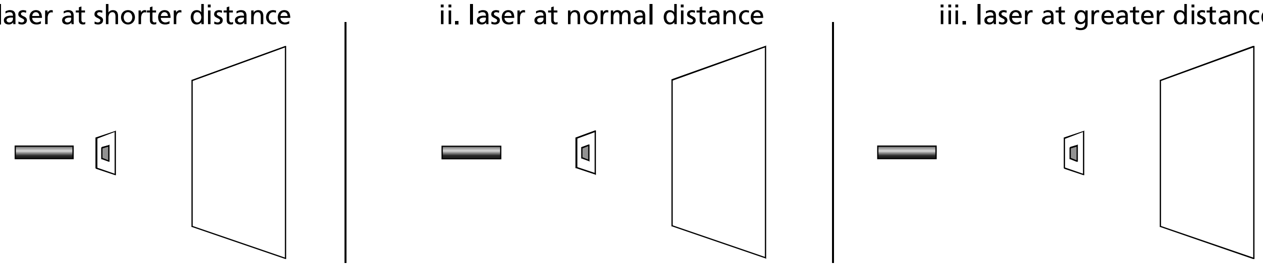


d. Is the **pattern**
___localized (i.e. in clear focus only at one particular distance from the grating), or
___continuous (i.e. clearly observable through a range of distances from the grating)?

e. Is the pattern symmetric? Do the spots vary in brightness or size? Describe.

f. Hold the diffraction grating in place while you move the laser closer to and farther from the grating (maintain the horizontal aim of the laser while doing so). In what ways—if any—is the diffraction pattern affected? Answer with words and by completing the overhead-view diagrams below. Complete diagram (ii) first.

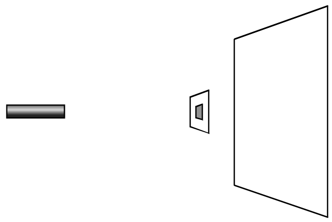
i. laser at shorter distance | ii. laser at normal distance | iii. laser at greater distance



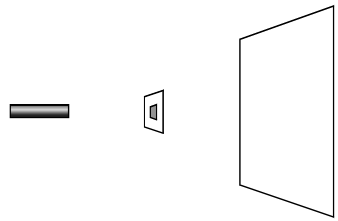
How—if at all—does the spacing of the dots depend on the laser-to-grating distance?

g. Hold the laser in place while you move the diffraction grating closer to and farther from the screen (maintain the horizontal aim of the laser while doing so). In what ways—if any—is the diffraction pattern affected? Answer with words and by completing the overhead-view diagrams below. Complete diagram (ii) first.

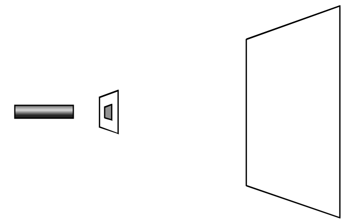
i. grating at shorter distance



ii. grating at normal distance



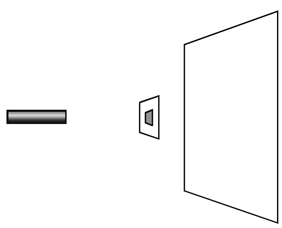
iii. grating at greater distance



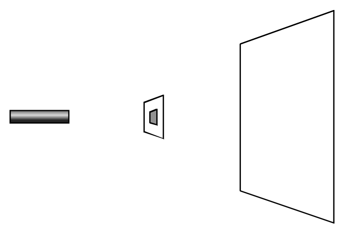
How—if at all—does the spacing of the dots depend on the grating-to-screen distance?

h. Hold the diffraction grating and laser in place while you move the posterboard screen closer to and farther from the grating. In what ways—if any—is the diffraction pattern affected? In what ways—if any—is the diffraction pattern affected? Answer with words and by completing the overhead-view diagrams below. Complete diagram (ii) first.

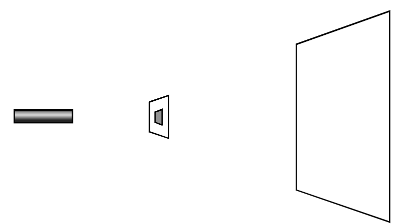
i. screen at shorter distance



ii. screen at normal distance



iii. screen at greater distance



What does this show?

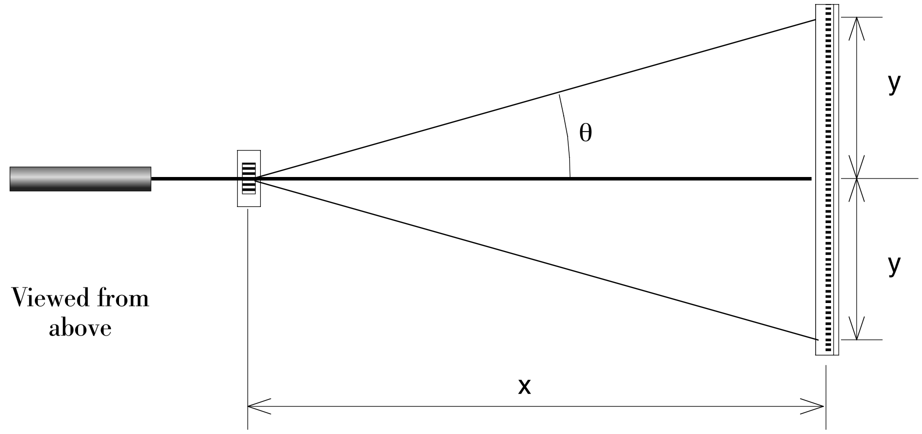
i. What happens to the pattern if the grating is rotated? Be specific.

Light passing through a diffraction grating produces pattern is described using the following terms.
Maximum: a bright region in the pattern. (Plural: maxima.)
Central maximum: the bright spot in the middle of the pattern.
Orders: the numerical sequence of the pattern. The zeroth order maximum is the central maximum. The first order *maxima* are the first bright regions *to either side* of the central maximum. The second order maxima are the second pair of bright regions, etc.

j. Replace the posterboard with a meterstick. Use a meterstick clamp (if available). Place the meterstick horizontally across the pattern at a distance (about 20 cm) from the diffraction grating. Center the meterstick so that the central bright spot hits it at the 50.00 cm mark. If the meterstick does not catch the full pattern, move it until it does. Arrange the distance between the grating and the meterstick (x) to be approximately 20 cm. Record the actual value on the table below.

k. Measure the distance from the central maximum (zeroth order maximum) to the first order maxima to the right of the center spot. Also measure the distance to the left of the center spot. It may be helpful to simply record the centimeter values directly from the meterstick first and calculate the distances later.

l. Take a second set of data with x arranged to be approximately 40 cm.



Grating to screen distance x (cm)	Location of central maximum	Locations of 1st order maxima (on the meterstick)		Distance from central maximum to 1st order maxima: y (cm)		AVERAGE y (cm)	1st order angle θ (°)
						AVERAGE:	

m. Calculate the quantities listed in the data table above. Use the arctangent technique from the prelab to determine the angles. Show the calculation for the first order angle when x is about 20 cm. (If you get an angle less than 10° or greater than 35°, you have made an error. Check your work.)

n. Record (do not calculate) the wavelength of the laser you are using. (If is most likely written on the laser, itself. Ask your instructor if you are not sure.) Write it in SI prefix and engineering notation.

λ = _______________ nm = ______________________________ m

o. The relation for a diffraction grating is $m\lambda = d \sin\theta$ where m is the order, λ is the wavelength, d is the slit spacing, and θ is the angle from the central maximum to the m^{th} order maxima. Since we used only the first order maximum, m = 1. So the equation becomes $\lambda = d \sin\theta$. Use that relation, your measurements of the diffraction pattern, and the wavelength of your laser to determine the distance d between the slits of the diffraction grating.

d = ____________________

(If your answer is less than 1E–6 m or greater than 10E–6 m, you have made an error. Check your work.)

p. Determine the actual slit spacing d using the line density information printed on the diffraction grating itself (or provided by the instructor). Show calculations. (Hint: What would be the spacing if there were 50 lines in 1 mm?)

Code written on grating: ___ ___ ___ Line Density = _______________ lines / millimeter

d = _______________

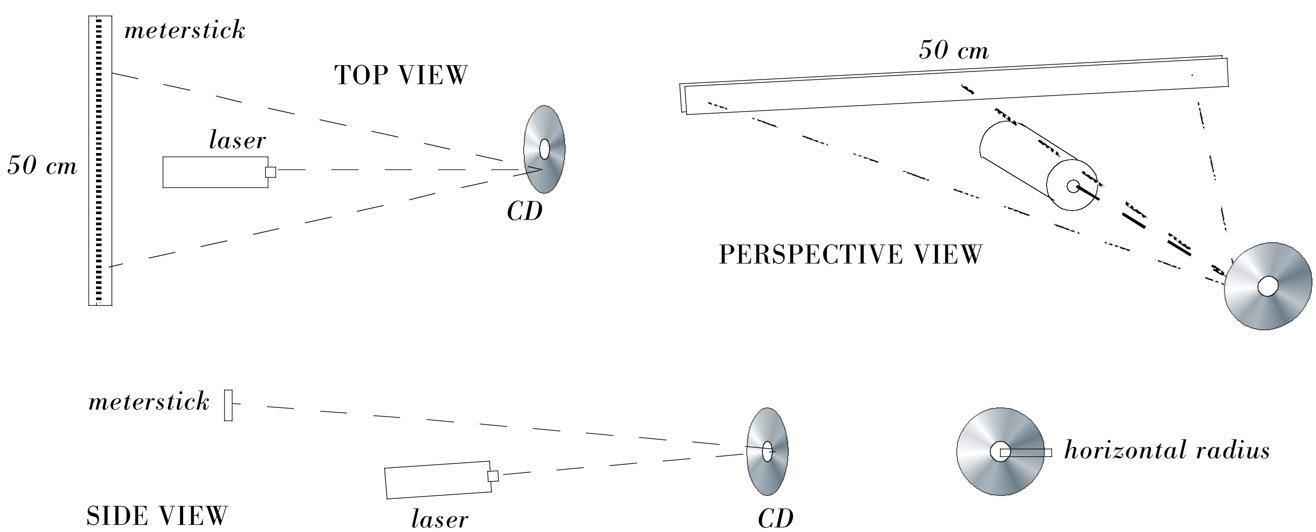
q. Determine the percent error (not percent difference) for the slit distance you calculated from your measurements.

% error = ___________

2. HOW GROOVY IS YOUR CD? AN INVESTIGATION OF THE COMPACT DISC

Based on "The compact disc as a diffraction grating" by Haym Kruglak in *Physics Education*, July 1991.

The compact disc has microscopic pitted grooves separated by a shiny aluminum gap. These features create a diffraction grating. (The reflective shiny spaces between the pitted grooves act like slits in a diffraction grating.) The CD is a **reflective** diffraction grating as opposed to a **transmission** diffraction grating like the one used in procedure A above. The diffractive nature of the CD produces the familiar rainbow effect seen when looking at the information side of the disc.



NOTES ON SET-UP (Set-up is the most difficult part of this activity)

i. The laser beam will reflect from the CD to form a diffraction pattern.

ii. The laser beam must strike the CD along a **horizontal radius**. This is where the grooves on the CD are vertical and will produce a horizontal diffraction pattern.

iii. The laser beam should not hit the CD at a perfect right angle; a slight vertical deviation is needed so that the diffraction pattern forms ***above*** the laser itself. The central bright spot should appear directly above the laser aperature. That is, the laser should be directly below the 50 cm mark.

iv. Align the meterstick so that the central maximum hits the 50.00 cm mark on the meterstick.

In this investigation, you will use your understanding of diffraction to determine the slit distance d (distance between grooves) of a compact disc.

a. Arrange the apparatus as shown and described. Correct arrangement is **critical.**

b. Determine the angle θ for the first order maxima in the diffraction pattern. Show data and calculations.

θ = ______________

c. Determine the groove spacing distance d.

d = _______________

d. Obtain the actual groove spacing value from your instructor and determine the percent error in your calculations.

Actual groove spacing: ____________________

% error = _______________

GOING FURTHER

1. A LASER OF A DIFFERENT COLOR

Obtain a mystery laser (one having a different color than any you used previously). Your goal here is to determine the wavelength of the new laser. Determine and record your procedure, data, and analysis.

Identify the color of the mystery laser: ______________________________

a. On a separate sheet, describe the procedure. Include a labeled diagram. Do not record data or calculations in this space.

b. On that sheet, record data in a clear, orderly manner.

c. On that sheet, show the appropriate calculation(s).

d. Record the result in nanometers. λ = _______________ nm.

2. HOW GROOVY IS YOUR DVD / HIGH-PRECISION GRATING?

Determine the groove spacing on a DVD (digital video disc) or a mystery (unlabeled) grating. Please handle these items carefully (touching only the edges) so that other students can use these items later.

Identify the object you are investigating: __DVD   __Precision grating: 5-character code:__________________

a. On a separate sheet, describe the procedure.

b. On that sheet, record data in a clear, orderly manner.

c. On that sheet, show the appropriate calculation(s).

d. Record the result in appropriate SI prefix notation (μm or nm). d = ____________________