

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Physics

8.02

Spring 2005

Experiment 13: Interference and Diffraction

OBJECTIVES

1. To explore the diffraction of light through a variety of apertures using a laser pointer.
2. To measure the wavelength of the laser light; the spacing between the tracks of an audio compact disk (CD); and the thickness of a human hair.

WARNING! The beam of laser pointers is so concentrated that it can cause *real* damage to your retina if you look into the beam either directly or by reflection from a shiny object.

USING THE SPREADSHEET

The data analysis for this experiment should be done using the Excel spreadsheet **exp13.xls**; your data should be entered into the appropriate places in this spreadsheet and reproduced in the tear-off sheet. Until you enter your data into the indicated boxes (or cells) in the spreadsheet, some of the displayed results will be of little use (there will be “#DIV/0!” in some cells).

INTRODUCTION AND PRELIMINARY OBSERVATIONS

Single-Slit Diffraction

When light passes through a small opening, secondary waves from different portions of the opening will generally travel different distances before hitting a wall or screen, so, although they were in phase at the slit, they will not be exactly in phase at the screen. Consequently, the brightness on the screen will vary from point to point. “Secondary waves” and *Huygens’s Principle* are discussed in the 8.02 *Course Notes*, **Section 14.4**, and the variation of intensity with position on a screen is discussed in **Section 14.5**.

Place the 35-mm slide containing four single slits with different widths in front of the laser pointer. The widths of the slits are printed on the slide, and reproduced in Table 1. You will note that one side of the slide has attached magnets, and you might want to use these to attach the slide to the metal bracket in front of the aperture. This will mean that the printed widths will not be readable, but this is not important.

Note that Table 1 below gives the widths in microns, μm , where $1\ \mu\text{m} = 10^{-6}\ \text{m} = 10^{-3}\ \text{mm}$.

Table 1 Single Slits

Pattern	A	B	C	D
Slit Width a (μm)	20	40	80	160

Shine the laser pointer through the slide and examine the patterns produced on a white card held some distance from the slide. Notice how the intensity (brightness) of the pattern fades with distance from the center. The dark spots are labeled by their order m , with m starting at 1 on each side of the center; these are the “first-order minima”. The maxima are similarly labeled. Notice that the center of the pattern, referred to as the “zeroth-order” maximum, is always bright.

Question 1 (*answer on your tear-off sheet at the end*): Why is the center of the pattern always bright?

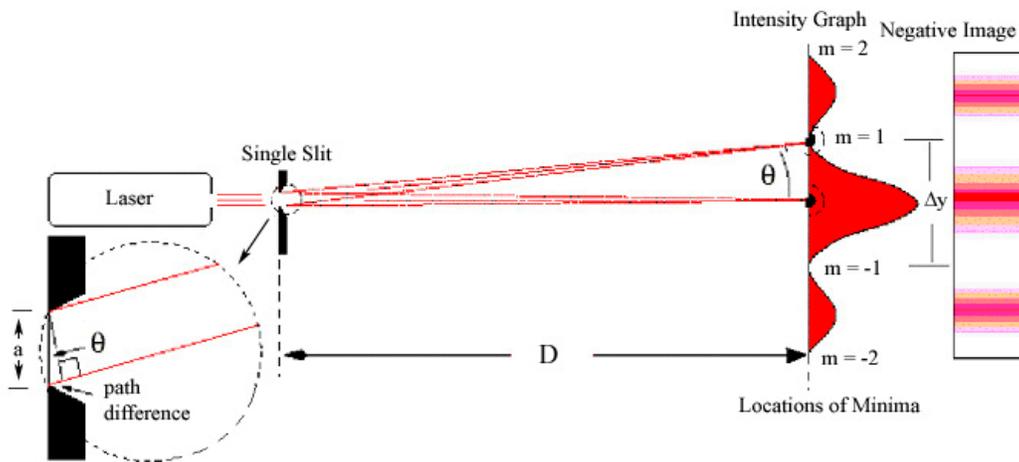


Figure 1 Single-slit diffraction

EXPERIMENT

Part 1: Laser Wavelength

Fasten a card (preferably without a hole in it) with the clips across the wooden slide. Then place the slide in its slot in the block on your optical bench, and shine the pointer through one of the slits (Figure 2).

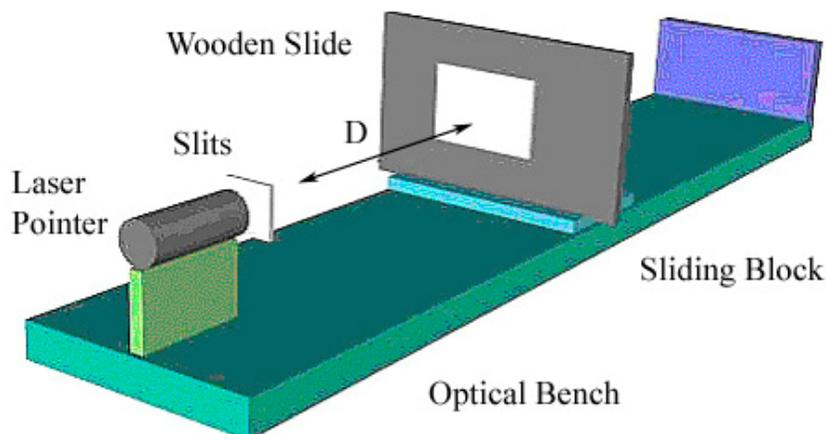


Figure 2 Optical Bench

Slide the block to a distance D of at least 30 cm from the laser. (Use a larger distance if it is dark enough at your table to still see the patterns.) Measure the distance D from the center of the card to the slit. For each pattern **A-D** in turn, carefully put marks on the card at the positions of the pair of first order minima and measure the distance Δy (as indicated in Figure 1) between them. **Enter your results, including the distance D , in the indicated places in the Excel Spreadsheet, and in the table in the tearoff sheet.**

The angle θ from the center of the slit to a *minimum* of order m (see Figure 1) is given by

$$a \sin \theta = m\lambda \quad (13.1)$$

where a is the width of the slit. The angle θ is related to D and Δy by

$$\tan \theta = \frac{\Delta y}{2D}. \quad (13.2)$$

(See the 8.02 Course Notes, Section 14.5, but note that in the Course Notes, L is used instead of D for the distance to the screen.)

The spreadsheet contains the needed calculations, both trigonometric and algebraic, needed to convert your measured values of Δy to a wavelength. The wavelength is given in nanometers, nm, $1 \text{ nm} = 10^{-9} \text{ m} = 10^{-6} \text{ mm} = 10^{-3} \mu\text{m}$. Optical wavelengths are conventionally given in nanometers.

Part 2: Thickness of Human Hair

What would happen if you replaced the slit (which blocks much of the laser beam except for a narrow open strip), with a thin wire or human hair (which blocks little of the laser beam except for a narrow opaque strip – just the reverse of a slit)?

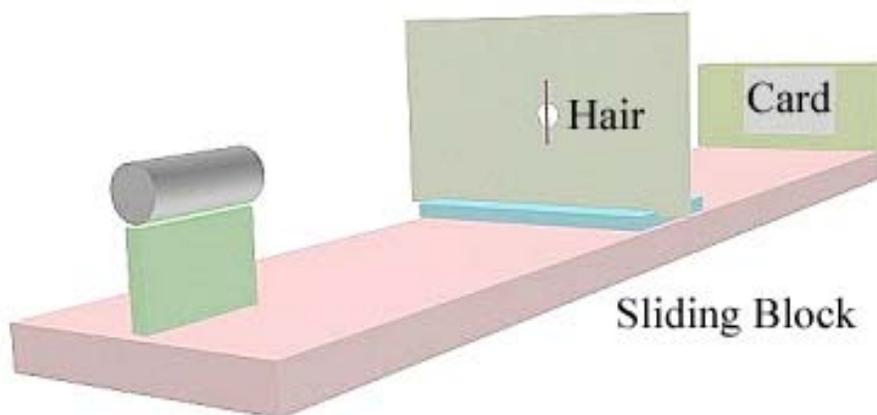


Figure 3 Hair diffraction

To find out, tape a short piece of hair (vertically, as indicated), donated by a group member, across the hole in the wooden slide and place the slide in its slot (see Figure 3). Tape a card to the far end of the optical bench. Shine the laser at the hair and observe the pattern. Surprised? (The fact that the pattern is virtually identical to that of a single slit is an example of a general rule called *Babinet's principle*.)

Measurement 2: Mark the location of the two first-order minima on the card. Then measure the distance Δy between these minima and measure the distance D between the card and the hair. Using the wavelength of the laser you just calculated, compute the diameter of the hair. **Enter your measurements in the indicated places in the spreadsheet, and record your results in the tearoff sheet.**

Part 3: Double-Slit Interference

Table 2 Double Slits

Pattern	A	B	C	D
Slit Width a (μm)	40	40	80	80
Separation d (μm)	250	500	250	500

Now place the slide containing the pairs of slits on the apparatus, in a similar manner to that used for the single-slit slide, and observe the patterns produced. Notice the appearance of closely (and uniformly spaced) fringes. The fringes as a whole vary in intensity in much the same way that the single-slit patterns did. This is most apparent when you compare the difference between patterns **A** and **C** (or **B** and **D**), which have the same distance d between the slits but different slit widths. (The slit parameters are reproduced in Table 2 above.)

Wavelength Check

The width Δy of these fringes, that is, the distance between adjacent minima is approximately

$$\Delta y \approx \frac{D\lambda}{d} \quad (13.3)$$

where D is the slit-to-screen distance, and d is the separation between slits. (This is accurate as long as $\Delta y \ll D$.)

Measurement 3: Measure the width of a group of fringes produced by Pattern **A** of slits, compute the average width of one fringe (the spreadsheet will do this for you) and then use this relationship to compute the wavelength of your laser. Compare with your previous measurement. Which measurement do you expect to be more precise? **Record your result on the tearoff sheet.**

Part 4: Grating

Suppose the number of slits is increased while the separation, d , between them remains constant. Then the separation between fringes remains the same as for two slits. However, the sharpness and visibility of the fringes increases. This is the principle of the *diffraction grating*. (See the 8.02 *Course Notes*, **Section 14.8**, for a further discussion of diffraction gratings.)

If white light, which is a mixture of light with different wavelengths, strikes such a grating, each wavelength will diffract in a slightly different direction causing rainbow effects. The closely-spaced tracks of an audio CD constitute a *reflection grating*, but the interference pattern will be the same as that for a diffraction grating.

Look at the reflection of the fluorescent lights in the room off the surface of the CD. You should see dominant red, green and violet bands that correspond to the wavelengths emitted by the mercury vapor inside the lamps. (The spectrum of an incandescent light bulb or the sun is much more continuous – try it with your own CD at home.)

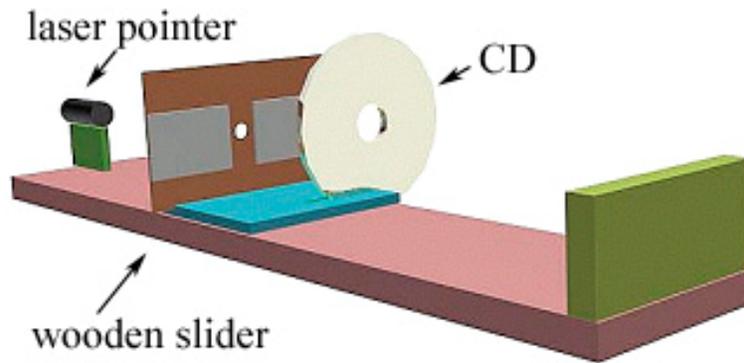


Figure 4: CD diffraction grating

CD Track Spacing

Since you now know the wavelength of your laser, you can use your CD as a grating to measure some very small distances. Place an audio CD in one of the slots on the block on your optical bench (see Figure 4). Attach a card with a punched hole to the wooden slide leaving the central hole unobstructed. (If you can only place the central hole so that some if not most of the laser light passes through, you should still be able to obtain the desired results.) Place the wooden slide in its slot on the block. Turn on your laser and observe the diffraction pattern reflected onto the cards. (Be careful not to reflect the laser into anyone's eye.) Because the distance d between the tracks is so small, the pattern you see is much wider than the one you observed earlier for one or two coarse slits, but the maxima are now much brighter and easy to see. Make small marks on the card at the location of the first-order maxima on each side of the center. For a grating, either a diffraction grating or a reflection grating, the angle of the maximum for a given order m and wavelength λ is

$$d \sin \theta = m\lambda \quad (13.4)$$

and

$$\tan \theta = \frac{\Delta y}{2D} \quad (13.5)$$

Measurement 4: Measure the distance Δy between the two first-order maxima on either side of the central maximum. Measure the distance D from the center of the card to the CD. **Enter these measurements in the indicated places in the spreadsheet, and record the calculated value of d on the tearoff sheet.**

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Tear off this page and turn it in at the end of class.

Note:

Writing in the name of a student who is not present is a Committee on Discipline offense.

Experimental Summary 13: Interference and Diffraction

Group and Section _____ (e.g. 10A, L02: Please Fill Out)

Names _____

Single-Slit Diffraction

Question 1: In a single-slit diffraction, why is the center of the pattern always bright?

Answer:

EXPERIMENT

Part 1: Laser Wavelength

Data for Single Slit: $D =$

Pattern	Δy
A	
B	
C	
D	

Results from either the spreadsheet or from Equations (13.1) and (13.2):

Give your answer in nanometers (1 nanometer = 1 nm = 10^{-9} m = 10^{-3} μ m).

Wavelength = λ =

Part 2: Thickness of Human Hair

Results from either the spreadsheet or from Equations (13.1) and (13.2):

Give your answer in microns (1 micron = $1\mu\text{m} = 10^{-6}$ m).

Results: Hair diameter = d =

Part 3: Double-Slit Interference

Measurement 3: Measure the width of a group of fringes produced by Pattern A of slits, compute the average width of one fringe (the spreadsheet will do this for you) and then use this relationship to compute the wavelength of your laser. Compare with your previous measurement.

Results from either the spreadsheet or from Equation (13.3):

Give your answer in nanometers (1 nanometer = 1 nm = 10^{-9} m).

Wavelength = λ =

Which measurement do you expect to be more precise?

Part 4: Grating

Measurement 4: Measure the distance Δy between the two first-order maxima on either side of the central maximum. Measure the distance D from the center of the card to the CD. Record the calculated value of d in nanometers.

Results: