Introduction

The material for this chapter is discussed in Hecht, Chapter 25. Light exhibits many of the properties of a transverse wave. Waves that overlap with other waves can reinforce each other or cancel each other out (called *constructive* and *destructive* interference). Everyday phenomena that result from interference include the colors of soap bubbles and of bird feathers. Practical applications of interference include masking radar on a Stealth fighter (Hecht 1011) and many others.

Light passing through a narrow slit tends to spread out. This initially surprising phenomenon is called **diffraction**. The effects of diffraction limit the sharpness of images formed by cameras and telescopes. It is important in determining the optimum separation of cones in the fovea of the eye. Understanding diffraction and interference is essential to appreciating the construction and physics of a hologram.

In these experiments you will use visible light, but any wavelength of electromagnetic radiation will demonstrate these effects. For example, if you drove around Mt. Soledad, where there are many radio transmitters, you might notice that the radio reception becomes poor, erratic, and can change dramatically as you move a just few yards. This is the result of **interference**. Radio waves are often transmitted from two towers. This helps to beam the signal, providing better reception at large distances. The waves from the two towers can also interfere with each other, as is especially noticeable near the towers.

Since the wavelength of light is so small compared with macroscopic human dimensions, the slits used and resulting patterns are also small. By making macroscopic measurements of the size of the pattern produced by interference of diffraction, you will be able to measure the wavelength of light. Likewise, if you know the wavelength of light, you can measure the size of the object under study based on the size of the resulting interference and diffraction patterns. Interference and diffraction are examined in Experiments A and B, respectively.

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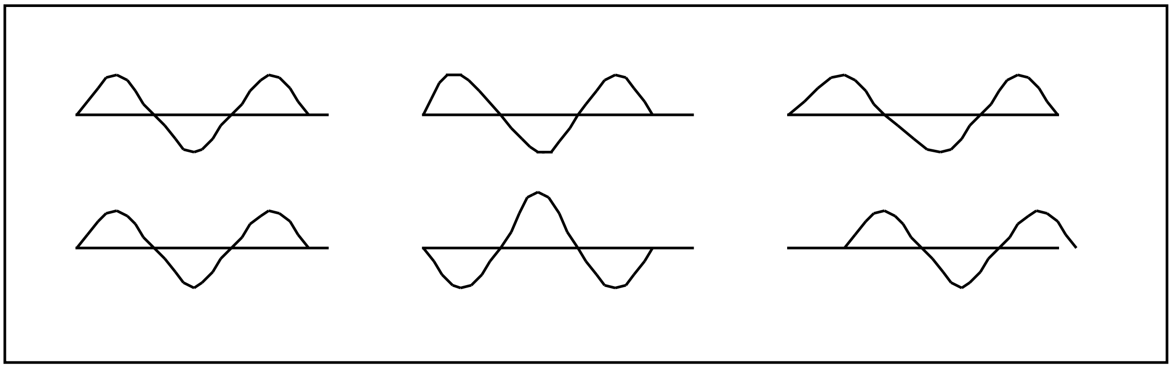
Experiment A: Interference with Slits – Young's Experiment

Read the material on waves and sound in Hecht, Chapter 11. In particular, review the section on the superposition of waves.

Pre-Lab Homework:

1. The figure below shows three pairs of waves. In each case, assume that the top wave interferes with the bottom wave. For each of the cases, draw the resulting wave and label whether the interference is constructive or destructive.



If you drop a stone into a smooth pool of water you see transverse water waves spread out in circles. If you then drop two stones in different places, you can see how the waves pass through each other adding together where they overlap. The phenomenon of interference describes what happens when two or more waves overlap.

Suppose you set up the two speakers of your stereo system so they are both connected to the same amplifier output. They emit the same sound at the same time. (Boring – no stereo!) This is an example of **coherence**. If you were wearing headphones you would hear exactly the same sound in your left ear as in your right. Would this be true if you were listening to the speakers? What would happen if you were closer to one speaker than the other?

2. What is coherence? What are the properties of two wave sources that are coherent with each other? In this experiment you will illuminate two slits with a laser beam. This makes the slits act as sources of light. Is the light from the two slits coherent? Are two lasers necessarily coherent with each other?

3. Perform the experiment described on Hecht, pg. 1008, "Exploring Physics On Your Own." Note that you need to find a "point source" to get dramatic results. Are there other optical phenomena that you have noticed similar to this?

4. Assume you have set up your loudspeakers as described above (that is, two speakers attached to the same amplifier output). Now we will assume that you are listening to loudspeakers, which are placed in the corners of the room. Is there a "best place" to sit and listen? If so, why, and where is it? Draw a diagram showing the loudspeakers and show where you would sit for the best sound. Is there just one spot?

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We will set up the optical equivalent of Pre-Lab #3. This is referred to as Young's Experiment. It was originally performed with a mercury vapor light source illuminating both slits and a filter to isolate just one line in the mercury spectrum. We can achieve similar results more easily by using a laser that emits light at just one well-defined wavelength. This experiment allows us to measure the wavelength of the laser light if we know the separation of the slits.

The setup consists of two parallel slits, S_1 and S_2, in the path of a laser beam as shown below. Interference fringes appear clearly on a screen some distance away. The distance to point P on the screen is r_1 from the lower slit and r_2 from the upper slit. The distances r_1 and r_2 nearly the same. (Note that this diagram is not drawn to scale.) The point B is included so that points S_1, S_2, and B form a right triangle. The separation between the slits is about 1 mm and the distance to the screen is approximately 2 m. The angle θ is assumed to be small.

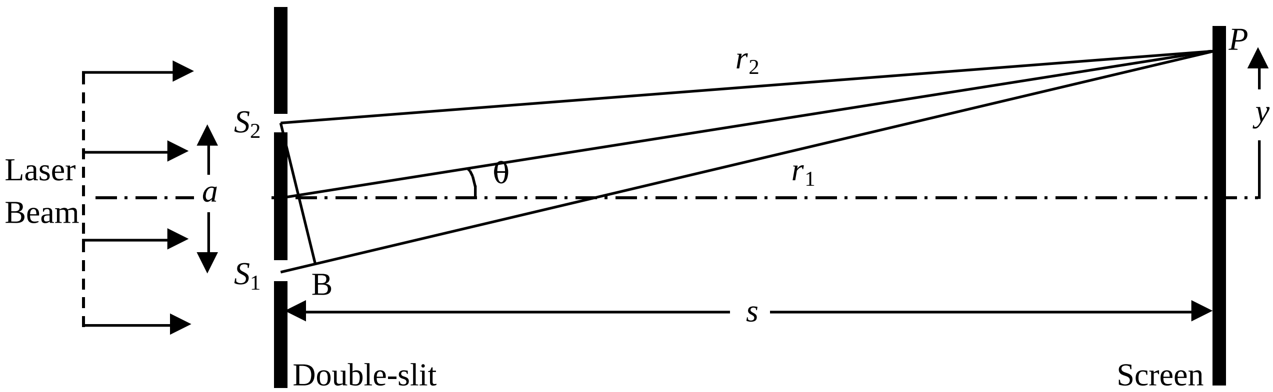

Fig. 1: Diagram of Young's double-slit experiment. The bright and dark fringes appear on the screen at some distance, y_m from the center of the screen.

The alternating bands of light and darkness ("fringes"), occur because the **coherent** laser light that passes through slit S_1 interferes constructively or destructively with the light that passes through slit S_2 depending on their **phase** relative to each other. For example, to reach point P on the screen, the ray from S_1 must cover the longer distance r_1 than the ray from S_2 (which only has to travel the shorter distance r_2). The former lags behind the latter by the difference in path

$$r_1 - r_2 = S_1B$$

where S_1B is the distance from the slit S_1 to point B.
If point P is to receive the maximum amount of light from the two slits, the two rays must arrive **in-phase** – even though one may lag behind the other – so they add constructively. In other words, the difference in path between the two rays must be an integer number $m = 0, \pm1, \pm2$, etc., of the wavelength λ of the light. So, for a bright fringe we have the condition that

$$r_1 - r_2 = S_1B = m\lambda \qquad (1)$$

5. Based on the triangle formed by S_1, S_2 and B and using similar triangles, show that the position, y_m, of the m^{th} maximum on the screen is

$$y_m = (s/a)m\lambda \qquad (2)$$

Show that the spacing between two consecutive maxima is

$$\Delta y = (s/a)\lambda \qquad (3)$$

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Procedure:

Although our light sources are slits, they act as two point sources. (We will do a similar experiment with two tiny circular holes.)

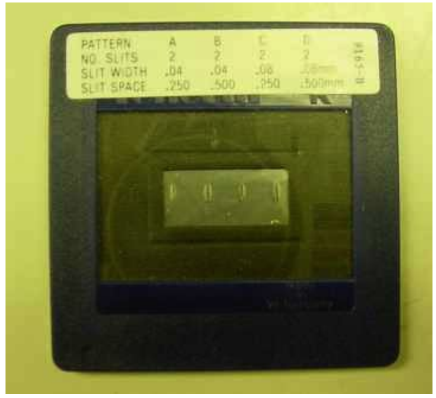

Fig. 2: Slide with four pairs of double-slit arrangements. Typical slit separation is 0.5 mm.

1. Position the laser straight at a wall from at least two meters away.
2. Tape a sheet of white paper onto the wall, centered on the laser spot.
3. Place the a pair of slits in the path of the beam and perpendicular to it, at a distance s = 2.0 m from the wall. Record the slit separation a between the slits that is specified on the slide by the manufacturer.
4. With a ruler, measure the spacing Δy between adjacent fringes on the paper on the wall. *Hint: You may find the dark fringes easier to locate than the bright ones. If it is easier, measure the spacing between the dark fringes, instead of the bright ones.* (Bright and dark fringes alternate and are evenly spaced.)

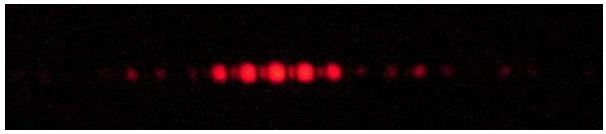

Fig. 3: Fringe pattern due to a laser beam passing through a double-slit arrangement. The brighter spots (maxima) are due to constructive interference between the two rays emerging from the double slit.

Questions:

A1. With the measured value of Δy, the distance s, and the given value a, use equation (3) to calculate the wavelength λ of the laser beam.

A2. Repeat this procedure with a second pair of slits. What is the calculated wavelength of the laser for this new pair of slits? How does it compare to your result from question A1?

A3. Do the fringes separate proportionately wider as the two slits get closer to each other, as predicted by equation (3)?

A4. Average your two values of the laser wavelength and compare to the actual value of the wavelength of red light given by your TA.

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Experiment B: Diffraction – Single-Slit and Others

Although it may be surprising, some of the light passing through a small hole is *bent* as it passes through. The smaller the aperture (hole) the more the light spreads out. This behavior is known as diffraction. Even the shadow of a sharp edge is not a simple division of light from dark. The aperture itself acts like a source of light, and the light it sends out is coherent. Since this does not depend on having a special geometry (such as two equal slits), it is of much more general use. We can use diffraction to measure the size of a small object if we know the wavelength of the light. Conversely, we can measure the wavelength of the light if we know the size of the diffraction pattern

Bright and dark fringes are visible on a screen even when one of the two slits in Young's Experiment is completely blocked off. These fringes are quite different from fringes due to interference (Expt. A). They are produced by the interference from light coming from different parts of the *single* slit. Every point in the single slit is itself an infinitesimal slit and light from it interferes with light from every other point in the slit. Such interference is given a special name, **diffraction**.

> *Pre-Lab Homework:*
>
> 6. If there were no diffraction, draw the pattern you would expect light from a distant point source passing through a single slit would make on the screen.

Refer to the text for proof that the angular displacements of the *dark* fringes that result from diffraction are given by,

$$D \sin \theta_{m'} = m'\lambda \qquad (4)$$

The width, D, of the single slit replaces the separation, a, between the two slits from equation (3). Otherwise, because m' is now the order of a dark fringe, not a bright one, m' can take on values ±1, ±2, etc., but not 0. The central fringe is bright (a maximum), but $m = \pm 1$ represent the position of the first dark (minima) fringes on *either side* of this bright central fringe. The positions on the screen of the dark fringes are given by,

$$y_{m'} = (s/D)m'\lambda \qquad (5)$$

> 7. For a single-slit experiment similar to that described in this procedure, assume the slit width is 0.1 mm, the distance from slit to screen is 1 m, and the wavelength of the laser light is 500 nm. Sketch *to scale* the fringe pattern predicted by the diffraction equation (5) above. Label the **order** of the fringes (the m'-values).

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Procedure and Questions:

Beginning with the same setup as Expt. A, replace the double-slit with a single slit. (It is better to replace the slides than to tape over one of the double-slits since repeated taping and untaping of a slit will eventually destroy its sharp edges.)

The width of the large central fringe is determined by the location of the first-order minima (dark fringes) on either side of it.

B1. Record the width of the single-slit, D, specified by the manufacturer. With a ruler, measure the width of the large central fringe that appears on the paper on the wall. Using equation (5), calculate the wavelength of the laser (Be careful with the m'-values!).

B2. Briefly observe the fringe pattern produced using single-slits with different slit widths, D. Does a smaller value of D give you a more spread-out pattern? Looking at the pattern you have formed can you identify the positions of the shadow of the edges of the slit?

Now you will perform some experiments to measure the size scale of small objects given (from Experiment A), since we know (or have calculated) the wavelength of the laser light.

Replace the single-slit with a strand of hair. If necessary, pull a strand from your head and tape it to the slide holder. You can think of this as the “inverse” of the single-slit. (i.e., Where there was an opening, is now blocked, and vice versa.) The fringes produced by this setup obey the same rules as the single-slit.

B3. Measure the width of the central fringe of the diffraction pattern created by the hair and calculate the thickness of the hair. Pool the data of the class together, and see if the width of a hair is related to its color. If there is a student in class with a beard you may be able to convince him to donate a sample so you can compare it to the width of hair from the scalp.

Look at the patterns formed by more complicated screens. Your TA will provide a square mesh of finely woven cloth. Put this in place of the slit beam and notice that you can see a 2-dimensional pattern.

B4. What happens to the diffraction pattern when you tilt the mesh? Can you tell from the pattern which way the mesh is tilted? Describe what you observe and explain what is happening.

B5. Use the panty-hose material provided to create another diffraction pattern. Compare the diffraction pattern from an unstretched sample to a stretched sample. What happens when you stretch the material? You may wish to bring other samples to try. Record your observations.

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