Diffraction and Interference Lab 7

<u>Equipment</u> laser, eye goggles, optical bench, slide holder, slide with 4 single slits, slide with 4 double slits, 11X14 in paper mounted on wall opposite to lab bench, masking tape, metric tape measure, vernier caliper

<u>Reading</u> Your first year textbook.

PRECAUTION

This experiment uses a laser. Do not let the laser beam or its mirror reflection strike your eye. Watch out for laser beams from other lab benches. It is OK to view the diffuse reflection of the laser beam from a piece of paper.

1 Introduction

Is light a wave or a particle? The Dutch physicist Christiann Huygens (1629-1695) advocated that light was a wave. Huygens principle is often used to describe how waves in general propagate. In 1704 Newton published the first edition of his book *Optiks* in which he championed the notion that light consisted of particles which we now call photons. Thomas Young performed a two slit interference experiment in 1801. The dark bands observed by Young can only be explained by destructive interference, a wave, not a particle, property. Maxwell's equations, with their wave solutions, also support a wave theory for light. On the other hand in the early 20th century there were phenomena involving light that could only be explained by a particle theory for light. Examples are the photoelectric and Compton effects. Is light a wave or a particle? It is both, but not at the same time. Whether the particle or wave description is used depends on what question is being asked. Questions about the propagation of light require a wave theory. Some, but not all, questions about the interaction of light with matter require a particle theory. This conundrum is commonly called wave-particle duality.

   In this experiment you will examine what happens when a plane coherent monochromatic beam of light from a laser is incident on single slits of various widths, and double slits of various widths and separations. The former is called single slit diffraction, and the latter is called two slit interference. The two terms are very much the same physical phenomena, with diffraction being very much part of any multi-slit interference pattern, and interference between waves from various parts of a single slit producing the single slit diffraction pattern. These patterns, which are produce by propagating light, can only be explained by a wave picture of light.

   This experiment is greatly facilitated by the use of a laser as a light source. The laser light is highly monochromatic and coherent. Coherence means that there are surfaces, in this experiment approximately planes, in which the light is in phase. When such light falls on a slit or slits, the electric field $\vec{E}$ oscillates in phase over the area of the slit(s) and Huygen's principle can be used to calculate where the transmitted light will interfere constructively and destructively. Young did not have a coherent light source. To achieve enough coherence to see fringes, he had to use a single source slit for his two slit experiments. This single slit was narrow enough to produce the coherence needed. It also gave him very much less intensity than you have at your disposal with the laser.

In the discussion of diffraction and interference it will be assumed that the light incident on the slit(s) is a monochromatic plane wave, and that the observing screen is far enough away so that all lines from the apertures(s) to a given point in the observed intensity pattern are essentially parallel. This is the far-field or Fraunhofer diffraction. When this is not true the situation is termed near-field or Fresnel diffraction.

2   Apparatus

A laser is mounted at one end of an optical bench which can magnetically hold the laser and a holder for the slits. The slits are mounted just in front of the laser. To achieve sufficient path length for the diffracted laser beam the beam is pointed across the room onto a sheet of paper attached to the opposite wall. You will need to measure the distance from the slits to the paper and various dimensions of the light pattern on the sheet of paper.

Provided are two slides. One of these has 4 single slits of various widths a, and the other has 4 double slits of various widths a and separations d, where d is the separation between the center of the two slits. These dimensions are written on the slides and are in mm.

3   Why Slits?

Diffraction and interference can be observed with apertures of any size and shape. Why are slits often chosen? The diffraction in the direction parallel to the long dimension of the slit is much less than in the direction parallel to the short dimension. We ignore the diffraction in the former case and concentrate on the latter situation, which has the far larger effect. The problem has become one dimensional.

4   Single Slit Diffraction- Theory

Consider a plane monochromatic wave of wavelength λ incident normally on a screen which has a tall slit of width a in it. Let θ be the angle between between the normal to the screen and the direction of the diffracted light. See Fig. 1. If I_0 is the intensity in the forward direction ($\theta = 0$), the intensity in the direction θ is given by

$$I = I_0 \left(\frac{\sin[\pi a(\sin \theta)]/\lambda]}{\pi a(\sin \theta)/\lambda} \right)^2 . \tag{1}$$

This function is plotted in Fig. 1. Zero intensity occurs when the numerator is zero, or when

$$\sin \theta = \frac{m\lambda}{a} \qquad (m = \pm 1, \ \pm 2, \ \ldots). \tag{2}$$

Note that the forward direction, $\theta = 0$, is maximum in intensity, not a zero. Why? The central maximum ($\theta = 0$) is very much more intense than the other maximums, and gets wider the smaller you make the slit width! The width of the central maximum goes as $1/a$.

5   Experiment With Single Slits

Mount the slide with the four single slits in the holder and place it in front of the laser. Observe the diffraction pattern across the room on a sheet of 11X14 in paper. The widths

of the slits are given on the slide. Move the slide back and forth several times, exposing the different slits to the laser light, noting how the pattern changes with the slit width. Make the best measurements you can of the positions of zero intensity with respect to the central maximum, and calculate the wavelength of the laser light. You will need to measure the distance from the slits to the screen and use some simple geometry to relate your measurements to θ.

6   Two Slit Interference- Theory

Consider two parallel slits, their centers separated by the distance d. First suppose that the common width of the two slits is so small that their single slit diffraction patterns are spread over a very large area. The intensity of the interference pattern is given by

$$I = I_0 \cos^2[\pi d \sin \theta / \lambda] \tag{3}$$

This function is plotted in Fig. 2. The larger the slit separation d the shorter the distance between the zeros of the intensity pattern.

If we now allow the two slits to have the common non-negligible width a, the resulting intensity pattern is given by the product of the single slit pattern for one slit and the interference pattern for two very narrow slits. The intensity has the form

$$I = I_0 \cos^2[\pi d \sin \theta / \lambda] \left(\frac{\sin[\pi a \sin \theta / \lambda]}{\pi a \sin \theta / \lambda} \right)^2. \tag{4}$$

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This is plotted in Fig. 3 for $d = 4a$. The two slit interference pattern oscillates faster than the single slit diffraction pattern, and the latter can be thought of modulating the former. For what angles is the itensity zero?

7   Experiment With Two Slits

Mount the slide with the four double slits in the holder and place it in front of the laser. Observe the interference pattern across the room on a sheet of 11X14 in paper. The widths of the slits a and the distance between them d are given on the slide. Move the slide back and forth several times, exposing the different slits to the laser light, noting how the pattern changes with the slit parameters. Make the best measurements you can of the positions of zero intensity with respect to the central maximum, and calculate the wavelength of the laser light. You will need to measure the distance from the slits to the screen and use some simple geometry.

8   Additional Observations

Be aware of easily observed diffraction and interference phenomena. Two dimensional patterns can be seen when looking at a street light or car tail light through a screen or gauze-like curtain. Sometimes a slightly cracked door with a light in the other room produces an appreciable pattern.

Press an index finger and middle finger together to make a slit. Look at a distance light source, noting what happens as you press the fingers closer together.

9   Finishing Up

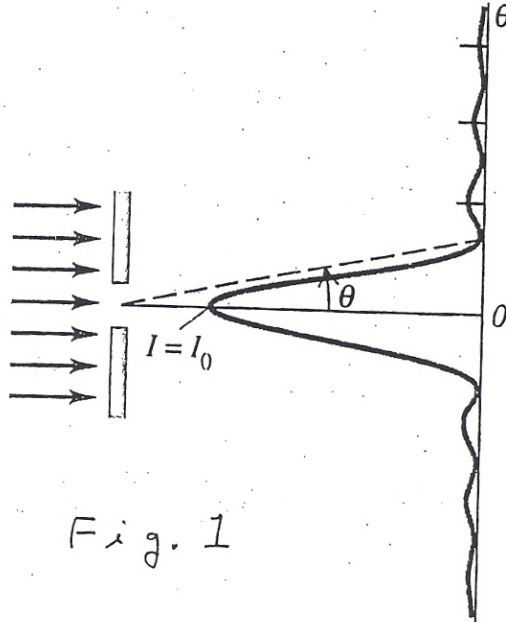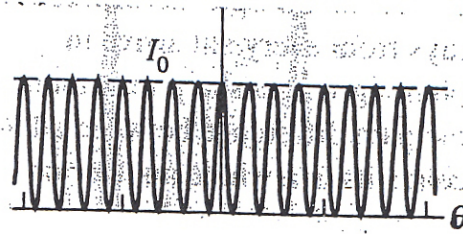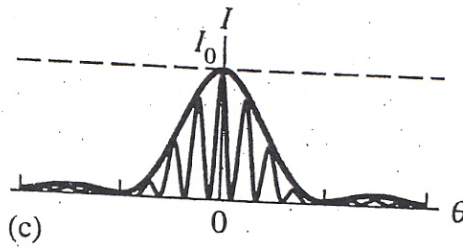Please leave the bench as you found it. Thank you.

Fig. 1

Fig. 2

Fig. 3