Vision Science 203B LABORATORY 8
OPTICS

INTERFERENCE AND DIFFRACTION

Purpose: This lab serves to familiarize the phenomena of physical optics. We have worked mainly with geometrical optics. The section on aberrations was when we first started looking more at the wave nature of light, which is referred to as physical optics. We will see that the geometric or ray description of light is only a special case, and that the wave model can describe many more properties of light. Light is an electro-magnetic wave. The electric field component (amplitude) of one beam can add or subtract from that of another, which is known as interference. Furthermore, the electric field interferes with itself when propagating through an aperture, which is known as diffraction. We will observe these two physical optics phenomena in this lab.

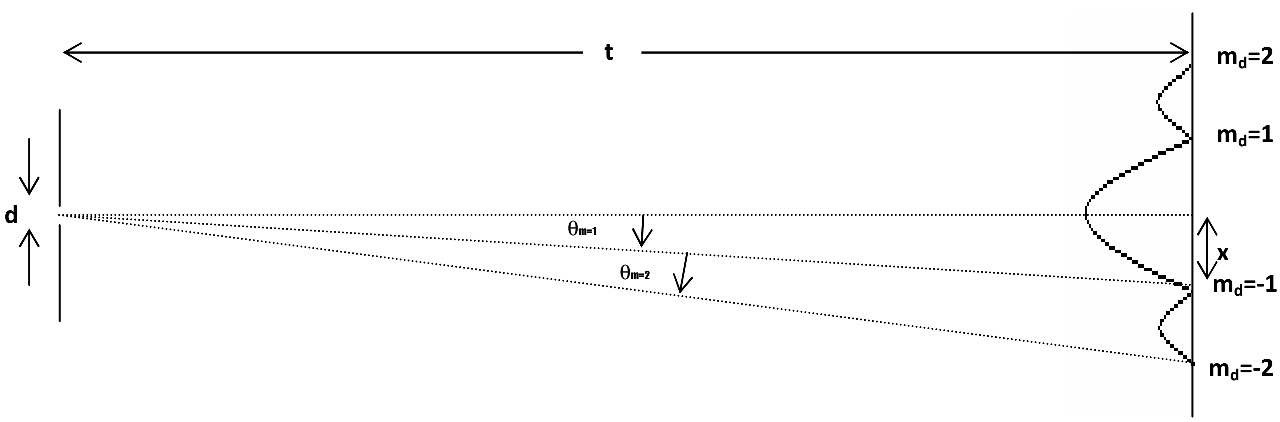
SECTION 1 - THEORY AND EQUATIONS FOR THIS LAB

Diffraction:

The fringes produced by the diffraction of light at a single slit are a surprisingly simple demonstration of the wave nature of light. Dark fringes (minima) occur when wavelets of light propagating from the slit arrive such that there is destructive interference among the wavelets. This occurs where:

$$d \sin\theta = \lambda m_d \text{ where } m_d = \pm 1, \pm 2, \pm 3...$$

In this formula, d is the slit width, θ is the angle the dark fringe subtends from the axis, m_d is the fringe order, and λ is the wavelength of the light source.



The distances from the central peak to the periodic minima is given by:

$$x = \frac{m_d \lambda t}{d}, \text{ where } m_d = \pm 1, \pm 2...$$

For a circular aperture, the formula is slightly different: $x = \frac{1.22\lambda t}{d}$ where d is the diameter of the aperture.

Interference:

When a coherent light source illuminates two slits in the manner of the famous experiment of Thomas Young the two spherical waves emerging from the slits interfere with each other to form a symmetrical pattern of varying intensity. This can be seen on a screen as an alternating pattern of bright and dark fringes. The bright interference fringes occur where:

$$h\sin\theta = \lambda m_i \text{ where } m_i = 0, \pm1, \pm2, \pm3...$$

In this formula, h is the separation between the two slits and the other variables have the same meanings as in the formulae for diffraction. The two sets of formulae are very similar as diffraction is just more interference at a different scale. Since the angles that the fringes subtend with the optical axis are very small, we may safely use the small angle approximations:

$$\tan\theta \approx \theta$$

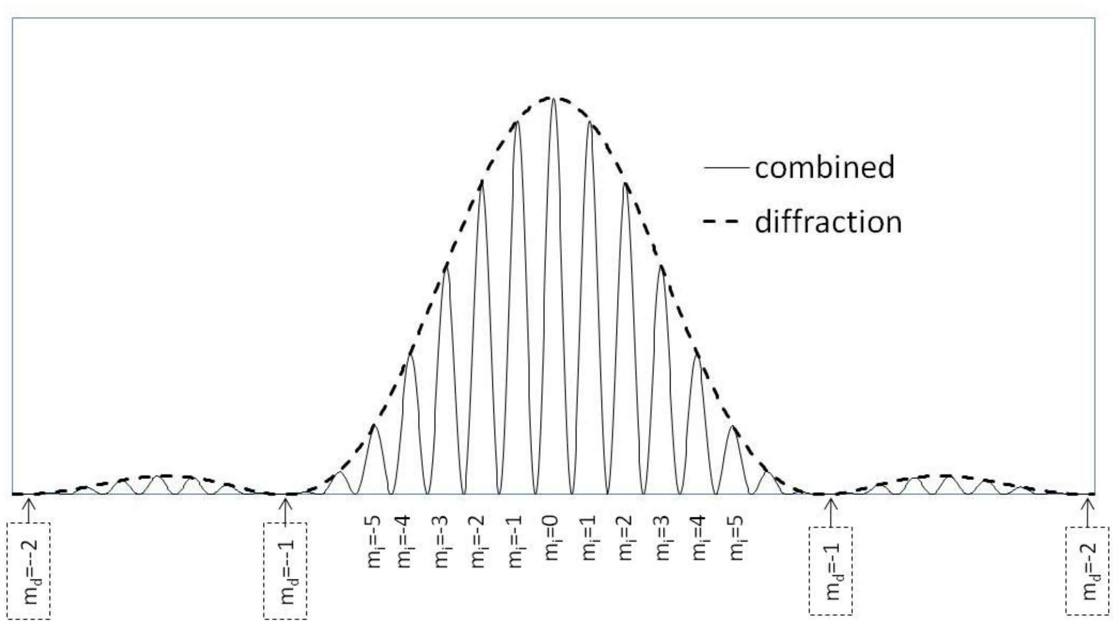
The distance on the screen (x) from a given interference maxima to the central maximum is then:

$$x = \frac{m_i t \lambda}{h}$$

Where x is measured in mm, λ is in µm, h is in mm, and t is in m.

Combined Diffraction and Interference:

In the lab, the double-slit apertures are comprised of two slits that have a fintie width (otherwise no light would get to he screen). Because of this, the double slit interference patterns contain effects of diffraction caused by each slit aperture. The combined effect is a fine double slit pattern, whose overall intensity is modulated by the diffraction patter of a single slit. The folloowing figure shows the combined pattern. The peaks casue dby interference are labeled m_i=0,+/-1… and the minima caused by diffraction are labeled m_d=+/-1, +/-2…..



SECTION 2 - DIFFRACTION AND INTERFERENCE DEMONSTRATIONS

Procedure 2.1

1. Place the slide with the single slits in the slide holder and then place this on the optical bench.
2. Mount the He-Ne laser on the optical bench 20cm from the slide.
3. Tape a piece of paper to the wall for an image screen, positioned so that the laser light will fall near the top.
4. Direct the laser beam through the single slit marked 0.16mm (w=0.16mm). You will observe a diffraction pattern formed on the wall. Measure the slit to screen distance. Keep this distance throughout the entire experiment. If you move the apparatus, then re-measure t.
5. Using a steady hand and a fine pencil, mark the location of the central peak, then mark the locations of the minima in the diffraction pattern on either side of the peak, up to the highest order that you can reliably see (ie. m_i = +/- 10). Measure the distance between the last minima on either side of the central peak. Divide this distance by two times the order of the last minima to get the average fringe spacing (ie if you measured the distance between the minima for m_i = +/- 10, then divide the total distance by 20). Use this value to calculate the wavelength of the laser.
6. Label your drawing with the slit width and slit to screen distance.
7. Move your paper higher up on the wall to provide a blank area for the next demonstration. Repeat steps 4 - 6 using d=0.08mm.

Demo	t (distance to wall)	d (slit width)	Avg fringe spacing	θ for m_d=1	λ for m_d=1
1		0.16mm			
2		0.08mm			

Questions:

- *What happened to the fringes when you decreased the slit width? Was there any change in the spacing of the diffraction minima, the width of the extrema, or the intensity of the bright fringes?*
- *The HeNe laser emits a wavelength of 632.8 nm. How accurately were you able to compute the wavelength? This is a practical way to double check your measurements*

$$\%error = 100\left|\frac{\lambda - \lambda_{measured}}{\lambda}\right|$$

Procedure 2.2a

1. Move your paper up to provide a blank imaging area, or put a new piece of paper on the wall if necessary.
2. Replace the single slit slide with the double slit slide. Direct the laser beam through the double slit labeled .08/.5 (so d=0.08mm, and h=0.5mm). A combined interference-diffraction pattern will appear on the screen. The combined pattern is afine double-slit interference pattern, modulated by a broader single-slit diffraction pattern.
3. Using a steady hand and a fine pencil, mark the locations of as many maxima in the fine fringe pattern that you can reliably identify within the central lobe of the distribution. Measure the total distance between the outermost peaks and compute the peak spacing. Record this value in the table on the next page.
4. Now repeat step 5 from the Procedure 2.1 to measure the minima in the broader diffraction pattern generated by the finite slit width.
5. From each of these average spacings, calculate the wavelength of light of the He-Ne laser.
6. Label your drawing with the slit width, slit separation and slit to screen distance.
7. Move or replace your image screen as necessary, and repeat steps 3 - 7 using the double slit slides labeled .08/.25 (so d=0.08mm and h=0.25mm), .04/.5 (so d=0.04mm and h=0.5mm), and .04/.25 (so d=0.04mm and h=0.25mm).

Questions: What happened to the fringes when you decreased the slit width? Was there any change in the spacing of the diffraction minima, the width of the extrema, or the intensity of the bright fringes? What about the interference fringes? For a given slit width, what happened when you changed the slit separation? Did the effects of decreasing slit separation differ between the narrower and wider slits?

# Slits	t	d	Avg diffraction minima spacing	θ_1 (diffraction)	λ	h	Avg interference maxima spacing	θ_1 (interference)	λ
2		0.08				0.5			
2		0.08				0.25			
2		0.04				0.5			
2		0.04				0.25			

Procedure 2.3

1. Now mount a screen on the track and bring it to about 50 cm from the aperture holder. Measure the distance *t*.
2. Replace the double slit slide with the slide containing the circular apertures.
3. Shine the beam through the larger circular aperture and observe the Airy disk diffraction pattern. If you are having trouble seeing the first ring in the Airy disk, then bring the screen closer (make sure you re-measure the distance *t*) or turn down the room lights further. Carefully measure the distance from the central peak to the first minimum. This will be your *x* in the formula for the circular aperture provided in Section 1.
4. With the wavelength and aperture to screen distance known, estimate the diameter of the aperture
5. Repeat steps 1-4 for the smaller circular aperture

aperture	t	λ (nm)	Actual aperture diameter	Measured aperture diameter (d)	% error
Circle dia = 0.08mm		632.8			
Circle Dia = 0.04 mm		632.8			