Lab 9 – Laser Interference and Diffraction

Name ______________________________________

I. Introduction/Theory

Interference is the cancellation or reinforcement that occurs when two or more waves, from different (coherent) sources, are present at the same point. *Diffraction* is the bending or spreading of waves from a source or aperture of finite size. In this experiment, you will observe the effects of interference and diffraction of light waves, and use them to determine the dimensions of various small apertures.

Both interference and diffraction may be analyzed by considering how waves that have traveled different paths combine at various points in space. For example, consider a beam of parallel monochromatic light incident upon a barrier in which there is a narrow slit, as in Fig. 1. If the slit width (a) is not very large compared to the wavelength of the light, some light will spread into the regions in which, geometrically, one would expect to see shadow. The intensity distribution of the light on a distant screen will be something like that drawn in Fig. 2.

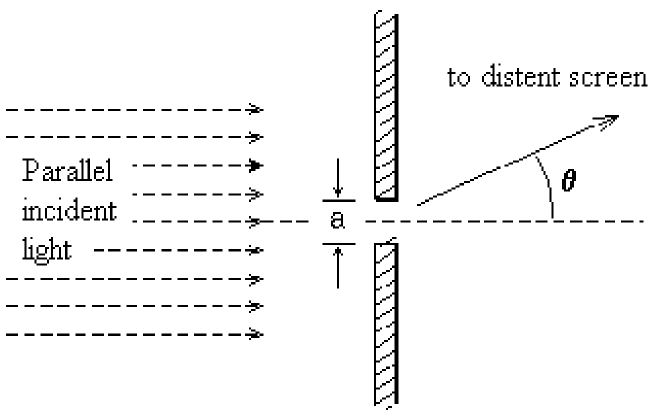

Figure 1 A diffraction Experiment

This pattern can be constructed by considering the superposition of "wavelets" reaching the screen from different parts of the slit opening. These differ in phase, because of the different path lengths they have had to travel. At certain points on the screen (certain directions θ), all these wavelets *cancel* one another and the intensity of light reaching the screen is very small, or even zero. These intensity *minima* are in directions (θ) given by

$$\sin(\theta) \cong m\frac{\lambda}{a} \quad \text{for } m = 1, 2, 3, 4, \ldots \qquad (1)$$

The intensity maxima are *approximately* halfway between the minima.

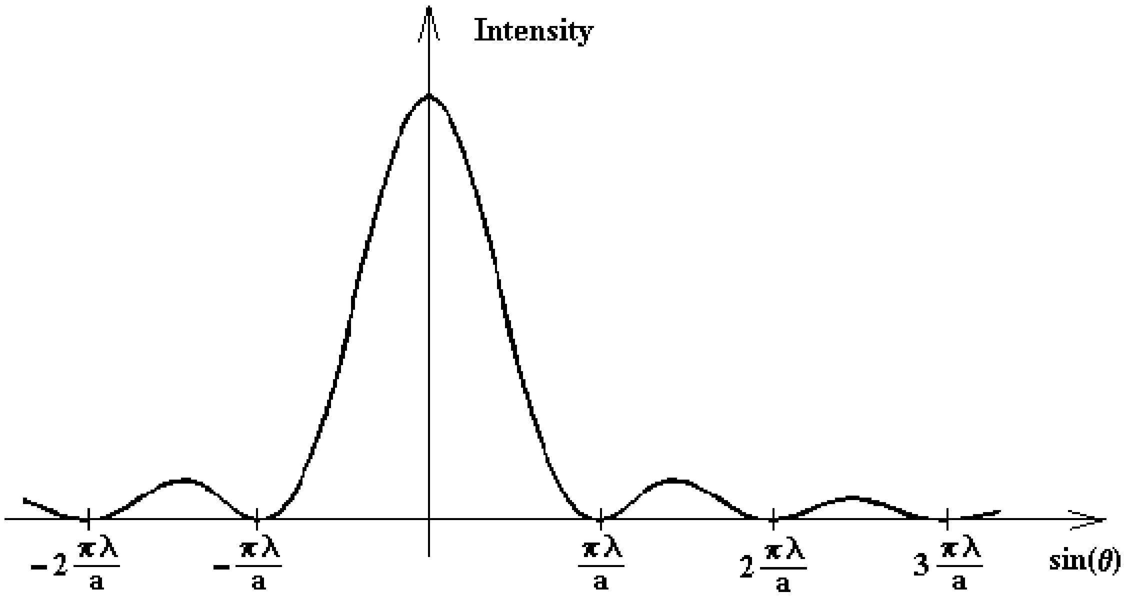

Figure 2: Intensity pattern in diffraction from aperture of width *a*.

Now consider a beam of parallel monochromatic light incident on a barrier in which there are *two* parallel narrow slits, as in Figure 3. The slits have width *a* and a center spacing *d*. Light that reaches a point on the screen from the center of one slit will have traveled a shorter distance, shorter by an amount $d\sin(\theta)$, than light reaching the same point from the other slit. If this distance is just $\lambda/2$ (or $3\lambda/2$, $5\lambda/2$, etc.), light from the two slits will be exactly π (or 3π, 5π, etc.) out of phase at the screen, and cancel. These *interference minima* will, therefore, occur at angles given by

$$\sin(\theta) \cong \left(m + \frac{1}{2}\right)\frac{\lambda}{d} \qquad (2)$$

for $m = 1, 2, 3, \ldots$ But the intensity of light coming from *each* slit has an intensity pattern like that of Figure 2, due to diffraction, which *modulates* this pattern, and the resultant intensity pattern is like what's shown in Figure 4.

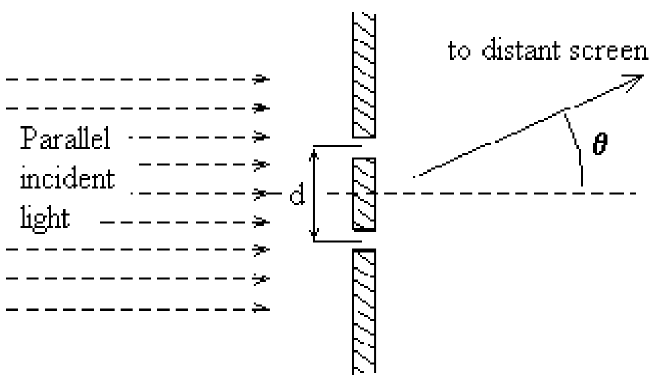

Figure 3: Two slit interference

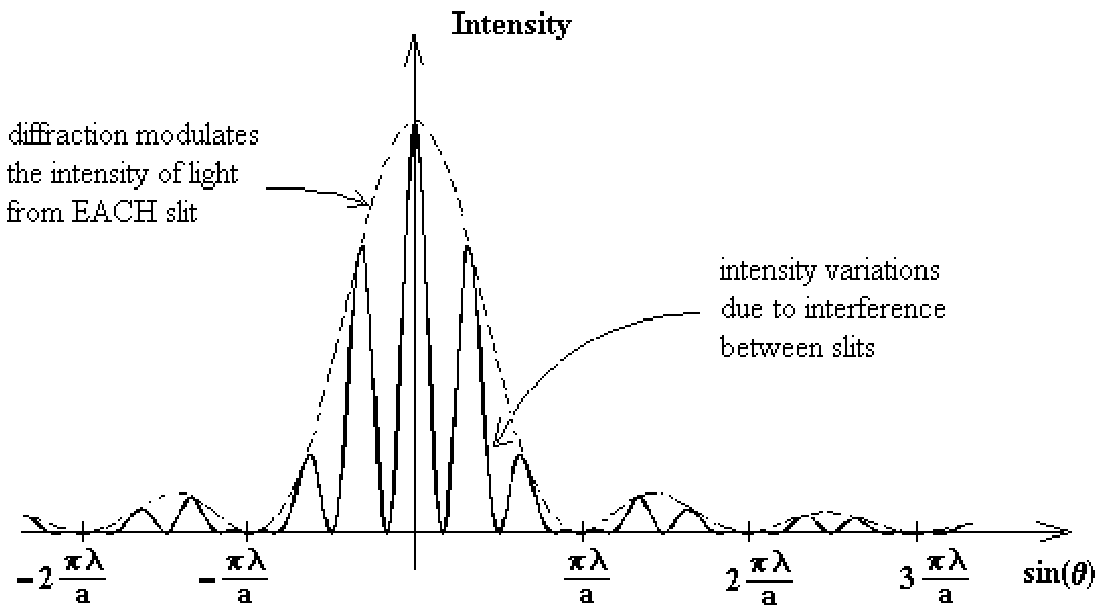

Figure 4: Intensity pattern from two slits spaced *a* distance *d* apart

II. Equipment

Diode laser (660 nm < λ < 680 nm)
optical bench
Screen
apertures: Single slit set and Multiple slit set
Ruler

III. Procedure/Data

The object of this lab is to measure the interference/diffraction patterns produced by each aperture, and infer the aperture dimensions. You will measure the patterns directly.

1. Set up the apparatus as indicated in Fig. 5. The "screen" is the location at which the pattern is.

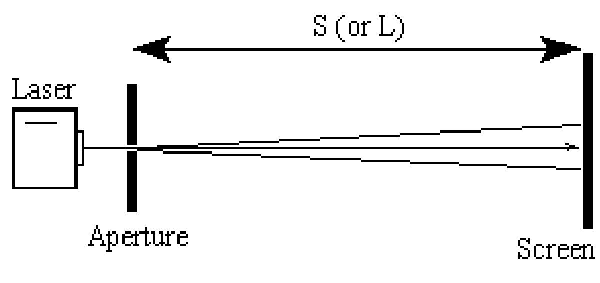

Figure 5: Experimental arrangement

2. Adjust the laser as necessary to have the beam at the right height.
3. You will need the aperture-to-screen distance in the laboratory. This should be measured at the start of the lab period. Each group should make whatever other measurements are necessary to obtain the distance *s* from the apertures to the points where the interference and diffraction patterns are being observed. Maintain this aperture to screen distance for the whole lab.

s = ____________________ ± ______________________

4. First, using the 0.04 mm single slit, record the diffraction pattern directly, by holding *notebook paper* against the screen, and marking the positions of as many dark spots or zones as is feasible. Record all significant features of the pattern you see. Everyone in the group needs to record this data on their own sheet of notebook paper. This data taken on paper needs to have a title. This paper should be attached via a staple to this lab.
5. Repeat the previous step except use the 0.08 mm single slit. Repeat again using the 0.02 mm single slit. Note the minima recorded on notebook paper may all be recorded *neatly* on one sheet of paper.
6. Replace the single slit set with multiple slit set. Adjust the aperture to screen distance to the previous value, s.
7. Using the a = 0.04 mm / d = 0.25 mm double slit, record the diffraction pattern directly, by holding *notebook paper* against the screen, and marking the positions of as many dark spots or zones as is feasible (you need not exceed the twenty around the central maximum). Record all significant features of the pattern you see. Everyone in the group needs to record this data on their own sheet of notebook paper. This data taken on paper needs to have a title. This paper should be attached via a staple to this lab.
8. Repeat the previous step except use the a = 0.04 mm / d = 0.50 mm double slit. Note the minima recorded on notebook paper may all be recorded *neatly* on one sheet of paper.
9. Using the a = 0.04 mm / d = 0.125 mm multiple slits in the MULTIPLE SLITS quadrant of the multiple slit set, observe and record the effect of changing from 2 slits to 3 slits to 4 slits to 5 slits.

IV. Analysis

1. Measure and tabulate all diffraction minima, y_{min}, from the central maximum of the three diffraction patterns. The tabulated value can be included with the interference pattern sheet. Record you best Δy_{min} for the first minimum with uncertainty for each of the three apertures $\{\Delta y_{min} = y_{min}(k+1) - y_{min}(k)\}$. Briefly describe the technique you used to determine the best Δy_{min} and S_y.

2. Using the average wavelength of the laser (670 nm ± 10 nm), calculate the slit width, *a*, for each single slit aperture. Extra Credit: use error propagation to calculate the uncertainty in *a*, and statistically compare your measured value with that on the single slit set (show work).

3. Does the distance between minima increase or decrease when the slit width, a, is increased?

4. Notice that, in the setup you'll be using here, the angles θ in Equation (l)-(2) are in all cases very small. Thus, the position of a maximum or minimum on the distant "screen" is given by

   y = s tan(θ) ≅ s sin(θ), so that sin(θ) ≅ y/s (3)

   Thus the interference minima from the double slit should be at angles θ such that

   $\left(m+\frac{1}{2}\right)\frac{\lambda}{d}=\frac{y}{s}$ or $y=\left(m+\frac{1}{2}\right)\frac{s\lambda}{d}$ which means they should be evenly spaced on the screen, with spacing Δy = s/d. Find the experimental values of d ~~and a~~ based on the interference patterns of the two double slits.

5. Does the distance between minima increase or decrease when the slit separation, d, is increased?

6. What are the similarities and differences between the single and double slit?

V. Conclusions (include physical concepts and principles investigated in this lab, independent of your experiments success, and summarize without going into the details of the procedure.)