

DIFFRACTION AND INTERFERENCE

In this experiment you will demonstrate the wave nature of light by investigating how it bends around edges and how it interferes constructively and destructively. You will observe these effects in a variety of situations and use the wave theory of light to measure wavelength.

SINGLE SLIT

If light is made of particles, a beam of such particles should pass straight through a long, narrow slit and form a single spot on a screen placed beyond the slit. If it is wavelike in nature, a more complex pattern results. The light waves reaching a given point on the screen each arrive from a different part of the slit, so their amplitudes must be added, and an interference pattern results. Consider pairs of points separated by a distance of half the slit width, such as (A,B) or (C,D) in Figure 1 below. There exists a location on the screen for which waves coming from point C are out of phase with waves from point D by exactly one-half of a wavelength, so their amplitudes add to zero.

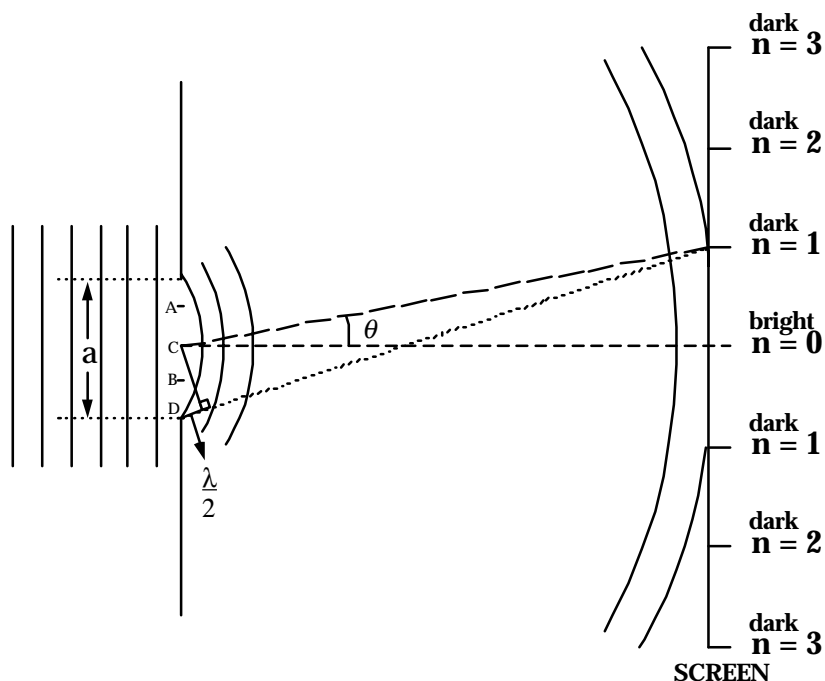


Figure 1

The situation shown ($n=1$) in Figure 1 is for the first destructive minimum and occurs at two positions with angles $\sin \theta = \lambda / a$.

Additional *minima* occur at $\sin \theta = n \lambda / a$. The $n = 1$ minimum is the most important one. For small θ , the angle in radians is $\theta = \lambda / a$. This angle is important because it is the

limit of the angular resolution of an optical system. For a circular lens, the smallest angle between two points of light which can be resolved is $\theta = 1.22 \lambda/a$, where the 1.22 factor depends on the shape of the lens and a is the diameter of the lens.

DOUBLE SLIT

Waves passing through one of two long, narrow slits will diffract in passing through each slit as described above, but in addition there will be interference with the waves from the other slit. Figure 2 below shows the geometry so you can convince yourself that there is constructive interference causing intensity maxima at points on the screen for which

$$\sin \theta = \frac{n\lambda}{d}, \quad n = 0, 1, 2, 3, \dots \quad (2)$$

The slits are separated by a distance d . If the distance nS (distance of maxima from $n = 0$) to the n th maximum is much smaller than the slit to screen distance L , one can also approximate: $\sin \theta \approx \theta = nS/L$. In this case, the maxima are equally spaced.

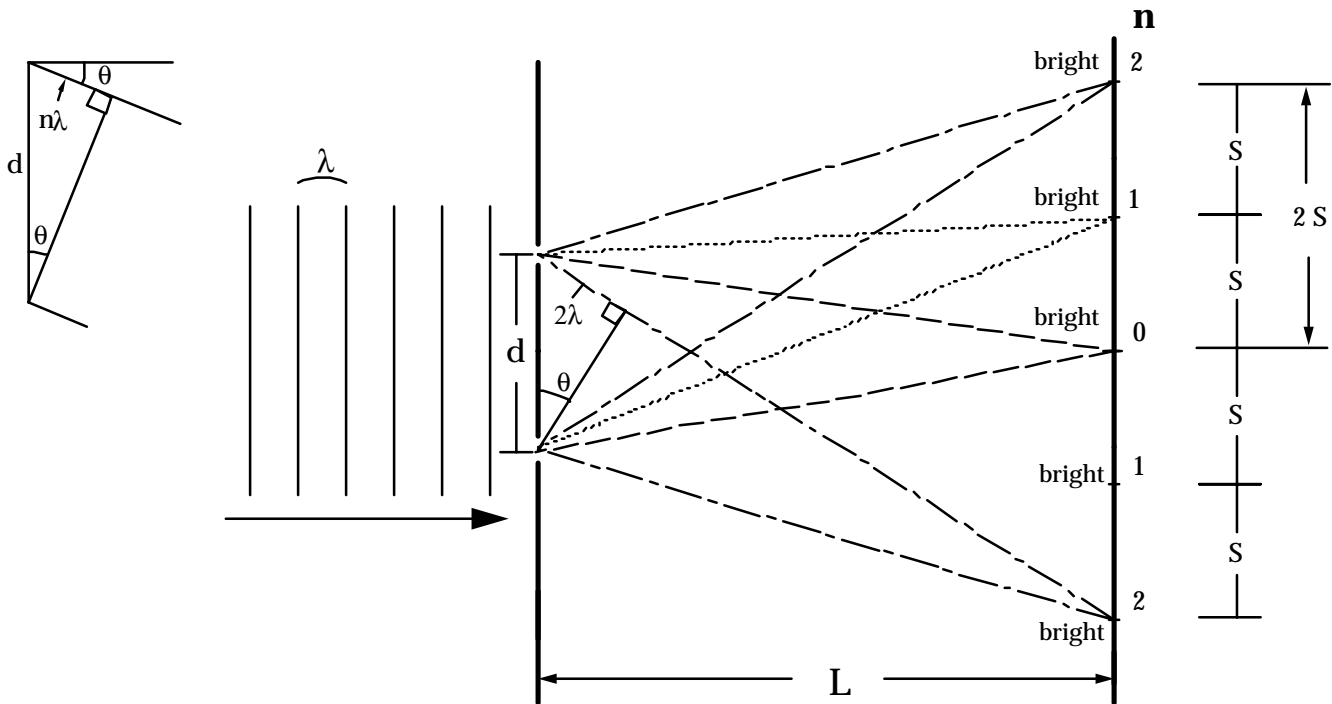


Figure 2

The interference is completely destructive (intensity *minima*) where

$$\sin \theta = \frac{(n + \frac{1}{2})\lambda}{d}, \quad n = 0, 1, 2, 3, \dots \quad (3)$$

The diffraction pattern that is actually observed from the double slit is the theoretical double slit maximum pattern shown in Figure 3 -- from Equations (2) and (3) -- modulated

by the single slit minimum pattern -- from Equation (1) -- shown in Figure 4. The result is shown in Figure 5. Note that some of the double-slit maxima have nearly zero intensity as they coincide with single slit minima, as shown in Figure 4. These are termed *missing orders*.

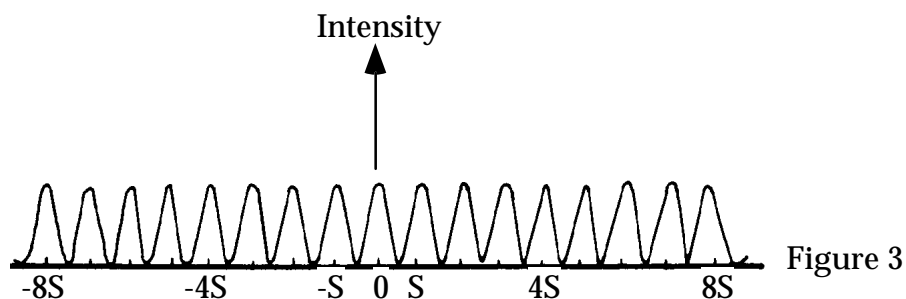


Figure 3

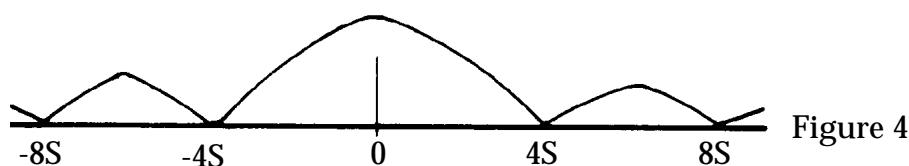


Figure 4

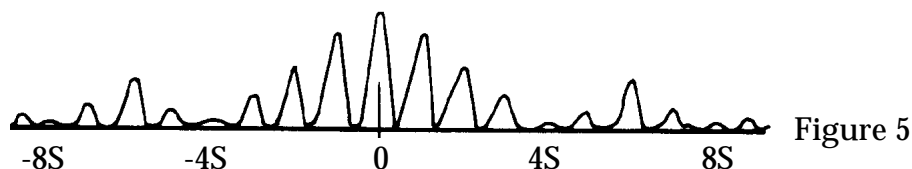


Figure 5

MULTIPLE SLITS: THE DIFFRACTION GRATING

For part of this lab you will be using an array of many slits, a *diffraction grating*. Because of the great number of slits, the interference at a small distance from a maximum will be very destructive and the maxima will be extremely narrow. This makes the diffraction grating a useful tool (i.e., a spectrometer) in measuring wavelength very accurately. Mathematically, the maxima occur when

$$\sin \theta = \frac{n\lambda}{d}, \quad n = 0, 1, 2, 3, \dots \quad (4)$$

as for the double slit (Equation 2). Figure 6 shows the situation.

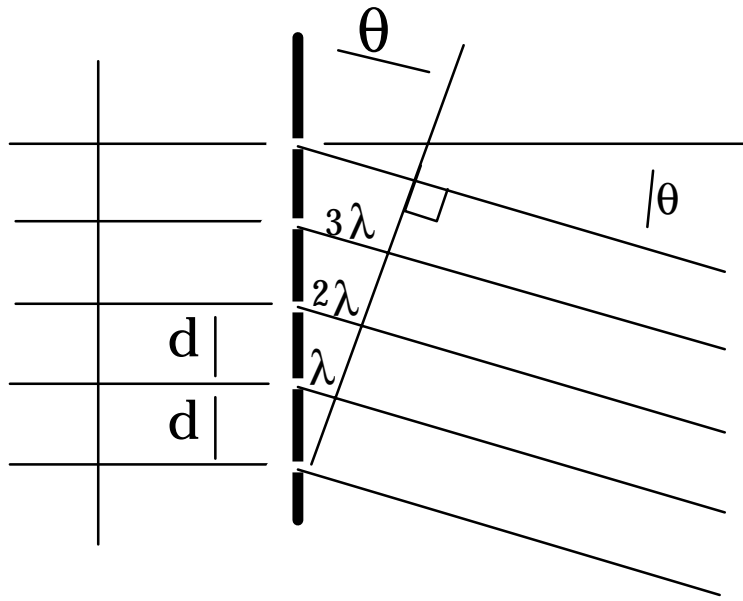


Figure 6

GRAZING INCIDENCE

A reflector with rulings on it will work in a similar way to the grating described above. In this case, the waves are not incident normal to the surface but instead are incident at a small angle. Light is not reflected from the ruling but from the smooth surfaces between the rulings. Consider the waves that reflect from between the rulings. It is possible for interference to occur. From Figure 7 below, convince yourself that the difference in the lengths of light paths #1 and #2 is $d(\cos \alpha - \cos \beta)$ where d is the spacing of the lines. There will be constructive interference for all pairs of angles α and β that satisfy

$$n\lambda = d(\cos \alpha - \cos \beta), \quad n = 0, 1, 2, 3, \dots \quad (5)$$

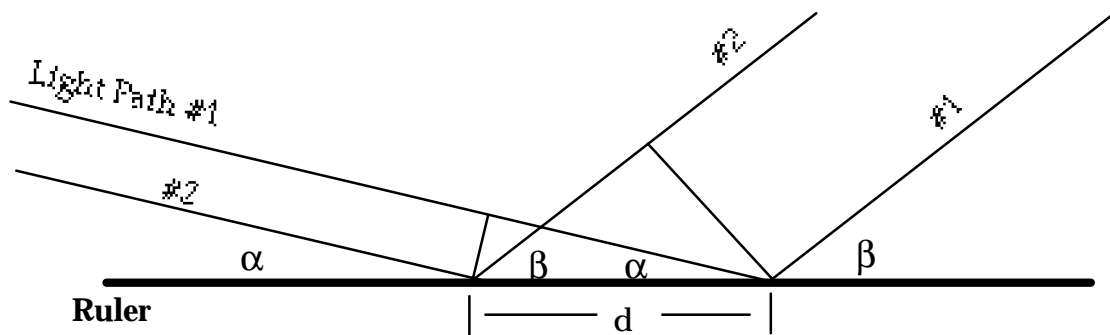


Figure 7

From Figure 7, the path length difference is seen to be smaller than the ruling separation d . $\cos \alpha$ and $\cos \beta$ are nearly equal to 1 if the angles are small (a few degrees). By using the small angle approximation for the cosine function, we can derive an expression that can be

more easily used to explain the pattern you will observe. If α is expressed in radians, we have for small angles $\cos \alpha \approx 1 - \frac{1}{2}\alpha^2$. Substituting this in Equation (5) gives

$$n\lambda \approx \frac{d(\beta^2 - \alpha^2)}{2} \approx \frac{d(S_n^2 - S_0^2)}{2L^2} \quad (6)$$

The last step uses the additional approximation that for small angles, $\alpha \approx \tan \alpha$. As shown in Figure 8, S_n is the distance from the n^{th} order to a line extended from the ruler to the screen.

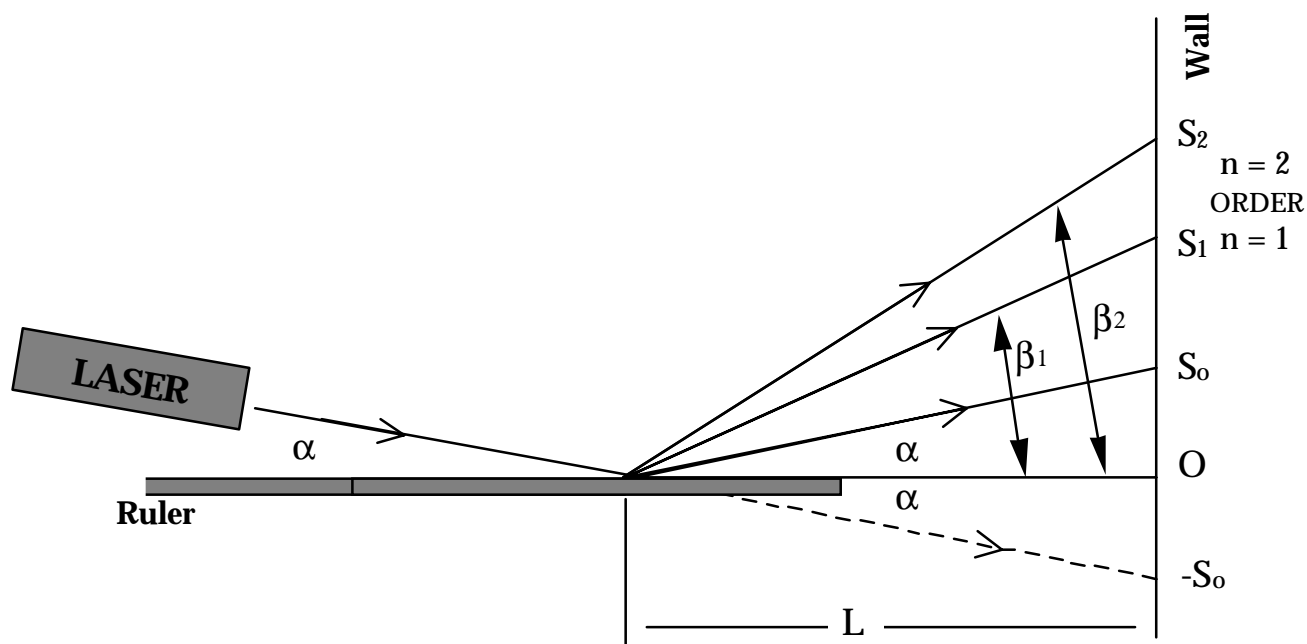


Figure 8

Because the path length difference is so small, this method can be used to measure wavelengths λ that are of order 1000 times smaller than the groove spacing d . One important use of grazing incidence is measuring the wavelength of X-rays ($\lambda \approx 10^{-8}$ cm) by means of an ordinary grating ($d \approx 10^{-4}$ cm).

THE APPARATUS

We have provided a diffraction grating, a steel ruler to be used for grazing incidence, and a glass plate containing a variety of single and multiple slits. Figure 9 is a key to the glass plate. The three numbers for each slit or set of slits are, from top to bottom: the number of slits; width of each slit; and separation between slits, respectively (the third number is obviously missing for single slits). The separation is given in *points* (a point in this instance is equivalent to .0017296 inch). The continuous line varies smoothly both in

width and number of slits, allowing an aesthetically pleasing investigation of the changes in the pattern (including missing orders) as a function of these parameters.

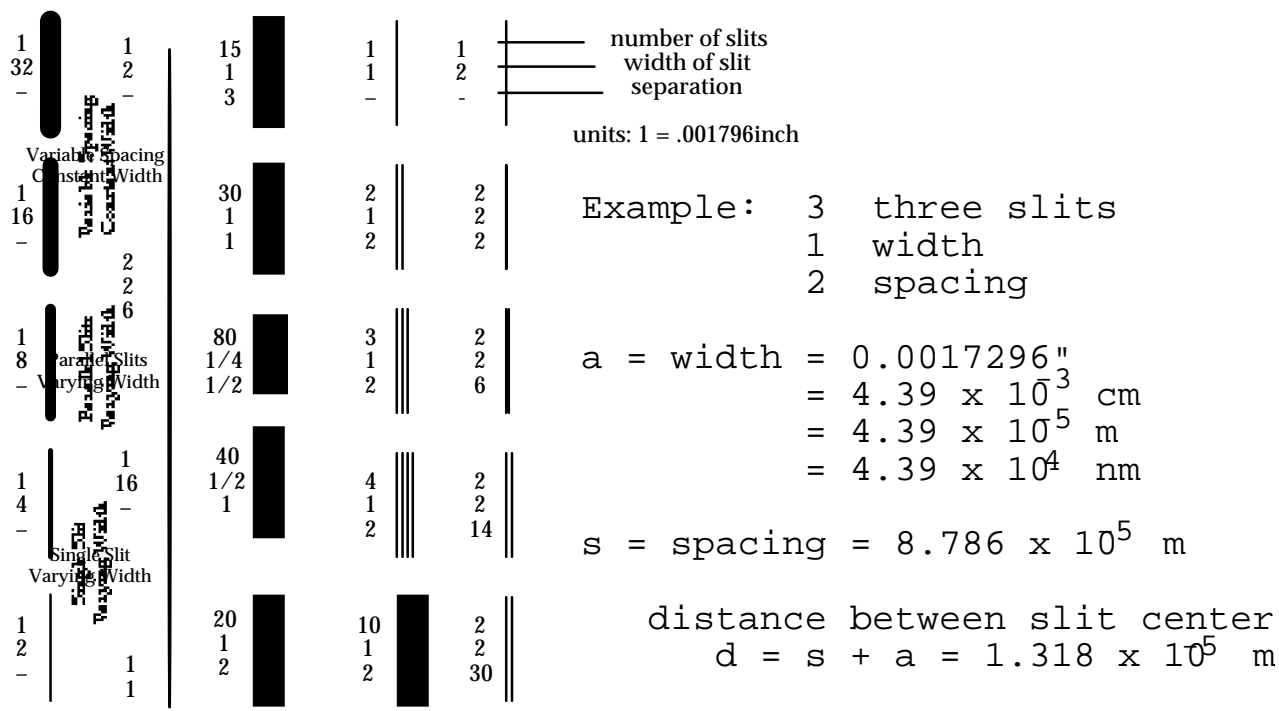


Figure 9

The diffraction grating is made by making a plastic mold of a metal surface in which thousands on uniformly spaced scratches are made. Their separation must be on the order of 10 wavelengths of the waves to be studied, or about $5 \times 10^{-4} \text{ cm}$ for visible light. When used with normal incidence waves, the spaces between the rulings pass the waves and the rulings scatter them.

Do not touch the diffraction/replica grating with your fingers. Dirt and oil from your hands will cause blurring of the light. Do not attempt to clean the diffraction grating, it scratches very easily.

APPARATUS

- ☐ Optical bench
- ☐ Meterstick
- ☐ Twometerstick
- ☐ mountings for gratings
- ☐ Masking tape
- ☐ 8.5 x 11" paper
- ☐ Diffraction grating/replica grating
- ☐ 4 Rod holders
- ☐ 1 Lens Clamp
- ☐ 6" steel ruler with 1/100 divisions
- ☐ Interference and diffraction glass slide
- ☐ Magnetic holder for diffraction grating
- ☐ HeNe laser

EXPERIMENT 1. SINGLE AND MULTIPLE SLITS

This is both quantitative and qualitative. Set up the glass diffraction set slide so that the laser beam is normal to the glass surface. If the glass plate has a magnet attached to it, use the U-shaped metal holder; otherwise, the glass slide can be mounted in a clamp with a rubber cushion -- be careful not to tighten the clamp too much, or you may break the glass slide. Adjust the height of the laser and/or plate so that the incident beam strikes an opening and a diffraction pattern appears on the wall (at least 2 meters away). Observe the patterns of bright and dark spots. Tape a piece of paper to the wall so you can mark their locations. In doing this, include enough information to answer the following questions:

1. How does varying the width of a single slit affect the separation and widths of diffraction maxima and minima?
2. For double slits, what is the effect of increasing the separation?
3. How does the change in number of slits change the width of the bright spots (intensity maxima)? Does this agree with prediction?
4. Look for missing orders in the double slit pattern. Use equations (1) and (2) to show that missing orders occur when $d / \lambda = 2, 3, 4, \dots$. Do the missing orders (for double slits) occur where they are predicted to by theory?
5. Use the data from the two slit and multiple slit measurements to calculate λ for the laser. This can be done using Equation 2 and $\sin \theta = n \lambda / d$ by measuring $\sin \theta$, n , and d . Measure to both the left and the right of $n = 0$ for $n = 1$ and $n = 2$.
6. Use the diffraction grating to obtain a more accurate value for λ . Mount the grating so that the laser beam is normal to the surface. Measure the distances to the $n = 1$ maximum on both sides of the $n = 0$ maximum. Measure the distances from wall to grating. Find θ using $\tan \theta = S / L$. The angle here is too large for the small angle approximation to be accurate. Find the grating spacing d from $1 /$ (the number of lines per cm). Find λ from $\lambda = d \sin \theta$. Compare with the expected $\lambda = 632.8 \text{ nm}$.

EXPERIMENT 2. GRAZING INCIDENCE: WAVELENGTH OF LASER LIGHT

Remove the glass plate and mount the ruler so that the laser light grazes the rulings at a small angle as shown in Figure 8. Aim the laser at the part of the ruler with the smallest spacing between the rulings. You should observe a diffraction pattern on the wall. Is it similar to any you have looked at? Try to explain the separation of the orders (bright spots) in terms of Equation (6) (i.e., how should the distance S_n vary with n ?). Also, compare the separation of these bright spots to the separation of those obtained when you double or halve the spacing between rulings.

Now you are ready to make measurements. Tape a piece of paper to the wall for marking the positions of the spots. Record as many as you can; include the direct beam spot and the spot caused by mirror reflection from the ruler. The direct beam spot is recorded before the ruler is put in place. These are both needed to calculate the angle α . Take care to identify the mirror reflection spot carefully. Record also the spacing of the markings on the ruler in inches or millimeters, and the distance from ruler to wall. Use equation (6) to find λ for laser light using the ruler.

ANALYSIS AND QUESTIONS

7. In Experiment 1, the slits are long and narrow. Why is the diffraction pattern one dimensional? What happens to the pattern in the long dimension? What would you observe for a small square slit? A round pinhole?
8. Explain why the separation of orders decreases as n increases in Exp. 2. Equation (6) may be helpful.

DATA SHEET — DIFFRACTION AND INTERFERENCE

TA []

NAME _____ INSTRUCTOR: _____

PARTNER _____ SECTION: _____ DATE: _____

EXPERIMENT 1: (FOR FIRST 3 COLUMNS, SEE KEY IN APPARATUS SECTION)

# of Slits	Width	Slit Sep.	Order Sep.	Other Obs. (missing orders, etc.)

EXPERIMENT 2

L	Ruling Sep.	$S_0 - (-S_0)$	α

n												
S_n												
λ												

Average λ : _____