

## WORLD OF LIGHT LABORATORY

### LAB 4

### Diffraction and Interference

#### INTRODUCTION:

Diffraction and interference are quintessential wavelike properties that essentially all waves exhibit but other things do not. Electromagnetic radiation propagates as waves so it exhibits diffraction and interference, as you will observe in this lab. Historically, diffraction and interference experiments in the early 19th century provided the key information that showed that light was a wave, which had been a matter of much debate for the preceding several hundred years. Diffraction and interference are also central to a substantial amount of modern technology, ranging from antireflection coatings on camera lenses to sparkly tinsel sold at drug stores. Outdoors, we observe interference effects on bird feathers, butterfly wings, oil sheens, and soap bubbles.

Diffraction and interference are often presented together, as they are here, but they are different phenomena. Diffraction is the bending of waves at an edge between transmitting and non-transmitting regions. For example, when light goes through a small hole, the light spreads out after it goes through the hole. Interference is the adding together of two waves to form a resultant wave that may have a greater or lower amplitude. These phenomena are often used together. For example, we will investigate a two-slit interference pattern here in which laser light diffracts after going through two slits and then the two new wave patterns interfere with each other.

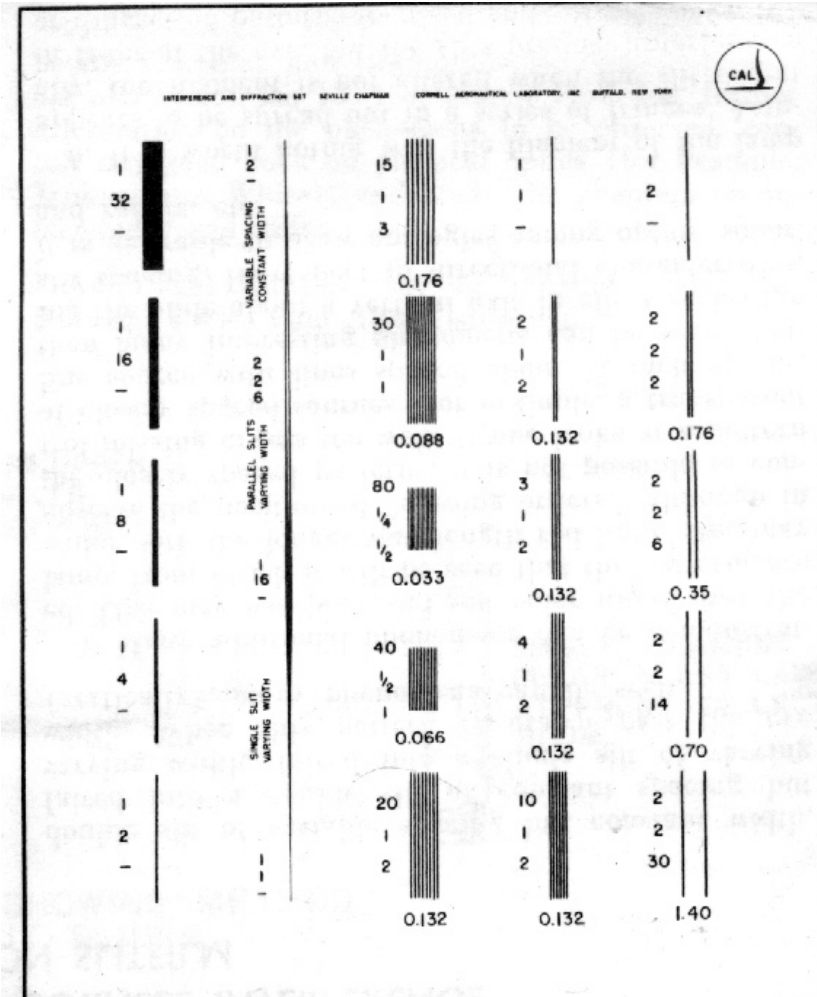
#### LASER SAFETY

*Lasers can damage your eyes! They can also damage other people's eyes!*

- Don't look directly into the laser beam.
- Take off your watch and any reflective bracelets *before starting this lab* because these can cause unintentional reflections.
- As you move optics around, keep them from reflecting laser light into your eyes or other people's eyes.
- As much as possible, keep the laser beam at table height and parallel to the table top. This will keep beams away from eye level.

#### MATERIALS

In this lab, you will use a HeNe laser, an optical bench, a sodium lamp, a Strathmore board (a long white board with a slit in the middle of it), and a slit film. Most of these are self-explanatory. The slit film is diagrammed in the following picture:

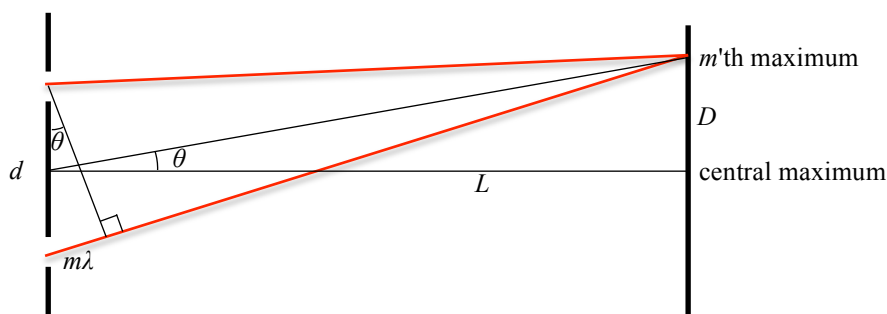


On the left side of each slit pattern, the numbers report: the number of slits in this pattern, the width of the slits, and the widths of the separations between the slits. These sizes are remarkably complicated, as they are given in printer's points (1/72 of an inch) before the original was scaled down 8-fold to produce the final slit film. Thus a slit width of 1 is 0.044 mm, 2 is .088 mm, 3 is 0.132 mm, 4 is .176 mm, 5 is .220 mm, 6 is .265 mm, 7 is .309 mm, 8 is .353 mm, etc. The separation of two slits, from center to center, is the sum of the slit width and the slit separation values. Thus, for example, the top multi-slit pattern has a center-to-center separation of 4 points, which is 0.176 mm. This value is shown below the pattern. Other values shown below the patterns also give the center-to-center slit separations in mm.

**THEORY**

The double slit arrangement is shown in the following figure. The slits are on the left, the screen is on the right and two light paths are shown in red. There is a central maximum on the screen directly opposite the center of the two slits because both light paths have the same distance to this point, so the waves will have the same phase and will interfere constructively. There are multiple maxima above and below this central maximum, of which the *m*'th is

highlighted here ( $m$  is some integer, of which 1 is the easiest one to think about). At this  $m$ 'th maximum, the lower beam is a distance  $m\lambda$  longer than the upper beam because there has to be an integer number of wave differences to achieve constructive interference again. Using this distance, we draw the right triangle on the left. It has hypotenuse  $d$ , which is the separation between the slits, and one side equal to  $m\lambda$ .



Using the definition of the sine function, the angle in this triangle that is opposite the side with length  $m\lambda$  relates to these distances as

$$\sin \theta = \frac{m\lambda}{d} .$$

We also draw another right triangle. It has a base of  $L$ , which is the distance between the slits and the screen, and height  $D$ , which is the distance between the central maximum and the  $m$ 'th maximum. A little geometry work shows that the angle opposite to the side with length  $D$  has the same angle  $\theta$  as above. Using the definition of the tangent function, this angle relates to the triangle sides as

$$\tan \theta = \frac{D}{L} .$$

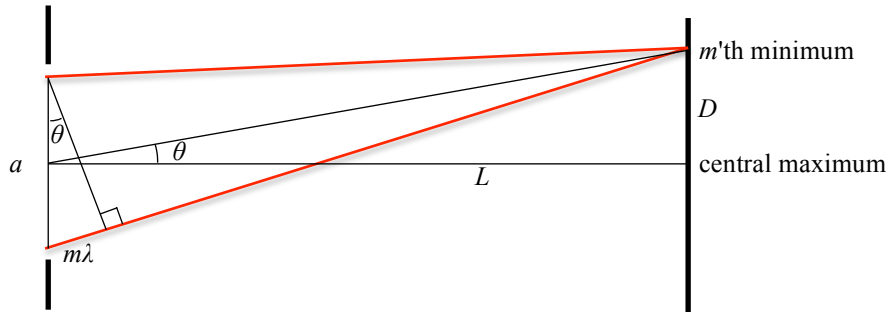
For small angles,  $\sin \theta \approx \tan \theta$ , enabling us to combine these two equations to give

$$\frac{m\lambda}{d} = \frac{D}{L} .$$

Thus, if you know any four of these quantities, you can use this equation to find the fifth one. The analysis for multiple slits, including for a diffraction grating, is identical to that for two slits.

On the other hand, the analysis for diffraction from a single slit is a little different, but has a deceptively similar result. Now, the key insight is that each *minimum* in the interference pattern will occur at the point where there is constructive interference between the ray traveling at one extreme edge of the slit with the ray at the other extreme edge of the slit. To see this, consider also the ray that goes through the center of the slit. This center ray will interfere destructively with the ray at the top edge. Likewise, a ray that is a little below the center will interfere destructively with one that is a little below the top edge. More generally, every ray that goes through the top half of the slit will interfere destructively with the ray that

is exactly half a slit width below it. This means that there is destructive interference for all rays, which makes this an intensity minimum.



The same mathematics then leads to the result that the intensity minima are at

$$\frac{m\lambda}{a} = \frac{D}{L} .$$

## **PROCEDURES**

### **Part 1. Two slits**

Place a laser at one end of your optical bench, a “slit film” near the middle of the bench, and a large screen at the other end of the bench. If you have a beam steerer, place that between the laser and the film. Aim the laser beam onto a two-slit section of the film and observe the resulting interference pattern. Sketch the intensity distribution ( $x$ -axis is position,  $y$ -axis is intensity). Aim the laser beam onto other two-slit sections of the film and observe those interference patterns, too. How does the slit spacing affect the interference pattern?

Pick one of the double slit arrangements. For that one, measure the interference pattern spacing. Note that you can measure this directly as the distance between two brightness maxima. Or, you might get more accurate results by measuring the distances between minima. Also, it might also help to measure the distance across multiple fringes and then dividing by the number of fringes. Use the appropriate equation from above to compute the slit spacing. For a HeNe laser, which is what you’re using, the wavelength  $\lambda$ , is 633 nm. Compare this slit spacing with the value published for the slit film, given above.

**Part 2. Many slits**

Using the same setup, aim the laser beam at the patterns in the middle column of the slit film, each of which has multiple slits. Observe the interference patterns and sketch an intensity distribution. How does the slit spacing affect the interference pattern? How are these interference patterns different from those for two slits?

Pick one multi-slit arrangement. For that one, measure the interference pattern spacing. Using the appropriate equation from above, compute the slit spacing. Compare this slit spacing with the value published for the slit film.

**Part 3. One slit**

Now aim the laser beam at the single slit patterns, observe the interference patterns, and sketch an intensity distribution. How does the slit width affect the interference pattern? How are these patterns different from the ones that you saw for two slits and many slits?

Pick one single-slit. For it, you want to measure the interference pattern spacing, which in this case is the distance between the central maximum and the first minimum. However, this is hard to measure accurately. So, instead, measure the distance between then two minima that are on either side of the central maximum and then divide by two. Once again, use the appropriate equation to compute the slit width. Compare your result with the value published for the film.

**Part 4. A human hair**

Replace the slit film with an empty lens holder. Tape one human hair across it. Aim the laser at the hair. Now, you should see a very prominent laser dot, along with a weak interference pattern. Sketch the intensity distribution. Babinet's principle says that the interference pattern from a narrow obstruction should be identical to that for a narrow slit (and, more generally, the interference pattern from any opaque body is identical to that from a hole of the same shape). Thus, the interference pattern should be essentially the same as that for a single slit. Is this what you observe? By measuring the interference pattern spacing, determine the width of the hair.

**Part 5. Diffraction grating**

Put a diffraction grating in the laser beam. Again, observe the interference pattern and sketch the intensity distribution. How does this compare to the one for the multi-slit arrangement? Determine the grating spacing. Compare your results to the value written on the grating.

**Part 6. Sodium lamp**

You're now done with the laser, so you can turn it off. However, keep the diffraction grating. At the "screen" end of the optical bench, mount a Strathmore board. Put a sodium light behind this board, aimed so that as much light as possible goes through the slit. One person should now stand on the other side of the diffraction grating. By looking at the grating, that person should see the slit through the grating when looking directly at the slit, and that person should also see multiple images of the slit that are substantially to the left and right of the actual one. These latter images should be dispersed into the spectral lines of the sodium lamp. The other group member should draw lines on the Strathmore board at the positions where the images of the yellow line appear to be. Measure these line positions and calculate the sodium light wavelength. Compare your results to the known value of 589 nm.

**Lab report**

As usual, this lab explanation and worksheet is purely for your own use and does not need to be turned in. Instead, turn in a more polished report, prepared using Microsoft Word or equivalent. It should have five clearly labeled sections: Introduction, Methods, Results, Discussion, and Conclusions.

**Introduction**

- Write a few sentences about why diffraction and interference are important.

**Methods**

- Briefly describe what you did in this lab. One paragraph should be adequate.

**Results**

- Present your qualitative results, regarding the effects of different patterns (two slits, multiple slits, one slit, hair, and diffraction grating) and the effects of different slit separations. Include sketches of the intensity distributions that you observed. Discuss similarities and differences among these patterns.
- Present your quantitative results, including the slit separations, the single slit width, the hair width, and the sodium lamp wavelength.

**Discussion**

- Compare your results against the known ones (the slit film data from the manufacturer and the sodium wavelength). Discuss how good the agreement is.
- What were the main sources of error? This is not about what mistakes you made, but what errors were unavoidable.

**Conclusions**

- Summarize your results and primary conclusions from them in 4-5 sentences. Include the key qualitative results and how well your experimental results agreed with theory. This section should not include new material, but should summarize the key findings from above. This is about the science results that you determined, not about how much you learned.