

Student Name _____ Date _____

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.237 Modern Optics Project Laboratory

Laboratory Exercise No. 4

DIFFRACTION

Spring 2023

To get the most out of your in-lab experience, you must come to Lab prepared (makes life easier for you and the TA and minimizes your time in the Lab). Thus, you should go through this Lab manual, complete the Pre-Lab exercises, and answer all the Pre-Lab questions BEFORE entering the Laboratory. In your lab notebook record data, explain phenomena you observe, and answer the questions asked. Remember to answer all questions in your lab notebook in a neat and orderly fashion. No data are to be taken on these laboratory sheets. Tables provided herein are simply examples of how to record data into your laboratory notebooks. Expect the in-lab portion of this exercise to take about 3 hours. **Also note that an oral report is required for this Laboratory Exercise.**

INTRODUCTION

The objectives of these exercises are to explore and investigate the phenomenon of diffraction through a series of simple and then more advanced experiments. The first set of diffraction experiments will be carried out with He-Ne laser light with a wavelength of 632.8 nm. These include:

- (1) Fraunhofer diffraction from single slits, double slits, multiple slits, gratings, circular, rectangular, triangular and hexagonal apertures, and rectangular grids.
- (2) Fresnel diffraction from circular apertures and obstacles
- (3) Investigation of the focusing and imaging properties of a Fresnel zone plate.

"If you cannot saw with a file or file with a saw, then you will be no good as an experimentalist."

– Augustin Fresnel (1788-1827)

PRE-LAB EXERCISES

PL4.1 – Getting Prepared to Start the Laboratory Exercises

Read the **entire** laboratory handout, and be prepared to answer questions before, during and after the lab session. Determine all the equations and constants that may be needed to perform all the laboratory exercises. Write them all down in your laboratory notebook before entering the Lab. This will ensure that you take all necessary data while in the Lab to complete the lab write-up. This preparatory work will also count toward your Lab Exercise grade.

Please answer the following pre-lab questions:

- For single-slit Fraunhofer diffraction, what is the theoretical expression for the angular location of the bright fringes?
- Explain why and how varying the slit separation in a double slit affects the diffraction pattern.
- How does the Fraunhofer diffraction pattern from a circular aperture depend on the diameter of the aperture?
- Why does the Fraunhofer diffraction pattern from a circular aperture always have a bright maximum at its center whereas the Fresnel diffraction from a circular aperture does not always have a bright maximum at its center?

IN-LAB EXERCISES

A. Fraunhofer Diffraction

The setup we will use to demonstrate and study Fraunhofer diffraction is shown below. Note that it is important to illuminate the objects with a planar wavefront to observe Fraunhofer diffraction. In many cases, a reasonably accurate Fraunhofer pattern can be obtained with the raw laser beam (i.e., without the beam expander) and with the screen sufficiently far away from the diffracting object (see Figure 1).

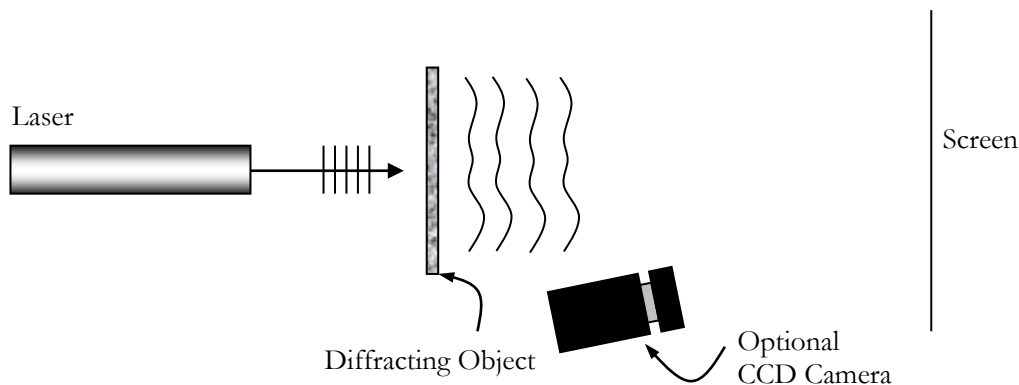


Fig. 1. Setup for observing Fraunhofer Diffraction

4.1 Single Slit

- (a) Set up and observe the Fraunhofer diffraction pattern owing to the variable single slit. Observe how the pattern changes as the slit width is varied. Qualitatively sketch the typical pattern. Describe your observations and explain why the pattern changes the way it does.
- (b) Have the TA set the slit width to a specific value. Record the corresponding micrometer reading in your notebook. Measure the angular distribution of the bright fringes (record the measurements in your notebook). Determine the slit width from your measurements.

4.2 Double Slit

Set up and observe the Fraunhofer diffraction pattern owing to the given double slits. These are contained on the upper level of the plastic slide labeled 4.2/4.3.

- (a) Sketch the pattern and measure the angular distribution of the bright fringes for the double slit with the widest separation. From your measurement calculate the slit width and the slit separation.
- (b) In addition, view the other double slits of varying separation on the top level of the same plastic slide. Qualitatively sketch your observations. Rank the double slits in order of increasing separation.
- (d) *Optional:* Using the CCD imager as shown in Figure 1, capture an image of the two-slit diffraction pattern. It is important that you not move the imager from its current location. Using the captured image, employ Matlab to calculate the relative spacing of the slits. Provide a reconstruction of the slits, and then compare their relative dimensions numerically.

4.3 Multiple Slits

Set up and observe the Fraunhofer diffraction pattern owing to the N-slit gratings. These are contained on the bottom row of the plastic-mounted slide of 4.2. The number of slits, N, in each grating is indicated beneath each set of the gratings.

- (a) Sketch the pattern for various values of N and explain **qualitatively** what happens as N increases from 2. What is the theoretically expected pattern as $N \rightarrow \infty$.
- (b) Examine the Fraunhofer patterns from the three transmission diffraction gratings (labeled as 2,400, 7,500 and 15,000 lines/inch) and describe the patterns you see. Do the patterns from the gratings behave as predicted by the theory?
- (c) For the grating labeled 15,000 lines per inch, measure the diffraction angles of the spots, and use this information to compute the actual periodicity of the grating. The grating material has aged over the past 15 years because of environmental effects. Did it shrink or expand?
- (d) Note that only 5 diffracted spots are visible with the 15,000 lpi grating. Why do we not see an infinite number of spots? What determines the maximum number of diffraction spots? Derive a mathematical expression for the maximum number of spots.

4.4 Rectangular Grid

Set up and observe the Fraunhofer diffraction due to the rectangular grid. Make a qualitative sketch of the pattern and explain how it differs from that of the rectangular aperture (below).

Rectangular, Triangular, Hexagonal and Circular Apertures

There are two glass plates labeled A1 and A2 containing transparent rectangular, triangular, hexagonal and circular apertures. A sketch of the two plates is shown in Fig. 2.

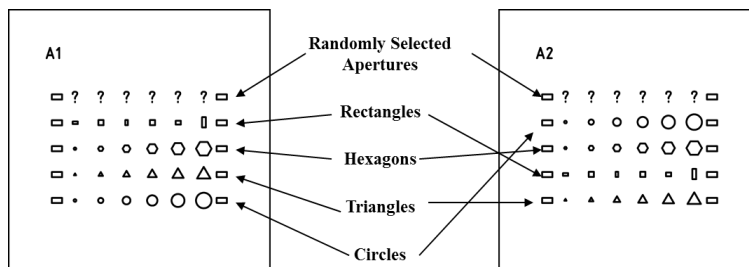


Fig. 2. Glass-plate diffracting apertures for 4.5 and 4.6

4.5 Rectangular Aperture

Choose one of the plates and set up and observe the Fraunhofer diffraction pattern due to the rectangular apertures. There are six different rectangles on the plate. Refer to the diagram above to find their locations on the plate. Illuminating the plate from behind with an incoherent light source (e.g., a flashlight) should prove helpful in locating and aligning the apertures in the plate.

- (a) Choose any rectangular aperture and sketch its diffraction pattern on a separate sheet of paper (to be pasted into your lab notebook). Make angular fringe location measurements and label your sketch with the measurements.
- (c) Use your measurements to compute the width (horizontal) and the height (vertical) of one of the apertures. If needed, have the TA or LA assist you in finding the diffraction objects on each plate provided. Size shown below is exaggerated.

4.6 Triangular and Hexagonal Apertures

Set up and observe the Fraunhofer diffraction pattern owing to the triangular and hexagonal apertures. These are located on the second row of the plate as illustrated in Figure 2.

- (a) Roughly sketch the patterns next to each other in your lab notebook.
- (b) What are the qualitative differences between the patterns?
- (c) Using the Matlab simulation of the hexagon and triangle diffraction intensity patterns (in Problem set 4), describe the difference between the two simulated diffraction patterns. What are the observable differences between the computer simulation, and the actual observed pattern?

4.7 Circular Aperture

Set up and observe the Fraunhofer diffraction pattern owing to the circular aperture.

- (a) Qualitatively sketch the pattern, but quantitatively measure the diameter of the Airy disc, and label the sketch with your measurement. Make sure you measure the Airy disc correctly! Check with the T.A. or L.A. to be sure. In your lab writeup, be sure to include the sketched pattern, and precisely indicate the boundaries of the Airy disc.
- (b) Use the results of (a) to calculate the size of the aperture.

4.8 2-D Grating Mirror

A thin substrate is provided which consists of a 2-D array of circular holes in a mirror substrate. Operate the system in reflection with an angle of incidence of 45° . Set up and observe the Fraunhofer pattern due to this grating.

- (a) Sketch the diffraction pattern.
- (b) What is the packing symmetry of the holes in the mirror?
- (c) Measure the dimensions of the diffraction pattern and label the sketch with the dimensions.
- (d) Compute the pitch of the grating.
- (e) Is this structure a phase grating, or an amplitude grating? Why?

B. Fresnel Diffraction

The setup for Fresnel diffraction is shown below. The wavefront incident on the apertures must be very non-planar and the screen-to-object distance small (5 to 40 cm) to obtain dramatic results.

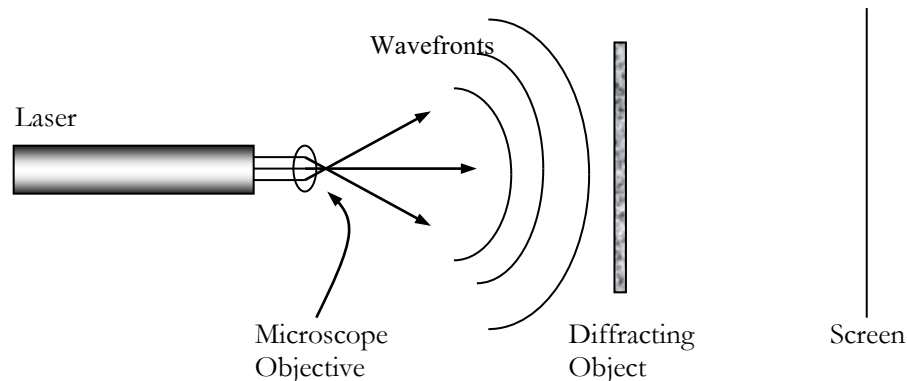


Fig. 3. Setup for observing Fresnel Diffraction

4.9 Circular Opening

Set up and observe the Fresnel diffraction pattern due to the small circular opening. The circular aperture must be less than 1 cm away from the objective lens (40X objective) to observe the Fresnel diffraction pattern. Slightly vary the distance between the aperture and the microscope objective.

- (a) Sketch a few of the different patterns you get.
- (b) Keeping the screen to microscope objective distance fixed, measure as best you can the distances between the microscope objective and the aperture (may be easier to measure the aperture to screen distance) that give 2 or 3 consecutive nulls at the center of the pattern on the screen. Use this information to get a rough estimate of the size of the aperture.
- (c) Compare the Fresnel diffraction patterns with the Fraunhofer pattern from the circular aperture.
- (d) Explain how and why the Fresnel patterns are different from the Fraunhofer patterns.

4.10 Circular Obstacle

Set up and observe the Fresnel diffraction patterns from the small spherical obstacle.

- (a) Qualitatively sketch the pattern.
- (b) Explain why there is always a bright spot in the center of the dark shadow.

4.11 Fresnel Zone Plate: Measurement of focal lengths

- (a) Place the Fresnel zone plate in a well-collimated beam of He-Ne laser light and measure the positions of the farthest three or four focused spots you can see.
- (b) From the data in (a) what are the primary, secondary and tertiary focal lengths (F_1 , F_2 , and F_3 , respectively) of the zone plate? What are your measured ratios: F_2/F_1 , F_3/F_1 and F_3/F_2 ? Are these in agreement with the theoretical values? If not, why?
- (c) From your data in (b) calculate the radius of the first zone of the zone plate. Measure the diameter of the first zone to the nearest half-millimeter with a ruler. Explain any significant difference between your measured and calculated values.

APPENDIX

As mentioned earlier, part of the Lab 4 write-up will be an oral presentation. You have two choices for topics. For the topic you choose you should discuss the relevant experiments as performed in lab and answer the related post lab questions.

A. Diffraction from repeated apertures (Experiments 4.1, 4.2, 4.3, and 4.4)

This topic deals with how the diffraction pattern changes as an aperture is repeated. You should address how the pattern of an N-slit grating can be built from the pattern of a single slit grating and an additional factor. You should discuss how the 'additional factor' is influenced by the spacing between adjacent slits and the total number of slits, and you should be prepared to discuss what happens as the number of slits goes to infinity. Finally, you should show how you can predict the pattern of the rectangular grating from the behavior of a single rectangular aperture.

B. Aperture patterns from the single slit pattern (Experiments 4.1, 4.5, and 4.6)

This topic deals with the diffraction pattern from apertures of different shapes, and how these can be predicted from the diffraction pattern of a single slit. You should show how you can create various new apertures from 'single slits' with different orientations. You should show how to use the Fourier Transform property of the far field diffraction pattern to predict the diffraction pattern of the new apertures using the pattern from the individual slits and their relative orientations. Further, you should be able to predict (though not exactly specify) the diffraction patterns of random, fixed-width line scratches based on the observations from the previous apertures and slits. Finally, you should discuss the differences you would expect to see in the far-field diffraction pattern between a circular aperture and a circular annulus that both have the same outer diameter

You should prepare a presentation that is no more than 10 minutes long with no more than 8 slides and be ready for 5 min of discussion on the topic you choose to present. Keep in mind that 8 is an upper limit, and you should really have 4-6 content slides. **Your presentation should cover the experimental work you did. Show the raw data and discuss your results. Does the theory explain your results? If not, why not?** The specified post-lab questions from the lab assignment for the topic you choose should also be covered in your presentations. Your presentation should be aimed at an audience similar to your 6.161 colleagues (who do not necessarily understand the lab material).

This cannot be said enough: **Practice your presentation.** It does make a difference.

The post lab questions for the rest of the experiments should be written up in your lab notebook; the TA will check them after the laboratory session next week.