OPTICS 380A
Lab 12: Diffraction

The study of diffraction is one of the most challenging, yet interesting topics in optics. Diffraction patterns can be simple in their visual appearance, yet difficult to describe mathematically. In this lab we take a qualitative and quantitative look at some fundamental diffraction patterns.

Whenever an aperture or obstacle is placed within the cross section of a beam of light, the transmitted light is diffracted. Fundamentally, this occurs because of the interaction of the light wave with the edge of the aperture. Geometrical optics and a ray picture lead to a sharp geometrical shadow--physical optics and a wave picture lead to diffraction. The result of this diffraction is to change the intensity distribution in the beam after the aperture. The degree to which this occurs depends on the size of the aperture relative to the wavelength of light, the distance from the source to the aperture, and the distance from the aperture to the point of observation.

The general problem of diffraction is handled mathematically by what is known as the Rayleigh-Sommerfeld formula. This is an integral which is usually not easily calculated unless some simplifying assumptions are made. Depending on the observation distance from the diffracting aperture, these assumptions lead to two formulations of diffraction--Fresnel and Fraunhofer.

An important parameter in the evaluation of diffraction patterns is the *Fresnel Number,*

$$N_f = \frac{a^2}{\lambda z} \quad , \qquad (12.1)$$

where a is the aperture radius (or ½ the maximum dimension of the aperture), λ is the wavelength and z is the distance from the aperture plane to the observation plane. Equation 12.1 assumes that the aperture is illuminated by an on-axis plane wave, like from a collimated laser beam. The Fresnel Number tells us the number of $\lambda/2$ Fresnel zones across the aperture, and it can help us to understand what the observation pattern should look like based on interference of light from the different zones. An atlas of diffraction patterns in the Fresnel region is given in the *Reference Material* section on the class website. Note that different diameters of apertures can produce the same diffraction pattern (except for a magnification factor) if they are observed at the same Fresnel number given by Eq. (12.1).

For Fresnel diffraction, the observation is typically made at a distance such that $N_f < 1000$. Note that the Fresnel number decreases as the observation plane moves *away* from the aperture, so the condition above sets a rough boundary on the *closest distance* where we observe Fresnel-pattern behavior.

For Fraunhofer diffraction, the observation is typically made at a distance such that $N_f < 0.01$. Note that the closest distance where Fraunhofer diffraction patterns can be observed is much farther away from the aperture than Fresnel patterns. In the Fraunhofer region, the diffraction pattern is given simply by the Fourier transform of the light transmitted through the aperture. For example, the Fraunhofer diffraction pattern of a rect function is a sinc function.

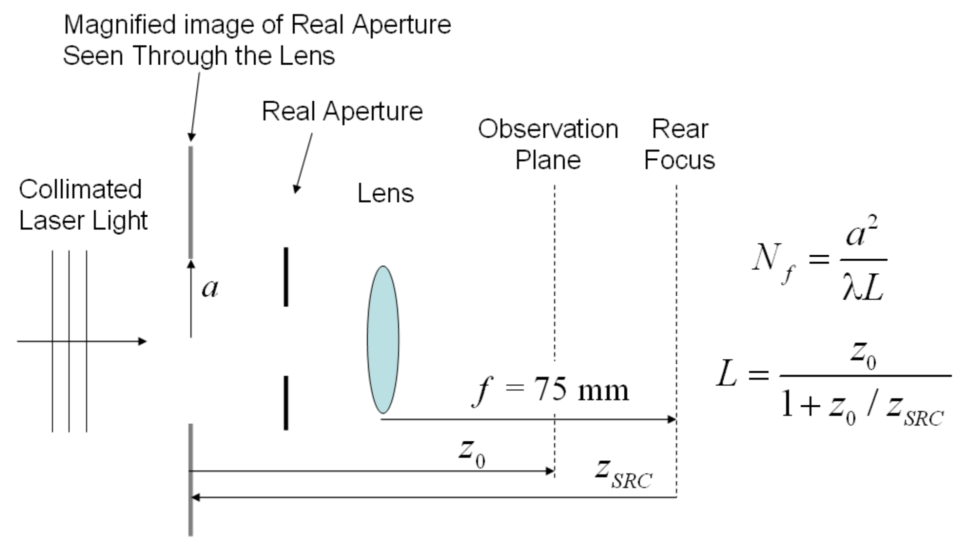

Figure 12-1. Setup used in lab with lens between real aperture and the observation plane.

Equation (12.1) must be modified slightly if a lens of focal length *f* is placed in system to converge the beam to focus, like the setup used in the experiment shown in Figure 12-1. The parameter *z* in Eq. (12.1) is replaced by *L*, where

$$L = \frac{z_0}{1 + z_0 / z_{SRC}} \quad , \tag{12.2}$$

and the Fresnel Number is given by

$$N_f = \frac{a^2}{\lambda L} \quad . \tag{12.3}$$

In this case, z_{SRC} is negative (as indicated by the backward arrow), so $L \to \infty$ as the observation is made at the rear focus, and $N_f \to 0$. With the lens, we are able to easily observe the Fresnel patterns and the Fraunhofer pattern simply by moving the objective lens.

For the experiment, we will use a camera to view the observation plane on a CCD camera, as shown in Figure 12-2. By moving the camera along the axis, we can view the diffraction patterns from an image of the aperture through the Fresnel region and to the Fraunhofer plane.

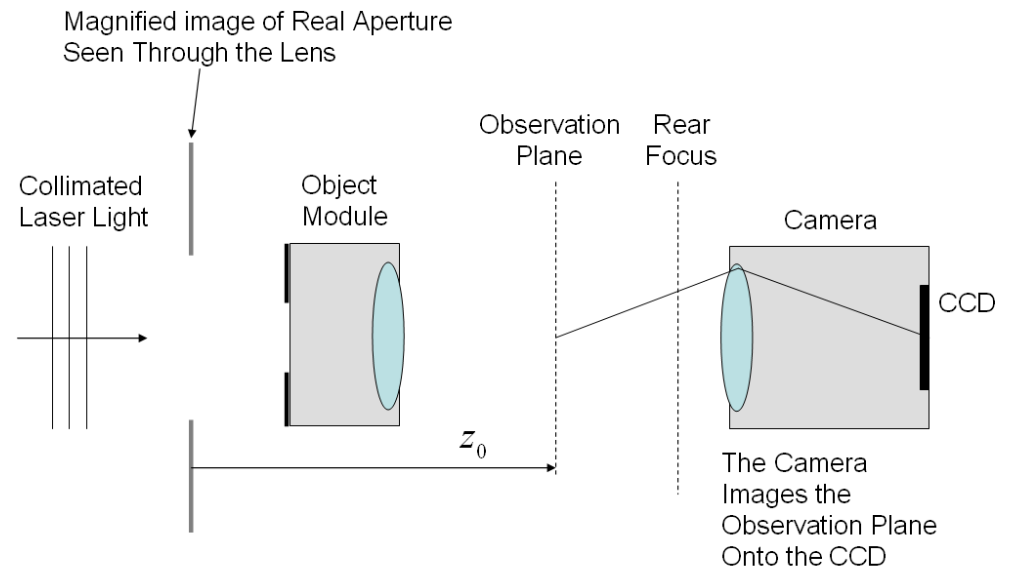

Figure 12-2. Physical modules used in the experiments to view the diffraction patterns. Moving the camera changes the observation plane. When the camera is adjusted to view the rear focus, we observe the Fourier transform of the aperture.

Part A: EXPERIMENTAL: DIFFRACTION--QUALITATIVE

You will look at a set of apertures under laser illumination. Use the experimental setup to look at the following:

(A) Sketch the setup, recording the distances between the optical elements.

(B) You have four single-slit patterns, which are 20µm, 40µm, 80µm and 160µm wide. For each of the 4 slits, calculate the distance at which the Fraunhofer region begins, according to Eq. (12.1).

(C) Describe the behavior of the diffraction pattern in the Fresnel region for the 160µm micron slit. (Hint: start with the Fraunhofer pattern and gradually move the camera toward the aperture, recentering the aperture as necessary to keep the diffraction pattern centered on the camera.)

(D) Describe the behavior of the diffraction pattern in the Fraunhofer region for the 160µm micron slit.

(E) Discuss qualitatively how the Fraunhofer pattern changes with increasing slit width.

(F) Use the double slits, which are 40µm and 80µm wide and separated by 250µm and 500µm (four total apertures). Discuss how the Fraunhofer pattern changes with different double slits.

(G) Use the complex apertures (circle, square, and triangle). Describe and sketch the behavior of the diffraction patterns the Fresnel region for the complex apertures.

(H) Describe and sketch the behavior of the patterns in the Fraunhofer region for the complex apertures.

Part B: FRAUNHOFER DIFFRACTION – Rectangular Aperture

Use the experimental setup to look at the following:

(I) Measure the Fraunhofer diffraction pattern of the 200μm by 400μm single slit by capturing the image on the camera and saving the image to the hard disk. Import the image into Matlab and plot the profile of through the peak in each transverse direction (x and y). A sample program is provided on the website to help you get started. Either work with your own laptop or one of the lab computers.

(J) Replot your normalized and scaled data, along with the plot of $\sin^2(x)/x^2$, the "sinc squared" function.

(K) From your plot, calculate I/I_o at the first maxima.

(L) How well does your value at the first maxima agree with the known value of 0.045 for the sinc squared function?

(M) From your plot, calculate I/I_o at the second maxima.

(N) How well does your value at the second maxima agree with the known value of 0.016 for the sinc squared function?

(O) Finally, draw vertical lines through the first and second minima, and the first maxima. Is the maxima located symmetrically between the two minima? Should it be?

Part C: FRAUNHOFER DIFFRACTION – Circular Aperture

(P) Replace the single slit with the 500μm circular aperture. Repeat (J)-(O) using a single profile of your image, and compare to the somb^2 function, as given in the reference material.

(R) (5pts Extra Credit) – Hold the test aperture up to you eye, as directed by the TA. Use a Maglite bulb to illuminate the aperture and describe what you see. Explain your observations in terms of part (P) and the lab bench setup. Explain what components of your eye correspond to what elements on the lab bench. Are you able to observe a Fraunhofer pattern? If so, why?