Physics 319 Laboratory: Optics

Diffraction I

Objective: In this and the next lab you will observe a variety of interesting diffraction effects.

Apparatus: You will need the Pasco optics bench, the alignment bench (looks like the optics bench, only shorter), the laser, and the optics kit.

Theory: This and the next lab are intimately related. They both consist of a series of experiments in which diffraction effect are observed. Since the list of good experiments is long, they have been split into two labs. The grouping has more to do with time than conceptual considerations, so there will be some overlap in the concepts presented in the two labs.

(Hect, section 10.1) Huygen’s principle says that every unobstructed point of a wavefront at a given instant of time serves as a point source of spherical wavelets having the same frequency as the primary wave. The amplitude of the optical field at any point beyond is the superposition of these wavelets. The superposition of wavelets is changed by obstructing portions of the wavefront. Obstacles placed in the path of a wavefront *diffract* the wavelets.

The diffraction effects are dependent on the geometry of the obstruction, the wavelength of light, and the distance between the plane of observation and the obstruction. Near the obstructing object, one observes **Fresnel diffraction**. Further away, one observes **Fraunhofer diffraction**. The condition for ‘far away’ in this case is $R >> a^2/\lambda$. One may observe Fraunhofer diffraction by projecting the diffracted light on a distant wall or by placing a convex lens in the diffraction pattern and placing a screen in the focal plane of the lens.

One simple obstruction geometry which lends itself well to mathematical analysis is that of a single slit (Hect, section 10.2.1). The irradiance of single slit Fraunhofer diffraction is

$$I(\theta) = I(0)\left(\frac{\sin\beta}{\beta}\right)^2,$$

Where $\beta = (kb/2)\sin(\theta)$, b is the slit width, and k is the wavenumber of the illuminating light. See Figures 10.9 b and 10.13 in Hecht

(Hecht, section 10.2.4) Holes of various shapes yield interesting diffraction patterns. The diffraction pattern for a square aperture is shown in Figure 10.24 in Hecht. The diffraction pattern of a circular aperture (Hecht, section 10.2.5) was first derived by Sir George Biddell Airy, and is named the Airy in his honor. See Firgures 10.28 – 10.31 for computer plots and photographs of Airy rings. The radius q_1 drawn to the center of the first dark ring is given by

$$q_1 = 1.22\,\frac{R\lambda}{2\,a}$$

where R is the distance between the aperture and the image, and 'a' is the radius of the aperture.

Procedure:

I. Alignment

Attached to this lab procedure are instructions for aligning the laser along the optics bench. Alignment is essential to this experiment, so follow these directions carefully. Do not dismantle the optics bench at the end of the lab, as you will need it again for the next lab meeting. Be sure that the laser is pointed toward a white wall for observation of the Fraunhofer diffraction.

II. Shadows

Attach a 18 mm lens to a component carrier and position it immediately in front of the laser. A large spot of laser light should be projected on the wall. You may notice some lens diffractions in the spot. Hold your hand in the laser light near the lens and observe the shadow. Observe the light and dark outlines around the shadow.

Place some objects with simple silhouettes in the laser light. Your kit has a razor blade and a coin along with some small magnets. You may use the magnets to attach the blade and coin to a component carrier so that you may sketch the shadows of these objects.

III. Shaped Holes

Assemble a beam expander in front of the laser (a 48 mm lens and a 252 mm lens exactly 300 mm apart, with the 48 mm lens closest to the laser). Illuminate the square aperture (on slide OS-9165D) with the laser light. It may be necessary to use the Aperture Mask (OS-9139) on the opposite side of the component carrier to insure that light is incident on the square only. Observe the Fraunhofer diffraction pattern on the wall. Make a sketch. Place a white card near the aperture to examine the Fresnel diffraction. Compare it to the Fraunhofer diffraction. Discuss.

Repeat the above procedure with the hexagonal aperture on the same slide.

IV. Airy Disk

Attach the smallest light source aperture (on slide OS-9118) directly on the front of the laser, so that the entire aperture is illuminated by the laser. Observe the pattern projected on the wall.

Tape a piece of paper on the wall, so that the pattern is now projected onto the piece of paper. With the most narrow pencil you have available, carefully mark the first dark ring. With a caliper, take at least three measurements of the diameter of the central bright spot (the inner diameter of the dark ring).

Now use the tape measure to as accurately as possible measure the distance from the aperture to the wall. Use these measurements (the number on the aperture refers to the diameter of the hole) to calculate the wavelength of the laser, using the equation from the theory section, making sure to use the radius, not the diameter.

Use the uncertainty calculations and write your results including uncertainty.

V. **Single Slit Diffraction**

Attach the slide of single slits (OS-9165A) on a component carrier and position the assembly midway down the bench. Adjust the slit position until the laser beam is incident on the full width of the slit. Observe the diffraction pattern on the wall. Try other slit widths and compare the distances between minima in the diffraction pattern to the slit widths.

With the slits attached to the side of the component carrier facing the laser, attach the 252 mm lens to the other side. Attach the viewing screen to a component carrier and position it at the focal plane of the lens (252 mm from the center of the lens). You should have a sharp image of the Fraunhofer diffraction pattern on the screen. Replace the screen with the linear translator so that the fiber optic probe is in the focal plane of the lens. Slowly scan the diffraction pattern with the translator. Plot irradiance vs. position. Verify that the irradiance falls off as the equation given in the Theory section. Note: You will need to take lots of data to get sufficient detail in your plot of the diffraction pattern. (See example graph and data table). You may also need to change the sensitivity of the photometer frequently to maximize the accuracy of your data. **Note: it is imperative that you re-zero your photometer every time you change the scale.**

Questions:

1. Compare and contrast Fraunhofer and Fresnel diffraction. Be sure to give a working definition of each, and refer to your sketches.

2. Qualitatively discuss the relationship between the width of the single slit, and the spacing of the corresponding minima.

3. We have $\beta = kb/2\sin\theta$, starting from there, find the expression for the angular width of the central maximum. Using that expression find the angular width of our central maximum in the lab with a He-Ne laser for slit width of 0.04 mm.

4. Do you think a Galiean telescope beam expander is better than a Keplerian beam expander? Explain with diagram.