PHYSICS 300 – –FALL 2007– – LAB #9

Diffraction

Introduction

In this experiment you will observe one of the fundamental properties of waves of any kind, but in particular, light waves. It is called diffraction, and arises whenever part of a propagating wave is blocked or otherwise altered by any object, for example, an aperture. You will have seen this phenomenon in movies of water waves.

In this experiment we will try to characterize the patterns produced by light passing through different types of apertures, and also measure the wavelength of your laser light. You will also use what you know about diffraction to measure the thickness of one of your own hairs. As you can see from pages 106 - 112 of Fowles, and also elsewhere in Chapter 5, calculating diffraction patterns is neither simple nor fun. They are often quite complicated, and even the simplest ones are not straightforward. In this experiment, we will restrict ourselves to the domain called Fraunhofer diffraction because it allows relatively simple analysis. Even so, for the most part you will be asked to make qualitative descriptions and/or sketches of the patterns, rather than quantitative measurements.

For this experiment you will need a laser, various fixed apertures for observing diffraction patterns easily, a variable circular aperture, a transmission diffraction grating, a white light source provided in your "optics kit", a piece of your hair, a photometer and probe for it, and a reasonably good linear translator.

Diffraction by Apertures

Mount your laser on one end of your optical bench, and place one of the magnetic mounts just in front of it. Verify that, for various apertures mounted on this magnetic mount, the Fraunhofer or far-field condition is satisfied. You may find it easiest to use the wall as your screen for this first part. Mount the variable aperture in front of the laser, with the edges vertical. Slide one edge towards the beam until it just touches it, keeping the other edge far (1 cm) away. Observe how this changes the pattern on the wall. Now move the other edge near to the first, so that the two edges form a slit for the beam to pass through. Observe how this changes the pattern. Make the slit as narrow as you can, and note how changing the slit width affects the pattern. Draw the patterns you see. Now, move the other two edges so that they form a second slit, on top of and perpendicular to the first one. You now have a rectangular aperture. Draw the pattern you see. Explain the origin of the pattern, in terms of the pattern that a single slit makes. Try changing the widths of the two perpendicular slits independently of one another, and describe how this affects the pattern.

Finally, replace the slits with your circular variable diaphragm, and close it as far as you can (by moving the lever on the side). Align the hole to the center of your laser beam, and observe the diffraction pattern produced. Apart from some irregularities (the hole in the middle of the diaphragm isn't perfectly circular), this pattern is called an Airy pattern. Again, explain how this arises from symmetry and the pattern produced by a single slit. Slowly open the diaphragm, and describe how the pattern changes with aperture diameter. What does the diffraction pattern look like when the aperture is very big?

Multiple Slit Diffraction

Now you will need to place the linear translator and photometer probe on the end of your bench so that it faces the laser and mounted so that it can move transverse to the laser beam. Mount the single slit with a width of 0.04 mm in the laser beam. Once again, verify that the Fraunhofer condition is satisfied. With the screen mounted in front of the photometer probe, observe the diffraction pattern produced.

You will notice that this fringe pattern has some features in common with the interference fringes you observed in the previous experiment, but a little thought will show that they are really fundamentally very different. Describe these differences both qualitatively and quantitatively.

Now select an appropriate aperture to use over the probe, and mount it in place of the screen. What is the basis for "appropriate" in this case? Translate this aperture across the diffraction pattern so that the light from various parts of it passes through to the probe, and record the intensity as a function of position of your photometer. Make sure that you record the locations of several maxima and minima (including the central maximum), and several points in between each one, to get a good idea of what the pattern looks like. Compare your graph to theory. Plot your data. Record the slit width and the distance from the slit to the probe. From this and your data, calculate the wavelength of the laser.

Now replace the single 0.04 mm slit with two adjacent and parallel 0.04 mm slits, and record the resulting pattern. Make sure you get each of the maxima and minima, covering the same range of positions that you measured for the single slit pattern. Plot this data on the same graph as the single slit pattern, and compare the two. Compare with theory. Again, comment on this fringe pattern in terms of the interference fringes you observed in the previous experiment. Now remove the linear translator and project the diffraction pattern on the wall. Look at the pattern produced by three 0.04 mm slits. Put a piece of paper on the wall, and trace the pattern. Try to indicate variations in intensity by shading your drawing. Repeat this procedure for four and five 0.04 mm slits. As you increase the number of slits, what aspects of the pattern remain the same? What changes?

Diffraction by Obstructions

Just as Fraunhofer diffraction is caused by transparent apertures, it can also be caused by opaque obstructions in an otherwise clear field. These can really be thought of as "negative" apertures. In fact, you know that the sum of the intensities for the presence of an aperture and the presence of a "negative aperture" should be exactly the same as if there were no aperture at all. To see this, mount the 0.5 mm light source aperture in the laser beam, and observe the diffraction pattern on the wall. You should see the Airy pattern. Now try mounting the 0.5 mm opaque spot in the beam, and look at its pattern. Compare the two patterns. What's the difference between them?

Now, gently pluck a hair from your head, or, since gently plucking a hair is impossible, find a more violent means of getting one (or use the scissors). Hold the hair taut across the aperture mask slide, and tape it down. Mount the mask with your hair in the beam, and carefully align things so that the beam strikes the hair, and the hair is vertical. Look at the diffraction pattern produced. Your hair is just a "negative" slit. Reposition the linear translator on the end of your bench, and measure the locations of the maxima and minima in the pattern. Measure the distance from the hair to the probe, and, knowing the wavelength, calculate the diameter of your hair.

If you rotate the hair about its long axis you may find that the diffraction pattern is different for different orientations. One of the characteristics of different people is that the cross section of their hair is round in some cases and elliptical in others. For example, Asians' hair is usually quite round, and Africans' hair is usually quite elliptical. Such differences are not quite as distinct as fingerprints, but are often important in identifications and in forensics.

Transmission Diffraction Grating

The transmission diffraction grating provided in your optics kit is just a series of very narrow slits. Try placing it in the beam of your laser, and observe its diffraction pattern. Describe the pattern. Now remove the grating and replace your laser with your white light source. Use a positive lens to focus an image of the filament on the wall. Place the grating between the lens and the wall, and describe the pattern produced. Calculate the wavelengths of some of the colors that you see. Observe the effect of placing colored filters over the light source.

Hints and Kinks Department

You may find that the laser beam is physically too small for some of these effects to be easily seen. Thus you may want to expand it using a single lens of relatively long focal length to cause some slight divergence. This can be easily mounted a few cm in front of your laser. Be careful to get the beam quite close to the center of the lens, both horizontally and vertically, to minimize deflection and also the effect of lens aberrations.