Experiment 5

Diffraction of Light

1 Introduction

We will look at the wave nature of light in a set of experiments where diffraction and interference patterns are produced when laser light is incident on various obstacles.

2 Background - *see Pedrotti[3], Chapter 11*

The general arrangement that will produce a diffraction pattern is illustrated schematically in Fig. 1. At a distance D from the obstacle, the intensity of the diffracted light will be measured as a function of the x coordinate. The diffraction patterns are relatively simple in the far field limit, where $a^2/D\lambda \ll 1$, where a is the characteristic dimension of the obstacle (such as the width of a slit) and λ is the wavelength of light. This is the Fraunhofer diffraction limit, and the diffraction patterns are simply Fourier transforms of the diffracting object. Closer to the object, the diffraction patterns are more complicated and are described by Fresnel diffraction theory.

2.1 Slit Diffraction

Consider a single slit with width a illuminated by a laser with wavelength λ. The diffraction pattern is observed on a screen a distance D away. The intensity as a function of θ that appears on the screen (in the far field) is given by

$$I(\theta) = I(0)\left(\frac{\sin\alpha}{\alpha}\right)^2 \tag{1}$$

where $I(0)$ is the intensity at $\theta = 0$ and

$$\alpha = \left(\frac{\pi a}{\lambda}\right)\sin\theta. \tag{2}$$

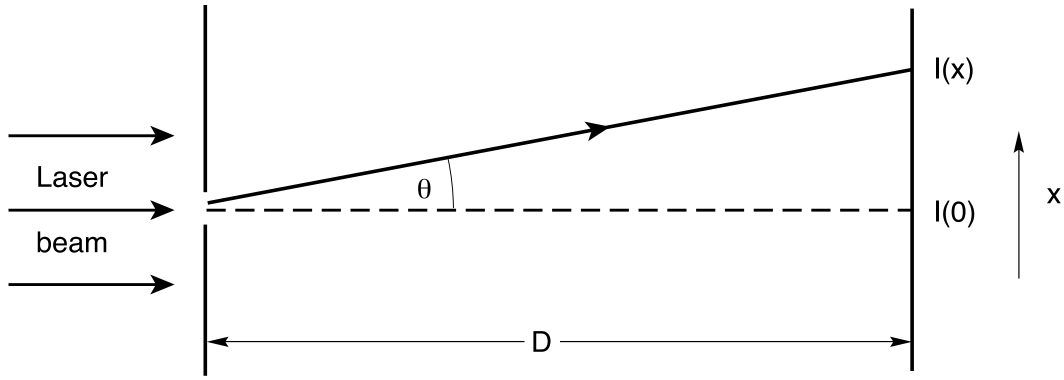

Figure 1: Schematic layout for diffraction

This is an Airy function, which is the Fourier transform of a top hat function. For light passing through N slits, with widths a and separations d, the intensity is given by

$$I(\theta) = N^2 I(0) \left(\frac{\sin \alpha}{\alpha} \right)^2 \left(\frac{\sin N\beta}{N \sin \beta} \right)^2, \tag{3}$$

where $I(0)$ is the intensity at $\theta = 0$ passing through one slit, α is defined in Eq. (2), and β is given by

$$\beta = \pi \frac{d}{\lambda} \sin \theta. \tag{4}$$

Notice that the α dependent term of Eq. (3) is related to the single slit diffraction pattern and the β is due to interference between the light emanating from the multiple slits. Note the N^2 dependence, which comes from the coherent addition of N sources.

3 Experiment

In the following experiments, you will scan the diffraction patterns with a linearly driven photodiode and record the data with the computer.

Measure the diffraction patterns from single and multiple slits. In the far field limit, you should be able to extract the slit parameters by analysis of your diffraction patterns. Verify the N^2 dependence for the multiple slits. Compare your results with a measurement of the slit widths with the microscope.

Using a razor blade, measure the diffraction pattern from an edge, and compare it to the expected pattern. Do not cut yourself!

Using Babinet's principle (which relates the diffraction pattern of a mask to its complement, see Pedrotti[3] page 330) measure the diameter of a human hair (your own if you have one to spare).

Using a lens, show that imaging can undo what diffraction does. Hint- place the lens to magnify the image so that it is large enough to resolve. Moving slightly away from the imaging condition allows you to record a near-field diffraction pattern, governed by the much more complex Fresnel diffraction theory.