UNIVERSITY OF WOLLONGONG IN DUBAI

Lab Experiment: Interference and Diffraction

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OBJECTIVES

1. To explore the diffraction of light through a variety of apertures.

2. To learn how interference can be used to measure small distances very accurately. By example, we will measure the wavelength of the laser, the spacing between tracks on a CD and the thickness of human hair.

WARNING! The beam of laser pointers is so concentrated that it can cause real damage to your retina if you look into the beam either directly or by reflection from a shiny object. Do NOT shine them at others or yourself.

PRE-LAB READING

INTRODUCTION

Electromagnetic radiation propagates as a wave, and as such can exhibit interference and diffraction. This is most strikingly seen with laser light, where light shining on a piece of paper looks speckled (with light and dark spots) rather than evenly illuminated, and where light shining through a small hole makes a pattern of bright and dark spots rather than the single spot you might expect from your everyday experiences with light. In this lab, we will use laser light to investigate the phenomena of interference and diffraction and will see how we can use these phenomena to make accurate measurements of very small objects like the spacing between tracks on a CD and the thickness of human hair.

The Details: Interference

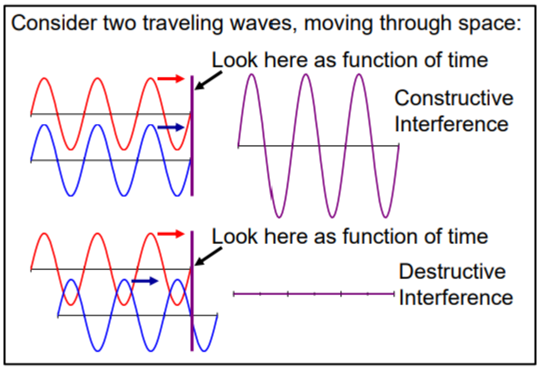

Figure 1 - Intereference Patterns

Figure 1 forms the basis of all the phenomena you will observe in the lab. Two different waves arrive at a single position in space (at the screen). If they are in phase then they add constructively and you see a bright spot. If they are out of phase then they add destructively and you see nothing (dark spot).

The key to creating interference is creating a phase shift between two waves that are then brought together at a single position. A common way to do that is to add extra path length to one of the waves relative to the other. In this lab the distance traveled from source to screen, and hence the relative phase of incoming waves, changes as a function of lateral position on the screen, creating a visual interference pattern.

Two Slit Interference

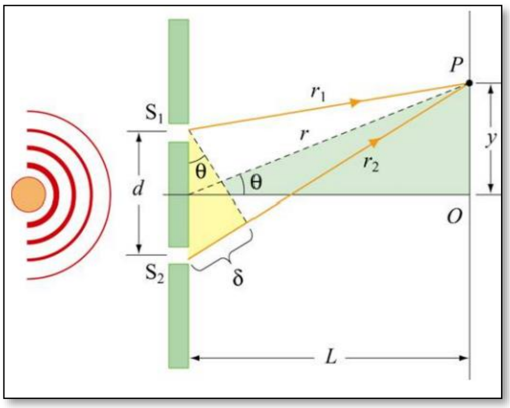

Figure 2 - Two Slit Interference

The first phenomenon we consider is two-slit interference. Light from the laser hits two very narrow slits, which then act like in-phase point sources of light. In traveling from the slits to the screen, however, the light from the two slits travel different distances. In Figure 2 light hitting point P from the bottom slit travels further than the light from the top slit. This extra path length introduces a phase shift between the two waves and leads to a position dependent interference pattern on the screen. Here the extra path length is $\delta = d \sin(\theta)$, leading to a phase shift $\emptyset$ given by $\frac{\delta}{\lambda} = \frac{\emptyset}{2\pi}$.

Realizing that phase shifts that are multiples of 2π give us constructive interference while odd multiples of π lead to destructive interference leads to the following conditions: Maxima: $d \sin(\theta) = m\lambda$; Minima: $d \sin(\theta) = (m + \frac{1}{2})\lambda$

Multiple Slit Interference


Figure 3 - Array of colors

If instead of two identical slits separated by a distance d there are multiple identical slits, each separated by a distance d, the same effect happens. For example, at all angles θ satisfying $d \sin(\theta) = m\lambda$ we find constructive interference, now from all of the holes. The difference in the resulting interference pattern lies in those regions that are neither maxima or minima but rather in between. Here, because more incoming waves are available to interfere, the interference becomes more destructive, making the minima appear broader and the maxima sharper. This explains the appearance of a brilliant array of colors that change as a function of angle when looking at a CD as shown in Figure 3. A CD has a large number of small grooves, each reflecting light and becoming a new source like a small slit. For a given angle, a distinct set of wavelengths will form constructive maxima when the reflected light reaches your eyes.

Diffraction

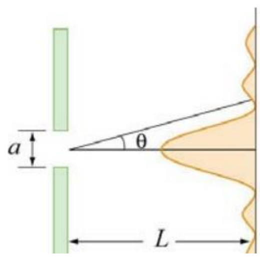

Figure 4 - Diffraction with a slit width of a

The next kind of interference we consider is light going through a single slit, interfering with itself. This is called diffraction and arises from the finite width of the slit (a in Figure 4). The resultant effect is not nearly as easy to derive as that from two-slit interference (which, as you can see from above, is straightforward). The result for the angular locations of the minima is $a \sin(\theta) = m\lambda$.

Putting it Together

If you have two wide slits, that is, slits that exhibit both diffraction and interference, the pattern observed on a distant screen is as shown in Figure 5.

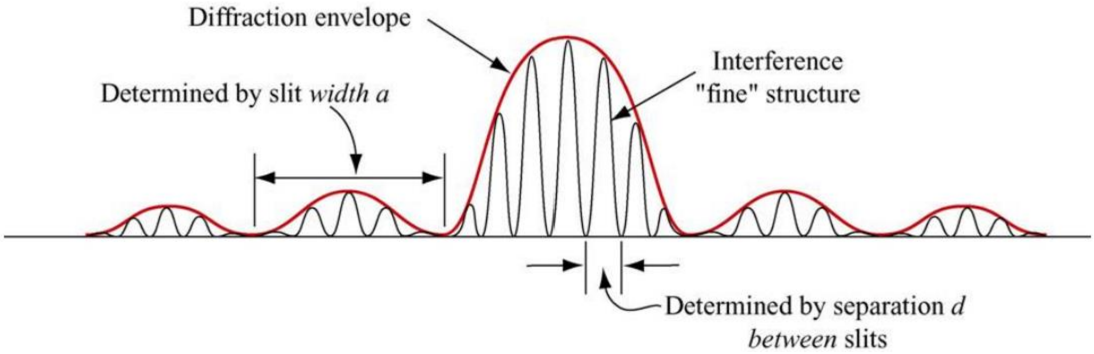

Figure 5 - Pattern observed due to both diffraction and intereference

Here the amplitude modulation (the red envelope) is set by the diffraction (the width of the slits), while the "individual wiggles" are due to the interference between the light coming from the two different slits. You know that this must be the case because d must be larger than a, and hence the minima locations, which go like 1/d, are closer together for the two slit pattern than for the single slit pattern.

When a wave encounters an obstacle, some of the wave bends or diffracts around the obstacle. Diffraction depends on size of obstacle (d) and the wavelength (λ).

The diffraction equation is given by:

$$w = \frac{L\lambda}{d}$$

Where:

W = pattern size

L = Distance to screen

D = size of an object

λ = wavelength of light

Lab structure

Part 1: You will measure the track spacing on a CD\DVD by reflecting laser light off of it and measuring the resulting diffraction pattern.

Part 2: Next you will discover the ability to measure the size of small objects using diffraction, by measuring the width of a human hair.

End of Pre-lab Reading.

Experiment 1 – Measuring Track spacing of a CD/DVD

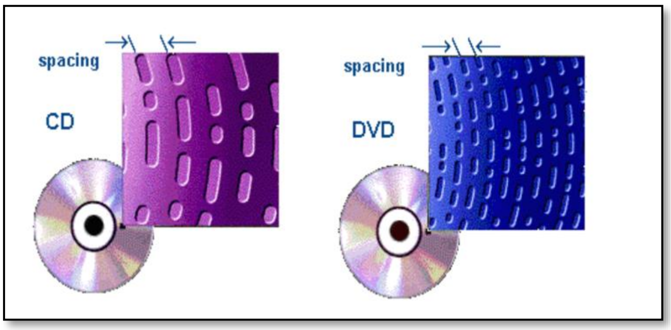

Figure 6 - shows the tracks on a CD and DVD

CDs and DVDs store information as dots on a plastic disk. The dots are in lines as shown in figure 6 below. To pack as much information onto the disk as possible, the tracks are very close to each other. In a CD/DVD player, a laser is focused on a sharp spot and scans along the tracks reading each dot. In the experiment, we will measure how close the tracks are on CDs and DVDs.

Procedure:

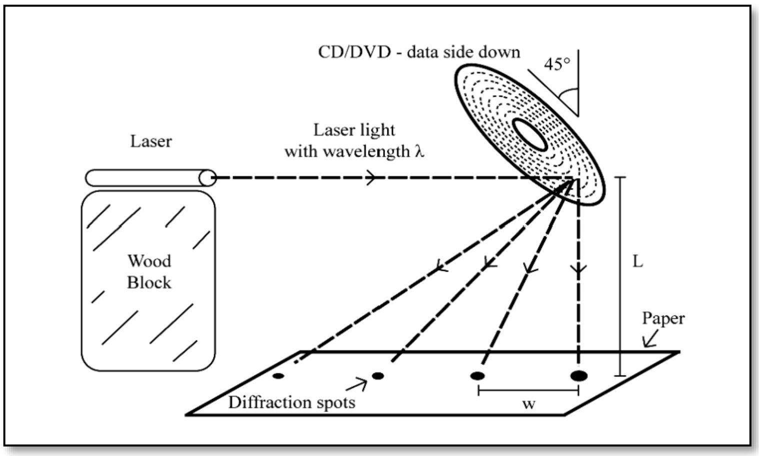

Figure 7 - Complete setup

1. Set up the laser, CD/DVD and a sheet of paper or a screen as shown above in Figure 7.

2. Place the CD/DVD at an angle of 45 degrees.

3. You should see a bright spot on the paper directly underneath the CD/DVD along with other diffraction spots in line with the laser.

4. Determine the position of each spot on the paper.

5. Measure the

   L = Distance of laser beam above paper
   w = Distance between diffraction spots

Measurements

CD Track Spacing

L = ...(cm)

w = ...(cm)

d = Distance between CD Tracks

= L × λ ÷ w
= ....(m)

= ....(mm)

Number of CD Tracks per millimeter

= ....

DVD Track Spacing

L = ...(cm)

w = ...(cm)

d = Distance between DVD Tracks

= L × λ ÷ w
= ....(m)

= ....(mm)

Number of DVD Tracks per millimeter

= ....

Experiment 2 – Measuring Hair Thickness

Without laser pointers, this isn't easy to do, but it can be used using the concept of diffraction. Note that the darker the room the better.

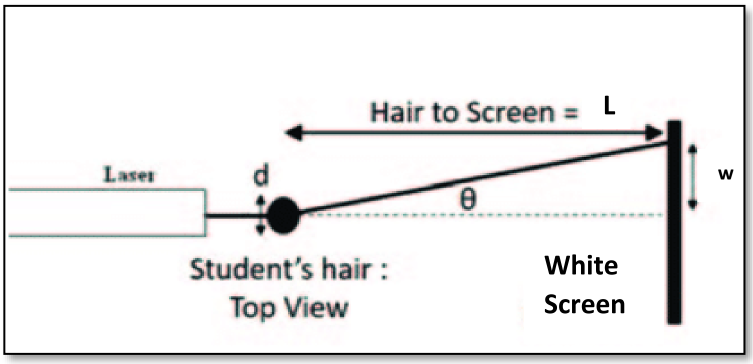

Figure 8 - Complete setup

Procedure:

1. Setup the laser beam to shine on the white screen at a distance of 1-2m as shown in Figure 8 (further is ok but the brightest of everything decreases so you will need a darker room).

2. The beam from the laser is rectangle in shape so make sure that the long side of the rectangle is horizontal on the white screen. You should be able to see a similar output as shown in Figure 9.

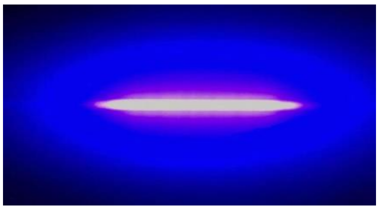

Figure 9 - Horizontal beam from the laser

3. Take a human hair (preferably dark, firm one to start with but it really doesn't matter much) and intercept the leaser beam with it.

4. Place the hair horizontally in front of the laser beam.

5. Now you should be able to mark out the bright and dark bands quite clearly.

6. Measure the spacing between the bands. The width of the hair d should be given by

$$d = \frac{L\lambda}{w}$$

$$L = Distance\ from\ the\ hair\ to\ the\ screen$$

$$\lambda = Wavelength\ of\ the\ laserpointer\ (650nm)$$

$$w = The\ spacing\ between\ the\ bands$$