Purpose:

Up until now in this lab we've been thinking of light as a particle that reflects off of surfaces or refracts into a medium. Now we are going to investigate light as a wave.

There are three parts to this experiment:

1. Observe and measure the fringes caused by Double Slit Interference.
2. Observe and measure the fringes caused by Single Slit Diffraction.
3. Observe and measure the maxima from diffraction caused by multiple slit diffraction by using the grooves of a CD/DVD.

Equipment

You will be using the same optical bench set-up as usual. See **Figure 4**. In this lab however you will be using a laser as the light source.

Some important notes:

1. **Be aware of the laser at all times, it should never be on if not attached to the optical track.**
2. **Do not shine the laser into your lab partner's, or anyone else's eyes.**
3. Do not look directly into the laser, treat it like the barrel of a gun and always assume it will blind you.

And note there should be paper on your table for you to attach to the screen with a black clip.

Please do not write on the screen!

FIGURE 4: Optical bench and accessories

Introduction:

Constructive and Destructive Interference

If you take two waves and add them together, or *superimpose* them, they will combine together to form a new wave. Below, in **Figure 1**, you see two different cases in which two waves a can add together.

In case **1a**, the two waves are in *phase*, which means that they both reach a peak (or valley) at the same time. When these waves are combined the result will give you *constructive interference*.

In case **1b**, the two waves are *out of phase* in such a way that peaks match with valleys. When these waves are combined the result will give you *destructive interference*.

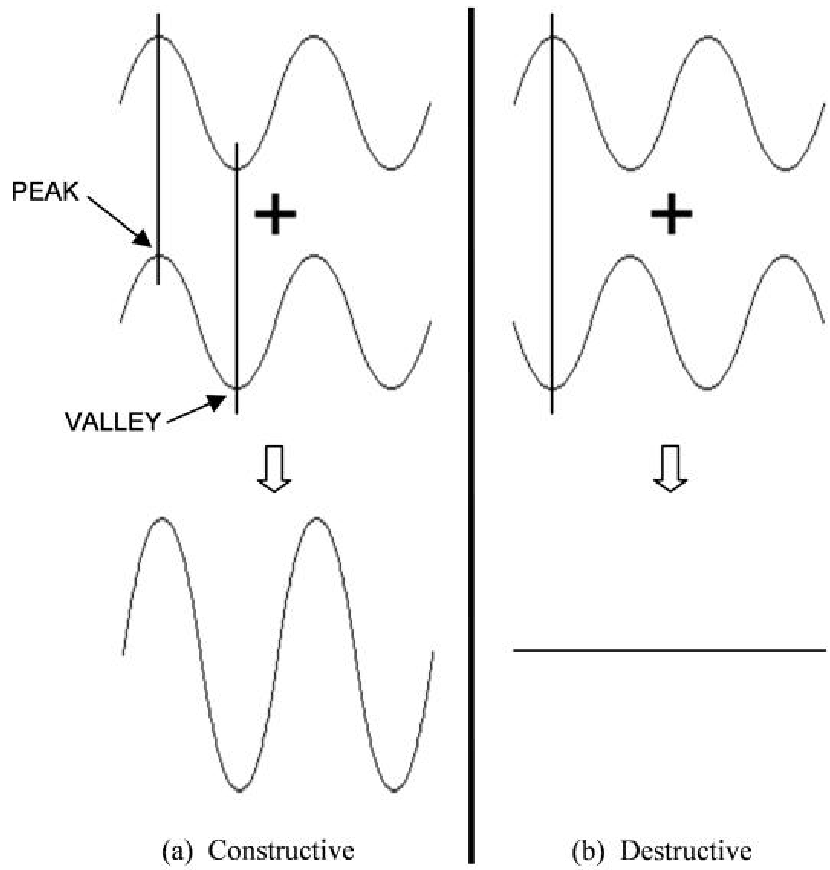


FIGURE 1 - Interference of two waves

If these are waves of light then we could say that constructive interference would give us a *brighter* light. For light waves that give us destructive interference, we would get *darkness*.

As waves travel through space from a source, if they travel different distances this can cause the waves to end up in phase, out of phase, or anywhere in between.

Experiment Part 1: Double Slit Interference

Introduction

Let's say that we have a situation in which laser light is incident on two very small slits. The slits are a distance, **d**, apart and a screen is placed a distance, **L**, from the slits. See **Figure 2**.

Light from a laser is monochromatic, meaning it is made up of light with one wavelength. We use this single wavelength light so that we can simplify the analysis of the interference effects. If we shine a laser on the slits, the light waves will travel through each slit and then proceed to the screen. For points on the screen that are off of the central axis, one wave of light will **travel a farther distance** than the other.

If the two waves of light are *in phase* when they meet at the screen then you will see a bright spot (*constructive interference*).

If the two beams of light are *out of phase* when they meet then you will see a dark spot (*destructive interference*). As a result, you should see on the screen a pattern of bright and dark spots (or fringes). This pattern is shown as peaks of brightness and valleys of darkness in Figure 2.

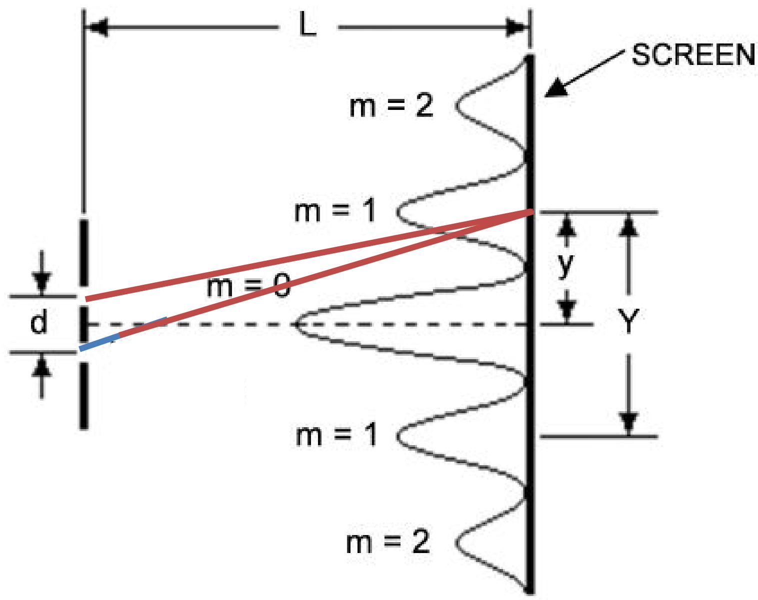


FIGURE 2 - Double slit interference

The location of the bright fringes can be found using the following equation.

$$y = \frac{m\lambda L}{d}$$

In the lab you will be measuring the distance, **Y**, from one bright fringe to its counterpart fringe on the other side of the central axis. See **Figure 2**. You will then divide this distance by two, ***y = Y/2***, and use this value in the above equation. This process will give you more accurate data.

Procedure

Table 1: Double Slit Data			
L (m) =		d (m)=	
m	Y (m)	y = Y/2 (m)	λ (m)
1			
2			
3			
4			
5			
6			
		λ_{avg} (m)	
		%Error	

A.) Open the course excel sheet to the Interference and Diffraction tab, or make a copy of the table here.

B.) Place the Multiple Slit Disc on the optical bench. It should be about 3 or 4cm from the laser.

C.) The screen should be at **110cm**. Using the black clip on the screen, attach the piece of paper to the screen.

D.) Shine the laser where **d = 0.25mm**, (this slit is in the Double Slit section where it says a = 0.04, d = 0.25.)

E.) Write on the piece of paper, "Double Slit, d = 0.25mm". Also place the value in your table after converting units.

   a. Take note that all distance measurements must be converted to meters.

F.) Measure the distance, L, from the slit to the screen and record it in the table.

   a. Slit to screen, not laser…

   b. NOTE: The disc is not even with marker at the base of the mount.

G.) Using the 1st through the 6th order **bright** fringes, make marks at the estimated centers of the bright fringes.

   a. The center, brightest fringe is m=0, count outward from there.

H.) Label on the paper the order number for each pair of fringes.

I.) Remove the paper and then using your marked pattern, do the following for each fringe pair ...

   a. Measure the distance, **Y**, from one bright fringe to the other for the **same order number**. See **Figure 2, you're measuring from m=1 to m=1, m=2 to m=2 and so on**. Place these values in the table.

   b. The distance y is just half of the measured Y, which is the distance from the center of the central maximum to a bright fringe. This should be calculated for you using an equation in excel, verify the equation works for your values.

J.) Solve the Double Slit - Bright Fringe equation for λ, then insert that equation into excel to calculate all 6 values of wavelength. (Make sure all the values are in **meters** before you substitute in the numbers).

a. All values in the equation are in the table so you should be using references and fixed references, refer to the graphical analysis lab or your instructor if you need help.

K.) Find the average of your 6 wavelengths using the =AVERAGE() function in excel.

L.) Calculate a percent error based on the known wavelength for the green laser light, 532 nm, or the red laser light, 650. nm.

Question #1

Turn the disc to the Variable Double Slit. Rotate the disc while the laser is centered on the variable slit.

a. Describe what happens to the pattern as the slit separation increases.

b. Does this agree with the $y = \frac{m\lambda L}{d}$ equation? Support your answer mathematically.

Question #2

While rotating the disc for question three note that while the slit separation was changing, the slit width was constant, what do you observe about the projection that isn't changing that might be related to the slit width being constant?

Experiment Part 2: Single Slit Diffraction

Introduction

There is also an interference effect when there is only one slit. This is called *diffraction*. In this situation the light interferes with itself to produce bright and dark fringes on the screen.

The main difference in the pattern is that the central bright spot for one slit is twice as wide as the central bright spot for two slits. See **Figure 3**. There are other differences but they will be left for you to discover during the lab. Also the width of the slit is **a**, note this is not the distance between the slits as before, but also note we had an a value for the double slit experiment.

NOTE: Observe how the minima are marked in the diagram. For diffraction you will be using the dark fringes as reference points when you are taking data.

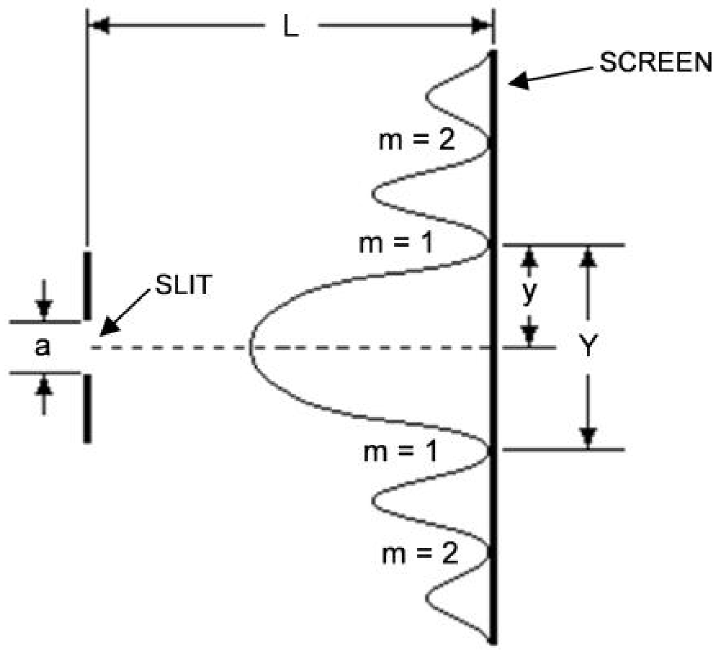


FIGURE 3 - Single slit diffraction

The equation for the locations of the dark fringes is given below.

$$y = \frac{m\lambda L}{a}$$

Notice that the two equations are pretty much the same except for

- Double slit has **d** in the denominator and single slit has **a**.
- One equation is for locating *bright* fringes due to *interference* with *two slits*. The other is for *dark* fringes due to *diffraction* with a *single slit*.

You will be using these two equations to calculate the wavelength of the light from the laser. You will then compare this value to the known value of the wavelength.

Procedure

Table 2: Single Slit Data			
L (m) =		a (m) =	
m	Y (m)	y (m)= Y/2	λ (m)
1			
2			
3			
4			
5			
6			
		λ_{avg} (m)	
		%Error	

A.) Place the Single Slit Disc on the optical bench. It should be about 3 or 4 cm from the laser. Rotate the disc so that the **0.08mm** (use **0.088mm** for calculations) slit is in the path of the laser beam.

B.) Adjust the laser to the left or the right so as to get as bright and sharp a pattern as possible on the screen. Make a copy of Table 1 in your lab report.

C.) Reattach your piece of paper to the screen with the blank side outward. Write on the piece of paper, "Single Slit, a = 0.088mm". Also place the value in your table.

D.) Measure the distance, L, from the **SLIT** to the screen.(*Not from the laser*)

E.) Using the 1st through the 6th order DARK fringes, make marks at the estimated centers of the DARK fringes.

  a. This time you are marking the dark space between bright spots.

F.) Label on the paper the order number for each pair of fringes.

  a. The first dark spot outside the central bright spot is m=1, count outward from there.

  b. Using your marked pattern, do the following for each fringe pair ...

G.) Remove the paper and then using your marked pattern, do the following for each fringe pair ...

  a. Measure the distance, **Y**, from one dark fringe to the other for the **same order number**. See **Figure 3, you're measuring from m=1 to m=1, m=2 to m=2 and so on**. Place these values in the table.

  b. The distance y is just half of the measured Y, which is the distance from the center of the central maximum to a bright fringe. This should be calculated for you using an equation in excel, verify the equation works for your values.

H.) Solve the Single Slit - Dark Fringe equation for λ, then insert that equation into excel to calculate all 6 values of wavelength. (Make sure all the values are in **meters** before you substitute in the numbers).

  a. This equation is mostly the same as in Part 1, copy it down and update references.

I.) Find the average of your 6 wavelengths using =AVERAGE().

J.) Calculate a percent error based on the known wavelength for the green laser light, 532nm, or red laser light, 650 nm.

Question #3

Turn the disc to the Variable Slit section. Rotate the disc while the laser is centered on the variable slit.

a. Describe what happens to the pattern as the slit width increases.
b. Does this agree with the $y = \frac{m\lambda L}{a}$ equation? Justify your answer mathematically.

Question #4

Turn the disc so that the laser is shining on one of the following three patterns: squares, hexes, holes.

a. For each pattern, describe or diagram what you are seeing.

b. Based on what you have seen in the first part of the lab, explain why the patterns look the way they do for each type of "slit".

Experiment Part 3: Multiple Slit Diffraction

Introduction

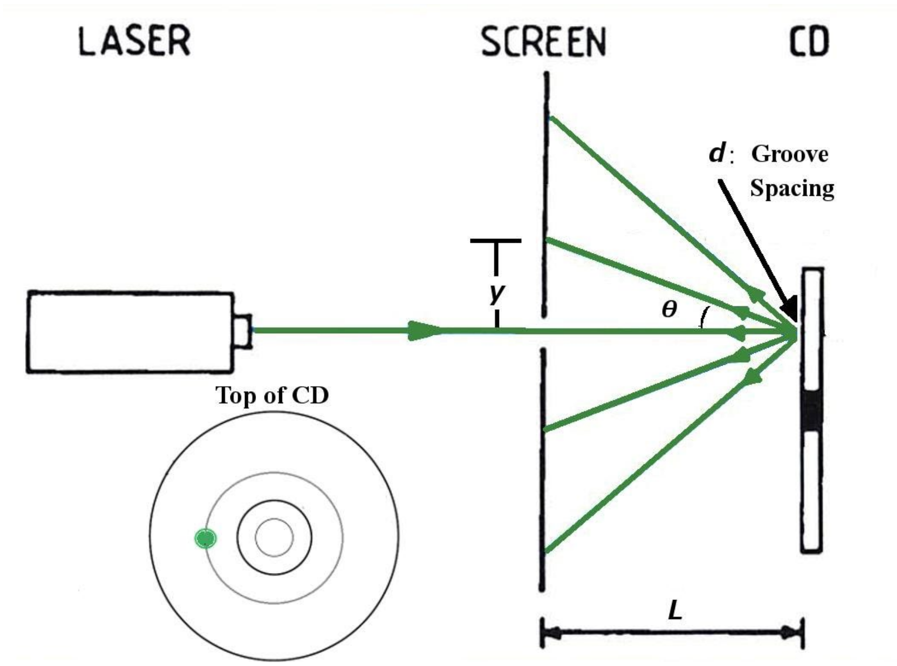
For this part of the experiment we will use the grooves on a cd for multiple slit interference.

To main effect of the increase in slits is refinement of the bright fringes due to an increase in dark spots. This will make the fringes very precise dots at much larger angles. Generally for diffraction gratings we refer to the angle from the center instead of the distance y.

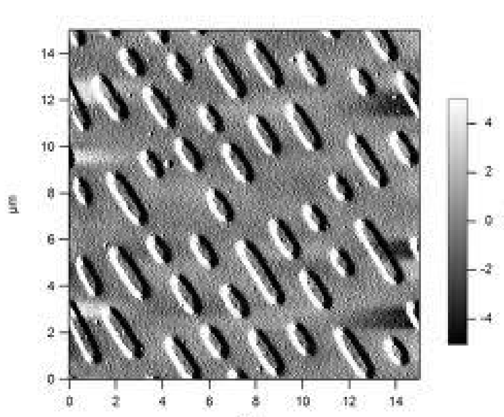
For a grating with distance d between slits with an incident light source of wavelength λ, and angle θ to the diffraction point with order m we have the diffraction equation:

$$d \sin\theta = m\lambda$$

The reflective setup you will use is shown above. Be sure to note the location of the laser is such so that it is hitting the groove where it is approximately vertical.



As shown on the right the actual slits we are working with are the lines of indents. For standard cases one side of the CD or DVD has a reflective material that allows for this setup. Keep in mind the area the laser will be shining on is much, much larger than that pictured here, approximately 1000 times so.



The following page has pictures of the physical setup.

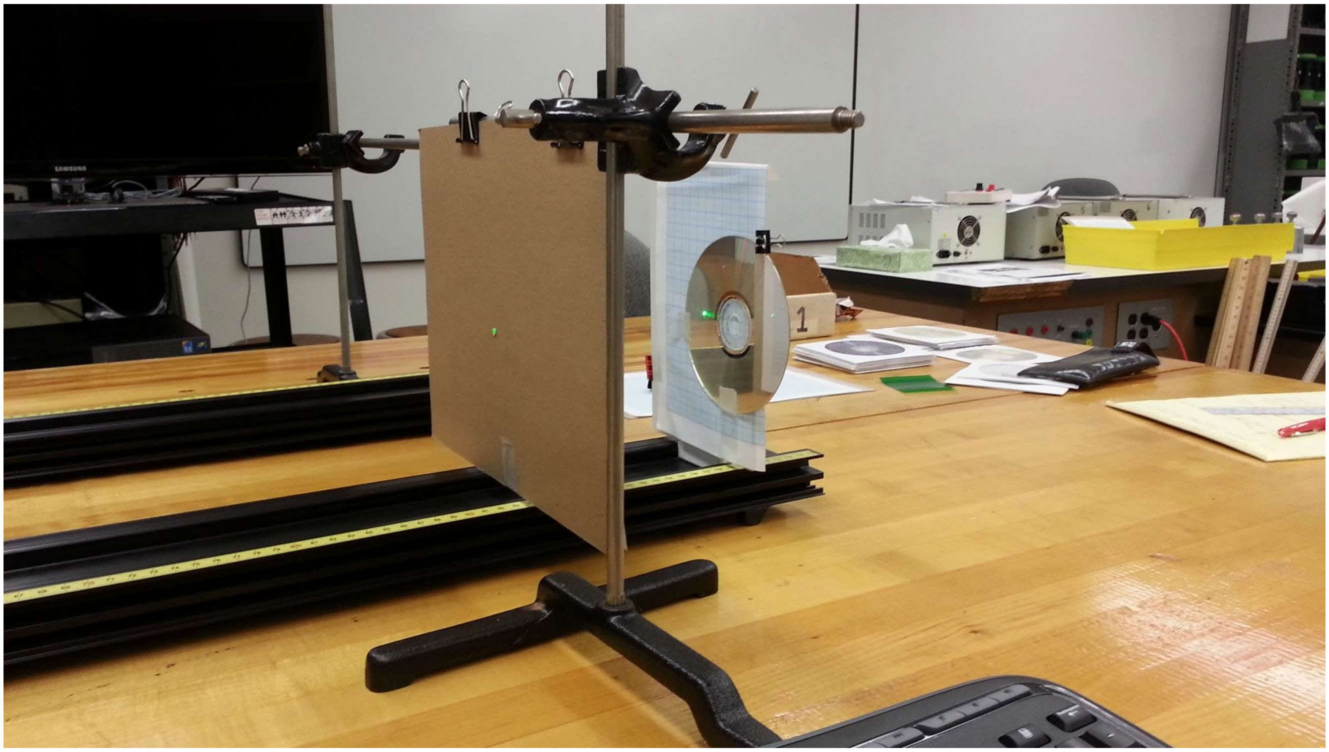


Figure 5: Picture of CD setup

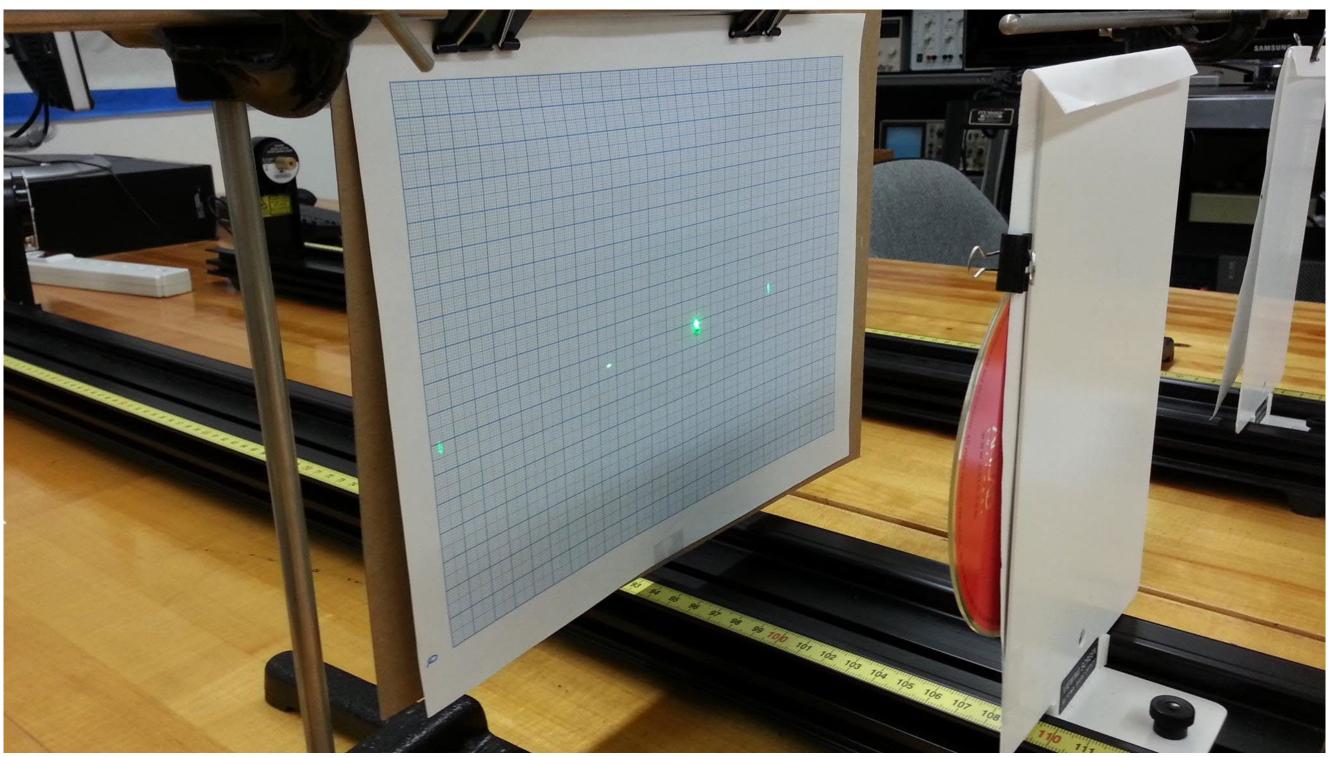


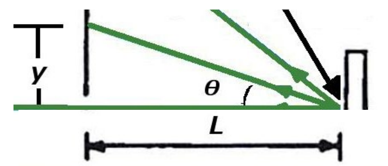
Figure 6: Picture of CD setup

Procedure

Your goal is to calculate d, the space between individual lines/grooves in this effective diffraction grating.

Question 5:

Using trig find an equation for θ in relation to the distance from cardboard to CD/DVD, L, and distance from center of screen to bright fringe, y.



A.) Setup the CD as shown on the previous page so that the reflected fringes appear on the paper.

B.) Measure the distance between bright fringes to find **Y** and divide by two to find **y**.

   a. Be sure you're measuring from m=1 to m=1, do not measure from the center point.

   b. You do not need to mark anything on the paper, just measure directly.

C.) Measure **L**, the distance from the cardboard screen to the CD (NOT FROM THE LASER), refer to the diagram in this part's introduction.

D.) Calculate θ using the equation you found in question 5.

E.) Use the diffraction equation to solve for the groove spacing d (a.k.a. track pitch).

   a. For your calculation here use the given lambda for the green or red laser light of 532nm, or 650nm.

F.) Calculate a percent error between this value and the given value for track pitch in the table on the next page.

G.) Repeat A,B,C,D, and E using either a transparent or reflective DVD.

H.) You should end with the track pitch for both CD and DVD.

Question 6:

You should now have a track pitch for CDs and DVDs.

a.) How do the track pitches (d values) of the CD and DVD compare? (shorter/longer etc.)

b.) What is the reason for the difference in values? (Why might one need closer lines than the other)

Question 7:

To get a feel for the size of these grooves look up something close to the size and compare them, for example compare it to the diameter of a red blood cell.

Appendix: What is the track pitch or groove spacing on a CD DVD or Blu-ray?

Answer: The groove spacing is also called the "track pitch". It is the distance between each track. Below is a list of the track pitches of some common for-mats.

Type	Capacity	Track pitch	Wavelength of laser light	Numerical Aperture
CD	0.7Gb	1.60 ±0.1 µm	780nm	0.45
DVD	4.7Gb	0.74 µm	650nm	0.60
Blue-ray	25 Gb	0.32 µm	405nm	0.85

Because of diffraction they can't make the 'grooves' to close together. (Diffraction is the reason you see a play of colors on CDs and DVDs.) Notice the shorter the wavelength of the laser light they use the closer they can make the grooves and the more information they can get on the disk. Also notice however that the track pitch decreases more rapidly than the wavelength of the lasers in the above table, this is because you can also reduce the track pitch if you increase what is called the Numerical aperture of the lens you use. In fact how much information you can store on a disk depends on how small you can get the "spot size" of the laser beam and the radius of the smallest spot that you can get equals the laser light wavelength divided by the numerical aperture. (R=/NA)

(1 µm = 1 micrometer = 1 micron = 0.000001 meters = 1x10^6 meters) (1 nm = 1 nanometer = 1x10^9 meters)