Introduction

An important property of waves is interference. You are familiar with some simple examples of interference of sound waves. This interference effect produces positions having large amplitude oscillations due to constructive interference or no oscillations due to destructive interference which can be considered to arise from superposition plane waves (waves propagating in one dimension). A more complicated behavior occurs when we consider the superposition of waves that propagate in two (or three dimensions), for instance the waves that arise from the two slits in Young's double slit experiment. Here, interference produces a two (or three) dimensional pattern of minima and maxima that depends on the relative position of the interfering sources and on the wavelength of the wave. The Young's double slit experiment clearly shows that light has wave properties. Interference effects are important because they are the basis for determining the positions of atoms in molecules using x-ray diffraction. An interference pattern arises from x-rays scattered from the individual atoms in a molecule. Each atom acts as a coherent source and the interference pattern is used to determine the spatial arrangement of the atoms in the molecule.

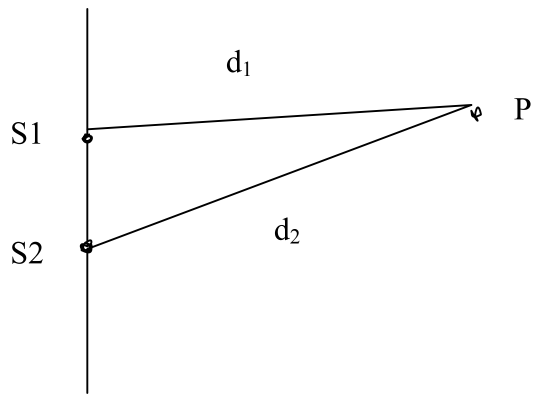
In this lab you will study the interference pattern of a pair of coherent sources. Coherent sources have a fixed phase relationship at all times. Several pairs of transparences are provided to facilitate the understanding and analysis of constructive and destructive interference. The transparencies are constructed to mimic the behavior of a pair of harmonic point source wave trains. The transparency exercises are performed to enhance the understanding of Young's double slit experiment. In this experiment, light from a laser source is incident on a double slit so that each slit behaves as a coherent source resulting in an interference pattern projected onto a screen. The interference patterns can then be analyzed to determine the wavelength (λ) of the laser light and the separation of the slits. Diffraction of light by a diffraction grating will be measured. A diffraction grating is an array of many closely spaced slits. Light passed through a grating behaves as many sources resulting in an interference pattern similar to the two slit pattern but with much sharper maxima. Compact discs and digital video discs have closely spaced lines that act as a diffraction grating. You will measure the spacing of these lines by diffraction measurements.

Before you start, review the Wave Optics chapter in Serway/Faughn. Pay particular attention to the following sections:

- 24.1 Conditions for interference
- 24.2 Young's experiment
- 24.5 Interference and CD's/DVD's
- 24.6 Diffraction
- 24.7 Single-slit diffraction
- 24.8 The Diffraction grating.

Pre-Lab Questions:

1. Two spherical waves with the same amplitude, A, and wavelength, λ, are spreading out from two point sources S1 and S2 along one side of a barrier. The two waves have the same phase at positions S1 and S2. The two waves are superimposed at a position P. If the two waves interfere constructively at P what is the relationship between the path length difference $\delta x = d_2 - d_1$ and the wavelength. If the two waves interfere destructively at P, what is the relation ship between the path length difference and the wavelength?



2. The first order maximum caused by a double slit illuminated with light of wavelength 645 nm is found at some spot on a screen. The light source is changed to a new wavelength which places its second order ($m = 2$) maxima at the same spot where the 645 nm first order maxima used to lie.
   (a) What is the wavelength of the new light source?
   (b) Is this wavelength in the visible range?

3. A pair of narrow slits is illuminated with light of wavelength $\lambda = 640$ nm. The slits are separated by a distance of 0.25 mm. How far apart are the neighboring maxima if they are observed on a wall 6.33 m away from the slits?

A. Interference pattern due to a pair of coherent sources

The aim of Part A of the lab is to give you a physical understanding of the origin of interference. You should focus on trying to understand the basic concepts rather than trying to make the most accurate measurements. You should finish Part A in about 1 hr and go on to Part B which concerns measuring interference patterns using light.

In this section you will use transparencies to simulate the interference pattern due to a pair of coherent light sources. You have 2 sets of transparencies: Black/clear transparencies representing a plane wave, red/yellow transparencies represent circular waves. Each transparency can be thought of as a snap shot of the spreading waves at a given time. For simplicity the waves are represented as square waves instead of sine waves. Square waves are easier to visualize and the phase relationships i.e. the criteria for constructive and destructive interference are the same as for sine waves.

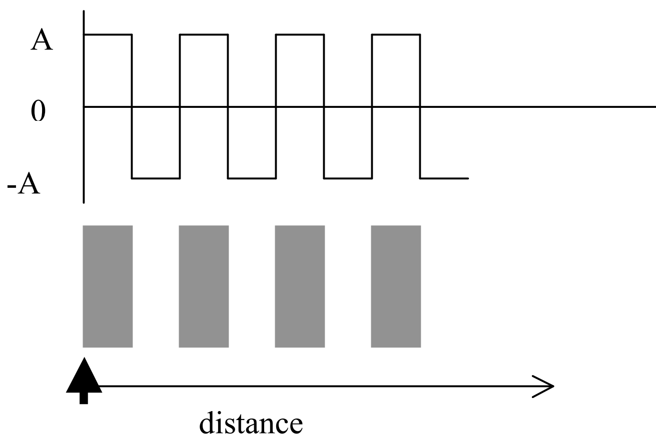


Figure 1. Representation of a square wave. Dark lines represent maximum amplitude A, Light lines represent minimum amplitude –A.
Note that when two waves are superimposed, a gray space + light space gives an amplitude of zero.

Black/clear: Dark gray indicates maximum wave amplitude (positive peak); clear indicates minimum wave amplitude (negative trough) and shades of gray indicate intervening values. "Pure" gray corresponds to zero field (total destructive interference).

A.1 Conditions for total destructive/constructive interference (in one dimension)
In this exercise you will use the dark gray/clear transparencies, a ruler, a pen or pencil, tracing paper, and the large paper.

A.1.1 In this section you will consider simplest case of the superposition of two plane waves, i.e. waves that are traveling in the same direction arising from a flat source as shown in figure 1. The plane waves are represented by the dark lines that originate from the source indicated by the arrow.
A1.2 Superimpose the two transparencies so that the arrows are overlapping. This represents a snapshot at a point in time of two superimposed waves. What is the amplitude from 0 to $\lambda/2$ (0 is position of the arrow) if the amplitude of one wave is A (recall that amplitude is always a positive value)? What is the amplitude of the two waves superimposed at a distance from $\lambda/2$ to λ? When the two waves are exactly superimposed the condition is called constructive interference and the two waves are said to be "in phase".

A.1.3 Move the top transparency in the direction of the propagating wave so that the two waves cancel, i.e. the total amplitude of the two waves is zero. This condition is called destructive interference. The two waves are said to be "out of phase". How many wavelengths has the second source moved?

A 1.4. Move top transparency again in the direction of the propagating wave. This time move it to achieve the condition of constructive interference. How many wavelengths has the second wave moved from its initial position?

A 1.5 Continue to move the top transparency in the direction of the propagating wave. Note the repeating occurrence of the conditions for constructive and destructive interference as the origin of the second wave is displaced relative to that of the first.

A1.6 Write an equation for the distance that the second source must be displaced in order to attain total destructive interference in terms of the wavelength λ and an integer m. where $m = \ldots -2, -1, 0, 1, 2 \ldots$ Note that the integer m can have negative values. In what direction does the top source have to be moved for m to be negative? State in words the condition for destructive interference.

A1.7 Write an equation for distance that the second source must be displaced in order to attain total constructive interference in terms of the wavelength λ, and an integer m. State in words the condition for constructive interference.

A.2 Interference pattern due to a pair of coherent sources

In this exercise you will use the red/yellow transparencies, a ruler, a pen or pencil, and large graph paper.

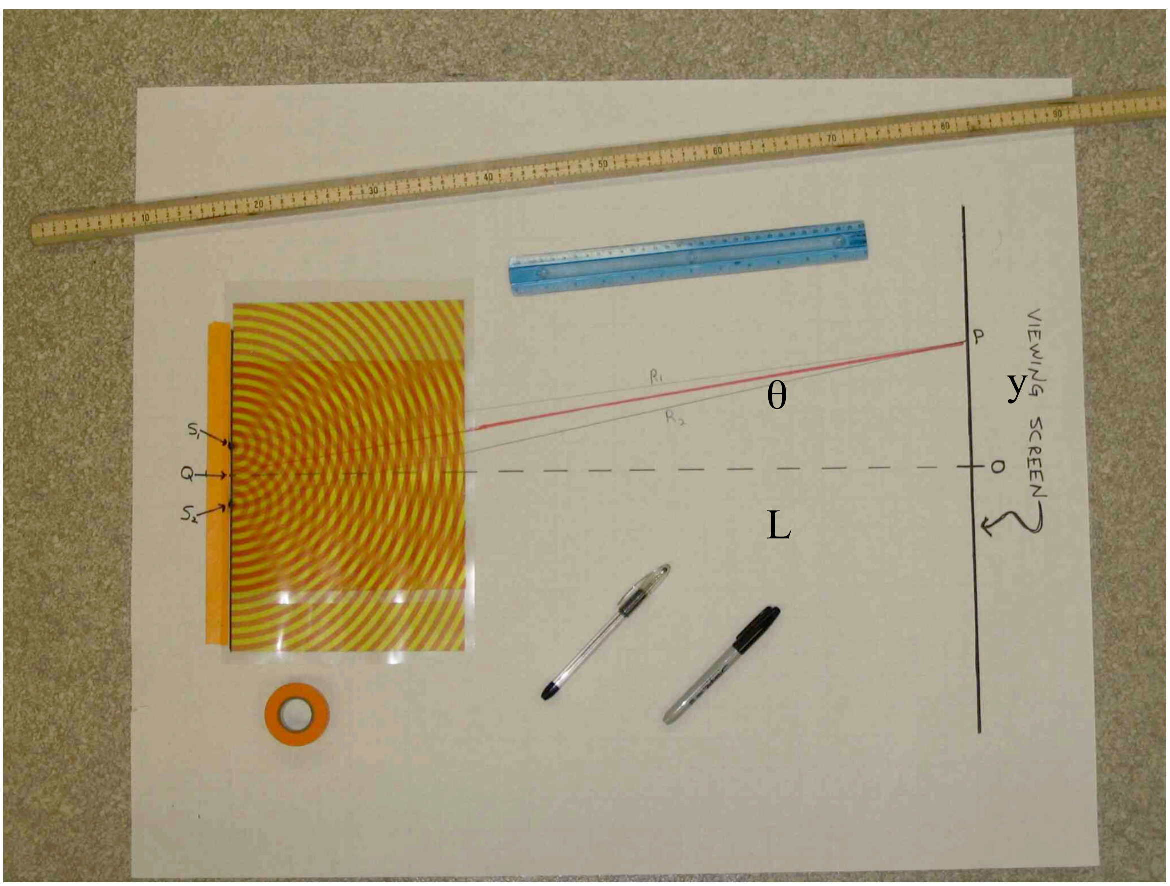
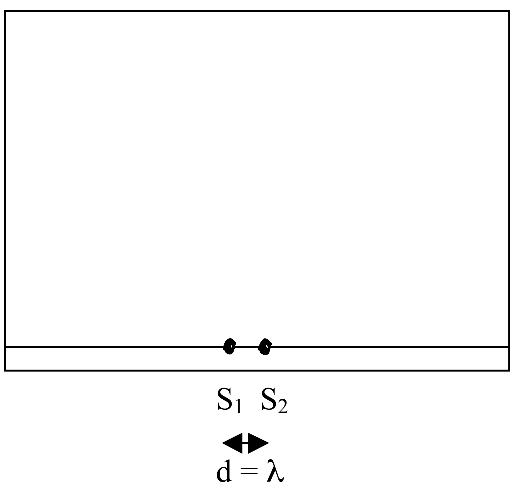
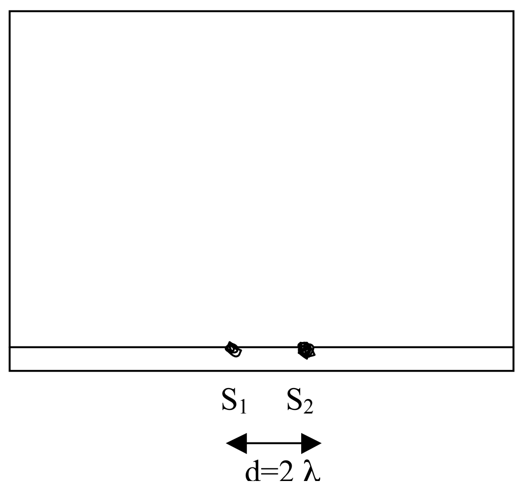


Figure 2. Layout for measuring the interference patterns due to two waves.

You will study the interference of waves originating in point sources that propagate in the radial direction in 2-dimensions. These waves are can be thought to arise when a plane wave hits a barrier with a small opening. Again for simplicity, we will consider square waves. The pattern of constructive and destructive interference is called the interference pattern and results from superposition of these waves. The interference pattern depends on the displacement of the two sources as well as on the wavelength of light. The layout for the experiment is shown in figure 2.

(A.2.1) Measure the wavelength, λ_{red}, of the waves on the red/yellow transparencies. Draw two parallel lines on the sheet of paper to represent the barrier and viewing screen. Place the red/yellow transparencies on the line representing the barrier so that the sources coincide. Separate the sources by moving one transparency over the other along the long edge parallel to the barrier line. Note the pattern of constructive and destructive interference. Where is there total destructive interference? Where is there total constructive interference? Can you identify lines radiating outward at which total destructive interference is attained? As you move outward along such a line the wave should look like a square wave with maxima and minima of 2A and -2A. Can you identify lines radiating outward that display total destructive interference? As you move outward along such a line the amplitude should be zero.
(A.2.2) Draw on the diagrams below the lines of total constructive interference (as solid lines) and lines of total destructive interference (as dashed lines) when the distance between the sources are 1 and 2 wavelengths. Describe how the interference pattern changes when the distance between the two sources changes. i.e. how does the angle θ vary with d?





(A.2.3) Test the statement for constructive interference that you obtained in A1.8 by measuring the path length difference along lines of total constructive interference. Arrange the transparencies so the sources are separated by d=4λ. Identify lines of total constructive interference. Each point on these lines should have a path length from S1 and S2 that differs by an integer number of wavelengths, m =0 ±1, ±2,….. Predict which line corresponds to m=0? Which lines correspond to m=± 1? Which lines correspond to m= ±2? Take a point on each line (not too close to the origin) and measure the distance of this point from S1 and S2. Does the path length difference agree with your prediction? Note that the + or – sign depends on whether the distance from S1 or S2 is smaller and is arbitrary.

(A.2.4) Determine the angle between the line of total constructive interference and the forward direction.

Separate the two sources by a distance d = 4λ. Draw a line perpendicular to the barrier from point Q midway between the two sources to a point O on the viewing screen. Measure the length of this line L. Place the ruler over the lines of total constructive interference and mark the position P on the viewing screen. This is the position of a bright spot produced by constructive interference on the viewing screen. Measure the length y, of the line OP which is the distance of the spot from the center. Tabulate the results in terms of the integer m which is the path length difference in wavelengths. The line for m=0 is in the forward direction and represents a wave that produces a central spot on the screen. The negative values of m correspond to negative values of y. Positive values of m correspond to positive values of y. Measure positive values of y. Negative values of y should have the same magnitude by symmetry.

m	y	y/L (tanθ)	sinθ
0			
1			
2			

Compare your results with the expression derived in the text.

$$d \sin\theta = m\lambda, \quad m = 0, \pm 1, \pm 2, \ldots \qquad (1)$$

The term on the left hand side of eq. (1) $d\sin\theta$ represents the path length difference between light starting at either of the two slits (essentially $r_2 - r_1$ in the figure below). Note that equation (1) is an approximation that holds when L>>d. Under these conditions the rays to P are parallel (see Figure 3(b)).

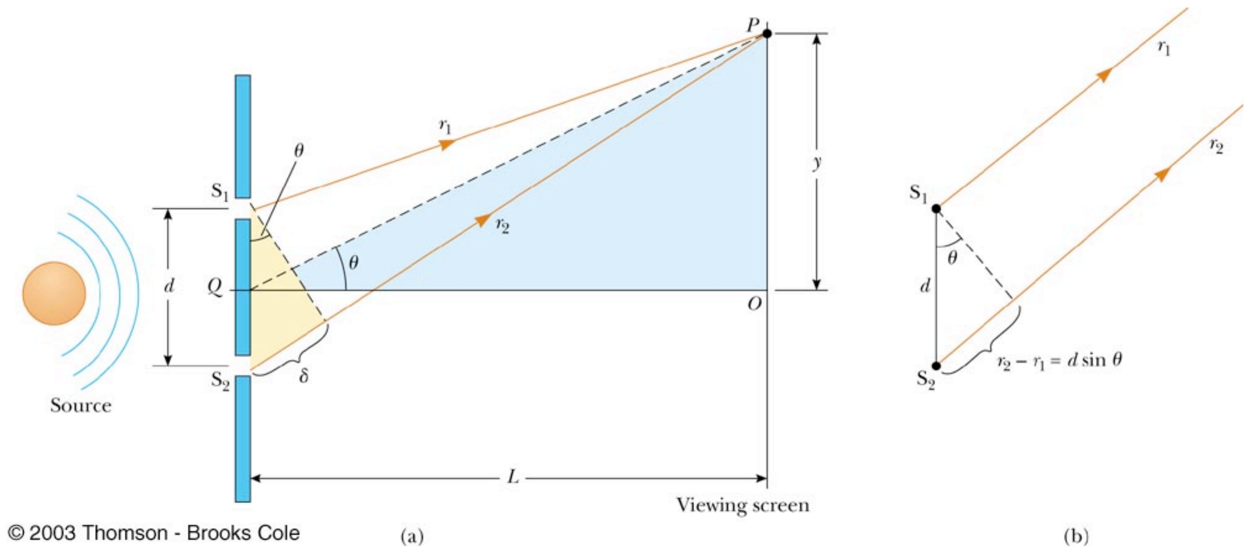


Figure 3. Two slit interference a) the path-length difference from the slit to the point P on the screen. b) when the screen is very far away the path-length difference is $d\sin\theta$

These conditions hold for light waves do generally hold for the waves studied in the lab. However, equation (1) is approximately true even for the transparencies when tan θ ~ sinθ. This occurs when the angle θ is small.

The number m is called the order. The central maximum at $\theta_{bright} = 0$ ($m = 0$) is the zeroth order maximum. The first maximum on either side, $m = \pm 1$, are the first order maxima. The second maxima on either side are the second order maxima, etc .

B Double-source interference of laser light

In this experiment you will create interference patterns using both red and green laser sources. Light from the lasers will be passed through a slide containing a double slit of known separation and the resulting interference pattern will be projected onto a distant screen. The measured patterns will be used to determine the wavelengths of the light from the respective lasers.

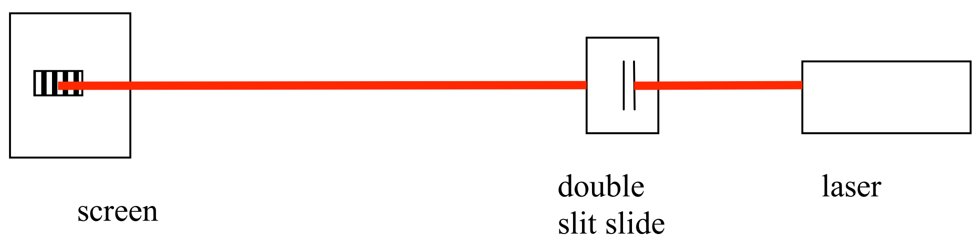
STANDARD CAUTIONARY PROCEDURES:

- **NEVER LOOK DIRECTLY INTO A LASER.**
- **NEVER POINT A LASER BEAM AT ANYONE'S EYE. PERMANENT BLINDNESS MAY RESULT.**
- **AT ALL TIMES BE AWARE OF WHERE REFLECTIONS ARE GOING.**
- **NEVER PUT YOUR HEAD IN THE PLANE CONTAINING THE BEAM.**
- **BEFORE YOU START, REMOVE YOUR WATCH AND HAND JEWLERY – A REFLECTION FROM SUCH HIGHLY REFLECTIVE SURFACES CAN GO ANYWHERE.**

B.1 Young's double-slit experiment: Using double-source interference to calculate the wavelength of laser light

In this part of the experiment you will use the optical bench set up, the red and green pen lasers and a double slit slide.

(B1.1) Place the red laser onto the optics bench so that the laser beam can be aimed through the double slit and onto a piece of paper taped to the viewing screen. **BE MINDFUL OF REFLECTIONS WHEN AIMING THE LASER THROUGH THE DOUBLE-SLIT SLIDE**. There are several double slits on the wheel having different spacings between slits and slit widths. The wheel can be rotated so that you can pass the laser through the different double slits. In what direction should the interference pattern be spread? (horizonatally or vertically?)



Carefully aim the laser through double slit opening with the smallest spacing. The interference pattern should be observed on a sheet of paper taped to the screen. Can you see the central peak and different orders of diffraction? Notice that the intensity of the peaks falls off at higher m, goes to zero and increases. This behavior is due to the diffraction from the finite width of the two slits.

(B1.2) How would you expect the interference pattern to change when you increased the slit spacing? Now move the slide and observe the interference pattern through the slit with the larger spacing. How does the interference pattern change when the spacing is larger?

(B1.3) Find the wavelength of light. (Try to measure the distances as accurately as possible. You will be comparing your results to the expected values). Go back to the slit with the smaller spacing. Observe the interference pattern and mark the positions of the peaks on the paper. Measure the distance between the highest order interference peaks that you can measure accurately, i.e. from the +m peak to the –m peak. This distance is larger than the separation between peaks and may be used to measure the wavelength more accurately. What is the m value for this peak? The measured distance is twice the value of y in figure 2. Measure the distance L, from the double slit to the screen. Calculate the value of sin θ using the two measured distances. Using the given value of the slit spacing, d, calculate the wavelength of red light. Compare the calculated values of the wavelength with the given values for the wavelength. What is the percent error?

(B1.4) What is the effect of changing the wavelength? Predict the interference pattern that you expect when green light is used instead of red light? (green light has a shorter wavelength than red light). Explain how the value of θ would change for green light.

(B1.5) Repeat B1.3 using the green laser. Observe the pattern using the smaller slit spacing. Measure the distance from the central peak to the first order spacing. Is it larger or smaller than the distance found for red light? Calculate the value of the wavelength of light using the first order and highest mth order peak. How do the calculated results compare with the expected values? What is the percent error?

C. The Diffraction grating

In this experiment you will create interference patterns using both red and green laser sources using a diffraction grating. A diffraction grating consists of a barrier with many slits having a spacing between slits of d. When light is passed through a grating, each line on the grating acts as a coherent source. Light from these sources interferes with to form an interference pattern similar to the two slit pattern but with peaks that are much sharper and brighter. The positions of the mth order maxima are given by equation (1). Light from the lasers will be passed through a diffraction grating of known slit spacing and the resulting interference pattern will be projected onto a distant screen. The measured patterns will be used to determine the slit spacing of the grating.

(C1.1) Aim the red laser through the diffraction grating. Spray some smoke between the diffraction grating and the viewing screen and describe what you see. You may have to move the position of the viewing screen. Compare and contrast the interference pattern from the grating with the interference pattern from the double-slit. What does the diffraction pattern tell you about the geometric orientation of the gratings compared with the geometric orientation of the double-slits? What can you say about the grating spacing compared to the spacing of the double-slits?
(C1.2) Take the green laser and direct the laser beam through the diffraction grating. Try to position the zeroth order maximum close to that of the red laser. How does the angle of the first order maxima compare with that for the red laser? What can you say about the wavelength of red and green light?
(C1.3) Locate the central maximum ($m = 0$) due to the red laser. Measure the separation distance between central maximum and the first maximum ($m = \pm 1$) in any direction. Does it matter which direction you choose? Explain. Use the constructive interference equation $d \sin\theta_{bright} = m\lambda$ to calculate the grating spacing.

D. Diffraction from a compact disc (CD) and a digital video disc (DVD).

A CD and DVD are both plastic discs that contain coded digital information. These discs have a series of raised dots arranged in concentric circular lines. The laser light scattered from the lines of dots propagate in all directions and act like light coming through a slit. The lines are spaced closely together with spacings that are close to the wavelength of light. Thus the CD and DVD can act as diffraction gratings. Note that although the lines are in concentric circles, in a small region of space, they appear as parallel lines. The DVD stores more information than a CD. Consequently, the lines in the DVD are closer together than in a CD. You can determine the spacing between the lines in a CD and DVD using diffraction of light.

Figure 5. A CD and DVD. Digital information is stored in closely spaced concentric lines of dots. The lines serve as a diffraction grating. The colors are due to the diffraction light.

(D1.1) Place the CD at the edge of the table with the flat face perpendicular to the top of the table with exactly half of the CD above the table.as shown in figure 6. Note that in this position the closely spaced tracks on the CD are in the vertical direction. Place a piece of paper on the table next to the CD. Hold the red laser close to the table and shine the beam onto the CD close to the edge of the table so that you can see the diffracted beams reflected off the paper. Why is the diffracted beam in the plane of the table? How many orders of diffraction can you see? Measure the angle of first order diffraction.

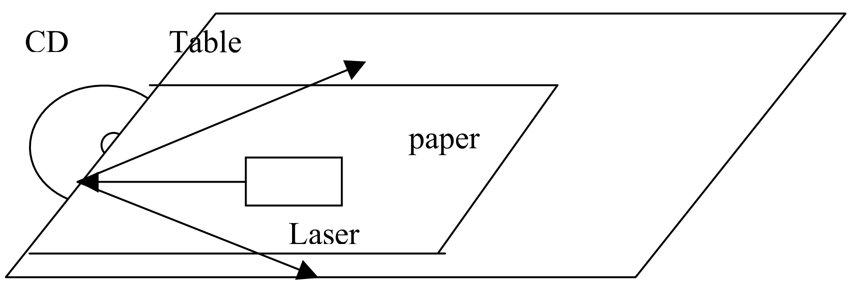


Figure 6. Arrangement for measuring diffraction from CD or DVD.

(D1.2) Repeat the experiment with the DVD. If the lines in the DVD are more closely spaced than in the CD, how would you expect the angle of the diffracted beam to change? Does the angle of the diffraction change as you predicted?
(D1.3) Calculate the spacing between the lines on the CD and DVD.

Conclusion:

1. Write a conclusion about part of the lab that will be designated by the TA.