Izmir Institute of Technology
Department of Physics

PHYS 212
Waves & Optics Laboratory Manual

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Contents

Chapter 1

BREWSTER'S ANGLE

INTRODUCTION

In this experiment, light is partially polarized when reflected off a nonconducting surface and Brewster's angle is measured.

Light from a diode laser is reflected off the flat side of an acrylic semi-circular lens. The reflected light passes through a polarizer and is detected by a light sensor. The angle of reflection is measured by a Rotary Motion Sensor mounted on the Spectrophotometer table. The intensity of the reflected polarized light versus reflected angle is graphed to determine the angle at which the light intensity is a minimum. This is Brewster's Angle, which is used to calculate the index of refraction of acrylic.

THEORY

When unpolarized light reflects off a nonconducting surface, it is partially polarized parallel to the plane of the reflective surface. There is a specific angle called Brewster's angle at which the light is 100% polarized. This occurs when the reflected ray and the refracted ray are 90 degrees apart.

According to Snell's Law,

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad (1)$$

where n is the index of refraction of the medium and θ is the angle of the ray from the normal.

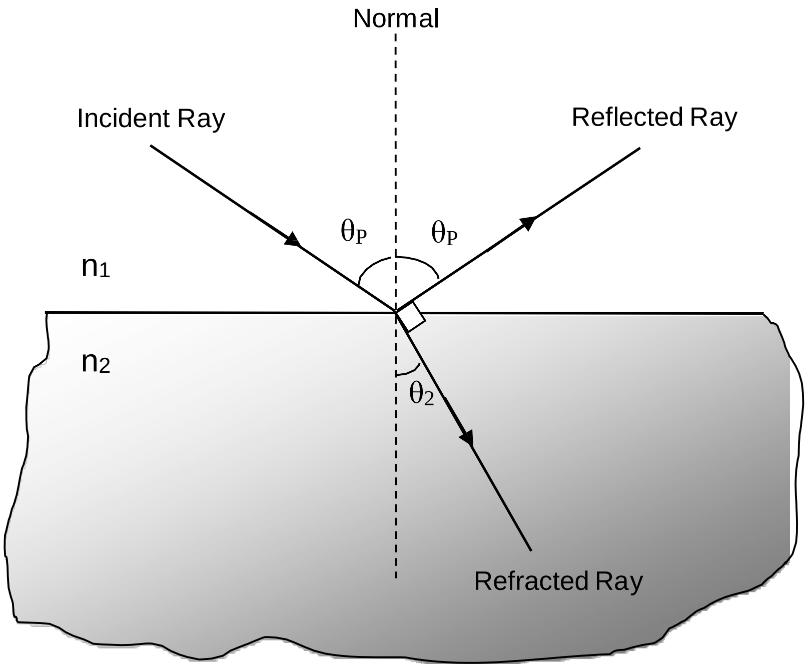


Figure 1: Theory

When the angle of incidence is equal to Brewster's angle, θ_P,

$$n_1 \sin\theta_P = n_2 \sin\theta_2 \qquad (2)$$

and since $\theta_P + \theta_2 = 90^o$, $\theta_2 = 90^o - \theta_P$, and

$$\sin\theta_2 = \sin(90^o - \theta_P) = \sin 90^o \cos\theta_P - \cos 90^o \sin\theta_P = \cos\theta_P$$

Substituting for $\sin\theta_2$ in Equation (2) gives

$$n_1 \sin\theta_P = n_2 \cos\theta_P$$

Therefore, $\frac{n_2}{n_1} = \tan\theta_P$. (3)

SET UP

1. Attach the spectrophotometer table to the track. Put the diode laser, 2 polarizers and the collimating slits on the track as shown in Figure 2. Mount the Rotary Motion Sensor with the bigger diameter of spindle against the spectrophotometer table (see Figure 3). Attach the spectrophotometer table base to ground as instructed by your teacher.

Figure 2: Complete Setup

2. The spectrophotometer disk should be put on "backwards" with the 180 degree mark at the position where the zero mark is normally.
3. Two round polarizers are used on the holder. Rotate the second polarizer (second from laser) to 45 degrees and lock it in place by tightening the brass screw. The first polarizer (closest to the laser) is used throughout the experiment to adjust the light level. Since the ratio of reflected light to incident light is measured, better data will be obtained if the incident light level is kept above 50%.

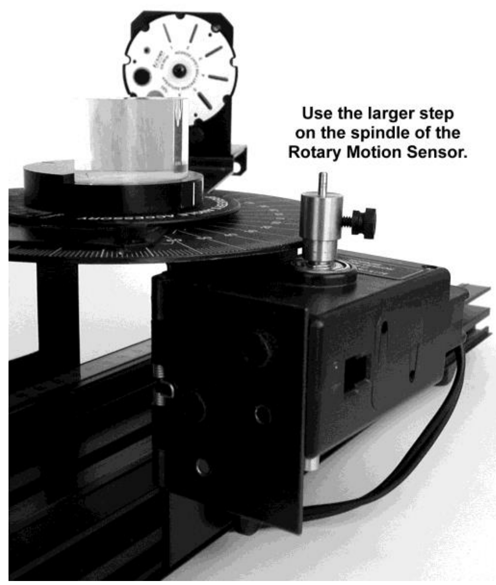


Figure 3: Large Spindle Is Used

4. The square analyzing polarizer (in Figure 4) has its transmission axis marked, and for normal use the label should be on top with its axis horizontal and thus 90 degrees from the polarization axis of the reflected light. This is finding the variation in the “p” (parallel) component of the reflected light and is used to determine Brewster’s angle and to calculate the index of refraction. But by placing the analyzing polarizer with its transmission axis vertical, you can also look at the variation in the “s” (perpendicular) component of the reflected light as well.

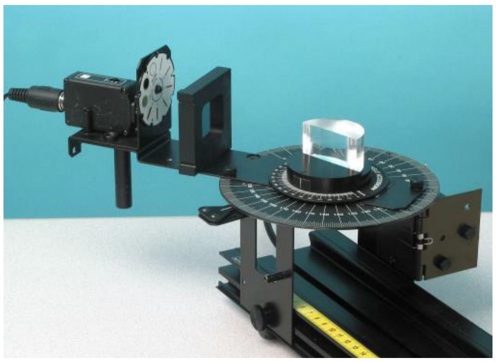


Figure 4: Square Analyzing Polarizer

5. The 45 degree polarizer is used to solve the problem that the laser light is already polarized. To make the relative intensities of the s and p components the same, the light is polarized at 45 degrees.

6. The small metal Brewster's angle base disk should be screwed in and zeroed so that the mark at the top of the label above the N in the word A<u>N</u>GLE is aligned with the zero angle mark on the spectrophotometer disk.

7. The plastic base has two zero marks. For reflected light, use the mark that is on the side with the higher step. The D lens is placed on the lower surface flush against the step when data is being collected. The other mark would be used for transmission, like for Snell’s Law.

8. To align the laser beam, remove all polarizers, collimating slits, and D lens. Set the spectrophotometer arm on 180 degrees. Use the x-y adjust on the laser to get the laser beam at the center of the Light Sensor slit. The Light Sensor bracket slit should be set on #4. Place the collimating slits on track and adjust the slit position so the laser beam passes through the #4 slit.

9. Plug the Rotary Motion Sensor into Channels 1 and 2 on the ScienceWorkshop 500 interface. Plug the Light Sensor into Channel A. Open the DataStudio file called "Brewsters".

PROCEDURE

1. With the D lens removed, zero the angle for Rotary Motion Sensor: Rotate the spectrophotometer arm so the laser beam is centered on the Light Sensor slit. The spectrophotometer disk should be near 180 degrees but it doesn’t matter if it is slightly off. Click on START and move the arm back and forth in front of the laser, watching the intensity on the computer. Stop at the position that gives the maximum intensity. Click on STOP and do not move the arm until program is started to take the actual data run. This insures that zero for Rotary Motion Sensor is at the center of the beam. Place the D lens on the platform against the step.

   Note about angle measurement: The angle is computed by dividing the actual angle (recorded by the computer) by two. The best procedure is to move the spectrophotometer arm, reading the angle on the digits display, and then rotate the plastic Brewster's disk to match same angle. Thus the markings on Brewster's disk are only there for convenience (in this experiment) and are not used directly. But, to get the laser beam exactly on to the slit, you must make fine adjustments while watching the digits display for the maximum light intensity. You can adjust either the disk or the spectrophotometer arm until the intensity is maximized.

2. Turn out the room lights. A small light might be useful for seeing the computer keys to type in values and to put the analyzing polarizer on and off. Click on START. Do not click on STOP until all of the procedure steps are completed. Set angle to 85 degrees. The square analyzing polarizer should not be in place. Rotate the Brewster disk to about 85 and, while watching the digits display of light intensity, fine tune the position to get into the beam. It doesn’t have to be exact, just so that you get enough light. Rotate the first polarizer (nearest to the laser) to adjust the level to be as high as possible without exceeding 90%. The Light Sensor should be on gain of 1 or 10.

3. Enter the angle into the table. Read the digits display of the light intensity and record the value under “Total Light” column. Place square analyzing polarizer (axis horizontal) on the arm just in front of slits. (Note: The square analyzing polarizes must sit level, flat on the arm.) Read the digits display of light intensity and record value under “Polarized Light” column. You must hit enter after typing each value. Check to see if the value is plotted on the graph.

4. Remove the analyzing polarizer and go to the next angle, in increments of 5 degrees. Since the results are live on the graph, you can see when the intensity is approaching the minimum. Take data points every 1 degree near the minimum.

5. Click on "Fit" at the top of the graph and choose the polynomial fit. Determine the angle at which the reflection is a minimum. This is Brewster's angle.

ANALYSIS

1. Use Brewster's angle to calculate the index of refraction of acrylic using Equation (3). What value should you plug in for n_1?

2. Would Brewster's angle be more or less for light in air reflecting off water?

3. How do polarized sunglasses reduce glare? Which direction is the axis of polarization in a pair of polarized sunglasses? How could you check this?

Chapter 2

INVERSE SQUARE LAW FOR LIGHT

Introduction

The relative light intensity versus distance from a point light source is plotted. As the Light Sensor is moved by hand, the string attached to the Light Sensor that passes over the Rotary Motion Sensor pulley to a hanging mass causes the pulley to rotate, measuring the position.

Using DataStudio, various curves are fitted to the data to see which fits better.

Theory

If light spreads out in all directions, as it does from a point light source, the intensity at a certain distance from the source depends on the area over which the light is spread. For a sphere of radius r, what is the equation for the surface area?

Intensity is calculated by taking the power output of the bulb divided by the area over which the light is spread:

$$\text{Intensity} = \frac{\text{Power}}{\text{Area}}$$

Put the surface area of a sphere into the intensity equation. How does the intensity of a point source depend on distance?

Setup

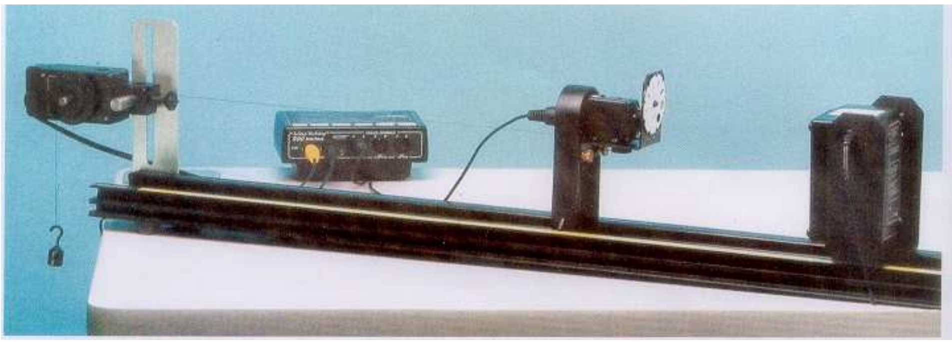


Figure 2.1:

1. Set up the equipment as shown in the figure. The thread is attached to the Light Sensor bracket and passes over the large pulley to a hanging 10g mass.

2. Plug the Rotary Motion Sensor into Channels 1 and 2 on the ScienceWorkshop 750 interface and plug the Light Sensor into Channel A.

3. Start the DataStudio program and open the file called ”Light Intensity”.

Procedure

I. Exploring Different Functions

1. Click on the graph called Functions. This graph shows y = x.

2. Click on the calculator button at the top of the graph.

3. Change the function in the calculator window to $y = x^2$ and click accept. Examine the resulting changes in the graph. Note the shape of the graph.

4. Change the function in the calculator window to y = 1/x, click accept, and examine the new graph.

5. Change the function in the calculator window to $y = 1/x^2$, click accept, and examine the new graph. Now that you have familiarized yourself with these different functions you are ready to plot the light intensity vs. distance for a point light source.

II. Adjusting the Sensitivity of the Light Sensor

The sensitivity of the Light Sensor must be adjusted so it does not max out or so it is not set so low that the signal is poor.

1. Set the front of the Light Sensor mask 15cm from the center of the point light source. Note that you must sight down the front of the Light Sensor mask to see where it lines up with the track measuring tape. The center of the point light source is indicated by the notch in the light source bracket. Plug in the point light source.

2. Rotate the aperture bracket to the white circle.

3. Press the Start button above and monitor the voltage output from the Light Sensor. Adjust the gain switch on the top of the Light Sensor so the voltage is as close to 4.5V as possible without exceeding 4.5V .

III. Taking the Intensity vs. Distance Data:

1. With the Light Sensor 15cm from the center of the light bulb, click on START. Squeeze the sides of the Light Sensor slowly from 15cm to 100cm away from the bulb. As you do this, the thread will rotate the Rotary Motion Sensor, recording the distance the Light Sensor is from the bulb.

2. Try moving the Light Sensor away from the light bulb now and check to make sure the distance is positive. If it is negative, exchange the Rotary Motion Sensor plugs in the 750 interface. Then click on STOP. Return the Light Sensor mask to the 15cm position.

3. With the Light Sensor mask at 15cm, click on START to take data. Slowly pull the Light Sensor back from 15cm to about 100cm or until the hanging mass touches the floor.

4. Press the upper left button on the Light Intensity vs. Distance graph to scale the data so it fits the whole graph.

5. Choose the various fits (linear, square fit, inverse fit, inverse square fit) from the pull-down Fit menu on the graph. For each fit, record the error given in the fit box.

6. The best fit is the one which has the least error. Which fit best for the point source? How does the light intensity depend on distance?

7. Do your results agree with your prediction from the theory?

8. Sketch the graph with the best fit or, if a printer is available, print it.

Question

Suppose you repeated this experiment with a long fluorescent bulb and the Light Sensor is moved along the axis perpendicular to the light bulb. Would you expect the light intensity for this line of light to depend on distance in the same way as it does for a point light source? Why or why not? What dependence on distance would you expect?

Chapter 3

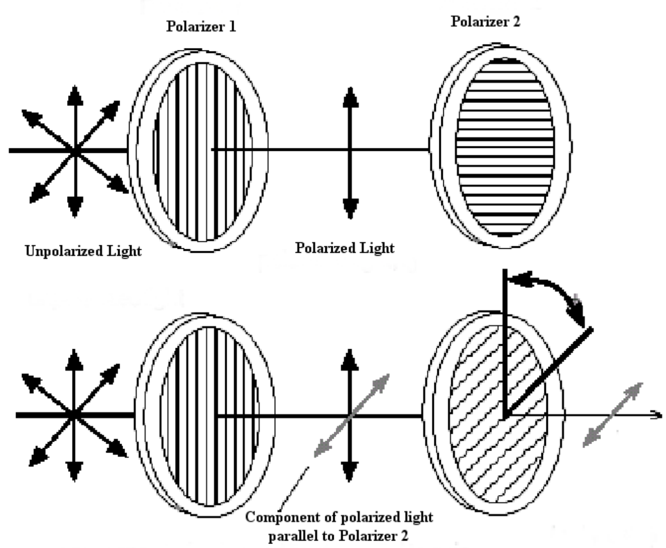
POLARIZATION OF LIGHT

INTRODUCTION

Laser light (peak wavelength = 650 nm) is passed through two polarizers. As the second polarizer (the analyzer) is rotated by hand, the relative light intensity is recorded as a function of the angle between the axes of polarization of the two polarizers. The angle is obtained using a Rotary Motion Sensor that is coupled to the polarizer with a drive belt. The plot of light intensity versus angle can be fitted to the square of the cosine of the angle.

THEORY

A polarizer only allows light which is vibrating in a particular plane to pass through it. This plane forms the "axis" of polarization. Unpolarized light vibrates in all planes perpendicular to the direction of propagation. If unpolarized light is incident upon an "ideal" polarizer, only half of the light intensity will be transmitted through the polarizer.



The transmitted light is polarized in one plane. If this polarized light is incident upon a second polarizer, the axis of which is oriented such that it is perpendicular to the plane of polarization of the incident light, no light will be transmitted through the second polarizer. See Fig.1. However, if the second polarizer is oriented at an angle not perpendicular to the axis of the first polarizer, there will be some component of the electric field of the polarized light that lies in the same direction as the axis of the second polarizer, and thus some light will be transmitted through the second polarizer.

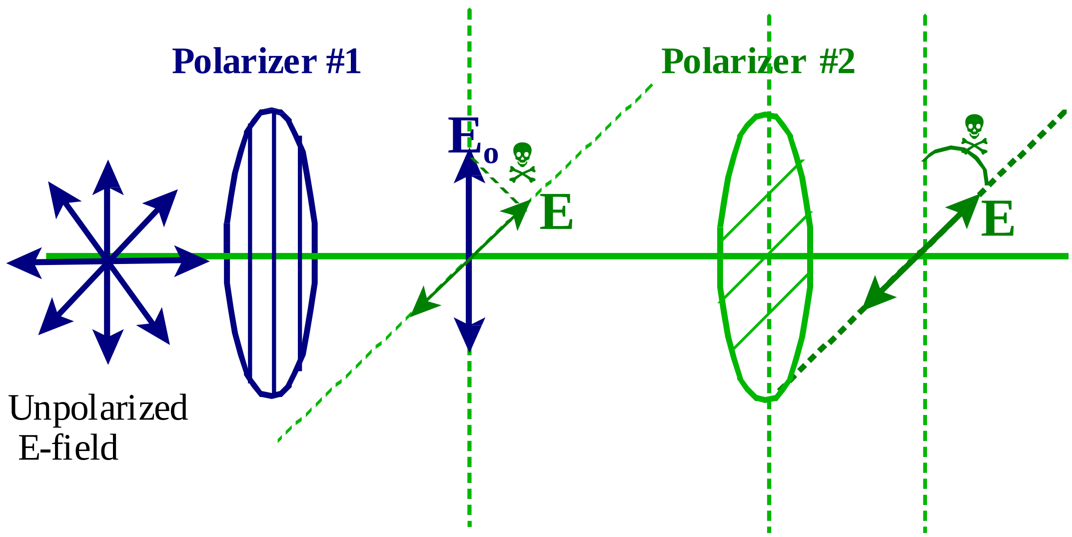


Figure 2: Component of the Electric Field

If the polarized electric field is called E_0 after it passes through the first polarizer, the component, E, after the field passes through the second polarizer which is at an angle ϕ with respect to the first polarizer is $E_0\cos\phi$ (see Fig.2). Since the intensity of the light varies as the square of the electric field, the light intensity transmitted through the second filter is given by

$$I = I_o \cos^2 \phi \qquad (1)$$

SET UP

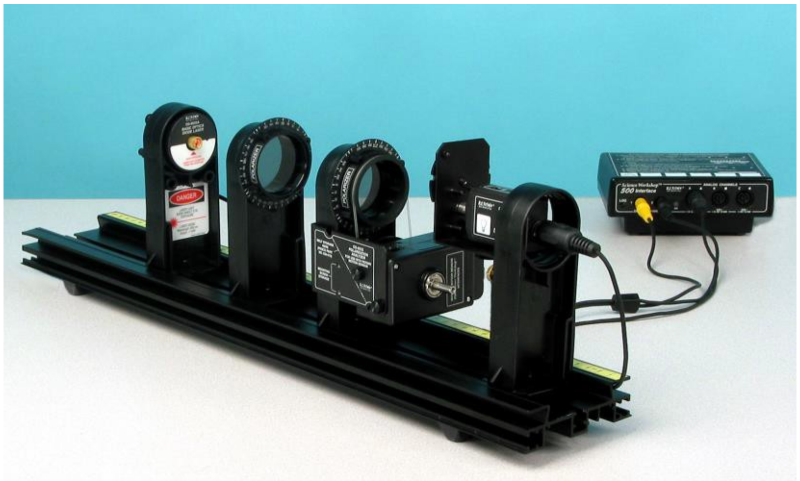


Figure 3: Equipment Separated to Show Components

1. Mount the aperture disk on the aperture bracket holder.

2. Mount the Light Sensor on the Aperture Bracket and plug the Light Sensor into the interface (See Fig.5).

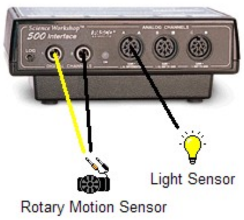


Figure 4: ScienceWorkshop 500 Interface with Sensors

3. Rotate the aperture disk so the translucent mask covers the opening to the light sensor (see Fig.6).

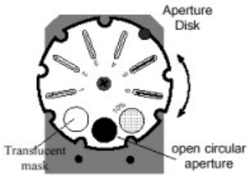


Figure 5: Use Translucent Mask

4. Mount the Rotary Motion Sensor on the polarizer bracket. Connect the large pulley on the Rotary Motion Sensor to the polarizer pulley with the plastic belt (see Fig.7).

5.	Plug the Rotary Motion Sensor into the interface (see Fig 5).

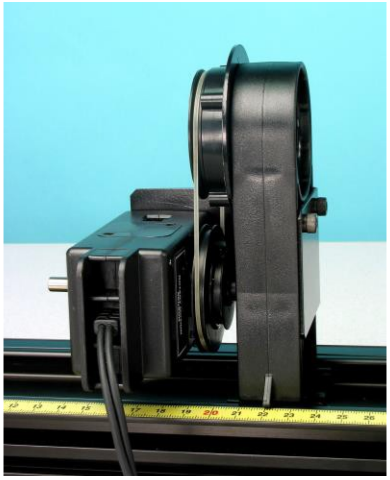


Figure 6: Rotary Motion Sensor Connected to Polarizer with Belt

6.	Place all the components on the Optics Track as shown in Fig.8.

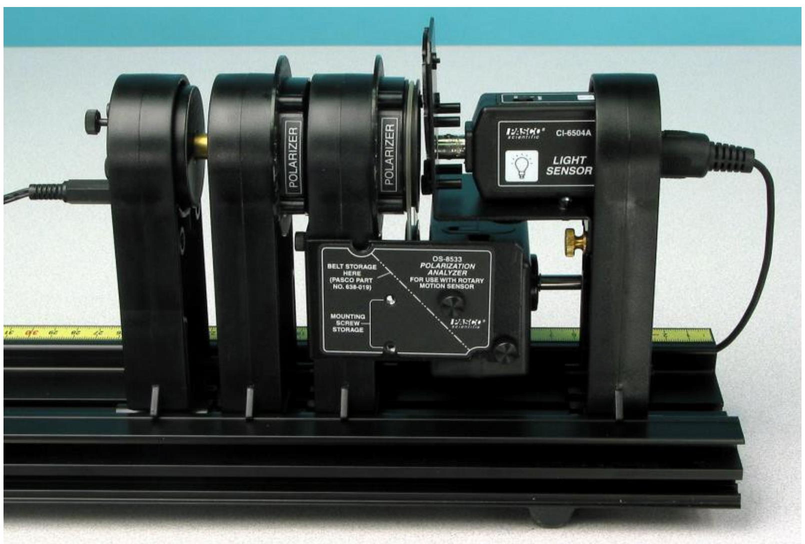


Figure 7: Setup with Components in Position for Experiment

SOFTWARE SET UP

Start DataStudio and open the file called "Polarization".

PROCEDURE

In the first two procedure steps, the polarizers are aligned to allow the maximum amount of light through.

1.	Since the laser light is already polarized, the first polarizer must be aligned with the laser's axis of polarization. First remove the holder with the polarizer and Rotary Motion

Sensor from the track. Slide all the components on the track close together and dim the room lights. Click START and then rotate the polarizer that does not have the Rotary Motion Sensor until the light intensity on the graph is at its maximum. You may have to use the button in the upper left on the graph to expand the graph scale while taking data to see the detail.

2. To allow the maximum intensity of light through both polarizers, replace the holder with the polarizer and Rotary Motion Sensor on the track, press Start, and then rotate polarizer that does have the Rotary Motion Sensor until the light intensity on the graph is at its maximum (see Fig. 9).

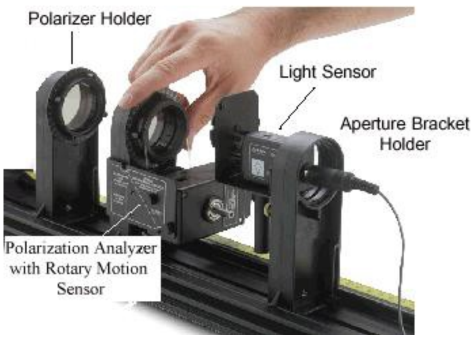


Figure 8: Rotate the Polarizer That Has the Rotary Motion Sensor

3. If the maximum exceeds 4.5 V, decrease the gain on the switch on the light sensor. If the maximum is less than 0.5 V, increase the gain on the switch on the light sensor.

4. Press Start and slowly rotate the polarizer which has the Rotary Motion Sensor through 180 degrees. Then press Stop.

ANALYSIS

1. Click on the Fit button on the graph. Choose the User-Defined Fit and write an equation (Acos(x)^2) with constants you can adjust to make the curve fit your data.

2. Try a $\cos^3(x)$ fit and then try a $\cos^4(x)$ fit. Does either of these fit better than your original fit? Does the equation that best fits your data match theory? If not, why not?

Chapter 4

INTERFERENCE AND DIFFRACTION OF LIGHT

INTRODUCTION

The distances between the central maximum and the diffraction minima for a single slit are measured by scanning the laser pattern with a Light Sensor and plotting light intensity versus distance. Also, the distance between interference maxima for two or more slits are measured. These measurements are compared to theoretical values. Differences and similarities between interference and diffraction patterns are examined.

THEORY

Diffraction

When diffraction of light occurs as it passes through a slit, the angle to the minima (dark spot) in the diffraction pattern is given by

$$a \sin \Theta = m'\lambda \quad (m'=1,2,3, \ldots) \qquad (1)$$

where "*a*" is the slit width, θ is the angle from the center of the pattern to the *a* minimum, λ is the wavelength of the light, and *m'* is the order (1 for the first minimum, 2 for the second minimum, ...counting from the center out).

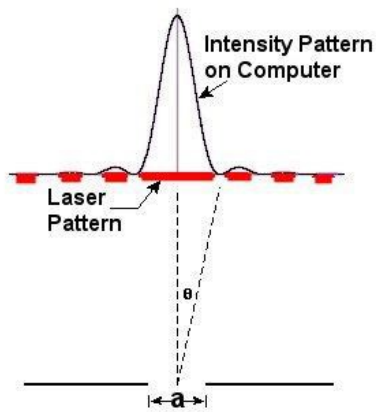


Figure 1: Single-Slit Diffraction

In Figure 1, the laser light pattern is shown just below the computer intensity versus position graph. The angle theta is measured from the center of the single slit to the first minimum, so m' equals one for the situation shown in the diagram.

Double-Slit Interference

When interference of light occurs as it passes through two slits, the angle from the central maximum (bright spot) to the side maxima in the interference pattern is given by

$$d \sin\Theta = m\lambda \quad (m=1,2,3, \ldots) \qquad (2)$$

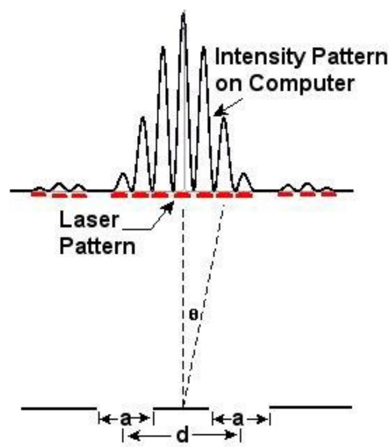


Figure 2: Double-Slit Interference

where "*d*" is the slit separation, θ is the angle from the center of the pattern to the m^{th} maximum, λ is the wavelength of the light, and m is the order (0 for the central maximum, 1 for the first side maximum, 2 for the second side maximum ...counting from the center out).

In Figure 2, the laser light pattern is shown just below the computer intensity versus position graph. The angle theta is measured from the midway between the double slit to the second side maximum, so m equals two for the situation shown in the diagram.

SET UP

1. Mount the Single Slit disk to the optics bench: Each of the slit disks is mounted on a ring that snaps into an empty lens holder. The ring should be rotated in the lens holder so the slits at the center of the ring are vertical in the holder (see Figure 3). Then the screw on the holder should be tightened so the ring cannot rotate during use. To select the desired slits, just rotate the disk until it clicks into place with the desired slit at the center of the holder.

Figure 3: Mounting the Slits

NOTE: All slits are vertical EXCEPT the comparison slits that are horizontal. The comparison slits are purposely horizontal Because the wide laser diode beam will cover both slits to be compared. If you try to rotate these slits to the vertical position, the laser beam may not be large enough to illuminate both slits at the same time.

2. Mount the Rotary Motion Sensor on the rack of the Linear Translator and mount the Linear Translator to the end of the optics track (see Figure 4). Mount the Light Sensor with the Aperture Bracket (set on slit #6) in the Rotary Motion Sensor rod clamp.

3. To complete the alignment of the laser beam and the slits, place the Diode Laser on the bench at one of the bench. Put the slit holder on the optics bench a few centimeters from the

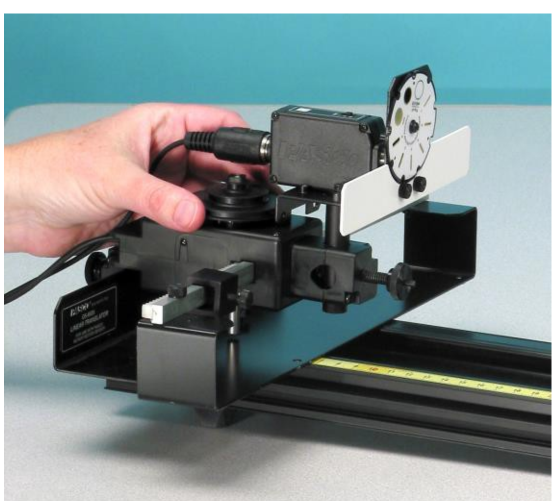


Figure 5: Adjusting the

Laser Figure 4: Scanner with Light Sensor laser, with the disk-side of the holder closest to the laser (see Figure 5). Plug in the Diode Laser and turn it on. CAUTION: Never look into the laser beam.

4. Adjust the position of the laser beam from left-to-right and up-and-down until the beam is centered on the slit. Once this position is set, it is not necessary to make any further adjustments of the laser beam when viewing any of the slits on the disk. When you rotate the disk to a new slit, the laser beam will be already aligned. Since the slits click into place, you can easily change from one slit to the next, even in the dark. When the laser beam is properly aligned, the diffraction pattern should be centered on the slits in front of the light sensor (see Figure 6). You may have to raise or lower the light sensor to align the pattern vertically.

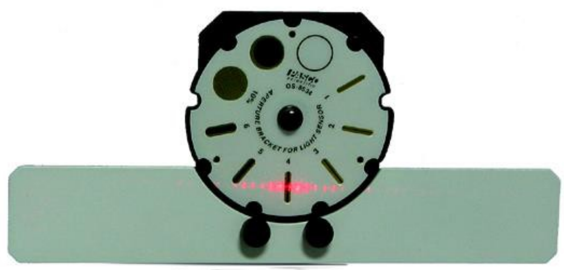
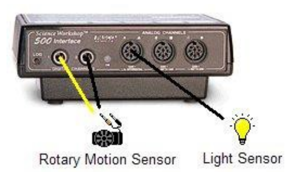


Figure 6: Aligning the Light Sensor

5. Begin with the Light Sensor gain switch set on x10 and if the intensity goes off scale, turn it down to x1.

6. Plug the Rotary Motion Sensor into Channels 1 and 2 on the ScienceWorkshop 500 interface and plug the Light Sensor into Channel A.



7. Open the DataStudio file called "Diffraction".

FAMILIARIZATION WITH THE PATTERNS

1. Start with the Single Slit Set. Rotate the wheel to the 0.16 mm single slit.

2. Look at the pattern produced by each selection on the Single Slit wheel. Draw a diagram of each slit and the corresponding diffraction pattern.

3. Repeat Steps 2 and 3 for the Multiple Slit wheel. Align the wheel on the 0.08/0.50 double slit.

Figure 7: Complete Setup

SINGLE SLIT PROCEDURE

1. Replace the Multiple Slit wheel with the Single Slit wheel and set it to the 0.04 mm single slit.

2. Before starting to record data, move the Light Sensor to one side of the laser pattern. You can mark your scan starting point using the black clamp on the linear translator.

3. Turn out the room lights and click on the START button. Then slowly turn the Rotary Motion Sensor pulley to scan the pattern. Click on STOP when you have finished the scan. If you make a mistake, simply do the scan again. You may have to change the gain setting on the light sensor (1x, 10x, 100x) depending on the intensity of the pattern. You should try to use slit #4 on the mask on the front of the light sensor. Sketch each graph or, if a printer is available, print the graph of the diffraction pattern.

4. Determine the slit width using Equation (1):

    (a) Measure the distance between the first minima on each side of the central maximum using the Smart Cursor in the computer program and divide by two.

    (b) The laser wavelength is given on the laser label.

    (c) Measure the distance between the slit wheel and the mask on the front of the light sensor.

    (d) Solve for "a" in Equation (1). Measure at least two different minima and average your answers. Find the percent difference between your average and the stated slit width on the wheel. Note that the stated slit width is given to only one significant figure so the actual slit width is somewhere between 0.035mm and 0.044mm.

DOUBLE SLIT PROCEDURE

1. Replace the single slit disk with the multiple slit disk. Set the multiple slit disk on the double slit with slit separation 0.25 mm (d) and slit width 0.04 mm (a).

2. Set the Light Sensor Aperture Bracket to slit #4.

3. Before starting to record data, move the Light Sensor to one side of the laser pattern, up against the linear translator stop.

4. Turn out the room lights and click the START button. Then slowly turn the Rotary Motion Sensor pulley to scan the pattern. Click STOP when you have finished the scan. You may have to change the gain setting on the light sensor (1x, 10x, 100x) depending on the intensity of the pattern. To get the most detail, use the smallest slit possible on the Light Sensor mask.

5. Use the magnifier to enlarge the central maximum and the first side maxima. Use the Smart tool to measure the distance between the central maximum and the first side maxima.

6. Measure the distance between the central maximum and the second and third side maxima. Also measure the distance from the central maximum to the first minimum in the DIFFRACTION (not interference) pattern.

7. Determine the slit separation using Equation (2):

   (a) Measure the distance between the slit wheel and the mask on the front of the light sensor.

   (b) Solve for "*d*" in Equation (2). Determine "*d*" using the first, second, and third maxima and find the average "*d*". Find the percent difference between your average and the stated slit separation on the wheel.

8. Determine the slit width using Equation (1) and the distance between the central maximum and the first minimum in the diffraction pattern (not interference pattern). Is this the slit width given on the wheel?

9. Repeat Steps 2 through 8 for the interference patterns for the double slits (a/d = 0.04/0.50 mm).

QUESTIONS

1. What physical quantity is the same for the single slit and the double slit?

2. How does the distance from the central maximum to the first minimum in the single-slit pattern compare to the distance from the central maximum to the first diffraction minimum in the double-slit pattern?

3. What physical quantity determines where the amplitude of the interference peaks goes to zero?

4. In theory, how many interference maxima should be in the central envelope for a double slit with d = 0.25 mm and a = 0.04 mm?

5. How many interference maxima are actually in the central envelope?

Chapter 5

MICROWAVE OPTICS

Experiment 1: Refraction Through A Prism

Theory

An electromagnetic wave usually travels in a straight line. As it crosses a boundary between two different media, however, the direction of propagation of the wave changes. This change in direction is called Refraction, and it is summarized by a mathematical relationship known as the Law of Refraction (otherwise known as Snell's Law):

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Where θ_1 is the angle between the direction of propagation of the incident wave and the normal to the boundary between the two media, and, θ_2 is the corresponding angle for the refracted wave (see Figure 5.1). Every material can be described by a number n, called its Index of Refraction. This number indicates the ratio between the speed of electromagnetic waves in vacuum and the speed of electromagnetic waves in the material, also called the medium. In general, the media on either side of a boundary will have different indices of refraction. Here they are labeled n_1 and n_2. It is the difference between indices of refraction (and the difference between wave velocities this implies) which causes "bending", or refraction of a wave as it crosses the boundary between two distinct media.

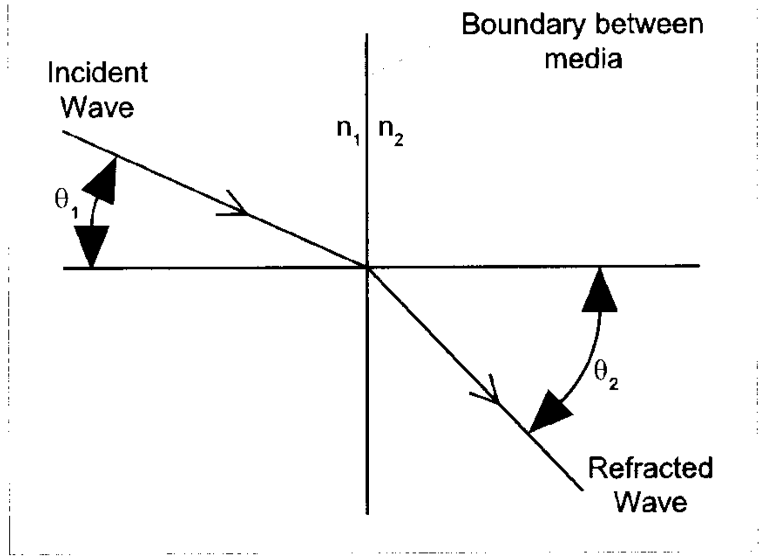


Figure 5.1: Angles of Incidence and Refraction

In this experiment, you will use the law of refraction to measure the index of refraction for styrene pellets.

Procedure

1. Arrange the equipment as shown in Figure 5.2. Rotate the empty prism mold and see how it effects the incident wave. Does it reflect, refract, or absorb the wave?

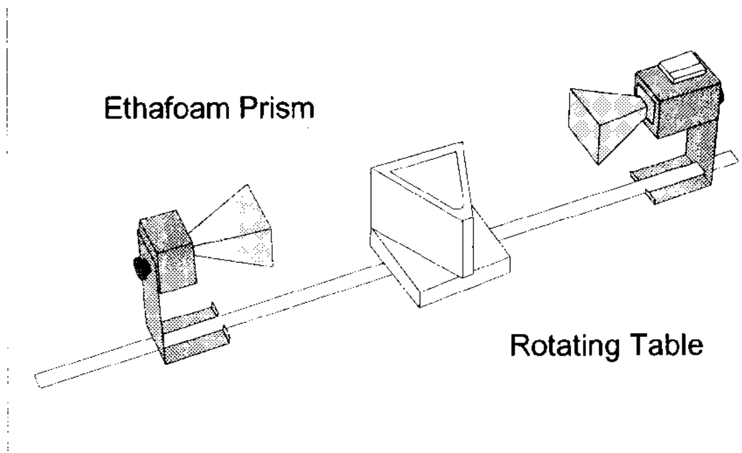


Figure 5.2: Equipment Setup

2. Fill the prism mold with the styrene pellets. To simplify the calculations, align the face of the prism that is nearest to the Transmitter perpendicular to the incident microwave beam.

3. Rotate the movable arm of the Goniometer and locate the angle θ at which the refracted signal is a maximum.

NOTE: θ is just the angle that you read directly from the Degree Scale of the Goniometer.

θ = ...

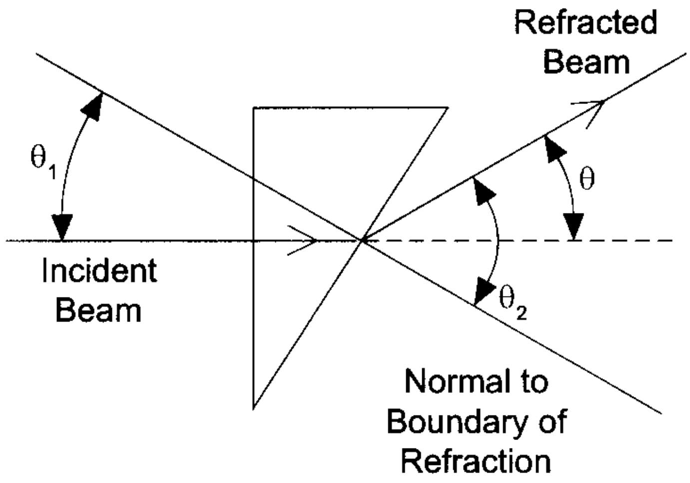


Figure 5.3: Geometry of Prism Refraction

4. Using the diagram shown in Figure 5.3, determine θ_1 and use your value of θ to determine θ_2. (You will need to use a protractor to measure the Prism angles.)

θ_1 = ...

θ_2 = ...

5. Plug these values into the Law of Refraction to determine the values of n_1/ n_2.

n_1/ n_2 = ...

6. The index of refraction for air is equal to 1.00. Use this fact to determine n_1, the index of refraction for the styrene pellets.

Questions

1. In the diagram of Figure 5.3, the assumption is made that the wave is unrefracted when it strikes the first side of the prism (at an angle of incidence of 0^{o}). Is this a valid assumption?

2. Using this apparatus, how might you verify that the index of refraction for air is equal to one.

3. Would you expect the refraction index of the styrene pellets in the prism mold to be the same as for a solid styrene prism?

Experiment 2: Fabry-Perot Interferometer

Theory

When an electromagnetic wave encounters a partial reflector, part of the wave reflects and part of the wave transmits through the partial reflector. A Fabry-Perot Interferometer consists of two parallel partial reflectors positioned between a wave source and a detector (see Figure 5.4).

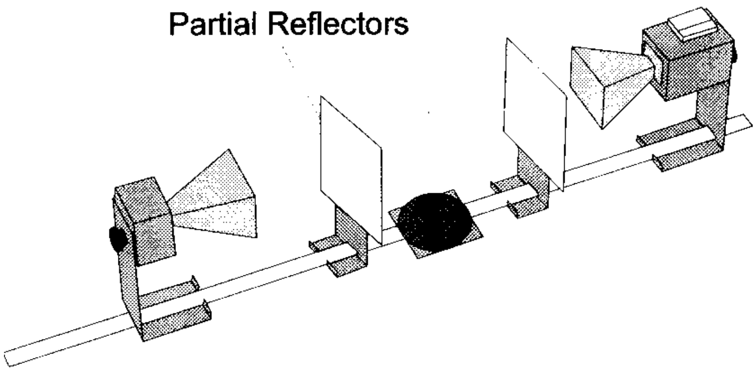


Figure 5.4: Fabry-Perot Interferometer

The wave from the source reflects back and forth between the two partial reflectors. However, with each pass, some of the radiation passes through to the detector. If the distance between the partial reflectors is equal to $n\lambda/2$, where λ is the wavelength of the radiation and n is an integer, then all the waves passing through to the detector at any instant will be in phase. In this case, a maximum signal will be detected by the Receiver. If the distance between the partial reflectors is not a multiple of $\lambda/2$, then some degree of destructive interference will occur, and the signal will not be a maximum.

Procedure

1. Arrange the equipment as shown in Figure. Plug in the Transmitter and adjust the Receiver controls for an easily readable signal.

2. Adjust the distance between the Partial Reflectors and observe the relative minima and maxima.

3. Adjust the distance between the Partial Reflectors to obtain a maximum meter reading. Record, d_1, the distance between the reflectors.

d_1 =.....................

4. While watching the meter, slowly move one Reflector away from the other. Move the Reflector until the meter reading has passed through at least 10 minima and returned to a maximum. Record the number of minima that were traversed. Also record d_2, the new distance between the Reflectors.

Minima traversed = ...

d_2 =.....................

5. Use your data to calculate λ, the wavelength of the microwave radiation.

λ = ...

6. Repeat your measurements, beginning with a different distance between the Partial Reflectors.

d_1 =.....................

d_2 =.....................

Minima traversed = ...

λ = ...

Questions

1. What spacing between the two Partial Reflectors shoul cause a minimum signal to be delivered to the Receiver?

2. In an optical Fabry-Perot interferometer pattern usually appears as a series of concentric rings. Do you expect such a pattern to occur here? Why? Check to see if there is one.

Experiment 3: Michelson Interferometer

Theory

Like the Fabry-Perot interferometer, the Michelson interferometer splits a single wave, then brings the constituent waves back together so that they superpose, forming an interference pattern. Figure shows the setup for the Michelson interferometer. A and B are Reflectors and C is a Partial Reflector. Microwaves travel from the Transmitter to the Receiver over two different paths. In one path, the wave passes directly through C, reflects back to C from A, and then is reflected from C into the Receiver. In the other path, the wave reflects from C into B, and then back through C into the Receiver.

If the two waves are in phase when they reach the Receiver, a maximum signal is detected. By moving one of the Reflectors, the path length of one wave changes, thereby changing its phase at the Receiver so a maximum is no longer detected. Since each wave passes twice between a Reflector and the Partial Reflector, moving a Reflector a distance $\lambda/2$ will cause a complete 360-degree change in the phase of one wave at the Receiver. This causes the meter reading to pass through a minimum and return to a maximum.

Procedure

1. Arrange the equipment as shown in Figure 5.5. Plug in the Transmitter and adjust the Receiver for an easily readable signal.

2. Slide Reflector A along the Goniometer arm and observe the relative maxima and minima of the meter deflections.

3. Set Reflector A to a position which produces a maximum meter reading. Record, x_1, the position of the Reflector on the Goniometer arm.

x_1 = ...

4. While watching the meter, slowly move Reflector A away from the Partial Reflector. Move the Reflector until the meter reading has passed through at least 10 minima and returned

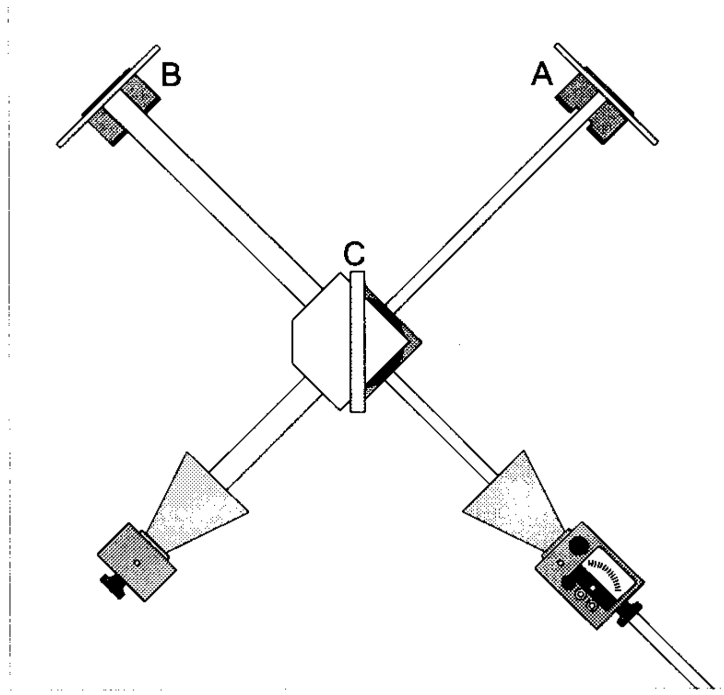


Figure 5.5: Michelson Interferometer

to a maximum. Record the number of minima that were traversed. Also record x_2, the new position of Reflector A on the Goniometer arm.

Minima traversed = ...

x_2 = ...

5. Use your data to calculate λ, the wavelength of the microwave radiation.

λ = ...

6. Repeat your measurements, beginning with a different position for Reflector A.

x_1 = ...

Minima traversed = ...

x_2 = ...

λ = ...

Question

You have used the interferometer to measure the wavelength of the microwave radiation. If you already knew the wavelength, you could use the interferometer to measure the distance over which the Reflector moved. Why would an optical interferometer (an interferometer using visible light rather than microwaves) provide better resolution when measuring distance than a microwave interferometer?

An Idea for Further Investigation

Place a cardboard box between the Partial Reflector and Reflector A. Move one of the reflectors until the meter deflection is a maximum. Slowly fill the box with styrene pellets while observing the meter deflections. On the basis of these observations, adjust the position of Reflector A to restore the original maximum. Measure the distance over which you adjusted the reflector. Also measure the distance traversed by the beam through the pellets. From this data, can you determine the styrene pellets' index of refraction at microwave frequencies? (The wavelength of electromagnetic radiation in a material is given by the relationship $\lambda = \lambda_o/n$; where λ is the wavelength, λ_o is the wavelength in a vacuum, and n is the index of refraction of the material). Try boxes of various widths. you might also try filling them with a different material.

CHAPTER 6

MICHELSON INTERFEROMETER

Introduction:

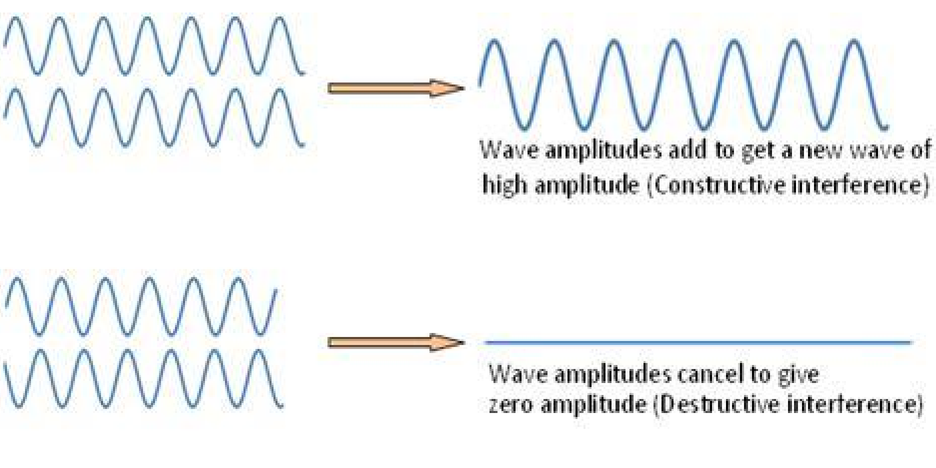
Purpose:

Interferometers are used to precisely measure the wavelength of optical beams through the creation of interference patterns . We will construct a Michelson interferometer, study the fringe patterns resulting from a point source. In this laboratory, we will use a Michelson interferometer to (a) measure the wavelength of light from a Ne-He laser, (b) measure the index of refraction of air, and (c) measure the index of refraction of glass.

Theory:

Interference theory:

Light is a transverse wave. When two waves of same wavelength and amplitude travel through same medium, their amplitudes combine. A wave of greater or lesser amplitude than the original will be the result. The addition of amplitudes due to superposition of two waves is called interference. If the crest of one wave meets with the trough of the other, the resultant intensity will be zero and the waves are said to interfere destructively. Alternatively, if the crest of one wave meets with the crest of the other, the resultant will be maximum intensity and the waves are said to interfere constructively. Suppose two coherent (*i.e.* their initial phase relationship remains constant) waves start from the same point and travel different paths before coming back together and interfering with each other. Suppose also that the re-combined waves illuminate a screen where the position on the screen depends on the difference in the lengths of the paths traveled by the two waves. Then the resulting alternating bright and dark bands on the screen are called interference fringes.



In constructive interference, a bright fringe (band) is obtained on the screen. For constructive interference to occur, the path difference between two beams must be an integral multiple $m\lambda$ of the wavelength λ, where m is the order, with m =0,1,2...

If the path difference between two waves is $(m+\frac{1}{2})\lambda$, the interference between them is destructive, and a dark fringe appears on the screen.

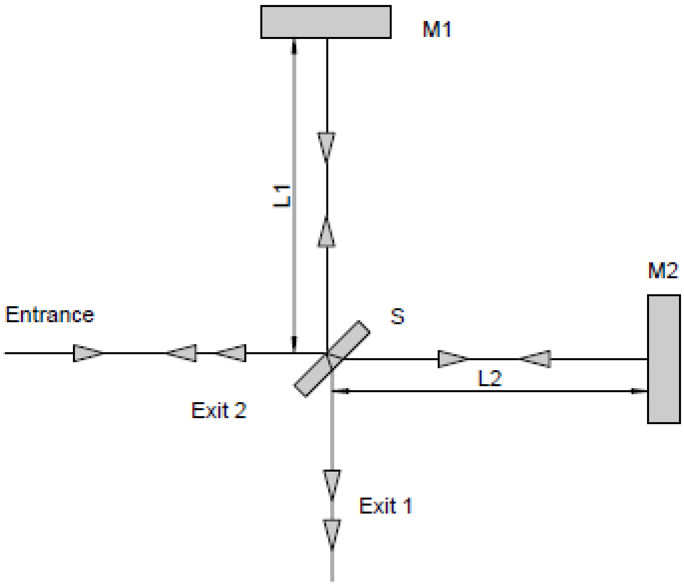


Fig. 1: Michelson interferometer.

Fig. 2: Michelson interferometer setup, circular fringes.

A simplified diagram of a Michelson interferometer is shown in the fig: 1. Light from a monochromatic source S is divided by a beam splitter (BS), which is oriented at an angle 45° to the beam, producing two beams of equal intensity. The transmitted beam (T) travels to mirror M_1 and it is reflected back to BS. 50% of the returning beam is then reflected by the beam splitter and strikes the screen, E. The reflected beam (R) travels to mirror M_2, where it is reflected. 50% of this beam passes straight through beam splitter and reaches the screen.

Since the reflecting surface of the beam splitter BS is the surface on the lower right, the light ray starting from the source S and undergoing reflection at the mirror M_2 passes through the beam splitter three times, while the ray reflected at M_1 travels through BS only once. The optical path length through the glass plate depends on its index of refraction, which causes an optical path difference between the two beams. To compensate for this, a glass plate CP of the same thickness and index of refraction as that of BS is introduced between M_1 and BS. The recombined beams interfere and produce fringes at the screen E. The relative phase of the two beams determines whether the interference will be constructive or destructive. By adjusting the inclination of M_1 and M_2, one can produce circular fringes, straight-line fringes, or curved fringes. This lab uses circular fringes, shown in Fig. 2.

From the screen, an observer sees M_2 directly and the virtual image M_1' of the mirror M_1, formed by reflection in the beam splitter, as shown in Fig. 3. This means that one of the interfering beams comes from M_2 and the other beam appears to come from the virtual image M_1'. If the two arms of the interferometer are equal in length, M_1' coincides with M_2. If they do not coincide, let the distance between them be d, and consider a light ray from a point S. It will be reflected by both M_1' and M_2, and the observer will see two virtual images, S_1 due to reflection at M_1', and S_2 due to reflection at M_2. These virtual images will be separated by a distance $2d$. If θ is the angle with which the observer looks into the system, the path difference between the two beams is $2d\cos\theta$. When the light that comes from M_1 undergoes reflection at BS, a phase change of π occurs, which corresponds to a path difference of $\lambda/2$.

Therefore, the total path difference between the two beams is,

$$\Delta = 2d\,Cos\,\theta + \frac{\lambda}{2}$$

The condition for constructive interference is then,

$$\Delta = 2d\,Cos\,\theta + \frac{\lambda}{2} = m\lambda\,, \quad m = 0, 1, 2... \qquad (1)$$

For a given mirror separation *d*, a given wavelength λ, and order *m*, the angle of inclination θ is a constant, and the fringes are circular. They are called *fringes of equal inclination*, or *Haidinger fringes*. If M_1' coincides with M_2, $d = 0$, and the path difference between the interfering beams will be $\lambda/2$. This corresponds to destructive interference, so the center of the field will be dark. If one of the mirrors is moved through a distance $\lambda/4$, the path difference changes by $\lambda/2$ and a maximum is obtained. If the mirror is moved through another $\lambda/4$, a minimum is obtained; moving it by another $\lambda/4$, again a maximum is obtained and so on. Because *d* is multiplied by $\cos\theta$, as *d* increases, new rings appear in the center faster than the rings already present at the periphery disappear, and the field becomes more crowded with thinner rings toward the outside. If *d* decreases, the rings contract, become wider and more sparsely distributed, and disappear at the center. For destructive interference, the total path difference must be an integer number of wavelengths plus a half wavelength,

$$\Delta_{destr} = 2d\,Cos\,\theta + \frac{\lambda}{2} = (m + \frac{1}{2})\lambda\,, \quad m = 0, 1, 2...$$

If the images S_1 and S_2 from the two mirrors are exactly the same distance away, d=0 and there is no dependance on θ. This means that only one fringe is visible, the zero order destructive interfrence fringe, where

$$\Delta_{destr} = \frac{\lambda}{2} = (m + \frac{1}{2})\lambda, \; m = 0$$

and the observer sees a single, large, central dark spot with no surrounding rings.

Objectives of the experiment:

1. To adjust the Michelson interferometer so that circular light fringes can be observed.

2. To calibrate the mirror movement using a He-Ne laser.
3. To determine an unknown wavelength.
4. To determine the refractive index of a thin glass plate.
5. To determine the refractive index of air.

Questions:

1. In the calculation to determine the value of   based on the micrometer movement, why was **dm** multiplied by two?
2. Why move the mirror through many fringe transitions instead of just one? Why take several measurements and average the results?
3. If the wavelength of your light source is accurately known, compare your results with the known value. If there is a difference, to what do you attribute it?
4. When measuring mirror movement using the micrometer dial on the interferometer, what factors limit the accuracy of your measurement?
5. When measuring mirror movement by counting fringes using a light source of known wavelength,
what factors might limit the accuracy of your measurement?
6. What role does polarization play in producing an interference pattern?