LAB 7: MICROWAVE OPTICS

Purpose:

Today we will begin experimenting with Microwave Optics. The question being addressed will be whether or not different magnitudes of wavelengths follow the same basic principles we have already verified for light, such as Reflection and Refraction, Polarization, and Interference and Diffraction.

You will perform experiments reviewing these concepts and checking their application to wavelengths on the order of centimeters (as opposed to light, which is on the order of nanometers), and some introducing new concepts, such as Fiber Optics.

This lab will be done over a period of two weeks, the individual experiments are:

1) Introduction to the Experiment
2) Reflection
3) Refraction Through a Prism
4) Polarization
5) Standing Waves
6) Double Slit interference
7) Michelson Interferometer
8) Fiber Optics
9) Lloyd’s Mirror
10) Fabry-Perot Cavity
11) Brewster’s Angle
12) Bragg Diffraction

Your lab instructor will determine which ones and how many you have to finish for your lab.

The following will have sections from the original write-up, for a guide to the specific equipment for your experiment see the original pdf online.

Experiment 1: Introduction to the System

EQUIPMENT NEEDED:

– Transmitter	– Goniometer
– Receiver	– Reflector (1)

Purpose

This experiment gives a systematic introduction to the Microwave Optics System. This may prove helpful in learning to use the equipment effectively and in understanding the significance of measurements made with this equipment. It is however not a prerequisite to the following experiments.

Procedure

A.) Arrange the Transmitter and Receiver on the Goniometer as shown in Figure 1.1 with the Transmitter attached to the fixed arm. Be sure to adjust both Transmitter and Receiver to the same polarity—the horns should have the same orientation, as shown.

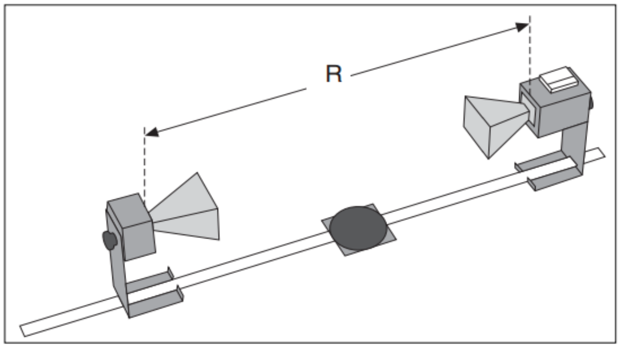


Figure 1.1 Equipment Setup

B.) Plug in the Transmitter and turn the INTENSITY selection switch on the Receiver from OFF to any Meter Multiplier that gives you a meter reading of between 0.4 and 1.

C.) Adjust the Transmitter and Receiver so the distance between the source diode in the Transmitter and the detector diode in the Receiver (the distance labeled R in **Figure 1.1**) is 40cm. Adjust the INTENSITY and VARIABLE SENSITIVITY dials on the Receiver so that the meter reads between 0.5 and 1.0 (full scale.) **MAKE SURE THE MEASUREMENT ISN'T OFF THE SCALE**

D.) Set the distance R to each of the values shown in Table 1.1. For each value of R, record the meter reading. (Do not adjust the Receiver controls between measurements.)

E.) Perform the calculations shown in the table to answer questions 1.1 and 1.2

Table 1.1

R (cm)	Meter Reading, M (unitless)	M x R(cm)	M x R^2 (cm^2)
40			
60			
70			
80			
90			
100			

For question 1 and 2, remember that x is directly proportional to y if you can write x=ay for some constant a. To answer these two questions you will use the third and fourth column of your table 1.1.

Q1.1) The electric field of an electromagnetic wave is inversely proportional to the distance from the wave source (i.e., $E = 1/R$). Use your data from step 4 of the experiment to determine if the meter reading of the Receiver is directly proportional to the electric field of the wave.

In other words, is M directly proportional to E?

Q1.2) The intensity of an electromagnetic wave is inversely proportional to the square of the distance from the wave source (i.e., $I = 1/R^2$). Use your data from step 4 of the experiment to determine if the meter reading of the Receiver is directly proportional to the intensity of the wave. **In other words, is M directly proportional to I?**

F.) Set R to some value between 70 and 90 cm. While watching the meter, slowly decrease the distance between the Transmitter and Receiver.

G.) Set R to between 50 and 90 cm. Move a Reflector, its plane parallel to the axis of the microwave beam, toward and away from the beam axis, as shown in **Figure 1.3**. Observe the meter readings.

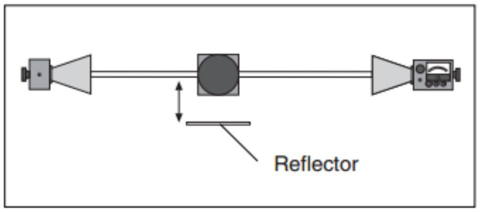


Figure 1.3 Reflections

Q1.3) Does the meter deflection in parts E and F increase steadily, or lightly oscillate as the distance decreases? Try to explain why.

H.) Loosen the hand screw on the back of the Receiver and rotate the Receiver as shown in Figure 1.4. This varies the polarity of maximum detection. (Look into the receiver horn and notice the alignment of the detector diode.) Observe the meter readings through a full 360 degree rotation of the horn. A small mirror may be helpful to view the meter reading as the receiver is turned.

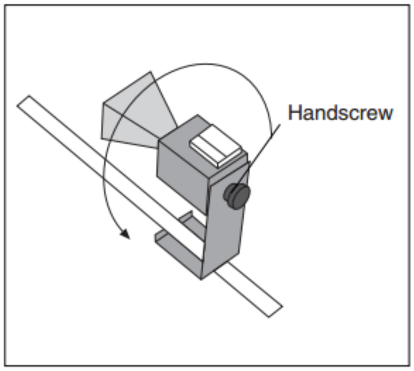


Figure 1.4 Polarization

I.) Try rotating the Transmitter horn as well. When finished, reset the Transmitter and Receiver so their polarities match (e.g., both horns are horizontal or both horns are vertical).

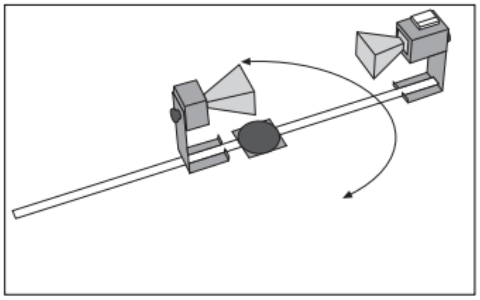


Figure 1.5 Signal Distribution

Q1.4) At what relative angles does the Receiver detect no signal? (i.e. receiver angle – transmitter angle)
- a) What angle is the signal at a maximum?
- b) What does this suggest about the microwaves?

J.) Position the Transmitter so the output surface of the horn is centered directly over the center of the Degree Plate of the Goniometer arm (see Figure 1.5). With the Receiver directly facing the Transmitter and as far back on the Goniometer arm as possible, adjust the Receiver controls for a meter reading of between 0.5 and 1.0. Then rotate the rotatable arm of the Goniometer as shown in the figure. Set the angle of rotation to each of the values shown in Table 1.2, and record the meter reading at each setting.

Q1.5) From the data in table 1.2 you should see that the transmission is in the form of a cone. Explain how you know this. Approximately how wide is the angle of the cone?

Table 1.2

Angle on Goniometer	Meter Reading	Angle on Goniometer	Meter Reading	Angle on Goniometer	Meter Reading
90°		180°		270°	
110°		185°			
130°		190°			
150°		200°			
160°		210°			
170°		230°			
175°		250°			

Experiment 2: Reflection

EQUIPMENT NEEDED:

- – Transmitter
- – Goniometer
- – Receiver
- – Metal Reflector
- – Rotating Component Holder

Procedure

A.) Arrange the equipment as shown in figure 2.1 with the Transmitter attached to the fixed arm of the Goniometer. Be sure to adjust the Transmitter and Receiver to the same polarity; the horns should have the same orientation as shown.

B.) Plug in the Transmitter and turn the Receiver INTENSITY selection switch on. Start on 1X setting but change as needed.

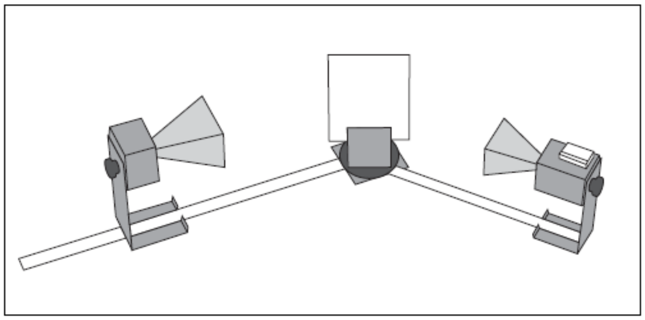


Figure 2.1 Equipment Setup

Again, make sure the receiver is on the movable arm and the transmitter is on the fixed arm of the goniometer.

C.) The angle between the incident wave from the Transmitter and a line normal to the plane of the Reflector is called the Angle of Incidence (see Figure 2.2). Adjust the Rotating Component Holder so that the Angle of Incidence equals 45-degrees.

MEASURE FROM THE NORMAL OF THE REFLECTOR PLATE

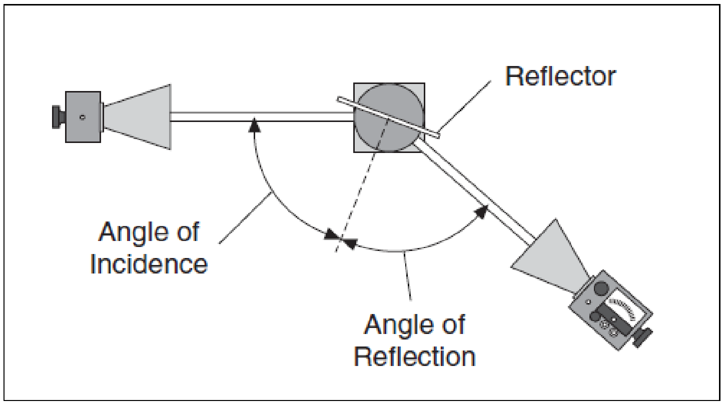


Figure 2.2 Angles of Incidence and Reflection

D.) Without moving the Transmitter or the Reflector, **rotate the movable arm of the Goniometer until the meter reading is a maximum**. The angle between the axis of the Receiver horn and a line normal to the plane of the Reflector is called the Angle of Reflection.

IT DOESN'T MATTER WHAT THE MAXIMUM IS, THE IMPORTANT PART IS GETTING THE READING TO A MAX.

E.) Repeat steps C and D for each angle of incidence in the table on the right to measure and record the angle of reflection. **Be sure to find the highest possible value, there may be multiple maxima in some cases.**

➢NOTE: At various angle settings the Receiver will detect both the reflected wave and the wave coming directly from the Transmitter, thus giving misleading results. Determine the angles for which this is true and mark the data collected at these angles with an asterisk "".*

Angle of Incidence (deg)	**Angle of Reflection (deg)**
30	
40	
50	
60	
70	
80	
90	

Questions

Q2.1) What relationship holds between the angle of incidence and the angle of reflection for the angles 30-60deg? Does this relationship hold for all angles of incidence? *(Hint: Your angles for 70, 90deg should not be equal)*

Q2.2) In measuring the angle of reflection, you measured the angle at which a maximum meter reading was found. Explain why some of the angles were different than what you expected. How does this affect your answer to question 1?
(Hint: Think about how the cone from experiment 1, question 1.5 is affecting the meter reading and how the reflected rays and rays straight from the transmitter interact)

Q2.3) a) How does reflection affect the intensity of the microwave?
b) Is all the energy of the wave striking the Reflector reflected?
c) Does the intensity of the reflected signal vary with the angle of incidence?

Q2.4) Metal is a good reflector of microwaves. Investigate the reflective properties of other materials.
a) How well does the Styrofoam reflect? Do you think the energy is transmitted through or absorbed by the foam?
b) What about the wood panels? Do you think the energy is transmitted through or absorbed by the board?
c) Compare the reflective properties of conductive and non-conductive materials. (i.e. compare results for metals v. nonmetals)

Experiment 3: Refraction Through a Prism

EQUIPMENT NEEDED:
- Transmitter
- Goniometer
- Receiver
- Rotating Table
- Ethafoam Prism mold with styrene pellets
- Protractor

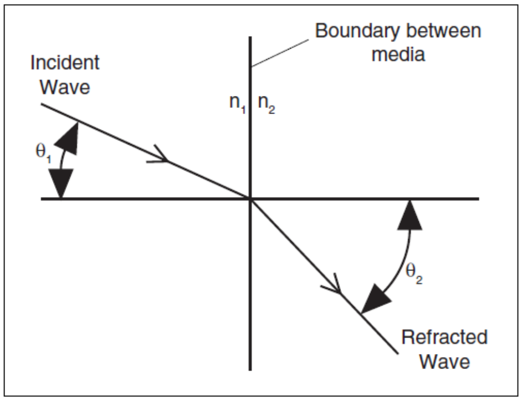


Figure 4.1 Angles of Incidence and Refraction

Introduction

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 θ2 is the corresponding angle for the refracted wave (see **Figure 4.1**). 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 n1 and n2. 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.

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

Procedure

A.) Arrange the equipment as shown in Figure 4.2. Rotate the empty prism mold and see how it affects the incident wave.

Q3.1.) Does it reflect, refract, or absorb the wave?

B.) Have your instructor 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.

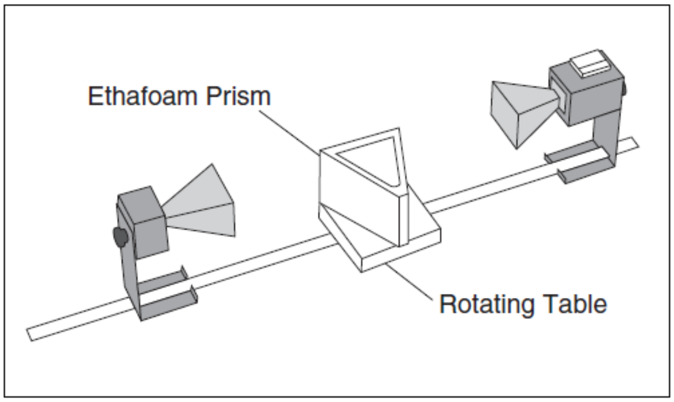


Figure 4.2 Equipment Setup

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

θ is then equal to the difference between your refracted beam and 180degrees, as shown in figure 4.3..

θ = ______________________.

D.) Using the diagram shown in **Figure 4.3**, determine **θ_2** and use your value of **θ** and **θ_2** to calculate **θ_1**. (You will need to use a protractor to measure the prism angles.)

θ_2 = ______________________.
θ_1 = ______________________.

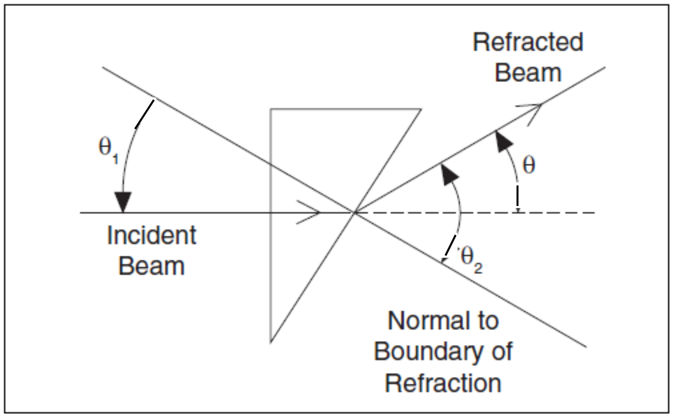


Figure 4.3 Geometry of Prism Refraction

E.) Plug these values into Snell's Law to determine the value **n_1/n_2.**

n_1/n_2 = ____________________________.

F.) Determine n_1, the index of refraction for the styrene pellets. Note the index of refraction for air is equal to 1.00.

Questions

Q3.2.) In the diagram of Figure 4.3, 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°). Is this a valid assumption?

Q3.3.) Would you expect the refraction index of the styrene pellets in the prism mold to be the same as for a solid styrene prism?
(Hint: Think about the index of refraction of air)

Experiment 4: Polarization

EQUIPMENT NEEDED:

-Transmitter -Receiver
-Goniometer -Component Holder (1)
-Polarizer (1).

Introduction

The microwave radiation from the Transmitter is linearly polarized along the Transmitter diode axis (i.e., as the radiation propagates through space, its electric field re-mains aligned with the axis of the diode). If the Transmitter diode were aligned vertically, the electric field of the transmitted wave would be vertically polarized, as shown in Figure 5.1. If the detector diode were at an angle θ to the Transmitter diode, as shown in Figure 5.2, it would only detect the component of the incident electric field that was aligned along its axis. In this experiment, you will investigate the phenomenon of polarization and discover how a polarizer can be used to alter the polarization of microwave radiation.

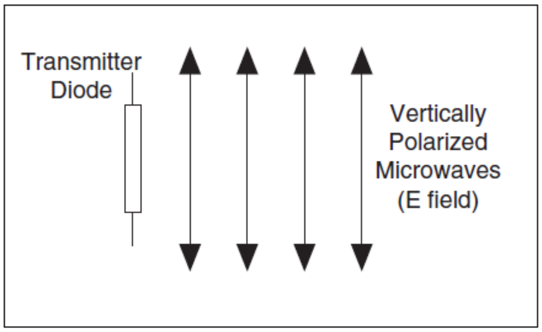


Figure 5.1 Vertical Polarization

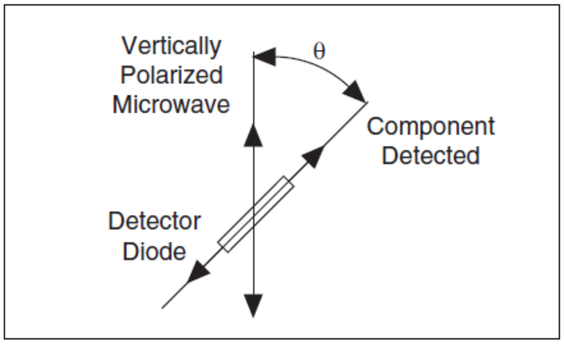


Figure 5.2 Detecting Polarized Radiation

Procedure

A.) Arrange the equipment as shown in Figure 5.3 and adjust the Receiver controls for close to a meter reading between 0.5 and 1.0, as you did before

B.) Loosen the hand screw on the back of the Receiver and rotate the Receiver to the values in Table 4.1. At each rotational position, record the meter reading in Table 4.1.

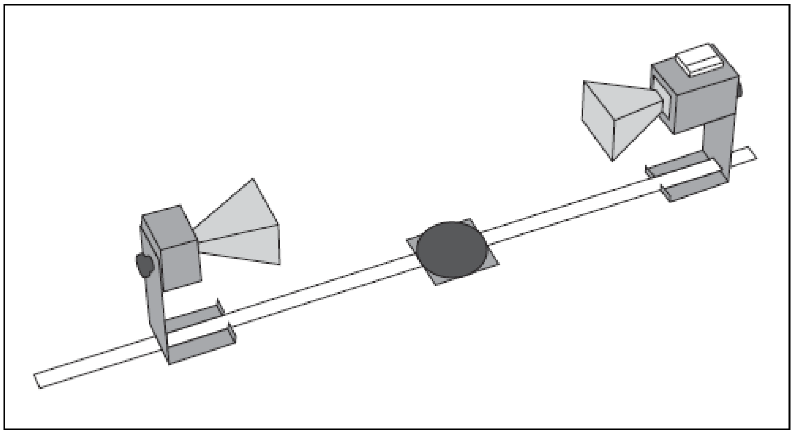


Figure 5.3 Equipment Setup

Q4.1.) What happens to the meter readings if you continue to rotate the Receiver beyond 180-degrees?

Table 4.1

Angle of Receiver	Meter Reading	Angle of Receiver	Meter Reading	Angle of Receiver	Meter Reading
0°		85°		140°	
20°		90°		160°	
40°		95°		180°	
60°		100°			
70°		105°			
75°		110°			
80°		120°			

C.) Set up the equipment as shown in Figure 5.4. Reset the Receivers angle to 0-degrees (the horns should be oriented as shown with the longer side horizontal).

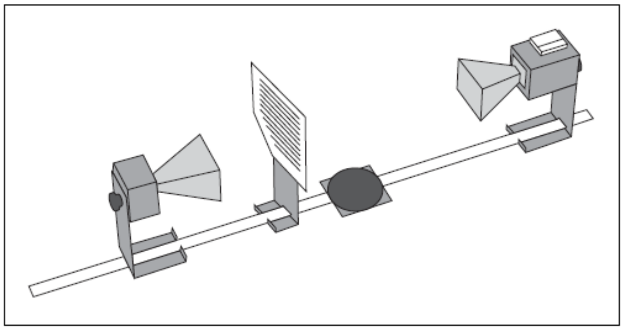


Figure 5.4 Equipment Setup

D.) Fill in table 4.2 by recording the meter reading when the Polarizer (Receiver or Transmitter) is aligned at 0, 22.5, 45, 67.5 and 90-degrees with respect to the horizontal.

E.) Remove the Polarizer slits. Rotate the Receiver **so the axis of its horn is at right angles to that of the Transmitter (This means the back of one should read 0°, the other should be 90°)**. Then insert the Polarizer slits and record the meter readings in table 4.3 with the Polarizer slits horizontal, vertical, and at 45 degrees.
(If you don't get 0 for horizontal and vertical call your instructor)

Table 4.2

Angle of receiver	Meter Reading
0° (Horiz.)	
22.5°	
45°	
67.5°	
90° (Vert.)	

Table 4.3

Angle of Slits	Meter Reading
Horizontal	
45°	
Vertical	

Questions

Q4.2.) If the Receiver meter reading (M) were directly proportional to the electric field component (E) along its axis, the meter would read the relationship $M_o\cos\theta$ (where θ is the angle between the detector and Transmitter diodes and Mo is the meter reading when θ = 0). (See Figure 5.2).

Using Excel Graph your data from step B of the experiment. (*M v. ϑ*)
Add a column to your excel sheet and calculate $M_o\cos\theta$ for every value of theta
On the same graph, add a series to plot the relationship $M_o \cos\theta$ v. θ (Be sure it looks like a cosine)
Compare the two graphs.

Q4.3.) The intensity of a linearly polarized electromagnetic wave is directly proportional to the square of the electric field (e.g., $I = kE^2$). If the Receiver's meter reading was directly proportional to the incident microwave's intensity, the meter would read the relationship $M = M_o\cos^2\theta$.

On the same Excel graph from Q4.2 Plot this relationship $M_o \cos^2\vartheta$ *v.* ϑ following the same method. Based on your graphs, discuss the relationship between the meter reading and the angle of the microwave (Compare your experimental data to Efield and Intensity)

Print out and include this graph with all three series on it in your lab report.

Q4.4.) Show or explain how the insertion of the polarizer slits increased the signal level at the detector when they were at 45 degrees through discussion, diagram, or mathematics.
(*HINT: Think back to the three-polarizer set up from our Polarization lab. Also, if your device read zero at 45 degrees in the second table something went wrong, recheck your data or ask your instructor.)*

Experiment 5: Standing Waves – Measuring Wavelengths

EQUIPMENT NEEDED:

- Transmitter
- Receiver
- Component Holder (2)
- Goniometer
- Reflector (1)

Introduction

When two electromagnetic waves meet in space, they superpose. Therefore, the total electric field at any point is the sum of the electric fields created by both waves at that point. If the two waves travel at the same frequency but in opposite direction they form a standing wave. Nodes appear where the fields of the two waves cancel and antinodes where the superposed field oscillates between a maximum and a minimum. The distance between nodes in the standing wave pattern is just 1/2 the wavelength (λ) of the two waves.

Procedure

A.) Set up the equipment as shown in Figure 3.2. Adjust the Receiver controls to get a full-scale meter reading with the Transmitter and Receiver as close together as possible. Slowly move the Receiver along the Goniometer arm, away from the Transmitter.

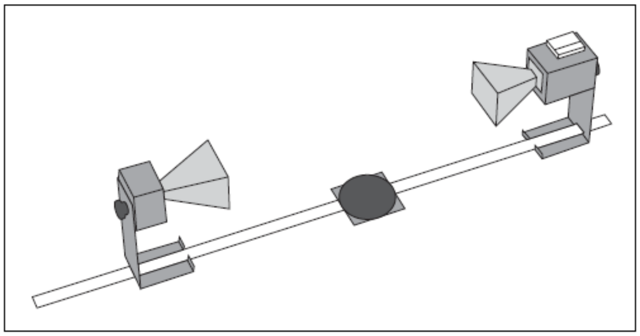


Figure 3.2 Equipment Setup

Q5.1.) How does this motion effect the meter reading?

The microwave horns are not perfect collectors of microwave radiation. Instead, they act as partial reflectors, so that the radiation from the Transmitter reflects back and forth between the Transmitter and Reflector horns, diminishing in amplitude at each pass. However, if the distance between the Transmitter and Receiver diodes is equal to nλ/2, (where n is an integer and λ is the wavelength of the radiation) then all the multiply-reflected waves entering the Receiver horn will be in phase with the primary transmitted wave. When this occurs, the meter reading will be a maximum. (The distance between adjacent positions to see a maximum is therefore λ/2.)

B.) Slide the Receiver one or two centimeters along the Goniometer arm to obtain a maximum meter reading. Record the Receiver position along the metric scale of the Goniometer arm.

Initial Position of Receiver =___________________________.

C.) While watching the meter, slide the Receiver away from the Transmitter. Do not stop until the Receiver passed through at least 10 positions at which you see a minimum meter reading and it returned to a position where the reading is a maximum. Record the new position of the Receiver and the number of minima that were traversed. (*the number of minima should be 10*)

Minima Traversed = ___________________________.
Final Receiver Position = ___________________________.

For the calculation say the first length $L_1=n(\lambda/2)$ where n is the number of half wavelengths. Also, say the second position length $L_2=(n+m)(\lambda/2)$ where m is the number of minimum you've gone through, a.k.a. the number of maxima you've added to n.

Clearly $L_2= L_1+d$, where d is the distance you moved to go through 10 minima. Substituting for L_1 and L_2 we have

$$n\left(\frac{\lambda}{2}\right) + d = (n+m)\left(\frac{\lambda}{2}\right) = n\left(\frac{\lambda}{2}\right) + m\left(\frac{\lambda}{2}\right),$$

hence by cancelling the $n(\lambda/2)$ terms we are left with

$$d = m\left(\frac{\lambda}{2}\right). \tag{5.1}$$

D.) Use the data you have collected and the equation 5.1 above to calculate the wavelength of the microwave radiation.

λ = ___________________________.

E.) Repeat your measurements and recalculate λ.

Initial Position of Receiver = ___________________________.

Minima Traversed = ___________________________.

Final Receiver Position = ___________________________.

λ = ___________________________.

Questions

Q5.2.) Calculate an average value for your two lambdas from earlier, then using this average and the relationship,

$$velocity = \lambda f\ ,$$

to calculate the frequency of the microwave signal (assuming velocity of propagation in air is $3\text{x}10^8$ m/s). *(You've seen this before as c= λf for speed of light c)*

Q5.3.) Compare the value from **Q5.2** to the expected frequency of the microwave radiation 10.525 GHz by finding a percent error and commenting

Experiment 6: Double-Slit Interference

EQUIPMENT NEEDED:

- Transmitter, Receiver
- Component Holder
- Slit Extender Arm
- Wide Slit Spacer
- Goniometer, Rotating
- Metal Reflectors (2)
- Narrow Slit Spacer

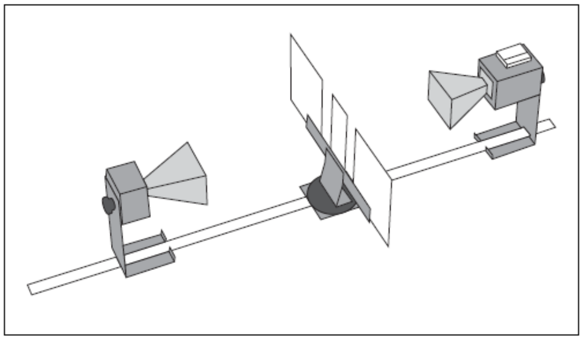


Figure 6.2 Equipment Setup

Introduction

In Experiment 5, you saw how two waves moving in opposite directions can superpose to create a standing wave pattern. A somewhat similar phenomenon occurs when an electromagnetic wave passes through a two-slit aperture. The wave diffracts into two waves which superpose in the space beyond the apertures. Like the standing wave pattern, there are points in space where maxima are formed and others where minima are formed.

With a double slit aperture, the intensity of the wave beyond the aperture will vary depending on the angle of detection. For two thin slits separated by a distance d, maxima will be found at angles such that

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

(Where θ = the angle of detection, λ = the wavelength of the incident radiation, and m is any integer) (See **Figure 6.1**). Refer to a textbook for more information about the nature of the double-slit diffraction pattern.

Procedure

➢**NOTE:** The experimenter's body position may affect the results.

A.) Arrange the equipment as shown in Figure 6.2. Use the Slit Extender Arm, two Reflectors, and the Nar-row Slit Spacer to construct the double slit. (We recommend a slit width of about 1.5 cm.) Be precise with the alignment of the slit and make the setup as symmetrical as possible.

B.) Adjust the Transmitter and Receiver for vertical polarization (0°) and adjust the Receiver controls to give a full-scale reading at the lowest possible amplification.

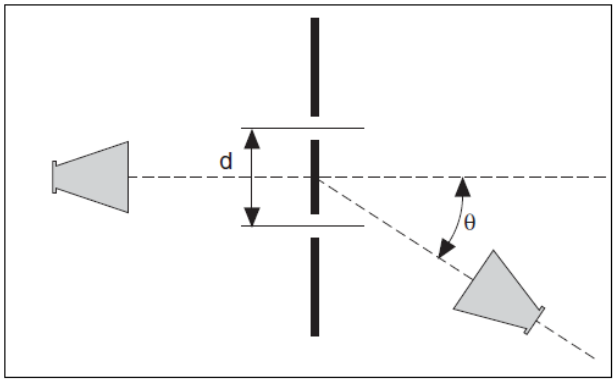


Figure 6.1 Double-Slit Interference

C.) Rotate the rotatable Goniometer arm (on which the Receiver rests) slowly about its axis. Observe the meter readings.

D.) Reset the Goniometer arm so the Receiver directly faces the Transmitter. Adjust the Receiver controls to obtain a meter reading of between 0.5 and 1.0. Now set the angle θ to each of the values shown in Table 6.1. At each setting record the meter reading in the table. (In places where the meter reading changes significantly between angle settings, you may find it useful to investigate the signal level at intermediate angles.)

E.) Keep the slit widths the same, but change the distance between the slits by using the Wide Slit Spacer instead of the Narrow Slit Spacer. Because the Wide Slit Space is 50% wider than the Narrow Slit Spacer (90mm vs 60mm) move the Transmitter back 50% so that the microwave radiation at the slits will have the same relative intensity. Repeat the measurements.

Table 6.1

Angle Reading	Meter Reading(Wide)	Meter Reading(thin)
180°		
185°		
190°		
195°		
200°		
205°		
210°		
215°		
220°		
225°		
230°		

Questions

Q6.1.) **In Excel** use your data to plot a graph of meter reading versus θ for both of your two data sets on one graph. Identify the angles at which the maxima and minima of the interference pattern occur for each spacer. **Include this graph in your report**

Q6.2.) Calculate the first two angles at which you would expect the maxima to occur and the angle where the first two minima to occur in a standard two-slit diffraction pattern for just one of your two spacers (two maxima, two minima)
If you have done experiment 5, 7, 9, or 10 use your wavelength that you've calculated from them for higher precision, otherwise use the given $\lambda_{th} = 2.8cm$
Remember maxima occur wherever $d\ sin\theta\ =\ m\lambda$*, minima occur wherever* $d\ sin\theta\ = \left(m + \frac{1}{2}\right)\lambda$ *.*
m is the order of diffraction, review your int. and diffraction experiment if you've forgotten.

Q6.3.) How does this compare with the locations of your observed maxima and minima? Can you explain any discrepancies?

Q6.4.) Can you explain the relative drop in intensity of maxima as you move from the center?
(*the difference in meter readings between peaks)*

Experiment 7: Michelson Interferometer

EQUIPMENT NEEDED:

- Transmitter,	- Receiver
- Goniometer,	- Fixed Arm Assembly
- Component Holders (2)	- Rotating Table, Reflectors (2)
- Partial Reflector (1)	

Introduction

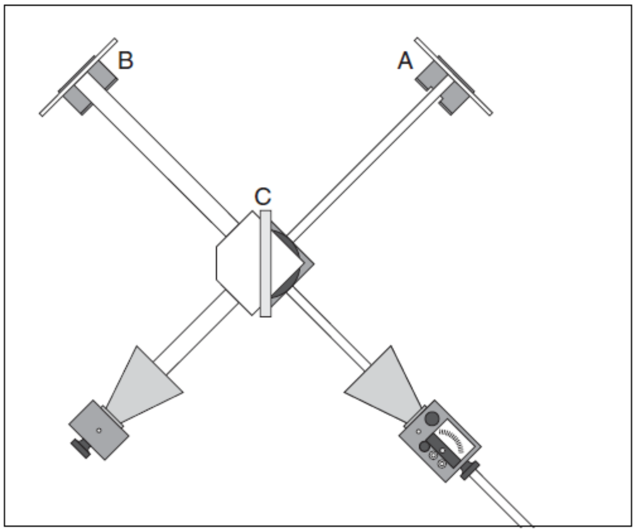


Figure 9.1 Michelson Interferometer

The Michelson interferometer splits a single wave, then brings the constituent waves back together so that they superpose, forming an interference pattern. Figure 9.1 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 Michelson Interferometer 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

A.) Arrange the equipment as shown in Figure 9.1. Plug in the Transmitter and adjust the Receiver for an easily readable signal.

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

C.) 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 = ____________________________.

D.) 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 to a maxi-mum. 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 = ___________________________.

E.) Use your data to calculate λ, the wavelength of the microwave radiation. Either Refer to the introduction or Experiment 5 for the equation.

λ = ___________________________.

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

x_1 = ___________________________.

Minima traversed = ___________________________.

x_2 = ___________________________.
λ = ___________________________.

G.) Calculate the average lambda and find the percent error to the known value 2.8 cm

Questions

Q7.1.) 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 nanometer wavelength light rather than microwaves) provide better resolution when measuring distance than a microwave interferometer? *(HINT: think about ticks on a ruler.)*

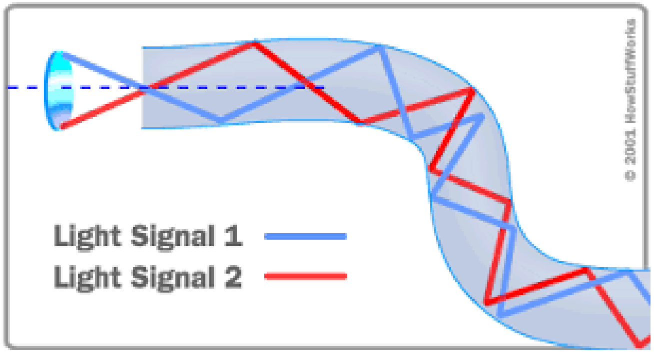
Q7.2.) On the same lines as question one, if you wanted to measure the amount of fluctuation(movements) of the atoms of the surface of a piece of metal how could you do so? What order of magnitude (for example centi, 10^{-7}, nano etc) would you need the wavelength to be if the fluctuations are on the order of 10^{-10}m?

Experiment 8: Fiber Optics

EQUIPMENT NEEDED:
- Transmitter
- Goniometer
- Styrene Pellets
- Receiver
- Tubular Plastic Bags

Introduction

Light can propagate through empty space, but it can also propagate well through certain materials, such as glass. In fiber optics, a thin, flexible glass tube functions as a transmission line for light from a laser, much as a copper wire can function as a transmission line for electrical impulses. In the same way that variation of the electrical impulses can carry information through the copper wire (for example as a phone message), variation in the intensity of the laser light can carry information through the glass tube.



This works through Total Internal Reflection as shown in the diagram above.

Procedure

A.) Align the Transmitter and Receiver directly across from each other on the Goniometer, and adjust the Receiver controls for a readable signal.

B.) Grab a tubular plastic bag that is prefilled with styrene pellets. Place one end of the bag in the Transmitter horn with the other end **NOT** in the receiver.

Q8.1.) What happens to the meter reading?

C.) Now place the other end in the Receiver horn.

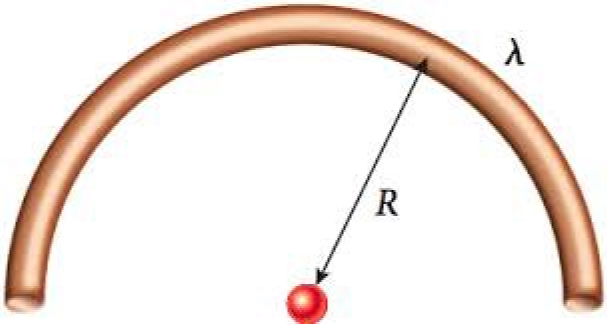
Q8.2.) How does the intensity of the detected signal compare to the intensity when the bag is not used?

D.) Remove the plastic bag and turn the Rotatable Goniometer arm until no meter deflection appears. Place one end of the bag in the Transmitter horn, the other in the Receiver horn. Note the meter reading.

E.) Vary the radius of curvature of the plastic bag, shown as R in Figure 8.2.
(You do this by shrinking or enlarging the bend of the tube shown.)

Q8.3.) How does this affect the signal strength? Does the signal vary gradually or suddenly as the radial curvature of the plastic bag changes?

Figure 8.2



Questions

Q8.4.) Would you expect the plastic bag filled with styrene pellets to work the same with radiation at optical frequencies (a.k.a light)? Why?
(*Think about the size of the pellets relative to the size of the waves, what do nanometer waves see when they come to a centimeter sized pellet?)*

Experiment 9: Lloyd's Mirror

EQUIPMENT NEEDED:

- Transmitter
- Goniometer
- Component Holder
- Meter Stick
- Receiver
- Fixed Arm Assembly
- Reflector (1)

Introduction

In earlier experiments, such as 3 and 6, you observed how a single electromagnetic wave can be diffracted into two waves and, when the two components join back together, they form an interference pattern. Lloyd's Mirror is another example of this phenomenon. Just as with the other interference patterns you have seen, this Interference pattern provides a convenient method for measuring the wavelength of the radiation

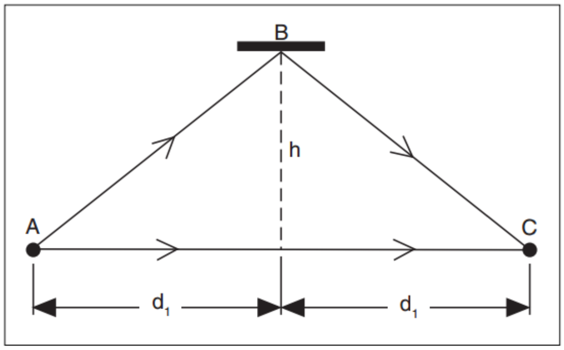


Figure 7.1 Lloyd's Mirror

Figure 7.1 is a diagram for Lloyd's mirror. An electromagnetic wave from point source **A** is detected at point C. Some of the electromagnetic wave, of course, propagates directly between point A and C, but some reaches C after being reflected at point B, a total distance $AB_1 + BC_1$. A maximum signal will be detected when the two waves reach the detector in phase. Assuming that the diagram shows a setup for a maximum signal, another maximum will be found when the Reflector is moved back so the path length of the reflected beam ($AB_2 + BC_2$. is $AB_1 + BC_1 + \lambda$.

Procedure

➤ **NOTE:** Don't stand in front of the apparatus while conducting the experiment. Your body acts as a reflector. Therefore, try to stand to one side behind the plane of the antenna horn.

A.) Arrange the equipment as shown in Figure 7.2. For best results, the Transmitter and Receiver should be as far apart as possible. Be sure the Receiver and Transmitter are equidistant (d_1) from the center of the Goniometer degree plate and that the horns are directly facing each other. (See Figure 7.3 for location of effective points of transmission and reception). Also, be sure that the surface of the Reflector is parallel to the axis of the Transmitter and Receiver horns.

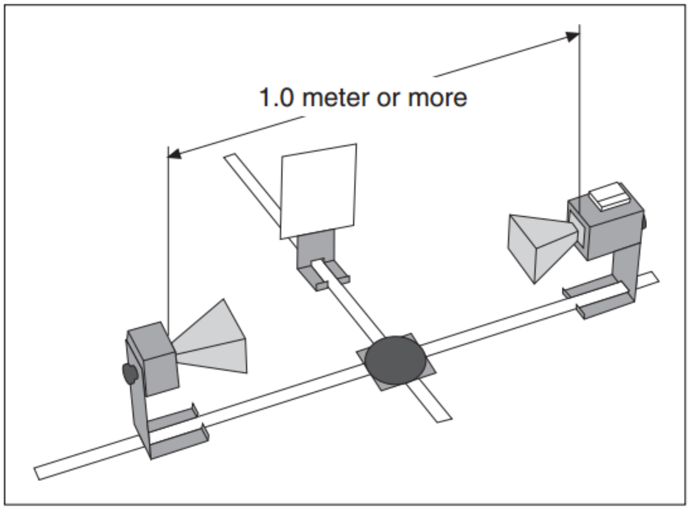


Figure 7.2 Equipment Setup

B.) While watching the meter on the Receiver, slowly slide the Reflector away from the Degree plate. Notice how the meter reading passes through a series of minima and maxima

C.) Find the Reflector position closest to the degree plate which produces a minimum meter reading.

D.) Measure and record **h_1**, the distance between the center of the degree plate and the surface of the reflector

h_1 = ___________________________.

E.) Slowly slide the reflector away from the degree plate until the meter reading passes through a maximum and returns to a new minimum. Measure and record h_2, the new distance between the center of the degree plate and the surface of the reflector.

h_2 = ___________________________.

F.) Measure **d_1** the distance between the center of the degree scale and the Transmitter diode.

d_1 = ___________________________.

G.) Use your collected data to calculate **λ**, the wavelength of the microwave radiation.

λ = ___________________________.

H.) Change the distance between the Transmitter and Receiver and repeat your measurements.

h_1 = ___________________________.

h_2 = ___________________________.

d_1 = ___________________________.

λ = ___________________________.

I.) Calculate an average wavelength and percent error to the known value 2.8cm.

Questions

Q9.1.) What is the advantage in having the effective transmission and reception points equidistant from the center of the degree plate in this experiment?

Experiment 10: Fabry-Perot Interferometer

EQUIPMENT NEEDED:

- Transmitter
- Receiver
- Goniometer
- Component Holders (2)
- Partial Reflectors (2)

Introduction

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 8.1).

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 **nλ/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 **λ/2**, then some degree of destructive interference will occur, and the signal will not be a maximum.

Procedure

A.) Arrange the equipment as shown in Figure 8.1 with two partial reflectors on the stands. Plug in the Transmitter and adjust the Receiver controls for an easily readable signal.

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

C.) Adjust the distance between the Partial Reflectors to obtain a maximum meter reading. Record, **d_1**, the distance between the reflectors.
d_1 = ___________________________.

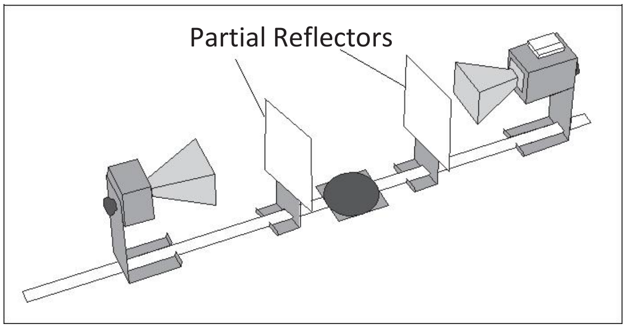


Figure 8.1 Fabry-Perot Interferometer

D.) 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 = ___________________________.

E.) Use your data to calculate **λ**, the wavelength of the microwave radiation.

λ = ___________________________.

F.) Repeat your measurements, beginning with a different distance between the Partial Reflectors.
d_1 = ___________________________.

Minima traversed = ___________________________.

d_2 = ___________________________.

λ = ___________________________.

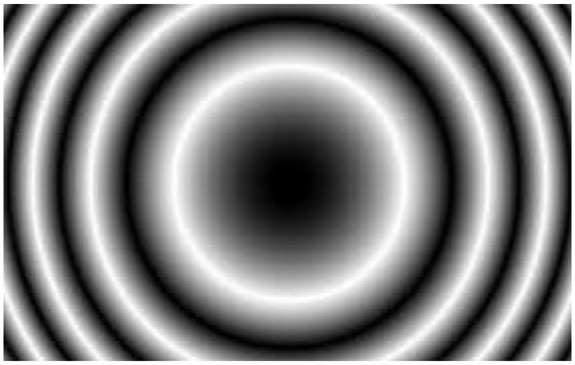
G.) Calculate an average wavelength and percent error to the known value of 2.8cm.

Questions

Q10.1.) What spacing between the two Partial Reflectors should cause a minimum signal to be delivered to the Receiver?

Q10.2.) In an optical Fabry-Perot interferometer the interference pattern usually appears as a series of concentric rings (The ones shown on the right are from an advanced Fabry-Perot experiment).

(If you replaced your detector with a screen this is what you might see)



a) Do you expect such a pattern to occur here? Explain your answer.

b) Check to see if there is one.

Experiment 11: Brewster's Angle

EQUIPMENT NEEDED:

- Transmitter
- Goniometer
- Polyethylene Panel
- Receiver
- Rotating Table

Introduction

When electromagnetic radiation passes from one media into another, some of the radiation usually reflects from the surface of the new medium. In this experiment, you will find that the magnitude of the reflected signal depends on the polarization of the radiation. In fact, at a certain angle of incidence—known as Brewster's Angle—there is an angle of polarization for which no radiation will be reflected. (Check your textbook for more information on Brewster's Angle.)

Procedure

A.) Arrange the equipment as shown in Figure 11.1, setting both the Transmitter and the Receiver for vertical polarization (both 0° on the back).

B.) Adjust the Panel so the angle of incidence of the micro-wave from the Transmitter is 20°. Rotate the Goniometer arm until the Receiver is positioned where it can detect the maximum signal reflected from the Panel. Adjust the Receiver controls for a mid-scale reading, and record the meter reading in Table 11.1. This is the same procedure as experiment 2.

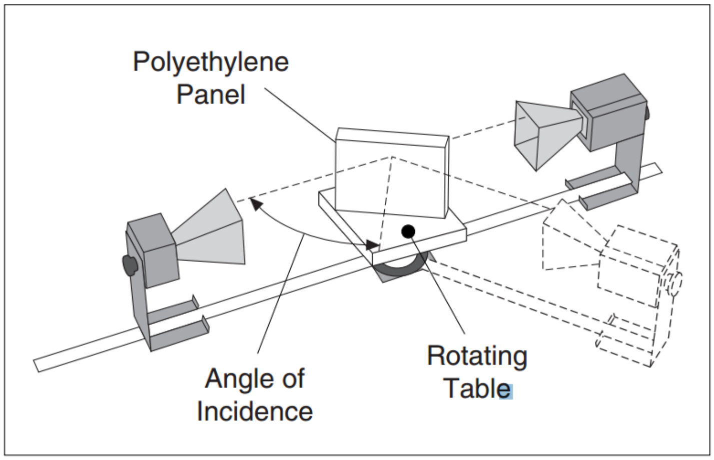


Figure 11.1 Equipment Setup

C.) Without changing the angles of incidence or reflection between the transmitted beam, the Polyethylene Panel, and the Receiver, rotate both the Transmitter and the Receiver horns so they align for horizontal polarization (90° on the back of both, you're just rotating both pieces). Record the new meter reading in the table.

D.) Repeat steps B and C, setting the angle of incidence to each of the values shown in the table below. At each point set the Transmitter and Receiver for vertical polarization and record the meter reading; then set them for horizontal polarization and record that reading as well.

If the reading goes off scale then change the meter and be sure to note it. For example If the meter is capped on the 1x, switch to the 3x and it should be on the scale then multiply the reading by 3.

E.) Plot a graph of “Meter Reading” versus “Angle of Incidence” in excel. Plot both the vertical and horizontal polarizations on the same graph. Label Brewster’s Angle—the angle at which the horizontally polarized wave does not reflect.

Questions

Q11.1.) Explain how Polaroid sun-glasses can be used to reduce the glare caused by the sun setting over a lake or the ocean. Should the glasses be designed to block vertically or horizontally polarized light?

Q11.2.) Could you use the microwave apparatus to locate Brewster’s Angle by examining the transmitted wave rather than the reflected wave? How?

Table 11.1

Angle	Meter Reading (Vertical Polarization)	Meter Reading (Horizontal Polarization)
25°		
30°		
35°		
40°		
45°		
50°		
55°		

Experiment 12: Bragg Diffraction

EQUIPMENT NEEDED:

- Transmitter
- Goniometer
- Cubic Lattice
- Receiver
- Rotating Table

Introduction

Bragg's Law provides a powerful tool for investigating crystal structure by relating the interplanar spacing in the crystal to the scattering angles of incident x-rays. In this experiment, Bragg's Law is demonstrated on a macroscopic scale using a cubic "crystal" consisting of 10-mm metal spheres embedded in an ethafoam cube.

Before performing this experiment, you should understand the theory behind Bragg Diffraction. In particular, you should understand the two criteria that must be met for a wave to be diffracted from a crystal into a particular angle. Namely, there is a plane of atoms in the crystal oriented with respect to the incident wave, such that:

1.) The angle of incidence equals the angle of reflection, and
2.) Bragg's equation, $2dsin\theta = n\lambda$, is satisified; where d is the spacing between the diffracting planes, θ is the grazing angle of the incident wave, n is an integer, and λ is the wavelength of the radiation.

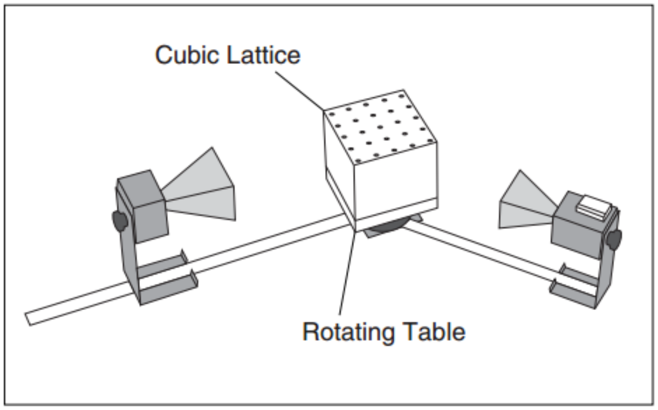


Figure 12.1 Equipment Setup

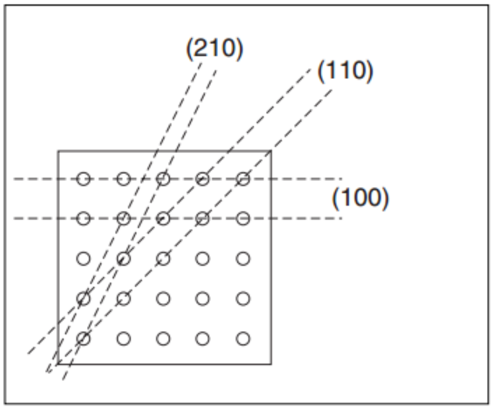
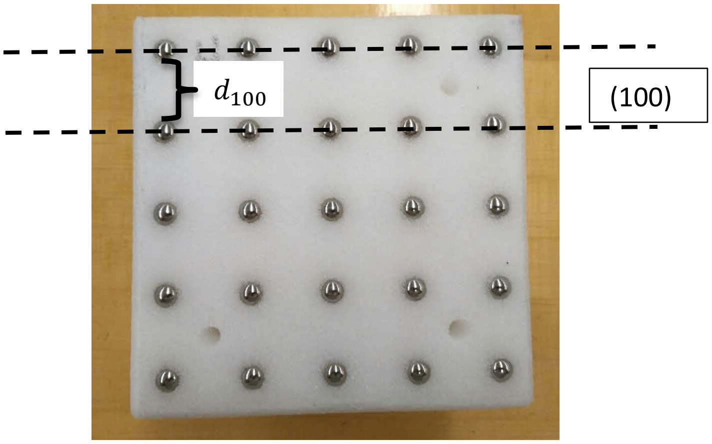


Figure 12.2 "Atomic" Planes of the Bragg Crystal

Procedure

A.) Arrange the equipment as shown in Figure **12.1**.

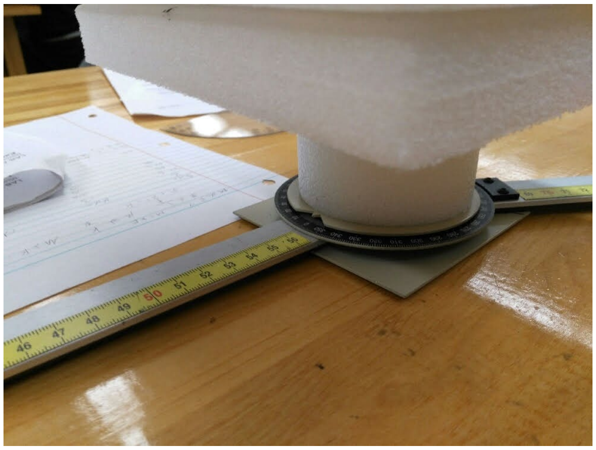
B.) Notice the three families of planes indicated in Figure **12.2**. (The designations (100), (110), and (210) are the Miller indices for these sets of planes.) Adjust the Transmitter and Receiver so that they directly face each other. Align the crystal so that the (100) planes are parallel to the incident microwave beam. Adjust the Receiver controls to provide a readable signal. Record the meter reading.



C.) Note that the first grazing angle you've set in **B.)** is 0 degrees, the angle of incidence to the surface is 90 degrees. When you rotate one degree clockwise you have increased the grazing angle to 1 and decreased the angle of incidence to 89.

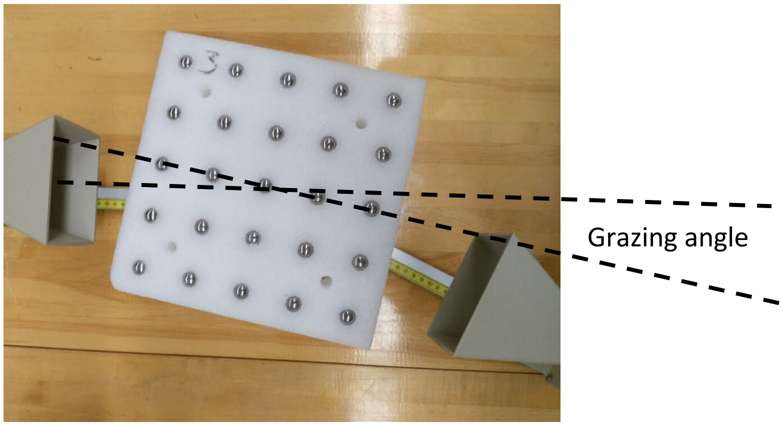
D.) It's important to note the difference between grazing angle and angle of incidence, to investigate each plane we need the grazing angle to that plane. Now set your grazing angle to 10 degrees (rotating clockwise) and rotate the goniometer 20 degrees clockwise, this will be your starting point, anything less than 10 is direct reading from the transmitter.

If you are set up properly the notch or mark on the Rotating table should be set to measure your grazing angle as shown in this picture (0 degrees shown)



E.) Rotate the crystal (with the rotating table) one degree clockwise and the Rotatable Goniometer arm two degrees clockwise. Continue in this manner, rotating the Goniometer arm two degrees for every one degree rotation of the crystal.

F.) Record the grazing angle and meter reading for every maximum that you find, skip any points that are zero or very near zero. You should find 4 maxima. Any maxima less than 35 degrees have n=1 (one plane to the next), any greater than 35 are n=2(one plane to the second next)

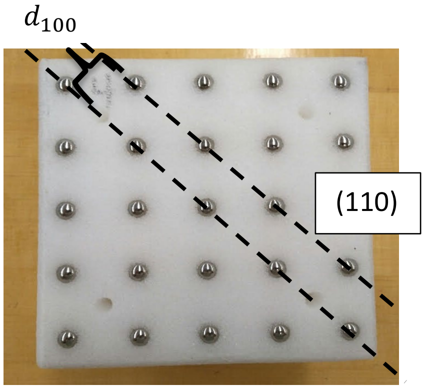


To find a maximum just keep taking measurements as long as the reading increases until the reading starts to decrease, then note the previous point. Then repeat to find the next.

G.) Use your θ data, the known wavelength of the microwave radiation λ (2.85 cm), and Bragg's Law to determine the spacing, d between the (100) planes of the Bragg Crystal and put these into the calculated column.

Table 12.1

n	θ	$d_{100_{calculated}}$	$d_{100_{average}}$	$d_{100_{measured}}$	% error
1					
1					
1					
2					



H.) Calculate the average for these 4 values and put it in the table

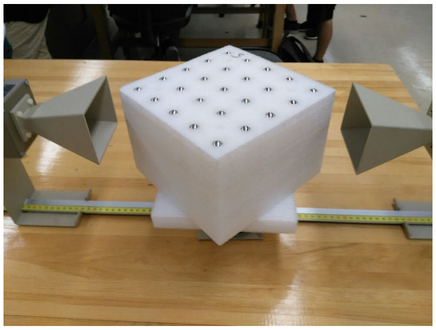
I.) Measure the spacing between the planes directly, measuring from the center of each ball and compare with your experimental determination.

J.) Calculate a percent error between average d and measured.

Next you are going to measure the (110) planes, as shown

K.) Return to the setup from step **B.)** then rotate the crystal to 45 degrees, leaving the base at zero degrees as shown in the picture below

L.) Now you will repeat the process for the 110 family of planes, again the grazing angle is measured from the family of planes so now your measurement on the bottom will be from that 45 degree family of planes instead of the parallel ones. This time you should only find one large maximum somewhere between 20 and 30 degrees



M.) Repeat the calculations to fill in the table below

Table 12.2

n	θ	$d_{110_{calculated}}$	$d_{110_{measured}}$	% error
1				

Questions

Q12.1.) What other families of planes might you expect to show diffraction in a cubic crystal? Would you expect the diffraction to be observable with this apparatus? Why?

Q12.2.) Suppose you did not know beforehand the orientation of the "inter-atomic planes" in the crystal. How would this affect the complexity of the experiment? How would you go about locating the planes?