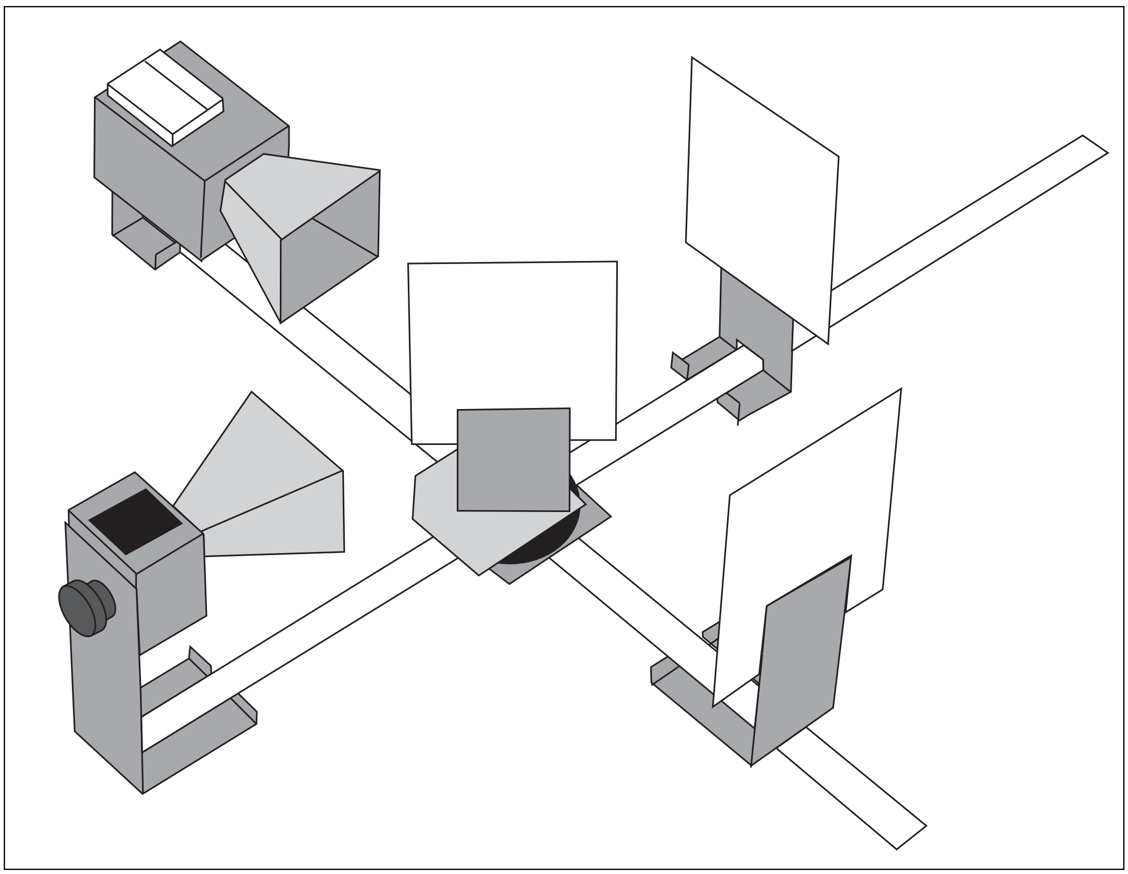
Includes Teacher's Notes and Typical Experiment Results

Instruction Manual and Experiment Guide for the PASCO scientific Model WA-9314B

012-04630G

MICROWAVE OPTICS



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Experiment 1: Introduction to the System

EQUIPMENT NEEDED:

– Transmitter
– Receiver
– Goniometer
– 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

① 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.

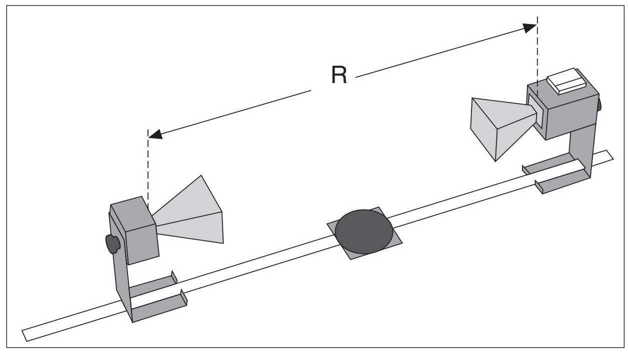

Figure 1.1 Equipment Setup

② Plug in the Transmitter and turn the INTENSITY selection switch on the Receiver from OFF to 10X. (The LEDs should light up on both units.)

③ 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 40 cm (see Figure 1.2 for location of points of transmission and reception). The diodes are at the locations marked "T" and "R" on the bases. Adjust the INTENSITY and VARIABLE SENSITIVITY dials on the Receiver so that the meter reads 1.0 (full scale).

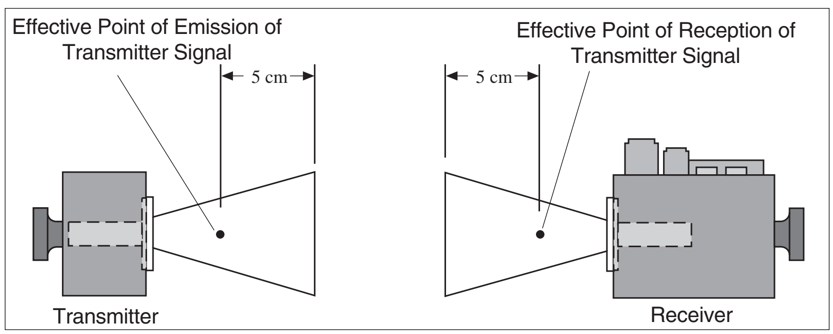

Figure 1.2 Equipment Setup

④ 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.) After making the measurements, perform the calculations shown in the table.

⑤ Set **R** to some value between 70 and 90 cm. While watching the meter, slowly decrease the distance between the Transmitter and Receiver. Does the meter deflection increase steadily as the distance decreases?

Table 1.1

R (cm)	Meter Reading (M)	M X R (cm)	M X R^2 (cm^2)
40	1.0	40	1600
50			
60			
70			
80			
90			
100			

⑥ 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. Can you explain your observations in steps 5 and 6? Don't worry if you can't; you will have a chance to investigate these phenomena more closely in Experiments 3 and 8, later in this manual. For now just be aware of the following:

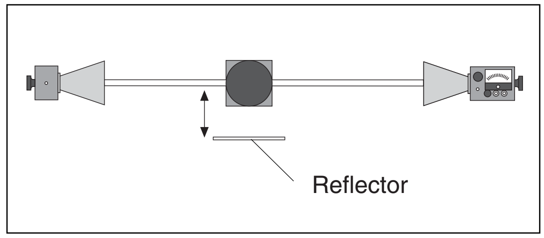

Figure 1.3 Reflections

➤ **IMPORTANT:** Reflections from nearby objects, including the table top, can affect the results of your microwave experiments. To reduce the effects of extraneous reflections, keep your experiment table clear of all objects, especially metal objects, other than those components required for the current experiment.

⑦ 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. At what polarity does the Receiver detect no signal?

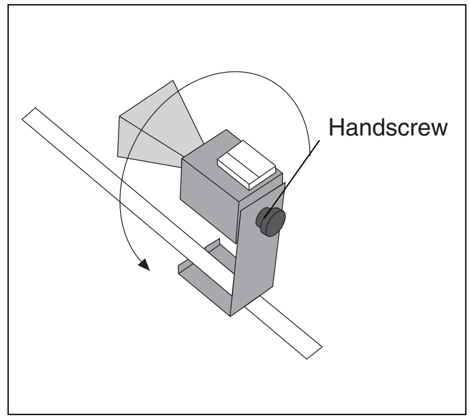

Figure 1.4 Polarization

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).

⑧ 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 1.0. Then rotate the rotatable arm of the Goniometer as shown in the figure. Set the angle of rotation (measured relative to the 180-degree point on the degree scale) to each of the values shown in Table 1.2, and record the meter reading at each setting.

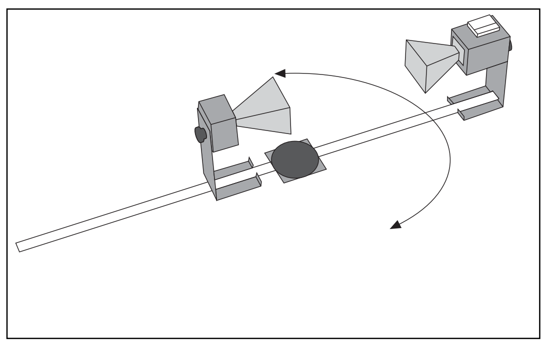

Figure 1.5 Signal Distribution

Table 1.2

Angle of Receiver	Meter Reading	Angle of Receiver	Meter Reading	Angle of Receiver	Meter Reading
0°		70°		140°	
10°		80°		150°	
20°		90°		160°	
30°		100°		170°	
40°		110°		180°	
50°		120°			
60°		130°			

Questions

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.

② The intensity of an electromagnetic wave is inversely proportional to the square of the distance from the wave source (i.e., $\mathbf{I = 1/R^2}$). 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.

③ Considering your results in step 7, to what extent can the Transmitter output be considered a spherical wave? - A plane wave?

Experiment 2: Reflection

EQUIPMENT NEEDED:

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

Procedure

① 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.

② Plug in the Transmitter and turn the Receiver INTENSITY selection switch to 30X.

③ 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.

④ 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**.

⑤ Measure and record the angle of reflection for each of the angles of incidence shown in Table 2.1.

➤ **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 "*".

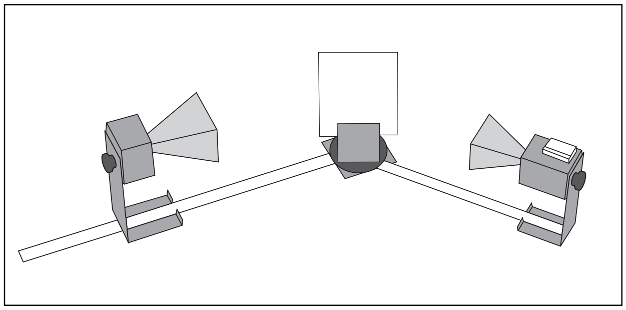

Figure 2.1 Equipment Setup

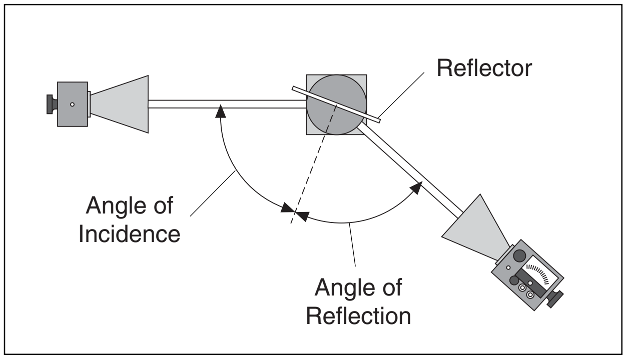

Figure 2.2 Angles of Incidence and Reflection

Table 2.1

Angle of Incidence	Angle of Reflection
20°	
30°	
40°	
50°	
60°	
70°	
80°	
90°	

Questions

① What relationship holds between the angle of incidence and the angle of reflection? Does this relationship hold for all angles of incidence?

② In measuring the angle of reflection, you measured the angle at which a maximum meter reading was found. Can you explain why some of the wave reflected into different angles? How does this affect your answer to question 1?

③ Ideally you would perform this experiment with a perfect plane wave, so that all the Transmitter radiation strikes the Reflector at the same angle of incidence. Is the microwave from the Transmitter a perfect plane wave (see Experiment 1, step 7)? Would you expect different results if it were a perfect plane wave? Explain.

Questions for Additional Experimentation

① How does reflection affect the intensity of the microwave? Is all the energy of the wave striking the Reflector reflected? Does the intensity of the reflected signal vary with the angle of incidence?

② Metal is a good reflector of microwaves. Investigate the reflective properties of other materials. How well do they reflect? Does some of the energy pass through the material? Does the material absorb some of it? Compare the reflective properties of conductive and non-conductive materials.

Experiment 4: Refraction Through a Prism

EQUIPMENT NEEDED:

– Transmitter
– Goniometer
– Receiver
– Rotating Table
– Ethafoam Prism mold with styrene pellets
– Protractor

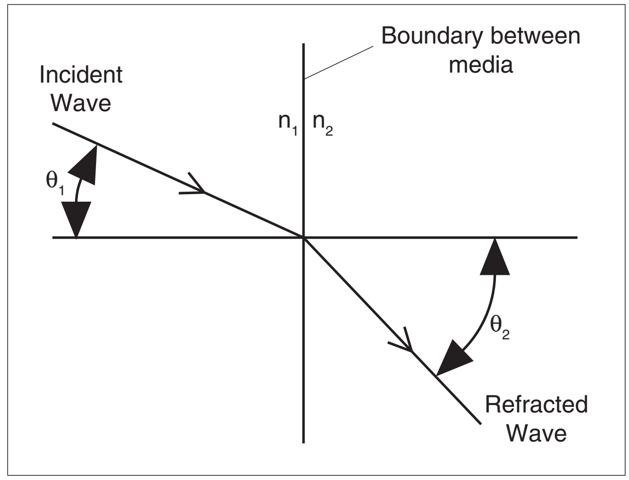

Figure 4.1 Angles of Incidence and Refraction

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 θ_2 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 electromegnetic 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 indeces of refraction. Here they are labeled n_1 and n_2. It is the difference between indeces 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

① Arrange the equipment as shown in Figure 4.2. Rotate the empty prism mold and see how it effects the incident wave. Does it reflect, refract, or absorb the wave?

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.

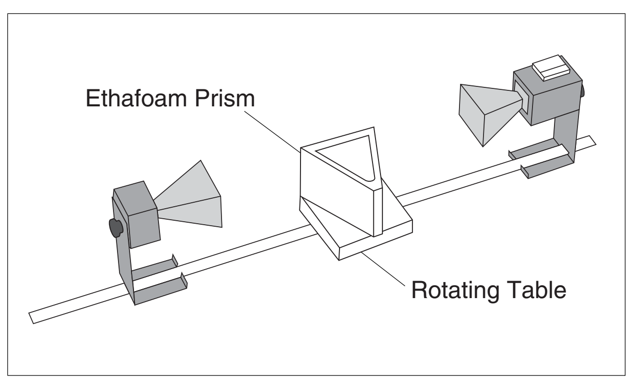

Figure 4.2 Equipment Setup

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

θ = ________________________.

④ Using the diagram shown in Figure 4.3, 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 value of $\mathbf{n_1/n_2}$.

n_1/n_2 = ________________________.

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

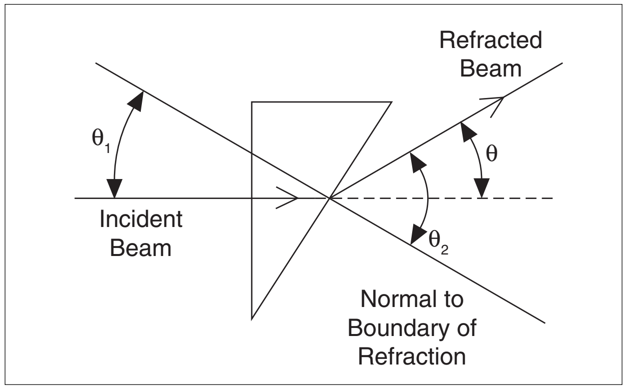

Figure 4.3 Geometry of Prism Refraction

Questions

① 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?

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 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 spacings 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, $\mathbf{2d\sin\theta = n\lambda}$, 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.

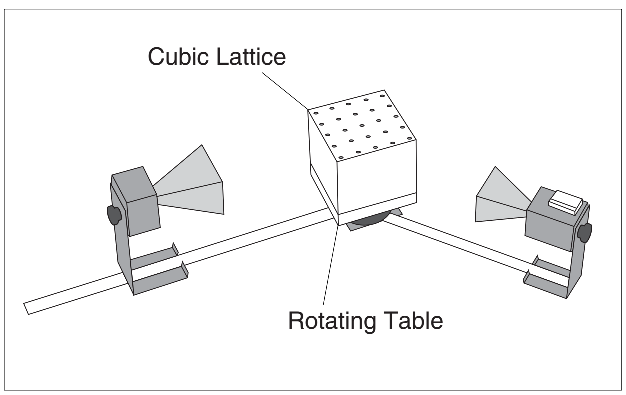

Figure 12.1 Equipment Setup

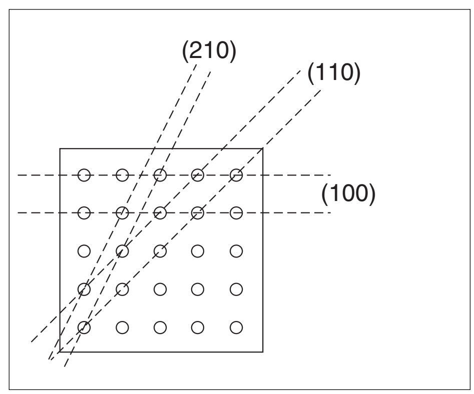

Figure 12.2 "Atomic" Planes of the Bragg Crystal

Procedure

① Arrange the equipment as shown in Figure 12.1.

② 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.

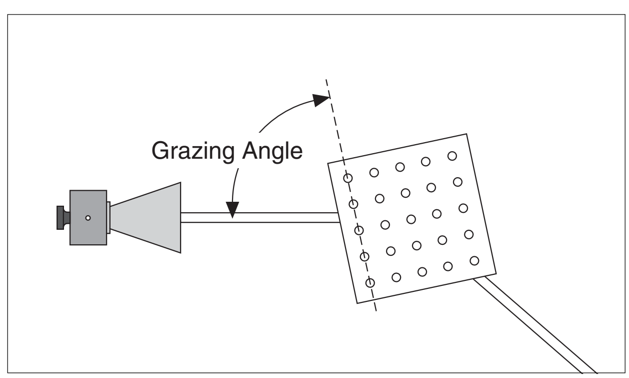

Figure 12.3 Grazing Angle

③ Rotate the crystal (with the rotating table) one degree clockwise and the Rotatable Goniometer arm two degrees clockwise. Record the grazing angle of the incident beam and the meter reading. (The grazing angle is the complement of the angle of incidence. It is measured with respect to the plane under investigation, **NOT** the face of the cube; see Figure 12.3.)

④ Continue in this manner, rotating the Goniometer arm two degrees for every one degree rotation of the crystal. Record the angle and meter reading at each position. (If you need to adjust the INTENSITY setting on the Receiver, be sure to indicate that in your data.)

⑤ Graph the relative intensity of the diffracted signal as a function of the grazing angle of the incident beam. At what angles do definite peaks for the diffracted intensity occur?

Use your data, the known wavelength of the microwave radiation (2.85 cm), and Bragg's Law to determine the spacing between the (100) planes of the Bragg Crystal. Measure the spacing between the planes directly, and compare with your experimental determination.

⑥ If you have time, repeat the experiment for the (110) and (210) families of planes.

Questions

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?

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?

> The Bragg Diffraction Experiment was developed by Dr. Harry Meiners of Rensselaer Polytechnic Institute.

Experiment 10: 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.

Procedure

① Align the Transmitter and Receiver directly across from each other on the Goniometer, and adjust the Receiver controls for a readable signal.

② Fill a tubular plastic bag with styrene pellets (tie the end or use a rubber band). Place one end of the bag in the Transmitter horn. What happens to the meter reading? Now place the other end in the Receiver horn. How does the intensity of the detected signal compare to the intensity when the bag is not used?

③ 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.

④ Vary the radius of curvature of the plastic bag. How does this effect the signal strength? Does the signal vary gradually or suddenly as the radial curvature of the plastic bag changes? Find the radius of curvature at which the signal begins to drop significantly.

Questions

① Check your textbook for information on Total Internal Reflection. Based on the radial curvature when the signal begins to show attenuation as it passes through the plastic bag, determine the angle of total internal reflection for the styrene pellets. Can you use this value to determine the index of refraction of the styrene pellets?

② Would you expect the plastic bag filled with styrene pellets to work the same with radiation at optical frequencies? Why?

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

Introduction

In Experiment 3, 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. Similar to the standing wave pattern, there are points in space where maxima are formed and others where minima are formed.

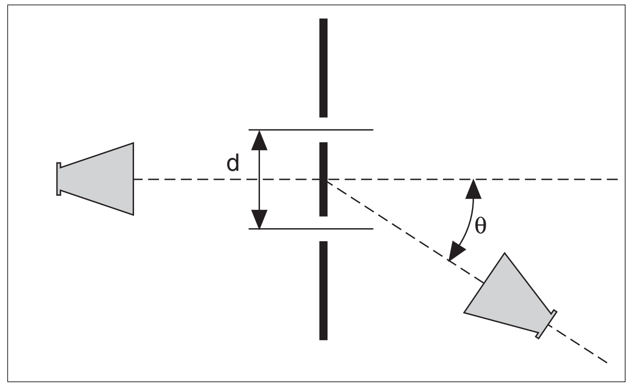

Figure 6.1 Double-Slit Interference

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 $\mathbf{d \sin\theta = n\lambda}$. (Where θ = the angle of detection, λ = the wavelength of the incident radiation, and **n** is any integer) (See Figure 6.1). Refer to a textbook for more information about the nature of the double-slit diffraction pattern.

Procedure

① Arrange the equipment as shown in Figure 6.2. Use the Slit Extender Arm, two Reflectors, and the Narrow 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.

② 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.

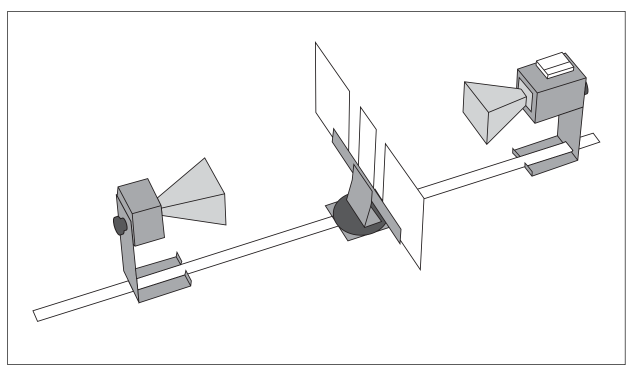

Figure 6.2 Equipment Setup

③ Rotate the rotatable Goniometer arm (on which the Receiver rests) slowly about its axis. Observe the meter readings.

④ Reset the Goniometer arm so the Receiver directly faces the Transmitter. Adjust the Receiver controls to obtain a meter reading of 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.)

⑤ 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. (You may want to try other slit spacings as well.)

Table 6.1

Angle	Meter Reading	Angle	Meter Reading
0°		45°	
5°		50°	
10°		55°	
15°		60°	
20°		65°	
25°		70°	
30°		75°	
35°		80°	
40°		85°	

Questions

① From your data, plot a graph of meter reading versus θ. Identify the angles at which the maxima and minima of the interference pattern occur.

② Calculate the angles at which you would expect the maxima and minima to occur in a standard two-slit diffraction pattern—maxima occur wherever $d \sin\theta = n\lambda$, minima occur wherever $d \sin\theta = n\lambda/2$. (Check your textbook for the derivation of these equations, and use the wavelength measured in experiment 3.) How does this compare with the locations of your observed maxima and minima? Can you explain any discrepancies? (What assumptions are made in the derivations of the formulas and to what extent are they met in this experiment?)

③ Can you explain the relative drop in intensity for higher order maxima? Consider the single-slit diffraction pattern created by each slit. How do these single slit patterns affect the overall interference pattern?

➤**NOTE:**

① Wavelength at 10.525 GHz = 2.85 cm.

② The experimenter's body position may affect the results.

Experiment 9: Michelson Interferometer

EQUIPMENT NEEDED:

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

Introduction

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 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.

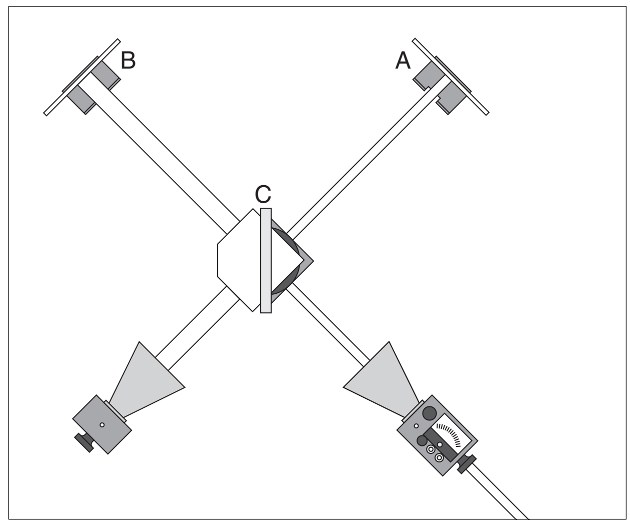

Figure 9.1 Michelson Interferometer

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 maxium is no longer detected. Since each wave passes twice between a Reflector and the Partial Reflector, moving a Reflector a distance **λ/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 9.1. 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, $\mathbf{x_1}$, 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 to a maximum. Record the number of minima that were traversed. Also record $\mathbf{x_2}$, 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 = ___________________________.

Questions

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 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 $\boldsymbol{\lambda = \lambda_0/n}$; where $\boldsymbol{\lambda}$ is the wavelength, $\boldsymbol{\lambda_0}$ 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.