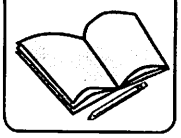
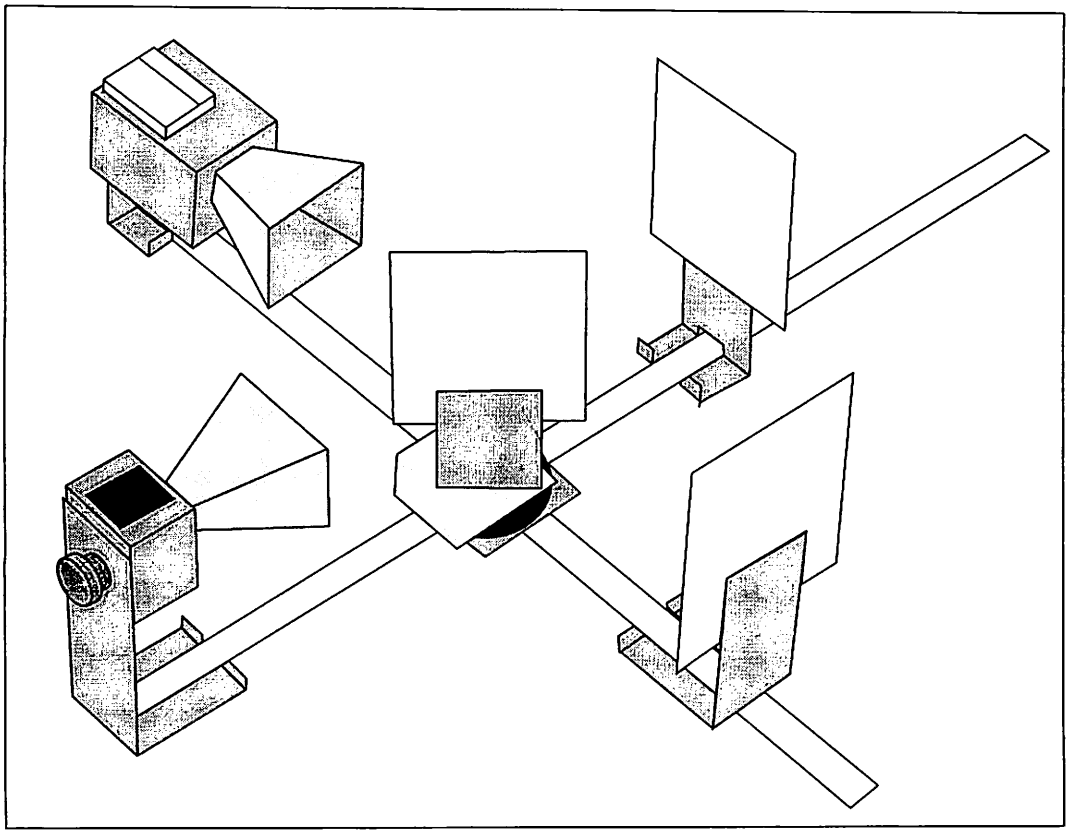
Includes Teacher's Notes and Typical Experiment Results



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

012-04630G

MICROWAVE OPTICS



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FC

➤ **This device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions:**

1. **this device may not cause harmful interference.**
2. **this device must accept any interference received, including interference that may cause undesired operation.**

Changes or modifications not expressly approved by Pasco Scientific could void the user's authority to operate the equipment.

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Credits

This manual edited by: Dave Griffith

Teacher's guide written by: Eric Ayars

Equipment Return

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When returning equipment for repair, the units must be packed properly. Carriers will not accept responsibility for damage caused by improper packing. To be certain the unit will not be damaged in shipment, observe the following rules:

① The packing carton must be strong enough for the item shipped.

② Make certain there are at least two inches of packing material between any point on the apparatus and the inside walls of the carton.

③ Make certain that the packing material cannot shift in the box or become compressed, allowing the instrument come in contact with the packing carton.

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Introduction

There are many advantages to studying optical phenomena at microwave frequencies. Using a 2.85 centimeter microwave wavelength transforms the scale of the experiment. Microns become centimeters and variables obscured by the small scale of traditional optics experiments are easily seen and manipulated. The PASCO scientific Model WA-9314B Basic Microwave Optics System is designed to take full advantage of these educational benefits. The Basic Microwave Optics System comes with a 2.85 centimeter wavelength microwave transmitter and a receiver with variable amplification (from 1X to 30X). All the accessory equipment needed to investigate a variety of wave phenomena is also included.

This manual describes the operation and maintenance of the microwave equipment and also gives detailed instructions for many experiments. These experiments range from quantitative investigations of reflection and refraction to microwave models of the Michelson and Fabry-Perot interferometers. For those who have either the Complete Microwave Optics System (WA-9316) or the Microwave Accessory Package (WA-9315), the manual describes experiments for investigating Bragg diffraction and Brewster's angle.

Equipment

Gunn Diode Transmitter

The Gunn Diode Microwave Transmitter provides 15 mW of coherent, linearly polarized microwave output at a wavelength of 2.85 cm. The unit consists of a Gunn diode in a 10.525 GHz resonant cavity, a microwave horn to direct the output, and an 18 cm stand to help reduce table top reflections. The Transmitter may be powered directly from a standard 115 or 220/240 VAC, 50/60 Hz outlet by using the provided power supply. Other features include an LED power-indicator light and a rotational scale that allows easy measurement of the angle of polarization.

The Gunn diode acts as a non-linear resistor that oscillates in the microwave band. The output is linearly polarized along the axis of the diode and the attached horn radiates a strong beam of microwave radiation centered along the axis of the horn.

To Operate the Microwave Transmitter

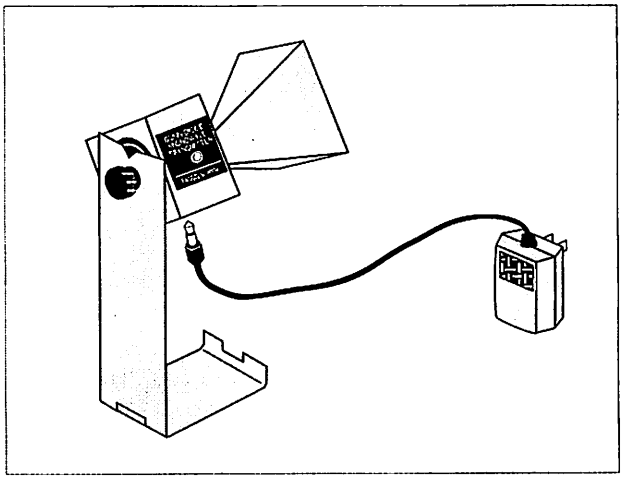
Simply plug the power supply into the jack on the Transmitter's bottom panel and plug the power supply into a standard 115 or 220/240 VAC, 50/60 Hz outlet. The LED will light indicating the unit is on.

➤ *CAUTION: The output power of the Microwave Transmitter is well within standard safety levels. Nevertheless, one should never look directly into the microwave horn at close range when the Transmitter is on.*

Power Supply Specifications:

9 Volt DC, 500 mA;

Miniature Phone Jack Connector (the tip is positive)

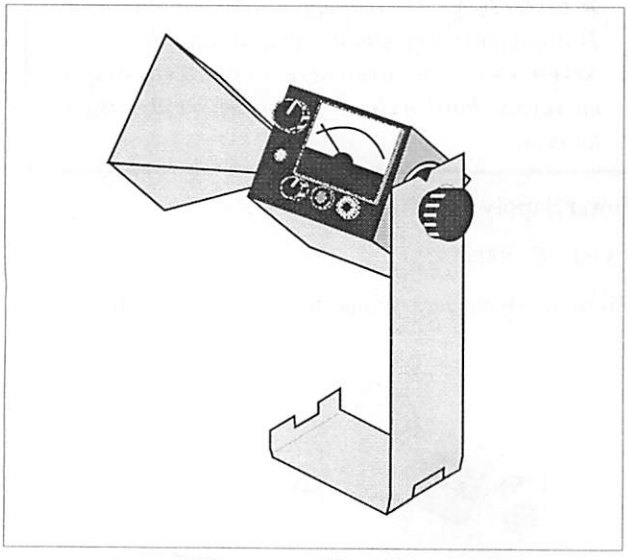


Microwave Transmitter with Power Supply

Microwave Receiver

The Microwave Receiver provides a meter reading that, for low amplitude signals, is approximately proportional to the intensity of the incident microwave signal. A microwave horn identical to that of the Transmitter's collects the microwave signal and channels it to a Schottky diode in a 10.525 GHz resonant cavity. The diode responds only to the component of a microwave signal that is polarized along the diode axis, producing a DC voltage that varies with the magnitude of the microwave signal.

Special features of the Receiver include four amplification ranges—from one to thirty—with a variable sensitivity knob that allows fine tuning of the amplification in each range. For convenience in class demonstrations, banana plug connectors provide for an output signal via hookup to a projection meter (such as PASCO Model ES-9065 Projection Meter or SE-9617 DC Voltmeter). This output can also be used for close examination of the signal using an oscilloscope. The receiver is battery powered and has an LED battery indicator; if the LED lights when you turn on the Receiver , the battery is working. As with the Transmitter, an 18 cm high mount minimizes table top reflections, and a rotational scale allows convenient measurements of polarization angle.



Microwave Receiver

The female audio connector on the side of the Receiver is for an optional Microwave Detector Probe (PASCO Model WA-9319). The probe works the same as the Receiver except it has no horn or resonant cavity. The Probe is particularly convenient for examining wave patterns in which the horn could get in the way, such as the standing wave pattern described in Experiment 3 of this manual.

> ➤***NOTE:*** *The detector diodes in the Receiver (and the Probe) are non-linear devices. This non-linearity will provide no problem in most experiments. It is important however, to realize that the meter reading is not directly proportional to either the electric field (E) or the intensity (I) of the incident microwave. Instead, it generally reflects some intermediate value.*

To Operate The Microwave Receiver:

> ➤***NOTE:*** *Before using the Receiver, you will need to install the two 9-volt transistor batteries—they are included with the system. See the instructions in the Maintenance section at the end of this manual.*

① Turn the INTENSITY selection switch from OFF to 30X, the lowest amplification level. The battery indicator LED should light, indicating that the battery is okay. If it does not, replace the battery following the procedures in the Maintenance section of this manual.

> ➤***NOTE:*** *The INTENSITY selection settings (30X, 10X, 3X, 1X) are the values you must multiply the meter reading by to normalize your measurements. 30X, for example, means that you must multiply the meter reading by 30 to get the same value you would measure for the same signal with the INTENSITY selection set to 1X. Of course, this is true only if you do not change the position of the VARIABLE SENSITIVITY knob between measurements.*

② Point the microwave horn toward the incident microwave signal. Unless polarization effects are under investigation, adjust the polarization angles of the Transmitter and Receiver to the same orientation (e.g., both horns vertically, or both horns horizontally).

③ Adjust the VARIABLE SENSITIVITY knob to attain a meter reading near midscale. If no deflection of the meter occurs, increase the amplification by turning the INTENSITY selection switch clockwise. Remember, always multiply your meter reading by the appropriate INTENSITY selection (30X, 10X, 3X, or 1X) if you want to make a quantitative comparison of measurements taken at different INTENSITY settings.

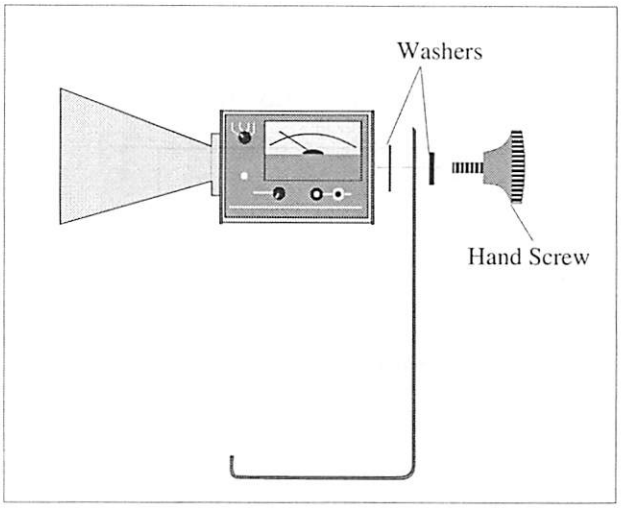
Initial Setup

To attach the microwave Transmitter and Receiver to their respective stands prior to performing experiments, proceed as follows:

① Remove the black hand screw from the back panel of both the Transmitter and the Receiver.

② Attach both units to the stands as shown below. Observe the location of the washers.

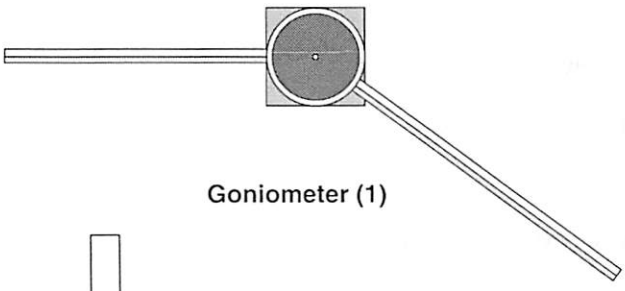
③ **To adjust the polarization angle of the Transmitter or Receiver**, loosen the hand screw, rotate the unit, and tighten the hand screw at the desired orientation. Notice the rotational scale on the back of each unit for measuring the angle of polarization. Be aware, however, that since the Transmitter and Receiver face each other in most experiments it is important to match their polarization angle. If you rotate one unit to an angle of 10-degrees, you must rotate the other to -10-degrees (350-degrees) to achieve the proper polar alignment.



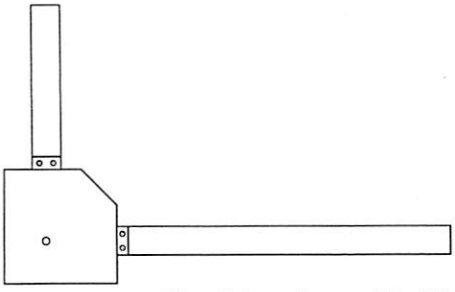
Attaching the Transmitter and Receiver Stands

Accessory Equipment

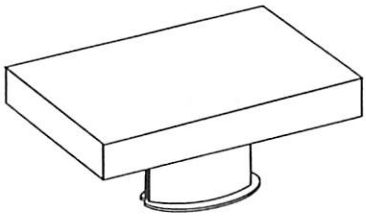
Accessory equipment for the Basic Microwave Optics System includes:



Goniometer (1)

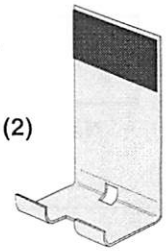


Fixed Arm Assembly (1)

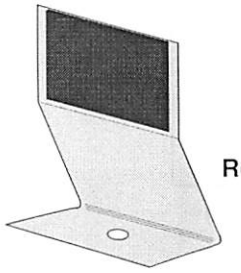


Rotating Table (1)

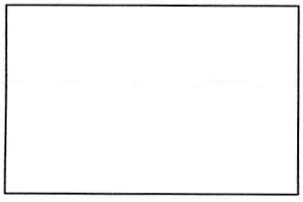
ROTATING TABLE



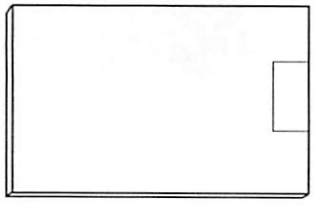
Component Holder (2)



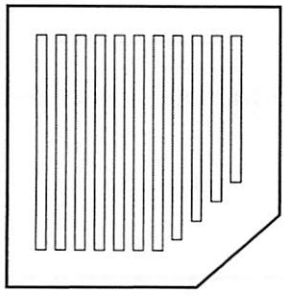
Rotating Component Holder (1)



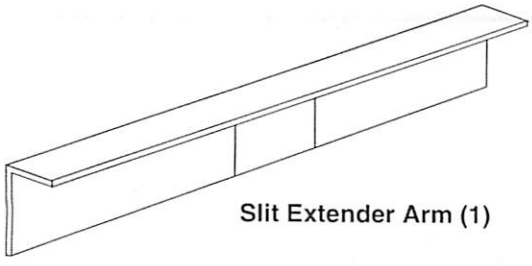
Metal Reflector (2)



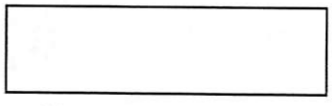
Partial Reflector (2)



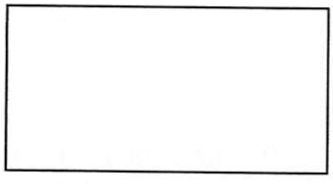
Polarizers (2)



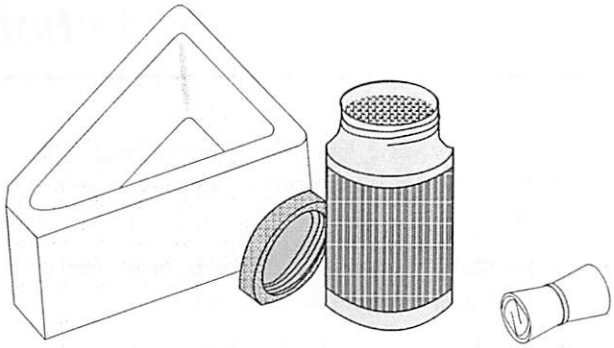
Slit Extender Arm (1)



Narrow Slit Spacer (1)



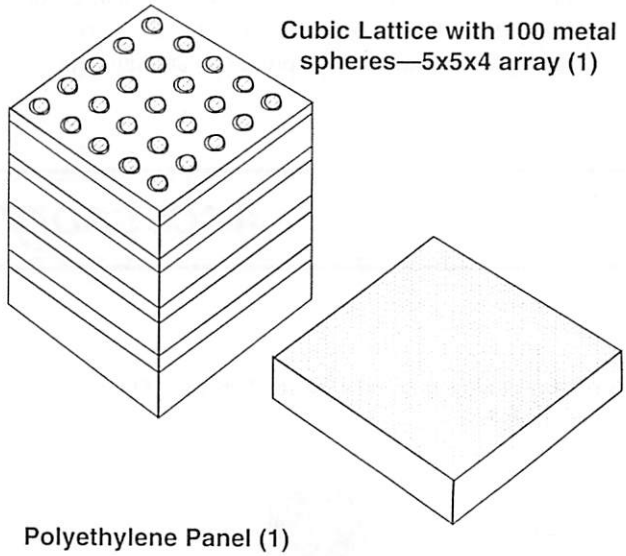
Wide Slit Spacer (1)



Ethafoam Prism Mold w/ Styrene Pellets (1)

Tubular Plastic Bags (4)

The WA-9315 Microwave Accessory Package (which is part of the Complete Microwave Optics System Model WA-9316) includes the following:



Cubic Lattice with 100 metal spheres—5x5x4 array (1)

Polyethylene Panel (1)

The following components, compatible with the WA-9314B Basic Microwave Optics System, are available from PASCO scientific:

Model WA-9319 Microwave Detector Probe plugs directly into the Microwave Receiver. The probe is essential for experiments in which the horn of the Receiver might otherwise interfere with the wave pattern being measured.

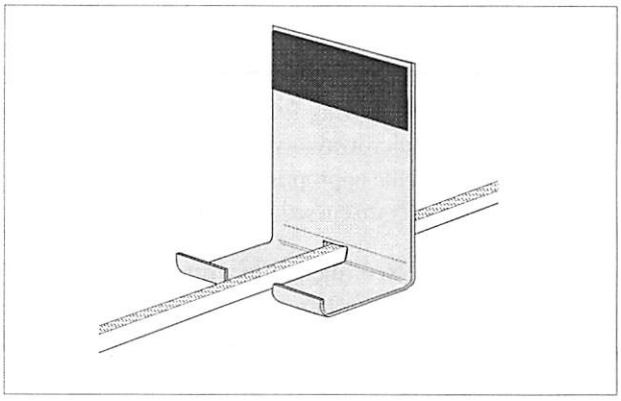
Model WA-9318 Microwave Modulation Kit includes a modulator and microphone. With this kit, you can use your Transmitter and Receiver as a microwave communications system.

Assembling Equipment for Experiments

The arms of the Goniometer slide through the holes in the Component Holders as shown. Make sure the magnetic strip on the bottom of the arm grips the base of the carriage. To adjust the position of the holders, just slide them along the Goniometer arms. Attach the mounting stands of the microwave Transmitter and Receiver to the arms of the Goniometer in the same manner.

For most experiments it is advantageous to attach the Transmitter to the long arm of the Goniometer and the Receiver to the shorter, rotatable arm. This maintains a fixed relationship between the microwave beam and components mounted on the long arm (or on the degree plate) of the Goniometer. In turn the Receiver moves easily to sample the output.

Reflectors, Partial Reflectors, Polarizers, Slit Spacers, and the Slit Extender Arm all attach magnetically to the Component Holders. The metric scale along the Goniometer arms and the degree plate at the junction of the arms allow easy measurement of component placement. When rotating the rotatable arm, hold the degree plate firmly to the table so that it does not move.



Mounting the Component Holder

➤ **IMPORTANT NOTES:**

1. **CAUTION**—Under some circumstances, microwaves can interfere with electronic medical devices. ***If you use a pacemaker, or other electronic medical device***, check with your doctor or the manufacturer to be certain that low power microwaves at a frequency of 10.525 GHz will not interfere with its operation.
2. Always mount the apparatus on a CLEAN, SMOOTH table. Before setting up the equipment, brush off any material—***particularly metal chips***—that might have adhered to the magnetic strips on the bottom of the Goniometer arms.

Copy-Ready Experiments

The following Experiments provide a thorough introduction to wave theory using the microwave system. We expect that the student approaches each experiment with the appropriate theoretical background, therefore, basic principles are only briefly discussed in each experiment.

The experiments are written in worksheet format. Feel free to photocopy them for use in your lab.

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.

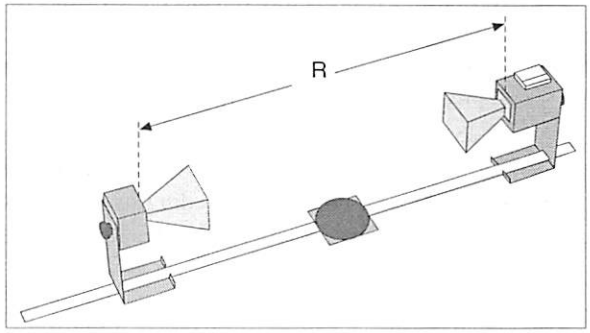


Figure 1.1 Equipment Setup

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).

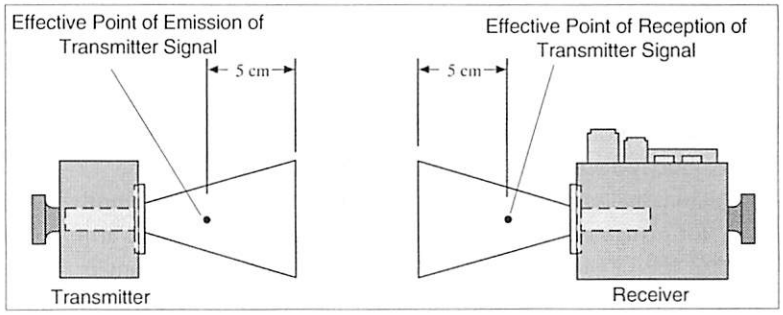


Figure 1.2 Equipment Setup

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.

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			

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?

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:

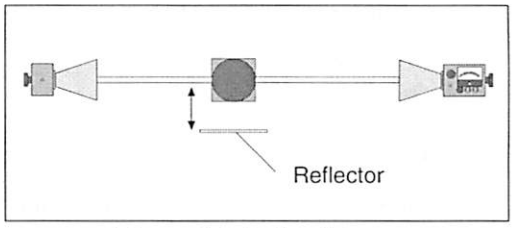


Figure 1.3 Reflections

➤ **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?

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).

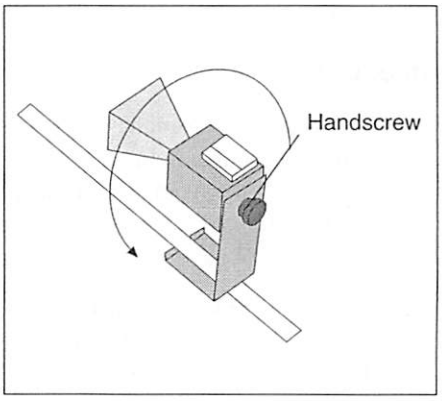


Figure 1.4 Polarization

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.

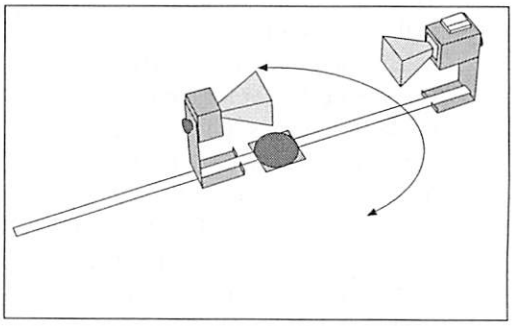


Figure 1.5 Signal Distribution

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., $\mathbf{E = 1/R}$). 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?

Notes

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.

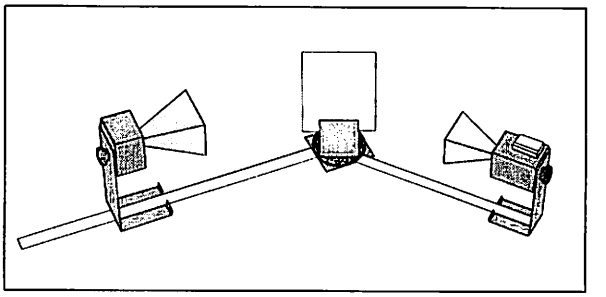


Figure 2.1 Equipment Setup

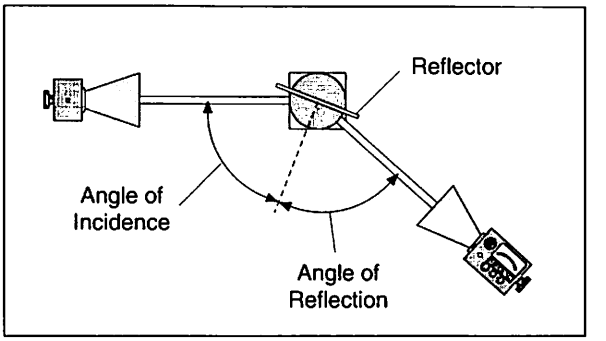


Figure 2.2 Angles of Incidence and Reflection

➤**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 "*".

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

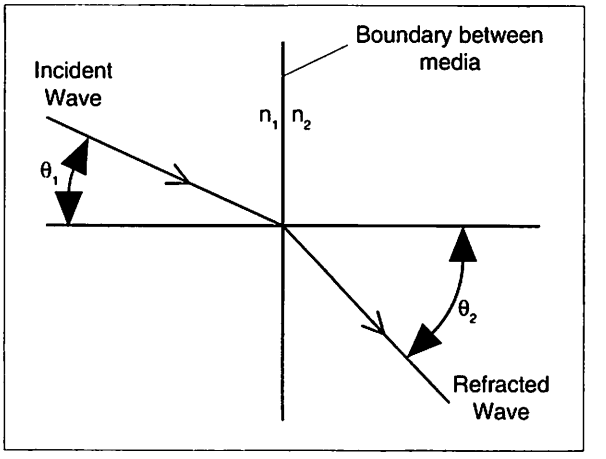


Figure 4.1 Angles of Incidence and Refraction

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.

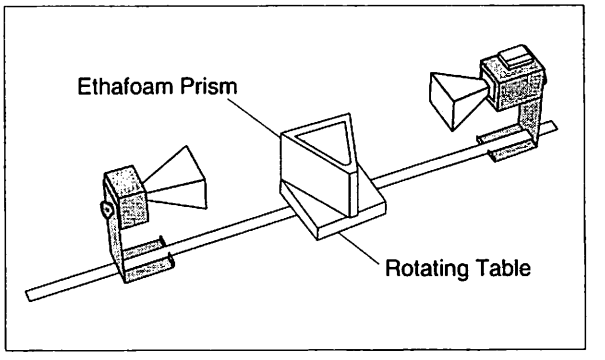


Figure 4.2 Equipment Setup

➤ **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 = _____.

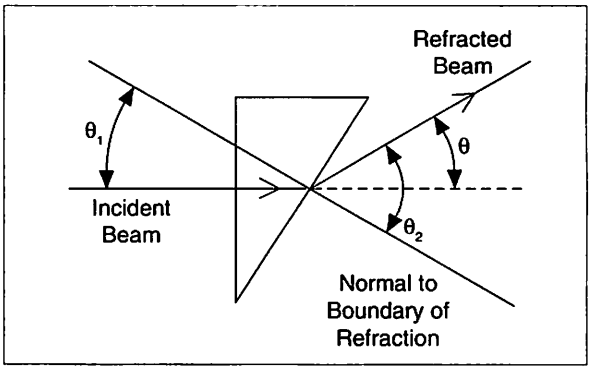


Figure 4.3 Geometry of Prism Refraction

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.

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 5: Polarization

EQUIPMENT NEEDED:

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

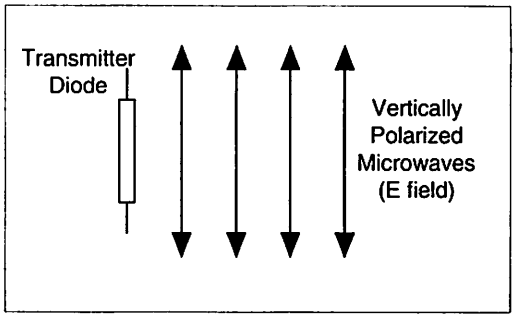


Figure 5.1 Vertical Polarization

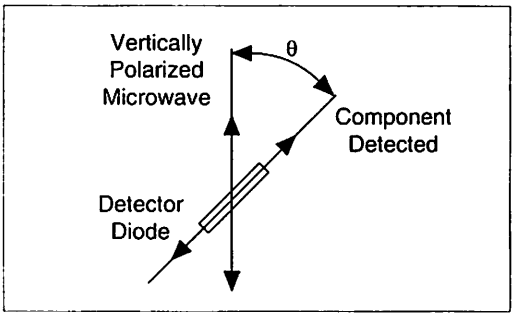


Figure 5.2 Detecting Polarized Radiation

Procedure

① Arrange the equipment as shown in Figure 5.3 and adjust the Receiver controls for nearly full-scale meter deflection.

② Loosen the hand screw on the back of the Receiver and rotate the Receiver in increments of ten degrees. At each rotational position, record the meter reading in Table 5.1.

③ What happens to the meter readings if you continue to rotate the Receiver beyond 180-degrees?

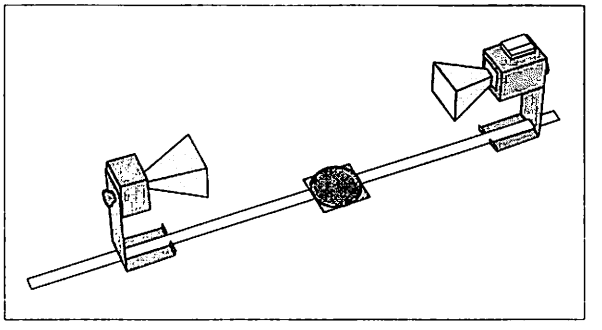


Figure 5.3 Equipment Setup

Table 5.1

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°			

④ 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).

⑤ Record the meter reading when the Polarizer is aligned at 0, 22.5, 45, 67.5 and 90-degrees with respect to the horizontal.

⑥ Remove the Polarizer slits. Rotate the Receiver so the axis of its horn is at right angles to that of the Transmitter. Record the meter reading. Then replace the Polarizer slits and record the meter readings with the Polarizer slits horizontal, vertical, and at 45-degrees.

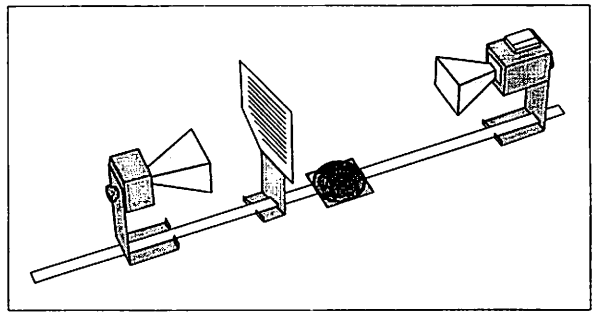


Figure 5.4 Equipment Setup

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

Angle of Slits	Meter Reading
Horizontal	
Vertical	
45°	

Questions

① If the Receiver meter reading (**M**) were directly proportional to the electric field component (**E**) along its axis, the meter would read the relationship $\mathbf{M = M_o \cos\theta}$ (where θ is the angle between the detector and Transmitter diodes and Mo is the meter reading when $\theta = 0$). (See Figure 5.2). Graph your data from step 2 of the experiment. On the same graph, plot the relationship $\mathbf{M_o \cos\theta}$. Compare the two graphs.

② The intensity of a linearly polarized electromagnetic wave is directly proportional to the square of the electric field (e.g., $\mathbf{I = kE^2}$). If the Receiver's meter reading was directly proportional to the incident microwave's intensity, the meter would read the relationship $\mathbf{M = M_o \cos^2\theta}$. Plot this relationship on your graph from question 1. Based on your graphs, discuss the relationship between the meter reading of the Receiver and the polarization and magnitude of the incident microwave.

③ Based on your data from step 5, how does the Polarizer affect the incident microwave?

④ Can you explain the results of step 6 of the experiment. How can the insertion of an additional polarizer increase the signal level at the detector? (**HINT:** Construct a diagram like that shown in Figure 5.2 showing (1) the wave from the Transmitter; (2) the wave after it passes through the Polarizer; and (3) the component detected at the detector diode.)

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.

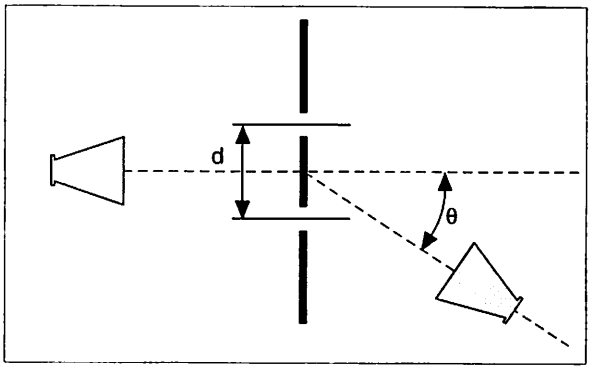


Figure 6.1 Double-Slit Interference

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 $d \sin\theta = n\lambda$. (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.

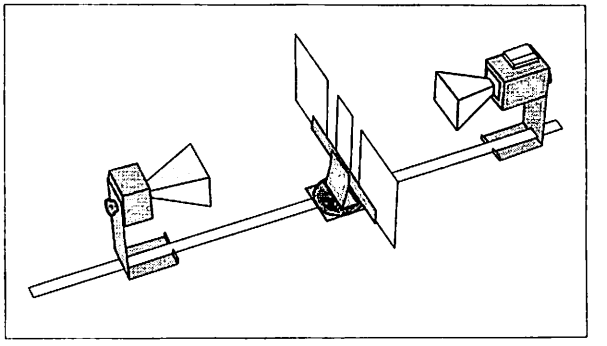


Figure 6.2 Equipment Setup

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 $\mathbf{d \sin\theta = n\lambda}$, minima occur wherever $\mathbf{d \sin\theta = n\lambda/2}$. (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 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, $2d\sin\theta = n\lambda$, 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.

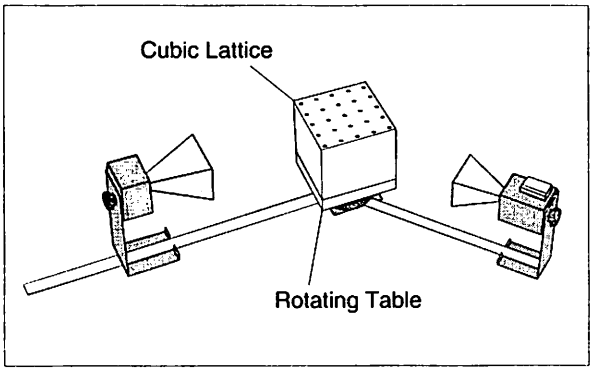


Figure 12.1 Equipment Setup

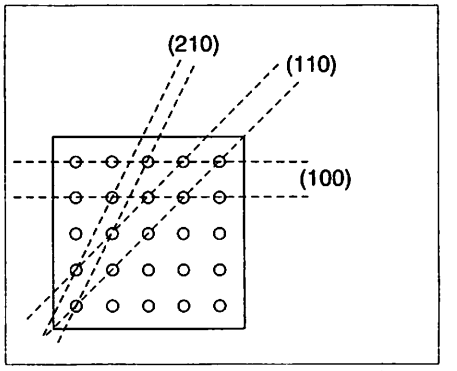


Figure 12.2 "Atomic" Planes of the Bragg Crystal

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.

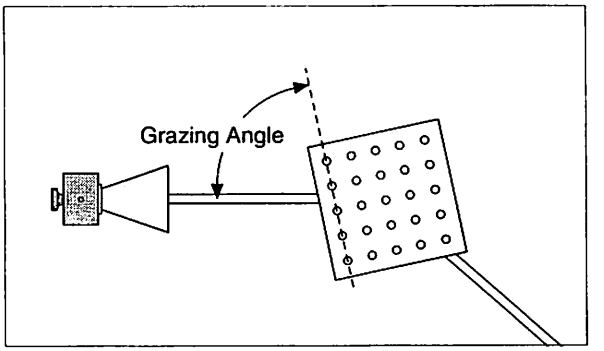


Figure 12.3 Grazing Angle

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.