Properties of Microwaves

I. EQUIPEMENT

- Transmitter
- Goniometer
- Metal Reflector
- Foam Prism with Styrene Pellets
- Polarizer
- Receiver
- Rotating Component Holder
- Rotating Table
- Component Holder
- Protractor

See last page for parts identification

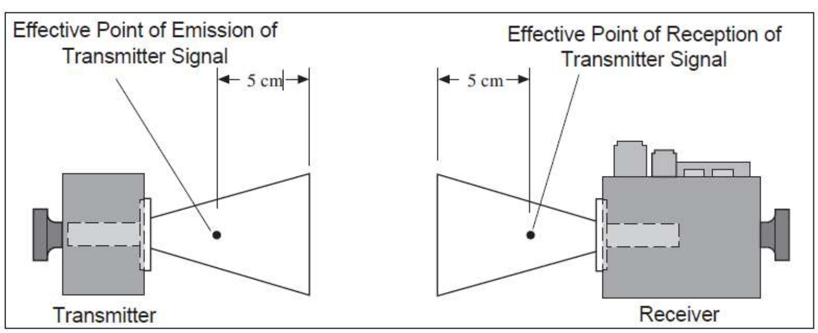
II. BACKGROUND INFORMATION

Microwaves are part of the electromagnetic spectrum with wavelengths on the order of centimeters. The Microwave Optics System has a set-up which allows the experimenter to measure several aspects of e-m waves. In this experiment you will study the intensity vs. distance and angle of the transmitter, reflection, refraction and polarization of waves.

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.*

The microwave optics system is useful in studying ray and wave optical phenomena in the microwave band. It uses wavelengths in the 3 cm range and will allow easily observable results. In the system is a microwave transmitter with power supply, a variable amplification receiver and equipment to observe the optical phenomena.

In setting up the equipment it is important to note that the transmitter and the receiver have orientations of the wave and that will have to be considered during the experiments. ***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.* 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.

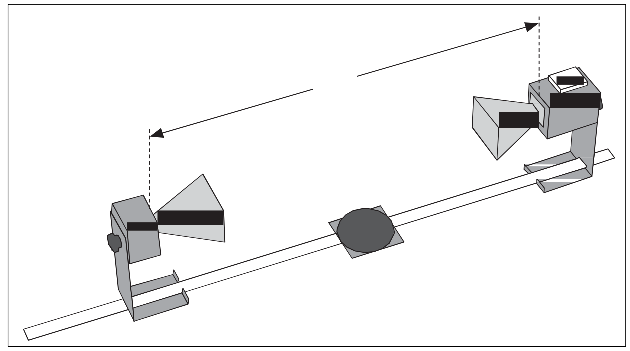


The effective position of the transmitter and receiver are shown in the following diagram.
When measuring distances or angles, these are the points needed for reference.
In this lab period you will look at several aspects of wave propagation: intensity vs. distance, reflection from a flat surface, refraction and polarization. Each section will have a set of procedures and there are some general instructions for the use of the equipment. There should be separate data tables and analysis for each section.

III. EXPERIMENTAL PROCEDURE

Intensity

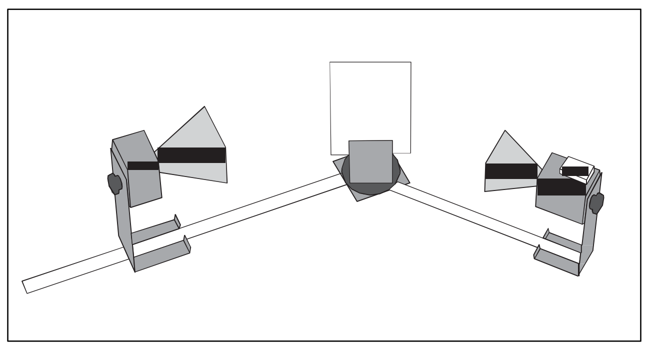
Arrange the Transmitter and Receiver on the Goniometer with the Transmitter attached to the fixed arm. (If you don't know what a Goniometer is, ask.) Be sure to adjust both Transmitter and Receiver to the same polarity—the horns should have the same orientation, as shown. Plug in the Transmitter and turn the INTENSITY selection switch on the Receiver from OFF to 10X. (The LEDs should light up on both units.) Adjust the Transmitter and Receiver so the distance between the source diode in the Transmitter and the detector diode is 40 cm.



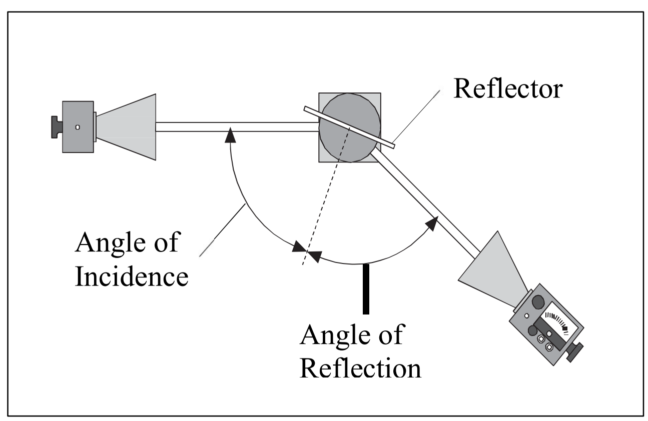
Adjust the INTENSITY and VARIABLE SENSITIVITY dials on the Receiver so that the meter reads 1.0 (full scale). Adjust the distance to various values from the 40 cm point out to about 1.0 m. Measure the intensity at each distance. (Do not adjust the Receiver controls between measurements.) Graph intensity as a function of distance and determine the mathematical relationship.

Reflection

Arrange the equipment as shown in figure to the right 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.



Plug in the Transmitter and turn the Receiver INTENSITY selection switch to 30X. 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**. Adjust the Rotating Component Holder so that the angle of incidence equals 45-degrees. See figure to the right.



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**. Adjust the Transmitter and Reflector so that the incidence angles range from 20^o to 90^o at ten degree increments Measure and record the angle of reflection for each incident angle.

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 "*".

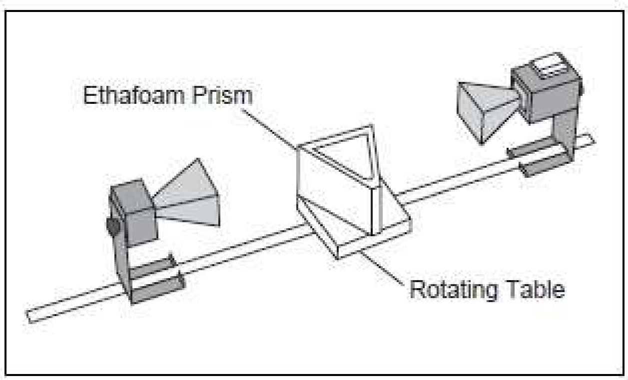
1. What relationship holds between the angle of incidence and the angle of reflection? Does this relationship hold for all angles of incidence?
2. In measuring the angle of reflection, you measured the angle at which a maximum meter reading was found. Can you explain why some of the wave reflected into 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 (Consider how you could test this)? Would you expect different results if it were a perfect plane wave? Explain.

<u>Refraction through a Prism</u>

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):

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

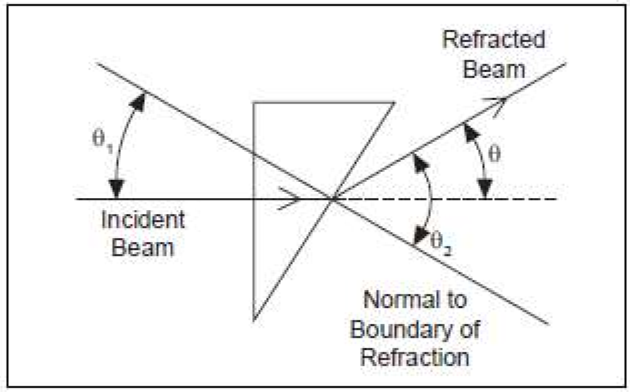
where θ_1 is the angle between the direction of propagation of the incident wave and the normal to the boundary between the two media, and θ_2 is the corresponding angle for the refracted wave. Every material can be described by a number n, called its Index of Refraction. This number indicates the ratio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



The prism has been prepared for you. Do NOT attempt to open the prism. Your instructor can provide a sample of the material inside the prism. To simplify the calculations, align the face of the prism that is nearest to the Transmitter perpendicular to the incident microwave beam. Rotate the movable arm of the Goniometer and locate the angle θ at which the refracted signal is a maximum.

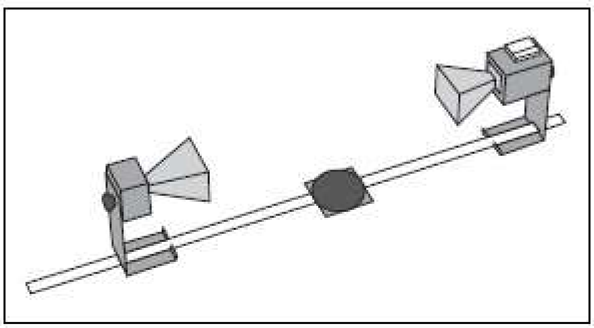
The angle θ can be measured directly from the goniometer, but θ_2 must be computed from the relationship of θ and the normal to the receiver side of the prism. See the figure below.

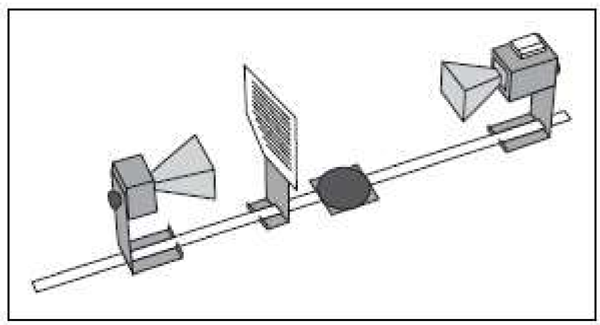
Record θ, compute θ_1, and θ_2. Place the values into Snell's law and compute the index of refraction for the styrene pellets using the index of refraction of air to be 1.00. Would you expect the refraction index of the styrene pellets in the prism mold to be the same as for a solid styrene prism?



Polarization

Arrange the equipment as shown in Figure 5 and adjust the Receiver controls for nearly full-scale meter deflection. **A.** 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. What happens to the meter readings if you continue to rotate the Receiver beyond 180-degrees?





Set up the equipment as shown in the figure to the left. Reset the Receiver's angle to 0-degrees (the horns should be oriented as shown with the longer side horizontal). Record the meter reading when the Polarizer is aligned at 0, 22.5, 45, 67.5 and 90- degrees with respect to the horizontal. 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.

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 M_o is the meter reading when θ= **0**). Graph your data for measurements of the angle of the transmitter and intensity of the experiment. On the same graph, plot the relationship $\mathbf{M_o cos}\ \theta$. Compare the two graphs.

The intensity of a linearly polarized electromagnetic wave is directly proportional to the square of the electric field (e.g., $\mathbf{I = k*E^2}$). 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. Based on your graphs, discuss the relationship between the meter reading of the Receiver and the polarization and magnitude of the incident microwave.

Based on your data from rotating the polarizer when starting with the horns aligned, how does the Polarizer affect the incident microwave?

Can you explain the results of the last step of the polarization experiment? How can the insertion of an additional polarizer increase the signal level at the detector? (**HINT:** Construct a diagram considering the field of the wave and the orientation of the polarizer what happens to the wave components as it passes through the polarizer.

IV. DATA

Record the data as suggested in each section. There should be a clear and neat data table for each part of the lab.

V. CALCULATIONS

1. Complete the graphs for intensity vs. distance and determine the mathematical relationship.
2. Determine the relationship for the angle of reflection as a function of the angle of incidence.
3. Determine the index of refraction of the styrene pellets.
4. Determine the relationship for the intensity of the wave and the angle of the polarizer.

VI. CONCLUSIONS/QUESTIONS

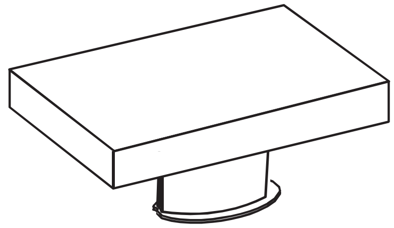
1. Answer the questions in each section.
2. What are the sources of error in the experiments?

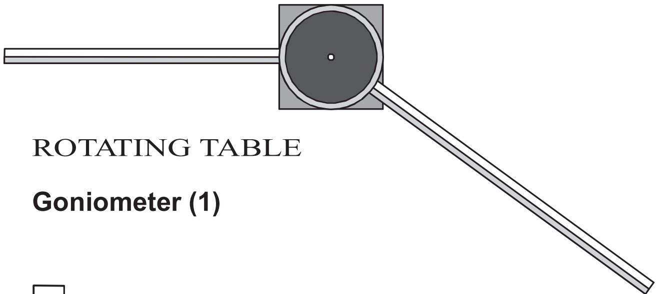
Notes for putting away the lab equipment!

There are a lot of pieces to the lab set-up. Students are expected to make sure all pieces are returned to the box and storage pockets just as they are when they take them out. There are two trays of equipment. Care must be taken when returning the items to the bottom tray to ensure they all fit correctly so the top tray goes back in the box like it should.

Parts Identification

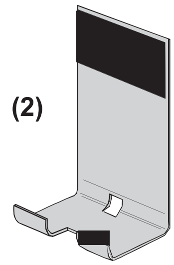
Rotating Table (1)

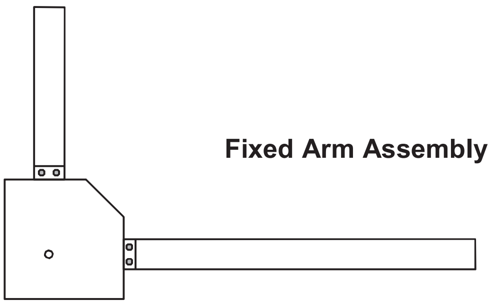




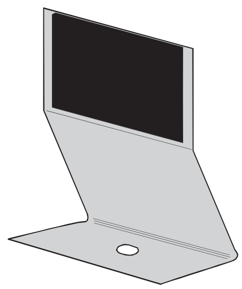
Goniometer (1)

Component Holder (2)

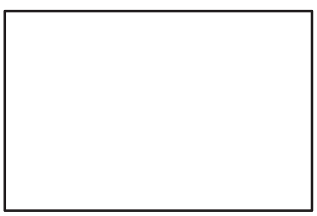


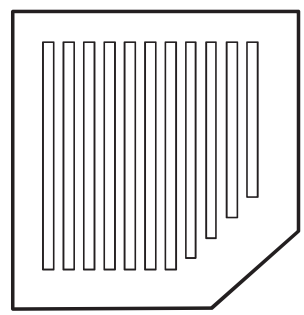


Fixed Arm Assembly (1)



Rotating Component Holder (1)

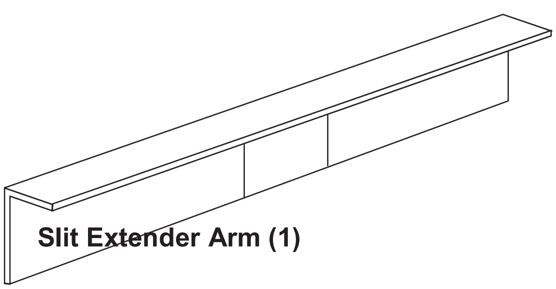




Metal Reflector (2)

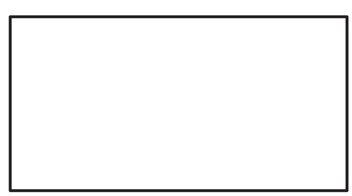
Polarizers (2)

Partial Reflector (2)



Narrow Slit Spacer (1)

Slit Extender Arm (1)



Wide Slit Spacer (1)