

Microwave Optics : Refraction and Polarization



OBJECTIVE: To examine the phenomena of refraction and polarization.

EQUIPMENT: Microwave transmitter & receiver, polystyrene & Delrin® prisms, goniometer (angle measuring device), protractor, metal polarizers, various stands & holders



INTRODUCTION: Have you ever placed your hand in the water of a pool or pond and noticed that your hand appeared closer to your eye than it actually was? The same effect can be observed when looking at objects from above and below the water line in an aquarium or fish tank. The apparent displacement of objects is due to **refraction**, the bending of light waves that occurs when they cross from one medium (water) into another (air). Since light bends as it traverses the air-water interface, it appears that the light rays reflecting off your hand that your eye perceives has shifted in location, giving rise to the illusion of false proximity.

While swimming in that same pool or pond early in the morning or late afternoon, you may have been blinded by the glare of the low sun reflecting off the water's surface. If you had remembered to bring your Polaroid™ sunglasses, you might have blocked off most of this annoying glare. Your sunglasses are constructed such that they absorb light waves of horizontal **polarization**, but transmit vertically polarized waves. Light reflected off the horizontal waters surface is horizontally polarized; the glasses absorb

most of that radiation but allow light of vertical polarization to pass through so that you can see everything else fine. You can even put on two pairs of sunglasses, rotate one pair through 90 degrees, and see that the combination blocks out all light.

In this lab, we will explore these concepts using **microwaves** instead of visible light. Microwaves are a category of electromagnetic radiation that differs fundamentally from light only in frequency and wavelength. Like light, microwaves propagate through a vacuum at $c=3 \times 10^8$ m/s, the speed of light. They have a wavelength much larger than light (10^{-2} m instead of 10^{-7} m), allowing us to use media or polarizers of centimeter size. With visible light, the water molecules that refract the light and the long-chain hydrocarbon molecules that polarize the light are certainly not visible to the naked eye.

Applications of refraction include fiber optics (communications, endoscopy, bronchoscopy, colonoscopy, arthroscopy), lenses, rear-view day/night mirrors and gemology; polarization is the principle behind LCD displays such as calculators, watches and flat-screen monitors.

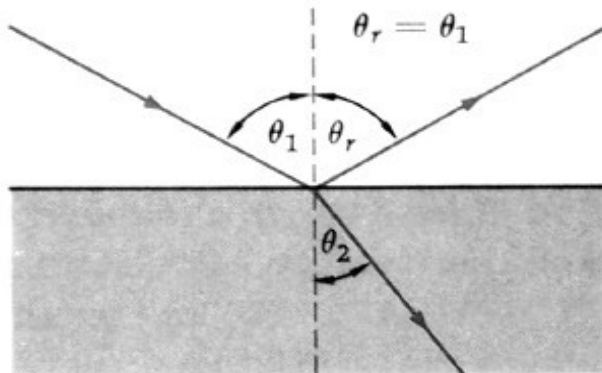
 **NOTE: You may be worried about being exposed to microwaves in this experiment. The output power of the transmitter is 15 mW (15×10^{-3} Watts), which is about five orders of magnitude (0.001 %) less than the power of your microwave oven at home. More importantly, the 10.5 GHz frequency used here is higher than the 2.45 GHz used in your oven, a frequency selected because it is the resonant frequency (the frequency where the most energy is absorbed) of the water molecule's rotational mode. Hence the water molecules of your body do not absorb microwave radiation of this frequency.** 

Refraction

Snell's Law, which relates the angles of incidence and refraction with respect to a line perpendicular to the plane of incidence, states that:

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

where the subscripts 1 and 2 denote the incident and refractive media, respectively.



n_1 and n_2 are the *indices of refraction* of the two media, and are a measure of how much they bend the waves in each media. The index of refraction of a medium is defined as $n = \frac{c}{v}$, the ratio of the speed of light to the speed of light in the medium. Note also that $\theta_i = \theta_{refl}$; the angles of incidence and reflection are equal.

PROCEDURE:

Measure the indices of refraction of Polystyrene and Delrin®

1. After making sure everything is off (there should be no glowing LEDs on either transmitter or receiver; meter should read zero), examine the setup. It consists of a transmitter, inside which there is a linear diode that emits microwaves. These waves are incident onto a prism, which then refracts the waves. A receiver, which also has a linear diode, has an intensity meter built in that registers the strength of the refracted wave. By moving around the receiver on the goniometer (angle-measuring device), one can measure the angle of highest intensity corresponding to the location of the refracted beam.



2. The receiver provides a reading that is proportional to the intensity of the microwaves. It has four sensitivity ranges: 30X, 10X, 3X, 1X, selectable by turning the knob (see below). There is also another knob to vary the sensitivity within each range. When both transmitter and receiver are on, you will be using both knobs to obtain a reading that is approximately midscale on the meter. Remember that you need to multiply the meter reading by the multiplier range to get the proper reading. For example, the meter below is reading $(0.5)(30X) = 15$. Of course, the reading will hold true only if you don't turn the variable sensitivity knob between measurements



3. Both transmitter and receiver can be rotated along their axes of transmission, respectively. This can be done by loosening the knob screw that attaches each unit to its support (below). There is a dial at the support to indicate the angular position; make sure that angles are the same on both on both transmitter and receiver. In the second part of this experiment, we will vary the relative angles to examine polarization.

4. Align the transmitter and receiver so that they directly face each other. Use the goniometer scale, on which the prism mold and rotating table is mounted, to ensure they lie along the same line. Rotate the prism such that the side of the prism facing the transmitter is perpendicular to the beam. This side is the “adjacent” side, if you consider the adjacent, opposite and hypotenuse sides of a right triangle.

5. You can now turn on both transmitter (using the toggle switch) and receiver (using the range selector knob). You will need the provided plastic protractor to help you measure prism angles (if the angles aren't "sharp" enough, you may need to extend lines until they meet and then measure the angles). Use the apparatus to measure, using a value of $n=1.00$ for air:

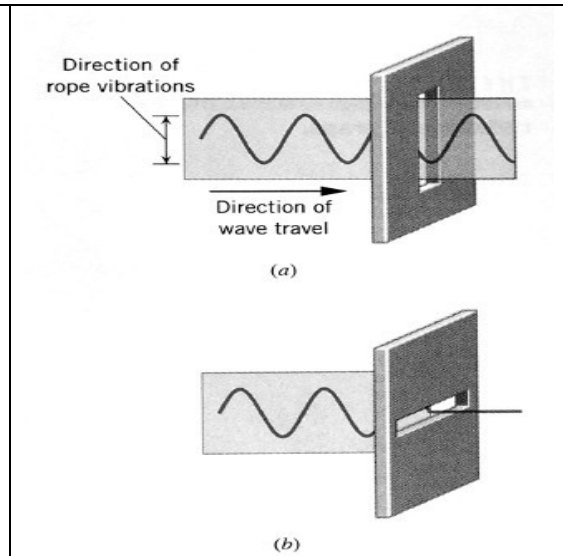
- a. The index of refraction of polystyrene.
- b. The index of refraction of Delrin®.

Note that there are **two** interfaces being studied here - there is the air-prism interface (as beam enters prism) and the prism-air interface (as beam leaves prism). There is **no deflection** at the first interface since the incident angle is zero, and hence the refracted angle is also zero from Snell's Law; however, there is deflection at the second interface, since the incident angle is **not** zero there. *The refracted beam will be present at the angle of highest meter reading; bear in mind that this angle as read off the goniometer is not the angle of refraction - you will have to work out the geometry of the prism to figure that out.*

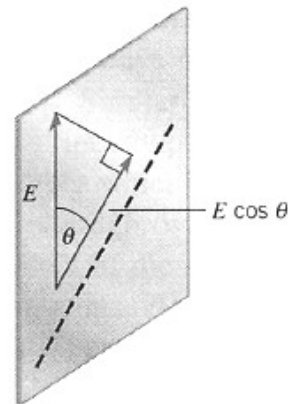
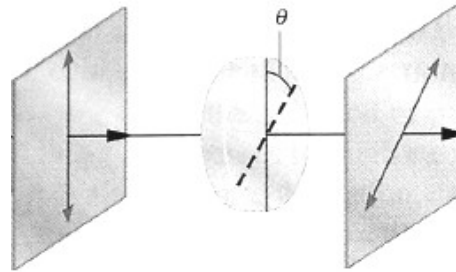
Polarization

Picture yourself holding onto the end of a rope while the other end is tied to a doorknob. There is enough slack on the rope such that it hangs without touching the floor. If you were asked to make a standing wave with this rope, chances are you would wiggle it up and down periodically to produce the familiar sinusoidal shape. However, you could just as easily have wiggled it side-to-side or even diagonally. You could even move it in a circular fashion the way jump ropes are swept around. In any transverse wave, where the direction of oscillation is perpendicular to the direction of propagation, you can have such polarization. Moving your hand up and down results in a **vertically** polarized wave; side-to-side makes a **horizontally** polarized wave. Moving the rope in a circle yields a **circularly** polarized wave.

Note that if you placed a long vertical slit between you and the doorknob, with just enough space in between them to let the rope go up and down, you would have created a **polarizer** that would only allow vertically polarized waves through. If you oriented this same slit horizontally, a vertically polarized wave would have its energy absorbed; there would be no oscillation past the slit. If you now generated a circularly polarized wave with the slit still in the horizontal orientation, only the horizontal component would survive past the poles; the vertical component would be *filtered out*.



Light, like any other electromagnetic waves, consist of electric and magnetic fields with **E** and **B** fields perpendicular to the direction of propagation and to each other. The direction of polarization refers to the plane in which the **E** vector oscillates since most detectors, including the human eye, are more sensitive to **E** than **B**. Typical light waves (from the sun or a light bulb, for instance) are produced by many atoms which act independently of each other and whose phases random with time – hence such light is **unpolarized**. Our microwave transmitter emits a linearly polarized wave along the axis of the diode, which is the shiny metallic rod inside the horn. The receiver also has such a rod, which detects only the component of a microwave polarized along the rod's axis (see diagram on right). This component is $E \cos \theta$. The receiver actually measures *intensity*, which is proportional to the square of the amplitude. The intensity I of the wave coming out of the polarizer is related to its initial intensity I_0 by: $I = I_0 \cos^2 \theta$ Note that a polarizer oriented 0° with respect to the original has its intensity undiminished; a poloraizer that is oriented 90° with respect to the original wave results in an intensity of zero.



PROCEDURE:

Measure intensity as a function of polarizer angle.

1. Remove the prism and the rotating table. Once again face the transmitter directly towards the receiver.
2. Before you put a polarizer between the transmitter and receiver, play around with the apparatus - predict which relative angles will give you the highest and lowest meter readings, thinking about the orientation of the diodes. Then, actually do this to check your predictions.

Reset the axial angle of the receiver such that it is the same as the transmitter's - they should both be **zero**. This way both transmitting and receiving diodes are aligned (both standing up). Fasten a metal polarizer to one of the magnetized supports and insert it where the rotating table used to be. Orient the bars or slits in the polarizer such that they are vertical (see photo below). What angle (relative to transmitter/receiver's zero degrees) do you expect the polarizer to allow the maximum reading? _____
The minimum reading? _____



Note that the polarizer has long bars along which current can travel under the influence of an electric field, if E is along the direction of the bars. If E is in this direction then the polarizer will absorb its energy. Conversely, E is not absorbed when it is perpendicular to the bars. There is no unbroken path for current – current can't "jump" across the slits of the polarizer. This is counterintuitive to the situation where a string wave is wiggled through the slit of a polarizer, unless you bear in mind the underlying physical processes.

Take meter intensity readings as you rotate both receiver and transmitter from 0 to 90 degrees in 10 degree increments. Write data in hand-in sheet.

4. Rotate the receiver to an angle 90° relative to the transmitter. Once again take readings as you rotate the transmitter from 0 to 90 degrees (10 degree increments) **but this time the receiver should be oriented 90 degrees from the transmitter at each increment**. At what polarizer angle (**as measured by the transmitter angle**) do you now expect a maximum? _____ A minimum? _____

5. At what angles do you actually experience a maximum and a minimum? _____

Applications of Refraction/Reflection

The principles of refraction and reflection are involved in the field of fiber optics. When light passes from a medium of large n into one of smaller n , the refracted wave bends away from the normal. If we increase the angle of incidence, so increases the refraction angle. We can increase this up to the **critical angle** – the angle at which the refracted angle is 90 degrees. When the incident angle exceeds this, **total internal reflection** occurs – the light is reflected back into the medium it came from and is essentially trapped until the proper angle or index of refraction is encountered for its release. The applications are myriad – we can now guide light through flexible fibers that "conduct" light via total internal reflection, resulting in innovations in internal medical diagnostic procedures and high-speed data and voice communications.

Applications of Polarization

Polarization is behind the now-ubiquitous LCD technology we see every day. From LCD watches and calculators, to sophisticated active-matrix thin-film transistor computer screens – these all rely on polarization to turn pixels or elements on or off. In an LCD, liquid crystal segments are sandwiched between two transparent electrodes. When a voltage is applied between the electrodes, the crystal is "on" and appears black. When the voltage is removed, it turns "off" and rotates the direction of polarization by 90° . By using additional polarizers, one can either light or darken a segment by turning the voltage on or off. In color LCDs, three LCD segments are grouped together to form a picture element (pixel). Color filters are used on each segment, which can be blended together to form the palette of hues we see on your computer or PDA screen.