REFRACTION OF LIGHT

References:
E. Hecht: *Physics: Calculus* (2nd ed.) Brooks/Cole 2000

1. The refractive index
A critical optical characteristic for any transparent material is the **refractive index (n).** The refractive index is the ratio of the speed of light in a vacuum (c_{vac}) to the speed of light in the transparent material (v_{mat}):

$$n = \frac{c_{vac}}{v_{mat}} \qquad \textbf{(1)}$$

Light always travels more slowly in a material than in a vacuum, so the refractive index is always greater than 1.0.
Although light usually travels in straight lines through optical materials, something different happens at surfaces. Light is bent as it passes through a surface where the refractive index changes, for example as it passes from air into glass. The amount of bending depends on the refractive indexes of the two media and the angle at which the light strikes the surface between them (Figure 1).

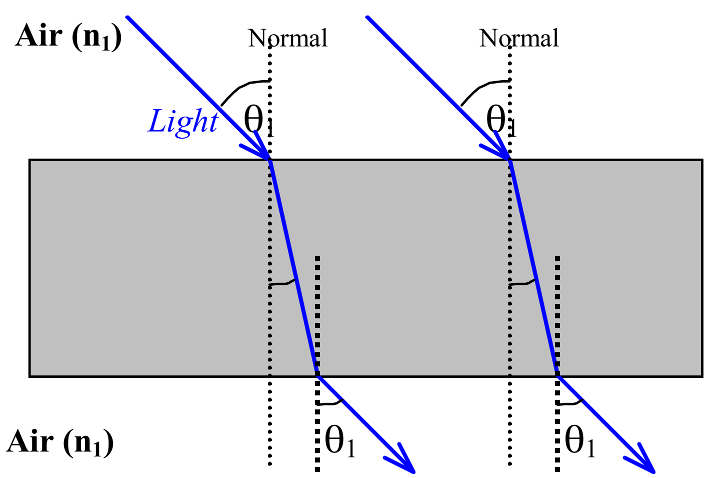


Figure 1 Bending of light as it passes through a rectangular piece of glass

If light passes from a medium with a lower n (n_1) to one with a higher n (n_2) the light is bent toward the normal. If the light passes from n_2 to n_1 it is bent away from the normal. ***Snell's Law*** determines the amount the light is bent, and for the passage from air to glass shown in Figure 1 it is given by:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad (2)$$

At the upper surface, θ_1 is called angle of incidence and θ_2 the angle of refraction.

2. The transparent prism

If you did the Spectra experiment, you may remember that the main component of the spectrometer is a system of three prisms. The passage of light rays through a prism can be traced by using Snell's Law at each of the two prism surfaces (Figure 2):

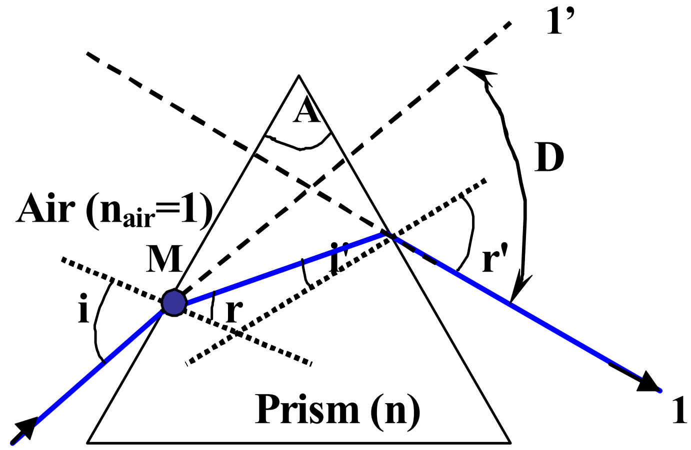


Figure 2 Refraction of light by a prism

From Snell's Law and assuming $\mathbf{n_{air} = 1; n_{prism} = n}$:

$$\sin i = n \sin r \qquad (3)$$
$$\sin r' = n \sin i'$$

From the geometry of the figure: $$i' = A - r \qquad (4)$$

The total deviation D (angle between the direction of the incident ray and that of the emerging ray) is given by:

$$D = i + r' - A \qquad (5)$$

Note: D is centered at point M.

Minimum deviation. When the deviation of the ray is a minimum, the passage through the prism will be symmetrical and:

$$i = r', \quad r = i' \qquad (6)$$

$$A + D_{min} = 2i = 2r' \qquad (7)$$

$$n = \frac{\sin\frac{1}{2}(A + D_{min})}{\sin\frac{1}{2}A} \qquad (8)$$

Equation (8) states that at minimum deviation the refractive index can be calculated from the deviation angle D_{min} and the prism angle A.

EXPERIMENT

Safety warning: Never look directly into the laser diode beam. Even a low power laser can cause permanent damage of your vision, if viewed directly.

Index of refraction of a glass prism

The experimental set-up includes: a light source (laser diode), a transparent prism with 60° angles, a turning table placed on a divided circle and a fixed screen. There are two opposite (by 180°) windows that can be used to read the circle divisions. Readings on the main circle are in degrees (°) and the precision is increased by the use of verniers (readings on the verniers are in minutes of angle ('); 60' = 1°).
Examine the relative rotation of the turning table and divided circle. Observe the two sets of knobs underneath it and find out how they work.

Procedure

a) Position the laser beam to form an angle of about 45° with the screen. Lock the laser screw. Place the prism on the prism table (between the marks) and arrange it with one transparent face perpendicular to the beam (you'll see the light reflected back on the diode head). Read the angle (reading 0).
b) Lock the prism table and rotate the laser diode until you get the refracted ray on the left of the screen (Position 1, Fig. 2). Read the angle (reading 1). Mark the first spot.

reading 1 - reading 0 = i (the incidence angle)

c) Remove the prism; you'll get the direct laser light on the screen (Position 1', Fig.2). Mark the second spot on the screen (use pencil, please!). In order to get the deviation angle, rotate the laser until you bring the spot over the first dot you started with. Read the angle (reading 1').

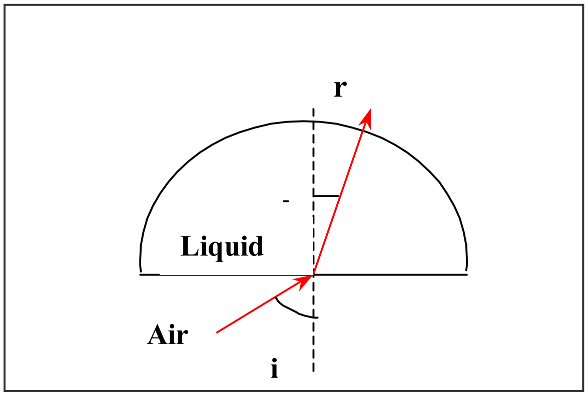
reading 1 - reading 1' = D (the deviation angle)

Equation (8) states that you need to know only *the minimum deviation angle* in order to calculate the refraction index.
In order to find the minimum deviation angle, repeat steps b) and c) by using all the marked dots from the screen; calculate all the 'D' values and find the smallest one (D_{min}).
Use Equation (8) to calculate the index of refraction n.
➔ Is the minimum deviation angle uniquely determined for a given prism?
➔ Comment on different sources of error present in this experiment.
Bonus problem (5 marks to be added to your experiment mark if you solve it): use Equations 3-5 to calculate the refraction index. Compare the n value to what you obtained by using the minimum deviation angle.

Index of refraction of a liquid

To determine the refraction index of a liquid, an optical cell (semicircular Plexiglas box) will be used. The passage of the light rays through the liquid is presented in Figure 3:

Figure 3



If the incident ray (incidence angle **i**) hits the center of the flat side, the refracted ray (refraction angle **r**) will follow the direction of the radius, which is normal to the semicircular surface. Thus, the ray emerging from the cell will not be bent at the passage from liquid to the air.
Note: we consider the thickness of the cell walls negligible, as compared to the cell radius of and we neglect the refraction of light in the Plexiglas material.

The Project
Design an experimental procedure that can be used to measure the index of refraction of a liquid (distilled water, glycerol). You will need 5-6 readings of incidence angles (**i**) and refraction angles (**r**). Evaluate the sources of error of your method.

Note*:* When you replace the liquid, make sure to empty and clean the box.
Note: When you are done, drain the glycerol to the storage bottle and wash carefully the semicircular box with warm water and detergent.

Preparatory Questions

1. Which are the limits of the incidence angle when passing from air (n_{air} = 1.00) to water (n_{water} = 1.33), that determine a light ray to emerge from air into water? Are these limits the same when the light ray passes from water to air?

2. If a clear solid crystal is placed in a clear liquid with the same index of refraction, is the crystal visible? Explain.

3. You see a coin some distance from a river bank in a calm pool. Is the actual location of the coin closer of farther than the image you see?

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