

REFRACTION

Purpose

- a. To study the refraction of light from plane surfaces.
- b. To determine the index of refraction for several substances.

Theory

When a ray of light passes from one medium into another one of different optical density, it undergoes a change of velocity and a consequent change in direction. Figure 1 is an example of refraction. The incident ray makes an angle with the normal to the refracting surface called the *angle of incidence, i*. The refracted ray makes an angle with the normal to the refracting surface called the *angle of refraction, r*.

In Figure 1, if the incident medium is vacuum or free space, the speed of light is c . (The speed of light in air is very nearly equal to that in vacuum.) If the speed of light in the refracting medium v is **less** than the speed of light in the incident medium, the refracted ray bends towards the normal so that **angle r is less than angle i** .

(If the speed of light v in the incident medium is less than that of the speed of light in the refracting medium, the refracted ray would bend away from the normal. This can be seen in Figure 1 if the light path is reversed. The refracted ray now becomes the incident ray, and the incident ray is now the refracted ray, bending away from the normal.)

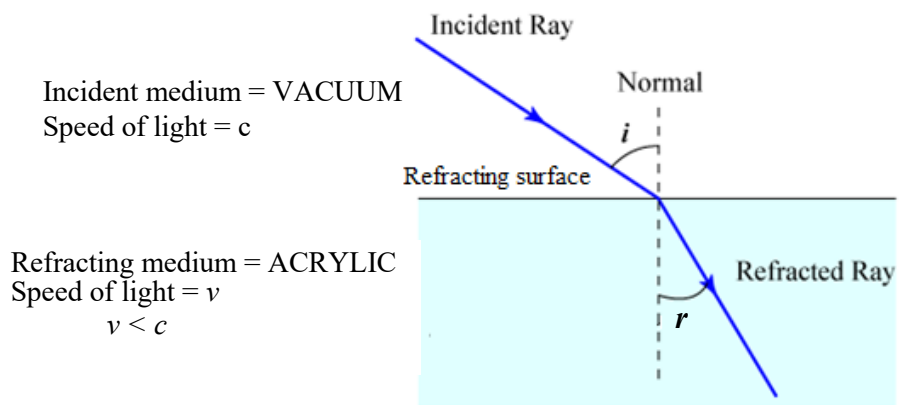


Fig. 1. The refraction of light as it passes from vacuum into Acrylic.

Snell's Law: If the incident medium is a vacuum (or air, approximately), the basic law of refraction is Snell's Law according to which

$$\frac{\sin i}{\sin r} = \frac{c}{v} \tag{1}$$

The ratio c/v is called the *index of refraction, n*, of the refracting medium:

$$n = c/v \tag{2}$$

Thus, Snell's Law may be written as

$$\frac{\sin i}{\sin r} = n \tag{3}$$

It is therefore possible to characterize a medium via its index of refraction by measuring the angles of incidence i and the angle of refraction r .

If the incident medium is *not* vacuum, the law of refraction can be more generally stated as:

$$\frac{\sin i}{\sin r} = \frac{n_r}{n_i} \quad (4)$$

where n_i and n_r are the refractive indices of the media through which the incident beam and refracted beam travel, respectively. [This formula will be useful for Part IV of the procedure.]

Finally, when light passes from one medium to the next, its frequency f does not change. The electrons in the refracting medium absorb energy from the light and undergo a vibrational motion with *the same frequency*. The motion of the electrons then causes reradiation of the energy *with the same frequency*. In any medium $v = \lambda f$. Since the speed of light in the refracting medium v is less than the speed of light c in vacuum, and its frequency f is unchanged, its wavelength λ is correspondingly reduced. Hence, the wavelength λ of light in a material of refractive index n is less than the wavelength λ_0 of the same light in vacuum by a factor of n :

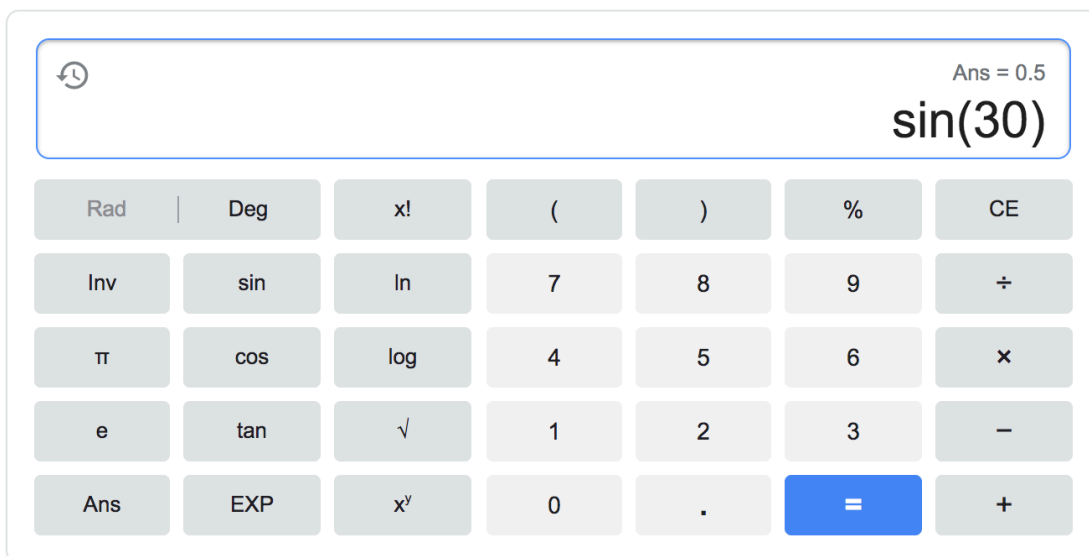
$$\lambda = \frac{\lambda_0}{n} \quad (5)$$

Mathematics Review

This laboratory exercise uses the *sine* function from trigonometry. The sine function inputs an angle as its argument and outputs a number between negative one and one, inclusive. For example, the sine of 30 degrees is one-half, and this is written as

$$\sin(30) = \frac{1}{2}$$

In order to perform the calculations required for this lab, one may use Google calculator (which can be found by googling ‘calculator’), or by any other method that the student prefers. Note that the calculator input must be set to *degrees* (“Deg”) rather than *radians* (“Rad”) in order to obtain the correct results. This can be set by clicking on “Deg” as seen in the upper-left area of the control panel in the below image.



Software

This online lab uses a refraction simulation tool at *the Physics Classroom.com*:

<https://www.physicsclassroom.com/Physics-Interactives/Refraction-and-Lenses/Refraction/Refraction-Interactive>

You will use several different material interfaces to study the refraction of light from surfaces to determine the index of refraction of the materials used by measuring the angles of incidence and refraction. The beam of a virtual laser is used to trace the direction of light.

You will also try to work out the identity of a mystery material from their refraction properties.

Finally, you will examine total internal reflection.

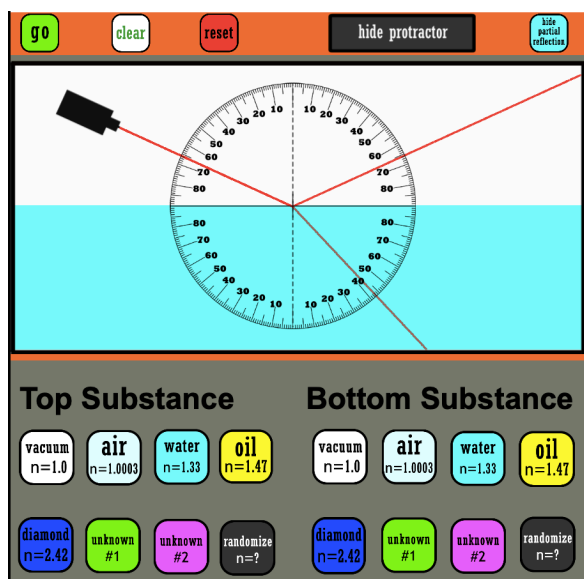


Figure 2: A view of the refraction simulation in action.

Procedure

Part I. Refraction at the vacuum / water interface

1. Open the simulator. The virtual laser emits light from the top, through the top “layer” of a 2-layer system. Light will reflect and/or refract at the interface. You can choose the material for both the top and bottom layer.
2. Choose vacuum for the top layer and water for the bottom layer. Click “Go” at the top left to fire the laser. What do you see?
3. Click on “*Show protractor*” to enable the protractor view, and slide the protractor over so that it is centered on the point where the light hits the interface (Figure 2). Measure the angles i and r .
4. Move the laser (click and drag it) within the upper layer to repeat the experiment for three other incident angles i . Record the data in Table 1.

Part II. Refraction by diamond

1. Now choose vacuum for the top layer and diamond for the bottom layer. Click “Go” at the top left to fire the laser.
2. With the protactor enabled, move the laser (click and drag it) within the upper layer to to carry out a refraction experiment for four incident angles i . Measure the angles i and r .
3. Record the data in Table 2.
4. What difference(s) do you note between the experiments in Parts I and II.

Part III. Refraction by an unknown material

1. Again choose vacuum for the top layer and now choose “unknown #1” OR “unknown #2” for the bottom layer. Click “Go” at the top left to fire the laser.
2. With the protactor enabled, move the laser (click and drag it) within the upper layer to carry out a refraction experiment for four incident angles i . Measure the angles i and r .
3. Record the data in Table 3.

Part IV. Total internal reflection

1. Now choose *oil* for the top layer and now *water* for the bottom layer. Click “Go” at the top left to fire the laser.
2. With the protactor enabled, move the laser (click and drag it) within the upper layer to carry out a refraction experiment for several incident angles i . Measure the angles i , and r each time. Check that Equation (4) is satisfied.
3. Find the angle at which there ceases to be any refracted beam. This is the angle of *total internal reflection*.

A note about the simulator: Sometimes for certain angles of incidence the ray passes right through in a straight line. This is probably an error in the code of the simulator. You can click ‘clear’ slowly a few times and then drag the laser to change the angle of incidence, i a little bit (to avoid this error) and then click ‘Go’ to restart.

Computations

1. Calculate the index of refraction of water from the data in Table 1 for angles of incidence and refraction, and record in Table 1.
2. Calculate the index of refraction of diamond from the data in Table 2 for angles of incidence and refraction, and record in Table 2.
3. Calculate the index of refraction of either Unknown #1 or Unknown #2 from the data in Table 3 for angles of incidence and refraction, and record in the Table 3.
4. Calculate the theoretical angle of total internal reflection for Part IV by using Equation (4). This is the angle of incidence at which $\sin(r) = 1$. Note that the refractive indices of both media are given in the simulation window. Compare the expected (calculated) angle of incidence, i , to your measured finding from the simulator in Part IV.

Question

1. If you desire to shoot a fish whose image can be seen in clear water, should you aim above or below the fish? Explain by the aid of a diagram.

Data Sheet

Date that the online experiment was performed:

Name(s) of the experimenter(s):

Table 1 (Part I) Upper layer: vacuum Lower layer: water

Incident angle, i (degrees)	Refracted angle, r (degrees)	Experimental refractive index (calculated from Eq. 3)

Average experimental refractive index:

Table 2 (Part II) Upper layer: vacuum Lower layer: diamond

Incident angle, i (degrees)	Refracted angle, r (degrees)	Experimental refractive index (calculated from Eq. 3)

Average experimental refractive index:

Table 3 (Part III) Upper layer: vacuum Lower layer: Unknown #1 or Unknown #2 (select)

Incident angle, i (degrees)	Refracted angle, r (degrees)	Experimental refractive index (calculated from Eq. 3)

Average experimental refractive index:

Table 4 (Part IV) Upper layer: oil Lower layer: water

Incident angle, i (degrees)	Refracted angle, r (degrees)	$\frac{\sin i}{\sin r}$	$\frac{n_r}{n_i}$	Total internal reflection? (yes/no)

Critical angle at which there is no longer any refraction: