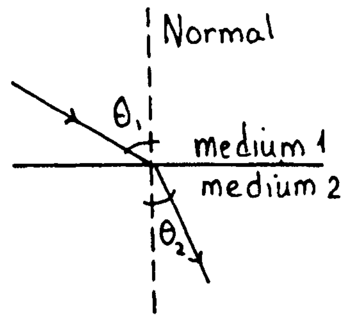
13-3 Refraction

Vocabulary **Refraction:** The change in direction of light due to a change in speed as it passes from one medium to another.



The path of light is described with respect to the normal. If light is slowed down as it enters a new medium, it bends toward the normal. If it speeds up, it bends away from the normal.

The amount of bending is represented with the letter n, which stands for the **index of refraction**. The index of refraction for a particular medium is a ratio of the speed of light in a vacuum to the speed of light in the medium.

$$\textbf{index of refraction} = \frac{\textbf{speed of light in a vacuum}}{\textbf{speed of light in another medium}} \quad \text{or} \quad n = \frac{c}{v}$$

Because light travels fastest in a vacuum, the index of refraction for any other medium is always greater than 1. Although the index of refraction for air is 1.0003, in this chapter the value will be written simply as 1.00.

The angle to which light will bend upon passing from one medium to another depends upon the index of refraction of each of the two media, n_1 and n_2, and the light's angle of incidence.

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

The symbols θ_1 and θ_2 stand for the angle of incidence and the angle of refraction, respectively.

A special case of this equation is used when light travels from a more-dense medium to a less-dense medium and the refracted ray makes an angle of 90.0° with the normal as it skims along the boundary of the two media. When this happens, the incident angle θ_1 is called the **critical angle**, θ_c.

$$n_1 \sin \theta_c = n_2 \sin 90.0°$$

If the incident angle is any bigger than the critical angle, there is no refraction. Instead, all the light is reflected back inside the object. This is called **total internal reflection**.

Solved Examples

Example 6: Hickory, a watchmaker, is interested in an old timepiece that's been brought in for a cleaning. If light travels at 1.90×10^8 m/s in the crystal, what is the crystal's index of refraction?

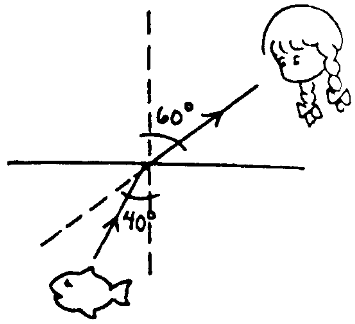
Given: $c = 3.00 \times 10^8 \text{ m/s}$
$v = 1.90 \times 10^8 \text{ m}$

Unknown: $n = ?$
Original equation: $n = \frac{c}{v}$

Solve: $n = \frac{c}{v} = \frac{3.00 \times 10^8 \text{ m/s}}{1.90 \times 10^8 \text{ m/s}} = \mathbf{1.58}$

Remember, the index of refraction has no units. It is just a ratio of the speed of light in two different media.

Example 7: While fishing out on the lake one summer afternoon, Amy spots a large trout just below the surface of the water at an angle of 60.0° to the vertical, and she tries to scoop it out of the water with her net. a) Draw the fish where Amy sees it. b) At what angle should Amy aim for the fish? ($n_{\text{water}} = 1.33$).



Solution: a. The fish will appear to be straight ahead according to Amy. However, because light travels slower in water than in air, the fish is closer to Amy than she thinks.

b. *Given:* $n_1 = 1.33$ (water)
$n_2 = 1.00$ (air)
$\theta_2 = 60.0°$

Unknown: $\theta_2 = ?$
Original equation: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Solve: $\sin\theta_1 = \frac{n_2 \sin\theta_2}{n_1} = \frac{(1.00)\sin 60.0°}{1.33} = 0.651 \qquad \theta_1 = \sin^{-1} 0.651 = \mathbf{40.6°}$

Example 8: Binoculars contain prisms inside that reflect light entering at an angle larger than the critical angle. If the index of refraction of a glass prism is 1.58, what is the critical angle for light entering the prism?

Given: $n_1 = 1.58$ (glass)
$n_2 = 1.00$ (air)

Unknown: $\theta_c = ?$
Original equation: $n_1 \sin\theta_c = n_2 \sin 90.0°$

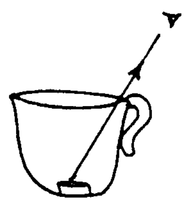
Solve: $\sin\theta_c = \frac{n_2 \sin\theta_2}{n_1} = \frac{(1.00)\sin 90.0°}{1.58} = 0.633 \qquad \theta_c = \sin^{-1} 0.633 = \mathbf{39.3°}$

Practice Exercises

Exercise 9: Alison sees a coin at the bottom of her swimming pool at an angle of 40.0° to the normal and she dives in to retrieve it. However, Alison doesn't like to open her eyes in the water so she must rely on her initial observation of the coin made in the air. At what angle does the light from the coin travel as it moves toward the surface? (n_{water} = 1.33)

Answer: ______________________

Exercise 10: Here's an interesting trick to try. Place a penny in the bottom of a cup and stand so that the penny is just out of sight, as shown. Then pour water into the cup. Without moving, you will suddenly see the penny magically appear. If you look into the cup at an angle of 70.0° to the normal, at what angle to the normal must the penny be located in order for it to just appear in the bottom of the cup when the cup is filled with water? (n_{water} = 1.33)



Answer: ______________________

Exercise 11: Rohit makes his girlfriend a romantic candlelight dinner and tops it off with a dessert of gelatin filled with blueberries. If a blueberry that appears at an angle of 44.0° to the normal in air is really located at 30.0° to the normal in the gelatin, what is the index of refraction of the gelatin?

Answer: ______________________

Exercise 12: A jeweler must decide whether the stone in Mrs. Smigelski's ring is a real diamond or a less-precious zircon. He measures the critical angle of the gem and finds that it is 31.3°. Is the stone really a diamond or just a good imitation? ($n_{\text{diamond}} = 2.41$, $n_{\text{zircon}} = 1.92$)

Answer: ____________________

9. $28.9°$
11. 1.39