Chapter 17: Reflection and Refraction

Practice Problems

1. Light in air is incident upon a piece of crown glass at an angle of 45.0° What is the angle of refraction?

   Assume the light is incident from air.
   From $n_i \sin \theta_i = n_r \sin \theta_r$,

   $$\sin \theta_r = \frac{n_i \sin \theta_i}{n_r} = \frac{(1.00) \sin 45.0°}{1.52}$$

   $$= 0.465, \text{ or } \theta_r = 27.7°$$

2. A ray of light passes from air into water at an angle of 30.0°. Find the angle of refraction.

   $n_i \sin \theta_i = n_r \sin \theta_r$ so

   $$\sin \theta_r = \frac{n_i \sin \theta_i}{n_r} = \frac{(1.00) \sin 30.0°}{1.33} = 0.376,$$

   or $\theta_r = 22.1°$

3. A ray of light is incident upon a diamond at 45.0°.

   a. What is the angle of refraction?

      Assume the light is incident from air.
      $n_i \sin \theta_i = n_r \sin \theta_r$ gives

      $$\sin \theta_r = \frac{n_i \sin \theta_i}{n_r} = \frac{(1.00) \sin 45.0°}{2.42} = 0.292,$$

      or $\theta_r = 17.0°$

   b. Compare your answer for part (a) to your answer for Practice Problem 1. Does glass or diamond bend light more?

      Diamond bends the light more.

4. A block of unknown material is submerged in water. Light in the water in incident on the block at an angle of 31°. The angle of refraction in the block is 27°. What is the index of refraction of the unknown material?

   $n_1 \sin \theta_1 = n_2 \sin \theta_2$, so
   $n_2 = n_1 \sin \theta_1/\sin \theta_2 = (1.33)(0.515)/(0.454)$
   $= 1.5$

Practice Problems

5. Use Table 17–1 to find the speed of light in

   a. ethanol.

      $$v_{ethanol} = \frac{c}{n_{ethanol}} = \frac{3.00 \times 10^8 \text{ m/s}}{1.36}$$

      $$= 2.21 \times 10^8 \text{ m/s}$$

   b. quartz.

      $$v_{quartz} = \frac{c}{n_{quartz}} = \frac{3.00 \times 10^8 \text{ m/s}}{1.54}$$

      $$= 1.95 \times 10^8 \text{ m/s}$$

   c. flint glass.

      $$v_{flint glass} = \frac{c}{n_{flint glass}} = \frac{3.00 \times 10^8 \text{ m/s}}{1.61}$$

      $$= 1.86 \times 10^8 \text{ m/s}$$

6. The speed of light in plastic is 2.00×10^8 m/s. What is the index of refraction of the plastic?

   $$n = \frac{c}{v} = \frac{3.00 \times 10^8 \text{ m/s}}{2.00 \times 10^8 \text{ m/s}} = 1.50$$

7. What is the speed of light for the substance of Practice Problem 4?

   $$n = 1.5 \text{ so } v = \frac{c}{n} = \frac{3.00 \times 10^8 \text{ m/s}}{1.5}$$

   $$= 2.0 \times 10^8 \text{ m/s}$$

8. Suppose you had two pulses of light "racing" each other, one in air, the other in a vacuum. You could tell the winner if the time difference is 10 ns (10×10^{-9} s). How long would the race have to be to determine the winner?

   $t = d/v = dn/c$.
   $\Delta t = d(n_{air} - n_{vacuum})/c$
   $= d(1.0003 - 1.0000)/3.00 \times 10^8$ m/s.
   $= d(1 \times 10^{-12} \text{ s/m})$.
   Thus, $d = \Delta t/(1 \times 10^{-12} \text{ s/m})$
   $= 1 \times 10^{-8} \text{ s/1} \times 10^{-12} \text{ s/m}$
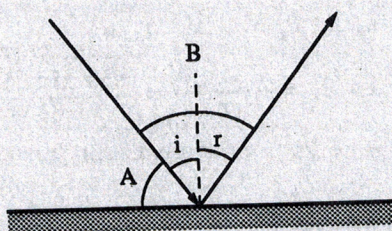 $= 10^4 \text{ m} = 10 \text{ km}.$

pages 364–365

1. A ray of light strikes a mirror at an angle of $53°$ to the normal.

   a. What is the angle of the reflection?

   The angle of reflection is $53°$.

   b. What is the angle between the incident ray and the reflected ray?

   The angle between the incident ray and the reflected ray, and B in the diagram is $53° + 53° = 106°$.

2. A ray of light incident upon a mirror makes an angle of $36.0°$ with the mirror. What is the angle between the incident ray and the reflected ray?

   Angle A in the diagram is $36.0°$ so the angle of incident is $90 - 36.0 = 54.0°$ and angle B is $54.0° + 54.0° = 108.0°$

3. A ray of light has an angle of incidence of $30.0°$ on a block of quartz and an angle of refraction of $20.0°$. What is the index of refraction for this block of quartz?

   $$n = \frac{\sin \theta_i}{\sin \theta_r} = \frac{\sin 30.0°}{\sin 20.0°} = 1.46$$

4. A ray of light travels from air into a liquid. The ray is incident upon the liquid at an angle of $30.0°$. The angle of refraction is $22.0°$.

   a. What is the index of refraction of the liquid?

   $$n = \frac{\sin \theta_i}{\sin \theta_r} = \frac{\sin 30.0°}{\sin 22.0°} = 1.34$$

   b. Refer to Table 17–1. What might the liquid be?

   water

Indices of Refraction	
Medium	**n**
vacuum	1.00
air	1.00*
water	1.33
ethanol	1.36
crown glass	1.52
quartz	1.54
flint glass	1.61
diamond	2.42

   *Index of refraction of air is 1.0003 which is higher than that of vacuum, 1.0000. However, for practical purposes, they are the same.

5. A ray of light is incident at an angle of $60.0°$ upon the surface of a piece of crown glass. What is the angle of refraction?

   $$n = \frac{\sin \theta_i}{\sin \theta_r}, \text{ so}$$

   $$\sin \theta_r = \frac{\sin \theta_i}{n} = \frac{\sin 60.0°}{1.52} = 0.570$$

   $$\theta_r = 34.7°$$

6. A light ray strikes the surface of a pond at an angle of incidence of $36.0°$. At what angle is the ray refracted?

   $$n = \frac{\sin \theta_i}{\sin \theta_r}, \text{ so}$$

   $$\sin \theta_r = \frac{\sin \theta_i}{n}$$

   $$= \frac{\sin 36.0°}{1.33} = 0.442$$

   $$\theta_r = 26.2°$$

7. Light is incident at an angle of $60.0°$ on the surface of a diamond. Find the angle of refraction.

$$n = \frac{\sin \theta_i}{\sin \theta_r}, \text{ so}$$

$$\sin \theta_r = \frac{\sin \theta_i}{n}$$

$$= \frac{\sin 60.0°}{2.42} = 0.358$$

$$\theta_r = 21.0°$$

8. A ray of light has an angle of incidence of $33.0°$ in crown glass. What is the angle of refraction.

$$n_A \sin \theta_A = n_g \sin \theta_g, \text{ so}$$

$$\sin \theta_A = \frac{n_g}{n_A} \sin \theta_g = \frac{1.52}{1.00} \sin 33.0° = 0.828$$

$$\theta_A = 55.9°$$

9. A ray of light passes from water into crown glass at an angle of $23.2°$. Find the angle of refraction.

$$n_w \sin \theta_w = n_g \sin \theta_g, \text{ so}$$

$$\sin \theta_g = \frac{n_w \sin \theta_w}{n_g}$$

$$= \frac{(1.33)(\sin 23.2°)}{1.52} = 0.345$$

$$\theta_r = 20.2°$$

10. Light goes from flint glass into ethanol. The angle of refraction in the ethanol is $25.0°$. What is the angle of incidence in the glass?

$$n_g \sin \theta_g = n_e \sin \theta_e, \text{ so}$$

$$\sin \theta_g = \frac{n_e \sin \theta_e}{n_g}$$

$$= \frac{(1.36)(\sin 25.0°)}{1.61} = 0.357$$

$$\theta_r = 20.9°$$

11. A beam of light strikes the flat, glass side of a water–filled aquarium at an angle of $40°$ to the normal. The index of refraction for glass and water are 1.50 and 1.33, respectively.

a. At what angle does the beam enter the glass?

$$n_A \sin \theta_A = n_g \sin \theta_g, \text{ so}$$

$$\sin \theta_g = \frac{n_A \sin \theta_A}{n_g} = \frac{1.00 \sin 40°}{1.50} = 0.43$$

$$\theta_g = 25°$$

b. At what angle does the beam enter the water?

$$n_g \sin \theta_g = n_w \sin \theta_w, \text{ so}$$

$$\sin \theta_w = \frac{n_g \sin \theta_g}{n_w} = \frac{1.50 \sin 25°}{1.33} = 0.48$$

$$\theta_w = 29°$$

c. What would be the entry angle in water if the beam struck the water directly?

$$n_A \sin \theta_A = n_w \sin \theta_w, \text{ so}$$

$$\sin \theta_w = \frac{n_A \sin \theta_A}{n_w} = \frac{1.00 \sin 40°}{1.33} = 0.48$$

$$\theta_w = 29°$$

12. A thick sheet of plastic ($n = 1.500$) is used as the side of an aquarium tank. Light reflected from a fish in the water has an angle of incidence of $35.0°$. At what angle does the light enter the air?

$$n_w \sin \theta_w = n_p \sin \theta_p, \text{ so}$$

$$\sin \theta_p = \frac{n_w \sin \theta_w}{n_p} = \frac{(1.33)(\sin 35.0°)}{(1.500)}$$
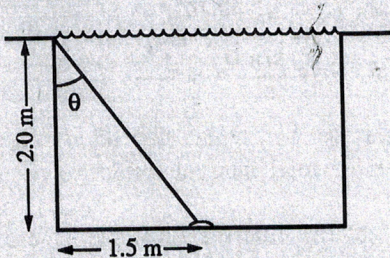
$$= 0.509$$

The angle of refraction from the water into the plastic is equal to the angle of incidence from the plastic in the air.

$$n_A \sin \theta_A = n_p \sin \theta_p, \text{ so}$$

$$\sin \theta_A = \frac{n_p \sin \theta_p}{n_A} = \frac{(1.500)(0.509)}{(1.00)} = 0.764$$

$$\theta_r = 49.8°$$

13. A light source, S, is located 2.0 m below the surface of a swimming pool and 1.5 m from one edge of the pool. The pool is filled to the top with water.

a. At what angle does the light reaching the edge of the pool leave the water?
Find the angle θ as shown in the figure.

$$\tan \theta_i = \frac{1.5 \text{ m}}{2.0 \text{ m}} = 0.75$$

$$\theta_i = 37°$$

Then find the angle in air

$n_A \sin \theta_A = n_w \sin \theta_w$, so

$$\sin \theta_A = \frac{n_w \sin \theta_w}{n_A} = \frac{(1.33)(\sin 37°)}{1.00}$$

$$= 0.80$$

$$\theta_r = 53°$$

b. Does this cause the light viewed from this angle to appear deeper or shallower than it actually is?

$$\tan 53° = \frac{\text{side opposite}}{\text{side adjacent}}$$

$$\text{side adjacent} = \frac{\text{side opposite}}{\tan 53°} = \frac{1.5 \text{ m}}{\tan 53°}$$

$$= 1.1 \text{ m, shallower}$$

14. A ray of light is incident upon a 60–60–60 degree glass prism ($n = 1.5$) as shown in Figure 17–19.

a. Using Snell's law, determine the angle θ_r to the nearest degree.

$n_A \sin \theta_A = n_g \sin \theta_r$, so

$$\sin \theta_r = \frac{n_A \sin \theta_A}{n_g} = \frac{(1.00) \sin 45°}{1.5} = 0.47$$

$$\theta_r = 28°$$

b. Using elementary geometry, determine the values of angles A, B, and C.

$$\theta_A = 90° - 28° = 62°$$
$$\theta_B = 180° - (62° + 60°) = 58°$$
$$\theta_C = 90° - 58° = 32°$$

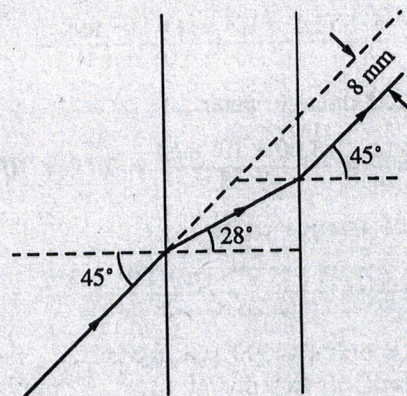c. Determine angle D.

$n_A \sin \theta_D = n_g \sin \theta_C$, so

$$\sin \theta_D = \frac{n_g \sin \theta_C}{n_A} = \frac{1.5 \sin 32°}{1.0}$$

$$= 0.795$$

$$\theta_D = 53°$$

15. A sheet of plastic, $n = 1.500$, 25 mm thick is used in a bank teller's window. A ray of light strikes the sheet at an angle of 45°. The ray leaves the sheet at 45° but at a different location. Use a ray diagram to find the distance between the ray that leaves and the one that would have left if the plastic were not there.

8 mm

16. What is the speed of light in diamond?

$$n_d = \frac{c}{v_d}, \text{ so}$$

$$v_d = \frac{c}{n_d} = \frac{3.00 \times 10^8}{2.42}$$

$$= 1.24 \times 10^8 \text{ m/s}$$

17. The speed of light in chloroform is 1.99×10^8 m/s. What is its index of refraction?

$$n_c = \frac{c}{v_c} = \frac{3.00 \times 10^8 \text{ m/s}}{1.99 \times 10^8 \text{ m/s}} = 1.51$$

18. The speed of light in a clear plastic is 1.90×10^8 m/s. A ray of light enters the plastic at an angle of $22°$. At what angle is the ray refracted?

$n_A \sin \theta_A = n_p \sin \theta_p'$ and $n_p = \dfrac{c}{v_p}$, so

$n_A \sin \theta_A = \dfrac{c}{v} \sin \theta_p$, so

$\sin \theta_p = \dfrac{v_p\, n_A \sin \theta_A}{c}$

$= \dfrac{(1.90 \times 10^8 \text{ m/s})(1.00) \sin 22°}{3.00 \times 10^8 \text{ m/s}}$

$= 0.237$

$\theta_r = 14°$

19. How many more minutes would it take light from the sun to reach Earth if the space between them were filled with water rather than a vacuum? The sun is 1.5×10^8 km from Earth.

Time through vacuum

$t = \dfrac{d}{v} = \dfrac{(1.5 \times 10^8 \text{ km})(10^3 \text{ m/km})}{(3.00 \times 10^8 \text{ m/s})} = 500 \text{ s}$

Speed through water

$v = \dfrac{c}{n} = \dfrac{(3.00 \times 10^8 \text{ m/s})}{1.33} = 2.26 \times 10^8 \text{ m/s}$

Time through water

$t = \dfrac{d}{v} = \dfrac{(1.5 \times 10^8 \text{ km})(10^3 \text{ m/km})}{(2.26 \times 10^8 \text{ m/s})} = 660 \text{ s}$

$\Delta t = 660 \text{ s} - 500 \text{ s} = 160 \text{ s}$
$= (160 \text{ s})(1 \text{ min/60 s}) = 2.7 \text{ min}$

20. Find the critical angle for diamond.

$\sin \theta_c = \dfrac{1}{n} = \dfrac{1}{2.42} = 0.413$

$\theta_c = 24.4°$

21. A block of glass has a critical angle of $45.0°$. What is its index of refraction?

$\sin \theta_c = \dfrac{1}{n}$, so

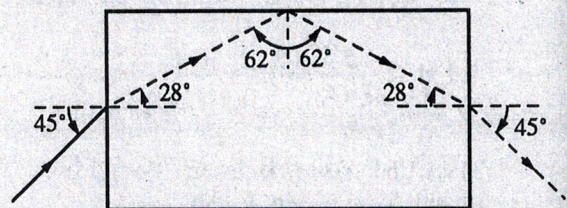$n = \dfrac{1}{\sin \theta_c} = \dfrac{1}{\sin 45.0} = 1.41$

22. A ray of light in a tank of water has an angle of incidence of $55°$. What is the angle of refraction in air?

$n_w \sin \theta_w = n_A \sin \theta_A$, so

$\sin \theta_A = \dfrac{n_w \sin \theta_w}{n_A} = \dfrac{1.33 \sin 55°}{1.00} = 1.1$

There is no angle for which $\sin \theta_r = 1.1$, therefore total internal reflection occurs.

23. A light ray enters a rectangle of crown glass as shown in Figure 17–20. Use a ray diagram to trace the path of the ray until it leaves the glass.

$n_A \sin \theta_A = n_g \sin \theta_g$, so

$\sin \theta_g = \dfrac{n_A \sin \theta_A}{n_g} = \dfrac{(1.00) \sin 45°}{1.52} = 0.465$

$\theta_g = 28°$

24. The critical angle for special glass in air is $41°$. What is the critical angle if the glass is immersed in water?

$n_g \sin \theta_g = n_w \sin \theta_w = n_w \sin 90° = n_w(1.00)$

and $\sin \theta_c = \dfrac{1}{n_g}$, so $n_g = \dfrac{1}{\sin \theta_c}$

therefore $\left[\dfrac{1}{\sin \theta_c}\right] \sin \theta_g = n_w$, so

$\sin \theta_g = n_w \sin \theta_c = 1.33 \sin 41° = 0.873$
$\theta = 61°$

25. The index of refraction for a diamond for red light, 656 nm, is 2.410, while that for blue light, 434 nm, is 2.450. Suppose white light is incident on the diamond at 30.0°. Find the angles of refraction for these two colors.

$$n_A \sin \theta_A = n_d \sin \theta_d, \text{ so } \sin \theta_d = \frac{(1.00) \sin \theta_A}{n_d}$$

For red light

$$\sin \theta_r = \frac{(\sin 30.0°)}{2.410} = 0.207$$

$$\theta_r = 12.0°$$

For blue light

$$\sin \theta_r = \frac{(\sin 30.0°)}{2.450} = 0.204$$

$$\theta_r = 11.8°$$

26. The index of refraction for crown glass for red light is 1.514, while that for blue light is 1.528. White light is incident on the glass at 30.0°.

a. Find the angles of refraction for these two colors.

$$n_A \sin \theta_A = n_g \sin \theta_g, \text{ so } \sin \theta_g = \frac{n_A \sin \theta_A}{n_g} = \frac{1.00 \sin \theta_A}{n_g}$$

For red light

$$\sin \theta = \frac{\sin 30.0°}{1.514} = 0.330$$

$$\theta = 19.3°$$

For blue light

$$\sin \theta = \frac{\sin 30.0°}{1.528} = 0.327$$

$$\theta = 19.1°$$

b. Compare the difference in angles to that for diamond found in Problem 25.

	Diamond		Crown Glass	
	Red	Blue	Red	Blue
Angle of incidence	30.0°	30.0°	30.0°	30.0°
Angle of refraction	12.0°	11.8°	19.3°	19.1°
Difference	18.0°	18.2°	10.7°	10.9°

c. Use the results to explain why diamonds are said to have "fire."

There is a much larger difference between the angles of incidence and refraction for diamond than for crown glass. This means that diamond has a much smaller critical angle. As a result, less light incident upon a diamond will pass completely through. Instead, more light will be reflected internally until it comes back out of the top of the diamond. Blue light has a smaller critical angle than red light. This means that more red light will emerge from a diamond than blue light. Hence, a diamond appears to have "fire."

27. The index of refraction of crown glass for violet light is 1.53, while for red light it is 1.51.

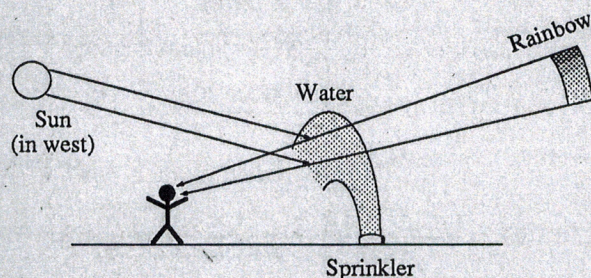$$n = \frac{c}{v}, \text{ so } v = \frac{c}{n}$$

a. What is the speed of violet light in crown glass?

$$v = \frac{c}{n} = \frac{3.00 \times 10^8 \text{ m/s}}{1.53} = 1.96 \times 10^8 \text{ m/s}$$

b. What is the speed of red light in crown glass.

$$v = \frac{c}{n} = \frac{3.00 \times 10^8 \text{ m/s}}{1.51} = 1.99 \times 10^8 \text{ m/s}$$

28. Just before sunset you see a rainbow in the water from a lawn sprinkler. Carefully draw your location and the locations of the sun and the water from the sprinkler that shows the rainbow.

Supplemental Problems (Appendix B)

1. A ray of light strikes a mirror at an angle of incidence of 28°. What is the angle of the reflection?

   The angle of reflection is equal to the angle of incidence, or 28°.

2. A ray of light passes from an unknown substance into air. If the angle of the unknown substance is 35.0° and the angle in air is 52.0°, what is the index of refraction of the unknown substance?

$$n_i \sin \theta_i = n_r \sin \theta_r,$$
$$n_i = n_r \sin \theta_r / \sin \theta_i$$
$$= (1.00)(\sin 52.0°)/(\sin 35.0°) = 1.37$$

3. A ray of light has an angle of incidence of 25.0° upon the surface of a piece of quartz. What is the angle of refraction?

$$n_i \sin \theta_i = n_r \sin \theta_r,$$
$$\sin \theta_r = n_i \sin \theta_i / n_r = (1.00)(\sin 25.0)/(1.54)$$
$$= 0.274$$
$$\theta_r = 15.9°$$

4. A beam of light passes from water into polyethylene, index of refraction = 1.50. If the angle in water is 57.5°, what is the angle in polyethylene?

$$n_i \sin \theta_i = n_r \sin \theta_r,$$
$$\sin \theta_r = n_i \sin \theta_i / n_r = (1.33)(\sin 57.5°)/(1.50)$$
$$= 0.748$$
$$\theta_r = 48.4°$$

5. Dave makes some hydrogen sulfide, index of refraction = 1.000 644. If Karen measures an angle of 85.000 000° in the hydrogen sulfide, what angle will Karen measure in air if the index of refraction of air is 1.000 292 6?

$$n_i \sin \theta_i = n_r \sin \theta_r,$$
$$\sin \theta_r = n_i \sin \theta_i / n_r$$

$$= \frac{(1.000\ 644)(\sin 85.000\ 000°)}{(1.000\ 292\ 6)}$$

$$= 0.996\ 544\ 7$$
$$\theta_r = 85.\ 235\ 60°$$

6. Sue submerged some ice in water and shined a laser beam through the water and into the ice. Sue found the angle in ice was larger than the angle in water. Which material has a larger index of refraction?

$$n_i \sin \theta_i = n_r \sin \theta_r,$$
$$n_i / n_r = \sin \theta_r / \sin \theta_i$$
$$\theta_r > \theta_i, \text{ so } n_i/n_r = \sin \theta_r/\sin \theta_i > 1, \text{ or } n_i > n_r$$
and water (the incident material) has the larger index of refraction.

7. A ray of light enters a triangular crown glass prism perpendicular to one face and it emerges from an adjacent side. If the two adjacent sides meet at a 30.0° angle, what is the angle the light ray has in the air when it comes out?
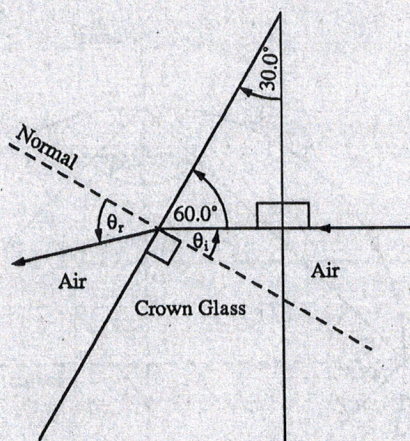

$\theta_i = 180.0° - 60.0° - 90.0° = 30.0°$
$n_i \sin \theta_i = n_r \sin \theta_r,$
$\sin \theta_r = n_i \sin \theta_i/n_r = (1.52)(\sin 30.0°)/(1.00)$
$\qquad = 0.760$
$\theta_r = 49.5°$

8. Make a drawing, to scale, of the side of an aquarium in which the water is 12.0 cm deep. From a single point on the bottom, draw two lines upward, one vertical and the other 5.0° from the vertical. Let these two lines represent two light rays that start from the same point on the bottom of the tank. Compute the directions the refracted rays will travel above the surface of the water. Draw in these rays and continue them backward into the tank until they intersect. At what depth does the bottom of the tank appear to be if you look into the water? Divide the apparent depth into the true depth and compare it to the index of refraction.
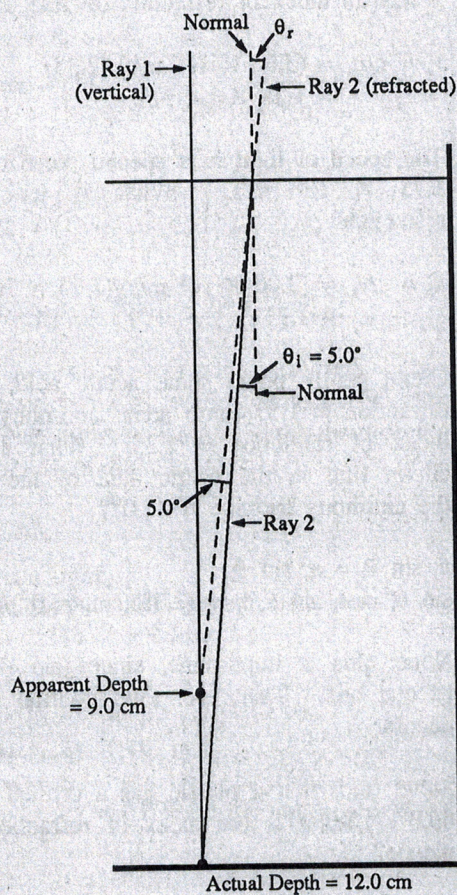
For ray 1, $\theta_r = \theta_i = 0°$.
For ray 2, $n_i \sin \theta_i = n_r \sin \theta_r,$
$\sin \theta_r = n_i \sin \theta_i/n_r = (1.33)(\sin 5.0°)/(1.00)$
$\qquad = 0.116, \ \theta_r = 6.7°$
The refracted rays appear to intersect 9.0 cm below the surface; this is the apparent depth.
(apparent depth)/(true depth)
$= (9.0 \text{ cm})/(12.0 \text{ cm}) = 0.75$
Also, $(n_{air})/(n_{water}) = (1.00)/(1.33) = 0.75.$
Therefore,
(apparent depth)/(true depth) $= (n_{air})/(n_{water})$

9. Find the speed of light in water.

$v_s = c/n_s = (3.00 \times 10^8 \text{ m/s})/(1.33)$
$= 2.26 \times 10^8 \text{ m/s}$

10. Find the speed of light in antimony trioxide, if it has an index of refraction of 2.35.

$v_s = c/n_s = (3.00 \times 10^8 \text{ m/s})/(2.35)$
$= 1.28 \times 10^8 \text{ m/s}$

11. The speed of light in a special piece of glass is 1.75×10^8 m/s. What is its index of refraction?

$n_s = c/v_s = (3.00 \times 10^8 \text{ m/s})/(1.75 \times 10^8 \text{ m/s})$
$= 1.71$

12. Glenn gently pours some acetic acid, index of refraction = 1.37, onto some antimony trioxide, index of refraction = 2.35. What angle will Glenn find in the acetic acid of the angle in the antimony trioxide is $42.0°$?

$n_i \sin \theta_i = n_r \sin \theta_r,$
$\sin \theta_r = n_i \sin \theta_i/n_r = (2.35)(\sin 42.0°)/(1.37)$
$= 11.5$
None; this is impossible, since ($\sin \theta_r$) cannot exceed one. Therefore, total internal reflection occurs.

13. Steve finds that a plastic has a critical angle of $40.0°$. What is the index of refraction of the plastic?

$\sin \theta_c = 1/n_i,$
$n_i = 1/\sin \theta_c = 1/(\sin 40.0°) = 1.56$

14. Kathy decides to find the critical angle of arsenic trioxide, index of refraction = 2.01, which is very toxic. What angle did Kathy find?

$\sin \theta_c = 1/ni = 1/2.01 = 0.498, \theta_c = 29.8°$

15. A light source is in a cylindrical container of carbon dichloride, index of refraction = 1.500. The light source sends a ray of light parallel to the bottom of the container at a $45.0°$ angle from the radius, to the circumference as shown. What will the path of the light ray be?
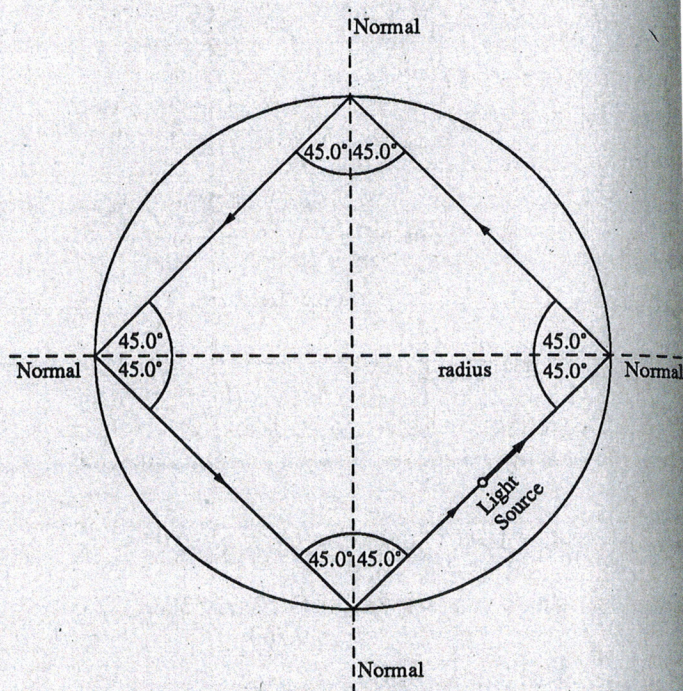

The ray from the light source is incident on the circumference at an angle of $45.0°$
$n_i \sin \theta_i = n_r \sin \theta_r,$
$\sin \theta_r = n_i \sin \theta_i/n_r = (1.500)(\sin 45.0°)/(1.00)$
$= 1.06$
This is impossible, since ($\sin \theta_r$) cannot exceed one. Therefore, total internal reflection occurs and the path of the light ray is a diamond, as shown.

16. With a square block of glass, index of refraction = 1.50, it is impossible, when looking into one side, to see out of an adjacent side of the square block of glass. It appears to be a mirror. Use your knowledge of geometry and critical angles to show that this is true.
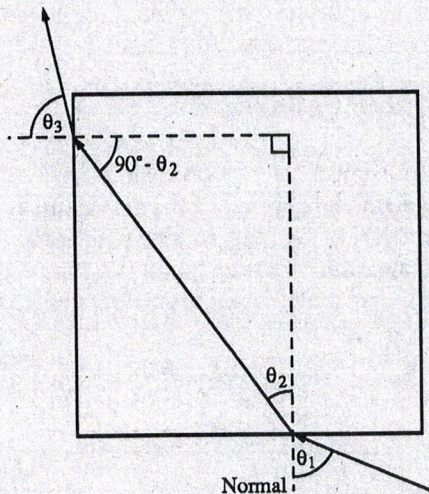
Say the light ray enters the glass at an angle θ_1, and is refracted to an angle θ_2.

$n_{air} \sin \theta_1 = n_{glass} \sin \theta_2$,

$\sin \theta_2 = (n_{air} \sin \theta_1)/(n_{glass}) = (1.0 \sin \theta_1)/(1.5)$

For the light ray to leave an adjacent side, $(90° - \theta_2)$ must be less than the critical angle. The critical angle is found from

$\sin \theta_c = \dfrac{1}{n_{glass}} = \dfrac{1}{1.5} = 0.67$, or $\theta_c \doteq 42°$.

Therefore, it must be true that

$(90° - \theta_2) < 42°$, or $\theta_2 > 48°$.

Recall that $\sin \theta_2 = (1.0 \sin \theta_1)/(1.5)$, so $\sin \theta_2$ and θ_2 are largest when θ_1 is $90°$. In this case, $\sin \theta = 1.0/1.5 = 0.67$, or $\theta_2 = 42°$. But we found above that θ_2 must be greater than $48°$ for the light ray to leave an adjacent side. Since this is impossible, we conclude that one cannot see out of an adjacent side of a block of glass.

17. The index of refraction for red light in arsenic trioxide is 2.010, while the index of refraction for blue light is 2.023. Find the difference between the angles of refraction if white light is incident at an angle of $65.0°$.

$n_i \sin \theta_i = n_r \sin \theta_r$,

$\sin \theta_r = n_i \sin \theta_i/n_r$

For red light,

$\sin \theta_r = (1.00)(\sin 65.0°)/(2.010) = 0.451$

$\theta_r = 26.8°$

For blue light,

$\sin \theta_r = (1.00)(\sin 65.0°)/(2.023) = 0.448$

$\theta_r = 26.6°$

Difference $= 26.8° - 26.6° = 0.2°$

18. The index of refraction for red light in a diamond is 2.410, while the index of refraction for blue light is 2.450. Find the difference in the speed of light in diamond.

$v_s = c/n_s$

For red light,

$v_s = (2.998 \times 10^8 \text{ m/s})/(2.410)$
$= 1.244 \times 10^8 \text{ m/s}$

For blue light,

$v_s = (2.998 \times 10^8 \text{ m/s})/(2.450)$
$= 1.224 \times 10^8 \text{ m/s}$

Difference $= (1.244 \times 10^8 \text{ m/s}) - (1.224 \times 10^8)$
$= 0.020 \times 10^8 \text{ m/s} = 2.0 \times 10^6 \text{ m/s}$