Page 763
1,5,6,7,10,15,18,19,23,26,29

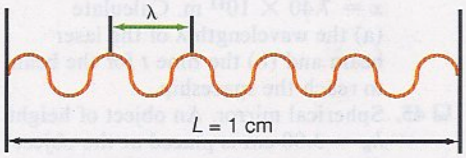
Problems for Chapter 26

26.1 Light as an Electromagnetic Wave

1. What is the frequency of (a) violet light of 380.0-nm wavelength and (b) red light of 720.0-nm wavelength?

2. What is the wavelength of the electromagnetic radiation of the following frequencies: (a) 100 kHz, (b) 10.0 MHz, (c) 4.00×10^{14} Hz, and (d) 6.00×10^{15} Hz.

3. How many light waves of 450-nm wavelength can you fit into a distance of 1.00 cm?



4. How long does it take light to reach earth from (a) the sun and (b) the moon?

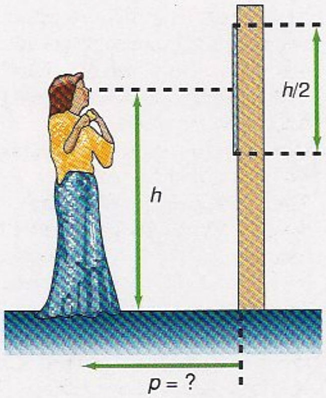
26.3 The Plane Mirror

5. An object 10.0 cm high is placed 20.0 cm in front of a plane mirror. Where is the image located and how big is it?

6. What is the minimum height of a mirror such that a student, 5′8″ tall, can see his entire body?

7. Repeat problem 6, but take into account that the eyes of the student are 4.00 in. below the top of his head.

8. A student stands in front of a plane mirror that is equal to half of her height, but when looking straight ahead, her eyes look directly into the center of the mirror. How far back from the mirror must she move in order to see her entire body in the mirror?



26.4 The Concave Spherical Mirror

9. What is the focal length of a spherical mirror if the radius of curvature is 25.0 cm?

10. An object 10.0 cm high is placed 50.0 cm in front of a concave spherical mirror of 15.0-cm focal length. Find the image by (a) a ray diagram and (b) the mirror equation. Is the image real or virtual? Is the image erect or inverted? What is the size of the image?

†11. Find the image with a concave spherical mirror of 10.0-cm focal length if the object is located at (a) 60.0 cm, (b) 40.0 cm, (c) 20.0 cm, (d) 10.0 cm, and (e) 5.00 cm. Draw a ray diagram for each case.

12. Find the magnification for each case in problem 11.

13. If the object is 5.00 cm high, find the height of the images in each case in problem 12.

†14. A concave spherical mirror has a focal length of 20.0 cm. Find the image distance, magnification, and height of the image when the object is located at (a) 100 cm, (b) 80.0 cm, (c) 40.0 cm, (d) 20.0 cm, and (e) 10.0 cm. Draw a ray diagram for each case.

15. An object is placed 15.0 cm in front of a concave spherical mirror mounted on an optical bench in the laboratory. A screen is moved along the optical bench until the object and image are located at the same point. Find the focal length of the mirror.

16. Find the focal length of a concave spherical mirror that has a magnification of 2.00 when an object is placed 20.0 cm in front of it.

17. An object 10.0 cm high is placed 10.0 cm in front of a concave spherical mirror of 15.0-cm focal length. Find the image by a ray diagram and the mirror equation. How high is the image?

18. Where should an object 5.00 cm high be placed in front of a 25.0-cm concave spherical mirror in order for its image to be erect and 10.0 cm high?

19. For a concave spherical mirror of 20.0-cm focal length, find two locations of an object such that the height of the image is four times the height of the object.

20. An object is placed 40.0 cm in front of a concave spherical mirror and its image is found 25.0 cm in front of the mirror. What is the focal length of the mirror?

21. A concave spherical mirror has a focal length of 15.0 cm. Where should an object be placed such that the height of the image is a quarter of the height of the object?

22. An object is placed 10.0 cm in front of a concave spherical mirror of 15.0-cm focal length. Find the location of the image and its magnification.

23. Find the radius of curvature of a shaving mirror such that when the object is placed 15.0 cm in front of the mirror, the image has a magnification of 2.

24. A concave spherical mirror has a focal length of 15.0 cm. Where should an object be placed to give a magnification of (a) 2.00 and (b) −2.00?

26.5 The Convex Spherical Mirror

25. A reflecting Christmas tree ball has a diameter of 8.00 cm. What is the focal length of such an ornament?

26. An object 10.0 cm high is placed 30.0 cm in front of a convex spherical mirror of −10.0-cm focal length. Find the image by a ray diagram and the mirror equation. Find the height of the image.

†27. Find the image with a convex spherical mirror of 10.0-cm focal length if the object is located at (a) 60.0 cm, (b) 40.0 cm, (c) 20.0 cm, (d) 10.0 cm, and (e) 5.00 cm. Draw a ray diagram for each case.

28. An object is 12.0 cm in front of a convex spherical mirror, and the image is formed 24.0 cm behind the mirror. Find the focal length of the mirror.

29. Where should an object be placed in front of a convex spherical mirror of 15.5-cm focal length in order to get a virtual image with a magnification of one-half?

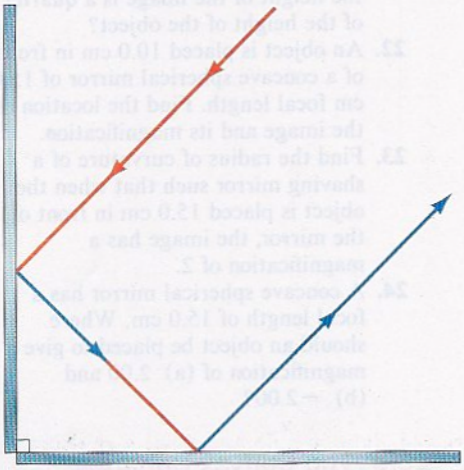
30. The distance between a real object and a virtual image formed by a convex spherical mirror is 50.0 cm. If the focal length of the mirror is $f = -25.0$ cm, find the two possible positions for the mirror.

Additional Problems

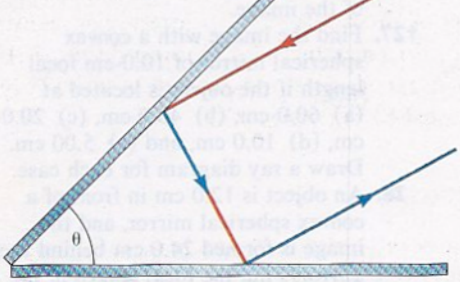
†31. A plane mirror is rotated through an angle θ. Show that the reflected ray will always be rotated through an angle of 2θ.

32. Show that a plane mirror is a special case of a concave spherical mirror whose radius of curvature is infinite. What does the mirror equation reduce to?

†33. Two mirrors make an angle of 90° with each other. Show that if a ray of light is incident on the first mirror at an angle of incidence i, the reflected ray from the second mirror makes an angle of reflection of $90° - i$.



†34. Two mirrors make an angle of θ with each other. Show that if a ray of light is incident on the first mirror at an angle of incidence i, the reflected ray from the second mirror makes an angle of reflection of $\theta - i$.



†35. Show that when an object is placed in front of a concave spherical mirror of focal length f and experiences a magnification M, the image is located at the image distance given by

$$q = f(1 - M)$$

36. An object is placed 25.0 cm in front of a concave spherical mirror. The image is found to be a quarter of the size of the object. Find the focal length of the mirror.

37. An object is magnified by a factor of 2 when it is placed 15.0 cm in front of a concave spherical mirror. Find the radius of curvature of the mirror.

38. A dentist uses a small concave spherical mirror to see a cavity in a tooth. If the image is to be magnified by a factor of 3 when the tooth is 2.50 cm in front of the mirror, what should be the focal length of such a mirror?

39. An optical system is designed so that an object for a convex spherical mirror of focal length $f = -15.0$ cm is 20.0 cm *behind* the mirror (a virtual object). Find the image distance and the magnification, and determine whether the image is real or virtual, erect or inverted.

40. Repeat problem 39 with an object located only 5.00 cm *behind* the mirror.

†**41.** Use a compass to draw a concave spherical mirror 10.0 cm in radius. Draw light rays parallel to the principal axis at every 1.00 cm above and below the principal axis. Using a protractor, carefully measure the angles of incidence and reflection for each of these rays, and see where they cross the principal axis. What does this tell you about the underlying assumption in the mirror equation? How does this relate to spherical aberration of the mirror?

†**42.** Draw a graph of the image distance q as a function of the object distance p for a concave spherical mirror of focal length 10.0 cm. Show the regions that represent the concave mirror and the convex mirror. Show the regions where the images are real and where they are virtual.

†**43.** Draw a graph of the magnification M of a concave spherical mirror as a function of the object distance p. Repeat for a convex spherical mirror.

Interactive Tutorials

44. A tower on earth transmits a laser beam of frequency $f = 5.00 \times 10^{14}$ Hz to a spaceship at a distance $x = 7.40 \times 10^{11}$ m. Calculate (a) the wavelength λ of the laser beam and (b) the time t for the beam to reach the spaceship.

45. Spherical mirror. An object of height $h_o = 3.00$ cm is placed at the object distance $p = 10.0$ cm of a spherical mirror of radius of curvature $R = 8.00$ cm. Find (a) the focal length f of the mirror, (b) the image distance q, (c) the magnification M, and (d) the height h_i of the resulting image.

46. Spherical mirror. An object of height $h_o = 8.50$ cm is placed at the object distance $p = 35.0$ cm of a spherical mirror of focal length $f = 15.0$ cm. Find (a) the radius of curvature R of the mirror, (b) the image distance q, (c) the magnification M, and (d) the height h_i of the resulting image.

The Language of Physics

Refraction
The bending of light as it travels from one medium into another. It occurs because of the difference in the speed of light in the different mediums. Whenever a ray of light goes from a rarer medium to a denser medium the refracted ray is always bent toward the normal. Whenever a ray of light goes from a denser medium to a rarer medium, the refracted ray is bent away from the normal (p. 765).

Law of refraction
The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant. The constant is called the relative index of refraction and it is equal to the ratio of the speed of light in the first medium to the speed of light in the second medium. Because of the changing speed of light, the wavelength of light changes as the light passes into the second medium (p. 767).

The critical angle of incidence
The angle of incidence that causes the refracted ray to bend through 90°. When the incident angle exceeds the critical angle no refraction occurs. In that case, it is called total internal reflection because all the light that strikes the interface is reflected (p. 773).

Prism
A triangular piece of transparent material whose angle exceeds the critical angle. A ray of light falling on one of the smaller sides of the prism enters the prism and is totally reflected from the longer side of the prism. Prisms are also used for analyzing the dispersion of white light into its component colors (p. 773).

Fiber optics
A flexible glass rod of high refractive index. Light entering the glass undergoes total internal reflection from the walls of the glass fiber and the light travels down the length of the fiber with little or no absorption of light (p. 774).

Dispersion
The separation of white light into its component colors. It occurs because the index of refraction of a medium varies slightly with the wavelength of light (p. 774).

Lens
A piece of transparent material, such as glass or plastic, that causes light passing through it to either converge or diverge depending on the shape of the material (p. 775).

Lensmaker's formula
An equation that relates the focal length, index of refraction, and the radii of curvature of the lens (p. 776).

Thin lens
A lens whose thickness is negligible compared to the distance to the principal focus and to any object or image distance (p. 776).

Converging lens
A lens that causes light, parallel to its principal axis, to converge to the principal axis. Converging lenses have positive focal lengths (p. 777).

Diverging lens
A lens that causes light, parallel to its principal axis to diverge away from the principal axis. Diverging lenses have negative focal lengths (p. 777).

The lens equation
An equation that relates the image distance, the object distance, and the focal length of a lens. It has the same form as the mirror equation (p. 781).

Dioptric power of a lens
The reciprocal of the focal length of a lens. The focal length must be expressed in meters. For a combination of any number of lenses in contact, the power of the combination is equal to the sum of the powers of each individual lens (p. 791).

Accommodation
The changing of the focal length of the eye in order to focus an image on the retina of the eye (p. 798).

Hyperopia, or farsightedness
A defect of the eye that causes objects far away to be seen clearly while close objects are blurred. The condition is remedied by placing a converging lens in front of the eye (p. 798).

Myopia, or nearsightedness
A defect of the eye that causes objects close to the eye to be seen clearly, while objects far away are blurred. The condition is remedied by placing a diverging lens in front of the eye (p. 799).

Near point of the eye
The minimum distance from the eye at which an object can be seen distinctly. For the average person the near point is about 25 cm (p. 799).

Angular magnification
The ratio of the angle subtended at the eye by an object, when a lens is used, to the angle subtended by the unaided eye (p. 800).

Summary of Important Equations

The law of refraction

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \text{constant} = n_{21} \quad (27.3)$$

$$n_1 \sin i = n_2 \sin r \quad (27.11)$$

The index of refraction

$$n = \frac{c}{v} \quad (27.4)$$

Speed of a wave in terms of wavelength and frequency

$$v = \lambda \nu \quad (27.5)$$

Index of refraction in terms of wavelengths in two mediums

$$n_{21} = \frac{\lambda_1}{\lambda_2} \quad (27.6)$$

Apparent depth for small angles

$$q = \frac{n_2}{n_1} p \quad (27.14)$$

Critical angle

$$\sin i_c = \frac{n_2}{n_1} \quad (27.17)$$

Lensmaker's formula

$$\frac{1}{f} = (n - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad (27.18)$$

Lens equation

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} \quad (27.21)$$

Magnification

$$M = \frac{h_i}{h_o} = -\frac{q}{p} \quad (27.23)$$

Height of image

$$h_i = M h_o \quad (27.24)$$

Combination of lenses
Final image

$$\frac{1}{q_2} = \frac{1}{f_2} - \frac{1}{p_2} \quad (27.26)$$

where

$$p_2 = d - q_1 \quad (27.27)$$

and

$$\frac{1}{q_1} = \frac{1}{f_1} - \frac{1}{p_1} \quad (27.25)$$

Magnification

$$M = M_1 M_2 \qquad (27.33)$$

Thin lenses in contact

$$\frac{1}{f_c} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} + \cdots \qquad (27.43)$$

Power of a lens

$$P = \frac{1}{f\,(\text{in meters})} \qquad (27.44)$$

Power of combinations of lenses

$$P_c = P_1 + P_2 + P_3 + P_4 + \cdots \qquad (27.45)$$

f-number of a lens

$$f\# = \frac{f}{d} \qquad (27.46)$$

Angular magnification, astronomical telescope

$$M_A = \frac{f_o}{f_e} \qquad (27.48)$$

Angular magnification, viewing at near point

$$M_A = \frac{25.0\text{ cm}}{f} + 1 \qquad (27H.5)$$

Angular magnification, viewing at infinity

$$M_A = \frac{25.0\text{ cm}}{f} \qquad (27H.6)$$

Questions for Chapter 27

†1. Why does a diamond sparkle?

2. When the angle of incidence is equal to zero, the angle of refraction is also zero. Does the wavelength of the light change when going from one medium to another under these circumstances?

3. If you are at the bottom of a pool of water and you look upward into the air at an angle greater than 50° can you see anything in the air?

4. Is it possible to have a ray of light refracted into a medium such that the new wavelength decreases to the point where it is no longer in the visible spectrum? What would you see? Does the eye interpret a wavelength or a frequency?

†5. What does a wide-angle lens and a telephoto lens do when each is attached to a camera?

†6. Describe the optical system used for (a) a slide projector, (b) a movie camera, and (c) an overhead projector.

7. A swimmer forgets to take off her glasses as she enters the pool. When she is under water, wearing the glasses, does the water have any effect on what she can see with the glasses?

8. When you see yourself in a mirror, your right and left hand are interchanged. Yet, if you see a picture of yourself made with a camera, containing lenses, your right and left are not changed. Why?

†9. What are bifocals and why are they used?

†10. What is a mirage and how is it explained by the index of refraction?

†11. How is a rainbow formed?

12. How is a convex lens used, with the help of the sun, to start a fire?

Problems for Chapter 27

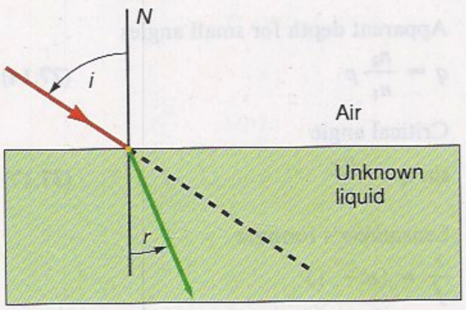
27.2 The Law of Refraction

1. A ray of light impinges on a piece of glass ($n_g = 1.52$) at an angle of incidence of 50.0°. Find the angle of refraction.

2. A ray of light passes from water to glass at an angle of incidence of 50.0°. Find the angle of refraction.

3. A ray of light is refracted by an angle of 34.5° as it enters water from glass. Find the angle of incidence.

4. A ray of light in air makes an angle of incidence of 35.0° as it enters an unknown liquid. The refracted ray in the fluid is measured to be 22.5°. Find the index of refraction of the unknown liquid. What substance might it be?



5. Determine the speed of light in (a) water, (b) glycerine, and (c) diamond.

6. If a ray of light of 480.0-nm wavelength in air enters into water, what is the wavelength of the light in the water? Is this light visible?

7. A ray of light of 580.0-nm wavelength in water, enters into the air. What is the wavelength of the light in the air?

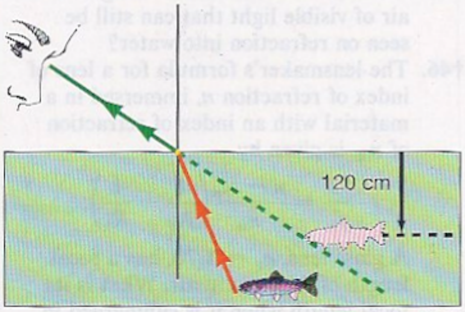
8. A ray of light of 700.0-nm wavelength in water enters into the air. What is the wavelength of the light in the air? Will the light be seen in the air?

page 803;
4,9,13,14, 21, 22, 25, 26, 29, 30

9. A ray of light of 590.0-nm wavelength in air impinges on a piece of flint glass at an angle of 30.0° with the vertical. The index of refraction of this flint glass is 1.57. Find (a) the angle of refraction, (b) the speed of light in the glass, and (c) the wavelength of light in the glass.

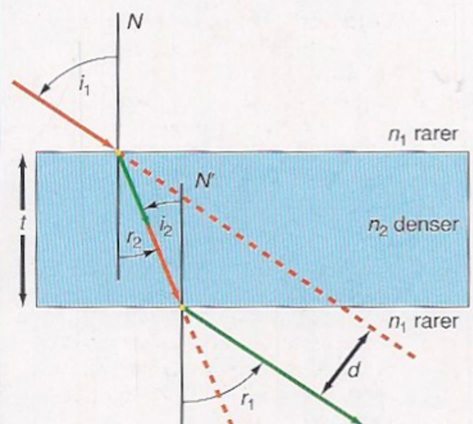
27.3 Apparent Depth of an Object Immersed in Water

10. A rock sits at the bottom of a 3.50-m-deep pool. What is its apparent depth?
11. A fish appears to be at a depth of 120 cm in water. What is its actual depth?



27.4 Refraction through Parallel Faces

12. A ray of light in air makes an angle of incidence of 30.0° with a sheet of glass 0.500 cm thick. Find the distance d that the final ray is displaced from its original direction.



27.5 Total Internal Reflection

13. What is the critical angle of refraction for a light ray going from water to glass?
14. Find the critical angle of refraction for a ray of light passing from glycerine ($n = 1.47$) into air.
15. The critical angle of a ray of light is measured as 41.8° as it goes from an unknown liquid into air. Find the index of refraction of the liquid.

27.7 Thin Lenses

16. A double convex glass lens of index of refraction 1.52, has radii of curvature $R_1 = +50.0$ cm and $R_2 = -25.0$ cm. Find its focal length.
17. A glass lens of index of refraction 1.52, has radii of curvature $R_1 = +40.0$ cm and $R_2 = -15.0$ cm. What is its focal length and is it a converging or a diverging lens?
18. A glass lens of index of refraction 1.52, has radii of curvature $R_1 = -40.0$ cm and $R_2 = +15.0$ cm. What is its focal length and is it a converging or a diverging lens?
19. A glass lens of index of refraction 1.52, has radii of curvature $R_1 = -40.0$ cm and $R_2 = -15.0$ cm. What is its focal length and is it a converging or a diverging lens?
20. A lens is made of transparent material, with radii of curvature $R_1 = 15.0$ cm and $R_2 = 90.0$ cm. If the focal length of the lens is 5.00 cm, find the index of refraction of the material.

27.9 The Lens Equation, and Section 27.10

Some Special Cases for the Convex Lens

21. An object 3.00 cm high is placed 20.0 cm in front of a converging lens of 15.0 cm focal length. Draw a ray diagram. Find (a) the image distance, (b) the magnification, and (c) the final size of the image. (d) Is the image real or virtual? (e) Is the image erect or inverted?
22. An object 3.00 cm high is placed 20.0 cm in front of a diverging lens of −15.0 cm focal length. Draw a ray diagram. Find (a) the image distance q, (b) the magnification M, and (c) the height of the image h_i. (d) Is the image real or virtual? (e) Is the image erect or inverted?
23. Where should an object be placed in front of a 20.0-cm lens in order for the image to be the same size as the object?
24. An object 7.00 cm high is placed 5.00 cm in front of a convex lens of 10.0 cm focal length. (a) Draw a ray diagram. Find (b) the image distance, (c) the magnification, and (d) the height of the image.
25. How far in front of a 20.0-cm converging lens should an object be placed in order to produce an image 25.0 cm from the lens on the same side of the lens as the object?
26. An object is placed 15.0 cm in front of a diverging lens of 5.00 cm focal length. Where is the image located and what is its magnification?
27. Where should an object be placed in front of a diverging lens of 10.0 cm focal length in order to give an image a magnification of 0.500?
28. An object 5.00 cm high is placed 20.0 cm in front of a converging lens. The image is measured to be 7.00 cm high. Where is the image located?
29. An object 5.00 cm high is placed 30.0 cm in front of a converging lens of 7.50 cm focal length. What is the size of the image?

27.11 Combination of Lenses

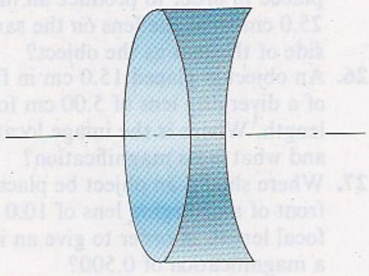
30. An object 5.00 cm high is placed 20.0 cm in front of a converging lens of 10.0 cm focal length. A second converging lens of 20.0 cm focal length is placed 30.0 cm behind the first lens. Find (a) the image distance for the first lens, (b) the object distance for the second lens, (c) the image distance for the second lens, and (d) the total magnification of the combination. Draw a ray diagram.

†31. An object 5.00 cm high is placed 10.0 cm in front of a 20.0-cm converging lens. A second converging lens, also of 20.0 cm focal length, is placed 20.0 cm behind the first lens. Find (a) the location of the final image and (b) its size. Draw a ray diagram.

†32. A converging lens of +20.0 cm is separated by a distance of 20.0 cm from a diverging lens of −5.00 cm. An object is located 30.0 cm in front of the first lens. Find (a) the image distance of the first lens, (b) the object distance for the second lens, (c) the image distance for the second lens, and (d) the magnification of the system.

27.12 Thin Lenses in Contact

33. A 20.0-cm convex lens is placed in contact with a diverging lens of unknown focal length. The lens combination has a focal length of 30.0 cm. Find the focal length of the diverging lens.



34. What is the power of (a) a 50.0-cm converging lens, (b) a 20.0-cm diverging lens, (c) the converging and diverging lenses in contact, and (d) the focal length of the combination when they are in contact?

35. Ten identical converging thin lenses, each of focal length 6.50 cm, are in contact. Find the focal length of the composite lens.

Additional Problems

36. A ray of light of 590.0-nm wavelength in glycerine impinges on a piece of flint glass at an angle of 30.0° with the vertical. The index of refraction of glycerine is 1.47 and for the flint glass used it is 1.70. Find (a) the angle of refraction, (b) the speed of light in the glycerine, (c) the speed of light in the glass, and (d) the wavelength of light in the glass.

37. Light travels in medium 1 at 1.50×10^8 m/s. The light is incident at an angle of incidence of 40.0° when entering medium 2, where the angle of refraction is 30°. Find the speed of light in medium 2.

38. A ray of light of 590.0-nm wavelength makes an angle of incidence of 40.0° on to the cornea of the eye. The index of refraction of the cornea is 1.35. Find (a) the angle of refraction, (b) the speed of light in the cornea, and (c) the wavelength of light in the cornea.

39. Light travels from glass of index of refraction 1.50 into water of index 1.33. If there exists a refracted ray, find the angle of refraction when (a) the angle of incidence is 55.0° and (b) the angle of incidence is 70.0°.

†40. If an object is placed a distance d_1 in front of the principal focus of a lens and the image is located a distance d_2 beyond the other principal focus, show that the focal length of the lens is given by

$$f = \sqrt{d_1 d_2}$$

41. An object is mounted 60.0 cm in front of a screen. At what two positions will a 12.0 cm focal length lens yield a distinct image on the screen?

42. An optical system creates a virtual object (an object *behind* the lens) for a diverging lens of focal length $f = -8.00$ cm. Find the position of the image and describe it for the following two object distances: (a) $p = -4.00$ cm and (b) $p = -10.0$ cm.

43. A farsighted person has a near point of 60.0 cm. What power lens should be used for eyeglasses such that the person can read this book at a distance of 25.0 cm?

44. A nearsighted person has a far point of 15 cm. (The far point of the eye is the farthest distance that an object can be seen clearly.) What power lens should be used to allow this person to view far distant objects?

45. What is the smallest wavelength in air of visible light that can still be seen on refraction into water?

†46. The lensmaker's formula for a lens of index of refraction n, immersed in a material with an index of refraction of n_m, is given by

$$\frac{1}{f_m} = \frac{n - n_m}{n_m}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

A glass lens, $n_g = 1.70$, has a focal length of 25.0 cm in air. What is its focal length when it is submerged in water?