**24.** Suppose that a 21-year-old with normal vision (near point = 25 cm) is standing in front of a plane mirror. How close can he stand to the mirror and still see himself in focus? Explain.

**25.** ⚕ If we read for a long time, our eyes become "tired." When this happens, it helps to stop reading and look at a distant object. From the point of view of the ciliary muscle, why does this refresh the eyes?

**26.** To a swimmer under water, objects look blurred and out of focus. However, when the swimmer wears goggles that keep the water away from the eyes, the objects appear sharp and in focus. Why do goggles improve a swimmer's underwater vision?

**27.** ⚕ The refractive power of the lens of the eye is 15 diopters when surrounded by the aqueous and vitreous humors. If this lens is removed from the eye and surrounded by air, its refractive power increases to about 150 diopters. Why is the refractive power of the lens so much greater outside the eye?

**28.** The light shining through a full glass of wine forms an irregularly shaped bright spot on the table, but does not do so when the glass is empty. Explain.

**29.** Jupiter is the largest planet in our solar system. Yet, to the naked eye, it looks smaller than Venus. Why?

**30.** By means of a ray diagram, show that the eyes of a person wearing glasses appear to be (a) smaller when the glasses use diverging lenses to correct for nearsightedness and (b) larger when the glasses use converging lenses to correct for farsightedness.

**31.** Can a diverging lens be used as a magnifying glass? Justify your answer with a ray diagram.

**32.** Who benefits more from using a magnifying glass, a person whose near point is located 25 cm away from the eyes or a person whose near point is located 75 cm away from the eyes? Provide a reason for your answer.

**33.** Two lenses, whose focal lengths are 3.0 and 45 cm, are used to build a telescope. Which lens should be the objective? Why?

**34.** Two refracting telescopes have identical eyepieces, although one telescope is twice as long as the other. Which has the greater angular magnification? Provide a reason for your answer.

**35.** Suppose a well-designed optical instrument is composed of two converging lenses separated by 14 cm. The focal lengths of the lenses are 0.60 and 4.5 cm. Is the instrument a microscope or a telescope? Why?

**36.** It is often thought that virtual images are somehow less important than real images. To show that this is not true, identify which of the following instruments normally produce final images that are virtual: (a) a projector, (b) a camera, (c) a magnifying glass, (d) eyeglasses, (e) a compound microscope, and (f) an astronomical telescope.

**37.** Why does chromatic aberration occur in lenses, but not in mirrors?

# PROBLEMS

***Unless specified otherwise, use the values given in Table 26.1 for the refractive indices.***

**ssm Solution is in the Student Solutions Manual. www Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell**
**⚕ This icon represents a biomedical application.**

### Section 26.1 The Index of Refraction

**1. ssm** What is the speed of light in benzene?

**2.** Find the ratio of the speed of light in diamond to the speed of light in ice.

**3.** The frequency of a light wave is the same when the light travels in ethyl alcohol as it is when it travels in carbon disulfide. Find the ratio of the wavelength of the light in ethyl alcohol to that in carbon disulfide.

**4.** Light has a wavelength of 340.0 nm and a frequency of $5.403 \times 10^{14}$ Hz when traveling through a certain substance. What substance from Table 26.1 could this be?

**5. ssm www** A glass window ($n = 1.5$) has a thickness of $4.0 \times 10^{-3}$ m. How long does it take light to pass perpendicularly through the plate?

**6.** The speed of light is 1.25 times as large in material $A$ than in material $B$. Determine the ratio $n_A/n_B$ of the refractive indices of these materials.

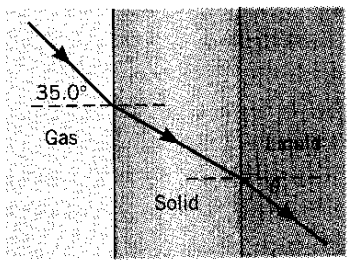
***7.** In a certain time, light travels 3.50 km in a vacuum. During the same time, light travels only 2.50 km in a liquid. What is the refractive index of the liquid?

***8.** A flat sheet of ice has a thickness of 2.0 cm. It is on top of a flat sheet of crystalline quartz that has a thickness of 1.1 cm. Light strikes the ice perpendicularly and travels through it and then through the quartz. In the time it takes the light to travel through the two sheets, how far (in cm) would it have traveled in a vacuum?

### Section 26.2 Snell's Law and the Refraction of Light

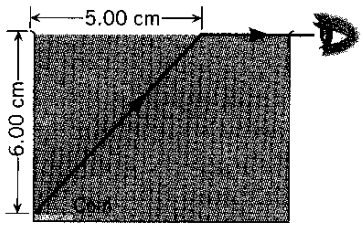
**9. ssm** A beam of light is traveling in air and strikes a material. The angles of incidence and refraction are 63.0° and 47.0°, respectively. Obtain the speed of light in the material.

**10.** Refer to Conceptual Example 7 as an aid in understanding this problem. The drawing shows a ray of light traveling through a gas ($n = 1.00$), a solid ($n = 1.55$), and a liquid ($n = 1.55$). At what angle $\theta$ does the light enter the liquid?




**11. ssm** The drawing shows a coin resting on the bottom of a beaker filled with an unknown liquid. A ray of light from the coin

travels to the surface of the liquid and is refracted as it enters into the air. A person sees the ray as it skims just above the surface of the liquid. How fast is the light traveling in the liquid?




**12.** As an aid in understanding this problem, refer to Conceptual Example 4. A swimmer, who is looking up from under the water, sees a diving board directly above at an apparent height of 4.0 m above the water. What is the actual height of the diving board?

**13.** A layer of oil ($n = 1.45$) floats on an unknown liquid. A ray of light shines from the oil into the unknown liquid. The angles of incidence and refraction are, respectively, 65.0° and 53.0°. What is the index of refraction of the unknown liquid?

**14.** Light in a vacuum is incident on a transparent glass slab. The angle of incidence is 35.0°. The slab is then immersed in a pool of liquid. When the angle of incidence for the light striking the slab is 20.3°, the angle of refraction for the light entering the slab is the same as when the slab was in a vacuum. What is the index of refraction of the liquid?

***15. ssm www** In Figure 26.7, suppose that the angle of incidence is $\theta_1 = 30.0°$, the thickness of the glass pane is 6.00 mm, and the refractive index of the glass is $n_2 = 1.52$. Find the amount (in mm) by which the emergent ray is displaced relative to the incident ray.

**16.** A ray of sunlight hits a frozen lake at a 45° angle of incidence. At what angle of refraction does the ray penetrate (a) the ice and (b) the water beneath the ice?

***17.** Refer to Figure 26.5*a* and assume the observer is nearly above the submerged object. For this situation, derive the expression for the apparent depth: $d' = d(n_2/n_1)$, Equation 26.3. *(Hint: Use Snell's law of refraction and the fact that the angles of incidence and refraction are small, so tan $\theta \approx$ sin $\theta$.)*

***18.** Review Conceptual Example 4 as background for this problem. A man in a boat is looking straight down at a fish in the water directly beneath him. The fish is looking straight up at the man. They are equidistant from the air/water interface. To the man, the fish appears to be 2.0 m beneath his eyes. To the fish, how far above its eyes does the man appear to be?

***19.** A silver medallion is sealed within a transparent block of plastic. An observer in air, viewing the medallion from directly above, sees the medallion at an apparent depth of 1.6 cm beneath the top surface of the block. How far below the top surface would the medallion appear if the observer (not wearing goggles) and the block were under water?

****20.** A beaker has a height of 30.0 cm. The lower half of the beaker is filled with water, and the upper half is filled with oil ($n = 1.48$). To a person looking down into the beaker from above, what is the apparent depth of the bottom?

****21. ssm** A small logo is embedded in a thick block of crown glass ($n = 1.52$), 3.20 cm beneath the top surface of the glass. The block is put under water, so there is 1.50 cm of water above the top surface of the block. The logo is viewed from directly above by an observer in air. How far beneath the top surface of the water does the logo appear to be?

****22.** The back wall of a home aquarium is a mirror that is 30.0 cm away from the front wall. The walls of the tank are negligibly thin. A fish is swimming midway between the front and back walls. (a) How far from the front wall does the fish seem to be located? (b) An image of the fish appears behind the mirror. How far does this image appear to be from the front wall of the aquarium? (c) Would the refractive index of the liquid have to be larger or smaller in order for the image of the fish to appear in *front* of the mirror, rather than behind it? Why?

### Section 26.3 Total Internal Reflection

**23. ssm** One method of determining the refractive index of a transparent solid is to measure the critical angle when the solid is in air. If $\theta_c$ is found to be 40.5°, what is the index of refraction of the solid?

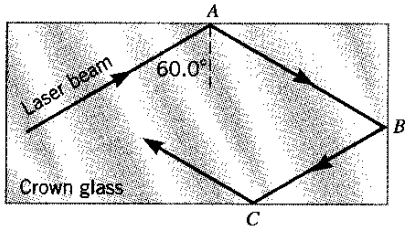
**24.** What is the critical angle for light emerging from carbon disulfide into air?

**25.** A ray of light is traveling in glass and strikes a glass/liquid interface. The angle of incidence is 58.0°, and the index of refraction of glass is $n = 1.50$. (a) What must be the index of refraction of the liquid such that the direction of the light entering the liquid is not changed? (b) What is the largest index of refraction that the liquid can have, such that none of the light is transmitted into the liquid and all of it is reflected back into the glass?

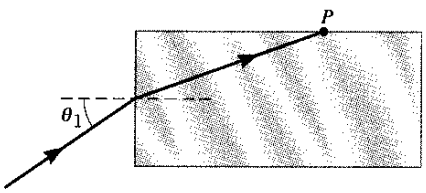
**26.** A point source of light is submerged 2.2 m below the surface of a lake and emits rays in all directions. On the surface of the lake, directly above the source, the area illuminated is a circle. What is the maximum radius that this circle could have?

**27. ssm** A person is sitting in a small boat in the ocean. A shark is swimming under water at a depth of 4.5 m. When the shark is beyond a certain distance (measured horizontally) from the boat, the shark cannot be seen. Assume that the person's eyes are very near the surface of the water and find that distance.

**28.** The drawing shows a crown glass slab with a rectangular cross section. As illustrated, a laser beam strikes the upper surface at an angle of 60.0°. After reflecting from the upper surface, the beam reflects from the side and bottom surfaces. (a) If the glass is surrounded by air, determine where part of the beam first exits the glass, at point *A*, *B*, or *C*. (b) Repeat part (a), assuming that the glass is surrounded by water.

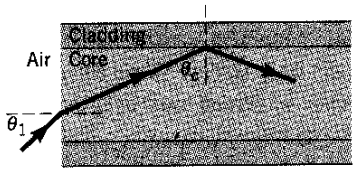



***29.** The drawing shows a crystalline quartz slab with a rectangular cross section. A ray of light strikes the slab at an incident angle of $\theta_1 =$



34°, enters the quartz, and travels to point $P$. This slab is surrounded by a fluid with a refractive index $n$. What is the maximum value of $n$ such that total internal reflection occurs at point $P$?

*30. The drawing shows an optical fiber that consists of a core made of flint glass ($n_{\text{flint}} = 1.667$) surrounded by a cladding made of crown glass ($n_{\text{crown}} = 1.523$). A beam of light enters the fiber from air at an angle $\theta_1$ with respect to the normal. What is $\theta_1$ if the light strikes the core-cladding interface at the critical angle $\theta_c$?




### Section 26.4 Polarization and the Reflection and Refraction of Light

31. **ssm** Light is reflected from a glass coffee table. When the angle of incidence is 56.7°, the reflected light is completely polarized parallel to the surface of the glass. What is the index of refraction of the glass?

32. For light that originates within a liquid and strikes the liquid/air interface, the critical angle is 39°. What is Brewster's angle for this light?

33. At what angle of incidence is sunlight completely polarized upon being reflected from the surface of a lake (a) in the summer and (b) in the winter when the water is frozen?

34. Light is incident from air onto a beaker of carbon tetrachloride. If the reflected light is 100% polarized, what is the angle of refraction of the light that penetrates into the carbon tetrachloride?

35. **ssm www** When light strikes the surface between two materials from above, the Brewster angle is 65.0°. What is the Brewster angle when the light encounters the same surface from below?

*36. When red light in a vacuum is incident at the Brewster angle on a certain type of glass, the angle of refraction is 29.9°. What are (a) the Brewster angle and (b) the index of refraction of the glass?

*37. In Section 26.4 it is mentioned that the reflected and refracted rays are perpendicular to each other when light strikes the surface at the Brewster angle. This is equivalent to saying that the angle of reflection plus the angle of refraction is 90°. Using Snell's law and Brewster's law, prove that the angle of reflection plus the angle of refraction is 90°.

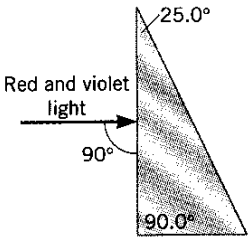
### Section 26.5 The Dispersion of Light: Prisms and Rainbows

38. Yellow light ($n = 2.417$) strikes a diamond at a 45.0° angle of incidence and is refracted when it enters the diamond. Blue light ($n = 1.684$) strikes a piece of flint glass and has the same angle of refraction as does the yellow light in the diamond. What is the angle of incidence of the blue light?

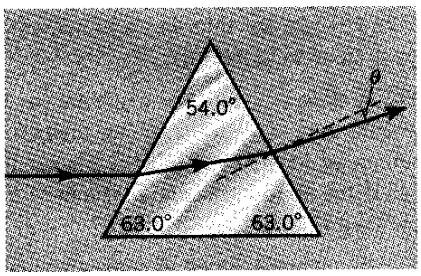
39. **ssm** A beam of sunlight encounters a plate of crown glass at a 45.00° angle of incidence. Using the data in Table 26.2, find the angle between the violet ray and the red ray in the glass.

40. A ray of sunlight is passing from diamond into crown glass; the angle of incidence is 35.00°. The indices of refraction for the blue and red components of the ray are: blue ($n_{\text{diamond}} = 2.444$, $n_{\text{crown glass}} = 1.531$), and red ($n_{\text{diamond}} = 2.410$, $n_{\text{crown glass}} = 1.520$). Determine the angle between the refracted blue and red rays in the crown glass.

41. Horizontal rays of red light ($\lambda = 660$ nm, in vacuum) and violet light ($\lambda = 410$ nm, in vacuum) are incident on the flint-glass prism shown in the drawing. The indices of refraction for the red and violet light are 1.662 and 1.698, respectively. What is the angle of refraction for each ray as it emerges from the prism?




*42. Refer to Conceptual Example 7 as background material for this problem. The drawing shows a horizontal beam of light that is incident on an ice prism. The base of the prism is also horizontal. The prism ($n = 1.31$) is surrounded by oil whose index of refraction is 1.48. Determine the angle $\theta$ that the exiting light makes with the normal to the right face of the prism.




*43. **ssm** This problem relates to Figure 26.18 which illustrates the dispersion of light by a prism. The prism is made from glass, and its cross section is an equilateral triangle. The indices of refraction for the red and violet light are 1.662 and 1.698, respectively. The angle of incidence for both the red and violet light is 60.0°. Find the angles of refraction at which the red and violet rays emerge into the air from the prism.

### Section 26.6 Lenses, Section 26.7 The Formation of Images by Lenses, Section 26.8 The Thin-Lens Equation and the Magnification Equation

***(Note: When drawing ray diagrams, be sure that the object height $h_o$ is much smaller than the focal length $f$ of the lens or mirror. This ensures that the rays are paraxial rays.)***

44. When a diverging lens is held 13 cm above a line of print, as in Figure 26.29, the image is 5.0 cm beneath the lens. What is the focal length of the lens?

45. **ssm** A macroscopic (or macro) lens for a camera is usually a converging lens of normal focal length built into a lens barrel that can be adjusted to provide the additional lens-to-film distance needed when focusing at very close range. Suppose that a macro lens ($f = 50.0$ mm) has a maximum lens-to-film distance of 275 mm. How close can the object be located in front of the lens?

46. To focus a camera on objects at different distances, the converging lens is moved toward or away from the film, so a sharp

image always falls on the film. A camera with a telephoto lens ($f = 200.0$ mm) is to be focused on an object located first at a distance of 3.5 m and then at 50.0 m. Over what distance must the lens be movable?

**47.** A diverging lens has a focal length of $-25$ cm. (a) Find the image distance when an object is placed 38 cm from the lens. (b) Is the image real or virtual?

**48.** A movie camera has a converging lens with a focal length of 85.0 mm. It takes a picture of a 145-cm tall person standing 16.0 m away. What is the height of the image on the film? Is the image upright or inverted relative to the object? Give your reasoning.

**49. ssm** An object is located 30.0 cm to the left of a converging lens whose focal length is 50.0 cm. (a) Draw a ray diagram to scale and from it determine the image distance and the magnification. (b) Use the thin-lens and magnification equations to verify your answers to part (a).

**50.** A slide projector has a converging lens whose focal length is 105.00 mm. (a) How far (in meters) from the lens must the screen be located if a slide is placed 108.00 mm from the lens? (b) If the slide measures 24.0 mm $\times$ 36.0 mm, what are the dimensions (in mm) of its image?

**51.** A camera is supplied with two interchangeable lenses, whose focal lengths are 35.0 and 150.0 mm. A woman whose height is 1.80 m stands 8.00 m in front of the camera. What is the height (including sign) of her image on the film, as produced by (a) the 35.0-mm lens and (b) the 150.0-mm lens?

**52.** The distance between an object and its image formed by a diverging lens is 6.0 cm. The focal length of the lens is $-3.0$ cm. Find (a) the image distance and (b) the object distance.

***53. ssm** An object is 18 cm in front of a diverging lens that has a focal length of $-12$ cm. How far in front of the lens should the object be placed so that the size of its image is reduced by a factor of 2.0?

***54.** When a converging lens is used in a camera (as in Figure 26.26*b*), the film must be placed at a distance of 0.210 m from the lens to record an image of an object that is 4.00 m from the lens. The same lens is then used in a projector (see Figure 26.27*b*), with the screen 0.500 m from the lens. How far from the projector lens should the film be placed?

***55. ssm www** The moon's diameter is $3.48 \times 10^6$ m, and its mean distance from the earth is $3.85 \times 10^8$ m. The moon is being photographed by a camera whose lens has a focal length of 50.0 mm. (a) Find the diameter of the moon's image on the slide film. (b) When the slide is projected onto a screen that is 15.0 m from the lens of the projector ($f = 110.0$ mm), what is the diameter of the moon's image on the screen?

***56.** From a distance of 72 m, a photographer uses a telephoto lens ($f = 300.0$ mm) to take a picture of a charging rhinoceros. How far from the rhinoceros would the photographer have to be to record an image of the same size using a lens whose focal length is 50.0 mm?

****57.** A converging lens ($f = 25.0$ cm) is used to project an image of an object onto a screen. The object and the screen are 125 cm apart, and between them the lens can be placed at either of two locations. Find the two object distances.

****58.** An object is 20.0 cm from a converging lens, and the image falls on a screen. When the object is moved 4.00 cm closer to the lens, the screen must be moved 2.70 cm farther away from the lens to register a sharp image. Determine the focal length of the lens.

### Section 26.9 Lenses in Combination

**59. ssm** A converging lens ($f = 12.0$ cm) is located 30.0 cm to the left of a diverging lens ($f = -6.00$ cm). A postage stamp is placed 36.0 cm to the left of the converging lens. (a) Locate the final image of the stamp relative to the diverging lens. (b) Find the overall magnification. (c) Is the final image real or virtual? With respect to the original object, is the final image (d) upright or inverted, and is it (e) larger or smaller?

**60.** Two identical diverging lenses are separated by 16 cm. The focal length of each lens is $-8.0$ cm. An object is located 4.0 cm to the left of the lens that is on the left. Determine the final image distance relative to the lens on the right.

**61.** A converging lens has a focal length of 0.080 m. An object is located 0.040 m to the left of this lens. A second converging lens has the same focal length as the first one and is located 0.120 m to the right of it. Relative to the second lens, where is the final image located?

**62.** A converging lens ($f_1 = 24.0$ cm) is located 56.0 cm to the left of a diverging lens ($f_2 = -28.0$ cm). An object is placed to the left of the converging lens, and the final image produced by the two-lens combination lies 20.7 cm to the left of the diverging lens. How far is the object from the converging lens?

**63.** An object, 0.75 cm tall, is placed 12.0 cm to the left of a diverging lens ($f = -8.00$ cm). A converging lens is placed 8.00 cm to the right of the diverging lens. The final image is virtual and is 29.0 cm to the left of the diverging lens. Determine (a) the focal length of the converging lens and (b) the height of the final image.

***64.** A coin is located 20.0 cm to the left of a converging lens ($f = 16.0$ cm). A second, identical lens is placed to the right of the first lens, such that the image formed by the combination has the same size and orientation as the original coin. Find the separation between the lenses.

***65. ssm** An object is placed 20.0 cm to the left of a diverging lens ($f = -8.00$ cm). A concave mirror ($f = 12.0$ cm) is placed 30.0 cm to the right of the lens. (a) Find the final image distance, measured relative to the mirror. (b) Is the final image real or virtual? (c) Is the final image upright or inverted with respect to the original object?

****66.** Two converging lenses ($f_1 = 9.00$ cm and $f_2 = 6.00$ cm) are separated by 18.0 cm. The lens on the left has the longer focal length. An object stands 12.0 cm to the left of the left-hand lens in the combination. (a) Locate the final image relative to the lens on the right. (b) Obtain the overall magnification. (c) Is the final image real or virtual? With respect to the original object, is the final image (d) upright or inverted and is it (e) larger or smaller?

### Section 26.10 The Human Eye

**67.** A farsighted person has a near point that is 48.0 cm from her eyes. She wears eyeglasses that are designed to enable her to read a newspaper held at a distance of 25.0 cm from her eyes. Find the focal length of the eyeglasses, assuming that they are worn (a) 2.0 cm from the eyes and (b) 3.0 cm from the eyes.

**68.** A woman can read the large print in a newspaper only when it is at a distance of 65 cm or more from her eyes. (a) Is she myopic or hyperopic? (b) What should be the refractive power of her glasses (worn 2.0 cm from the eyes), so she can read the newspaper at a distance of 25 cm from the eyes?

**69. ssm** A person has far points of 5.0 m from the right eye and 6.5 m from the left eye. Write a prescription for the refractive power of each corrective contact lens.

**70.** A student is reading a lecture written on a blackboard. The lenses in her eyes have a refractive power of 57.50 diopters, and the lens-to-retina distance is 1.750 cm. (a) How far (in meters) is the blackboard from her eyes? (b) If the writing on the blackboard is 5.00 cm high, what is the size of the image on her retina?

**71.** A nearsighted person cannot read a sign that is more than 5.2 m from his eyes. To deal with this problem, he wears contact lenses that do not correct his vision completely, but do allow him to read signs located up to distances of 12.0 m from his eyes. What is the focal length of the contacts?

**72.** A person holds a book 25 cm in front of the effective lens of her eye; the print in the book is 2.0 mm high. If the effective lens of the eye is located 1.7 cm from the retina, what is the size (including the sign) of the print image on the retina?

***73.** A nearsighted person wears contacts to correct for a far point that is only 3.62 m from his eyes. The near point of his unaided eyes is 25.0 cm from his eyes. If he does not remove the lenses when reading, how close can he hold a book and see it clearly?

****74.** Bill is farsighted and has a near point located 125 cm from his eyes. Anne is also farsighted, but her near point is 75.0 cm from her eyes. Both have glasses that correct their vision to a normal near point (25.0 cm from the eyes), and both wear the glasses 2.0 cm from the eyes. Relative to the eyes, what is the closest object that can be seen clearly (a) by Anne when she wears Bill's glasses and (b) by Bill when he wears Anne's glasses?

****75.** The far point of a nearsighted person is 6.0 m from her eyes, and she wears contacts that enable her to see distant objects clearly. A tree is 18.0 m away and 2.0 m high. (a) When she looks through the contacts at the tree, what is its image distance? (b) How high is the image formed by the contacts?

### Section 26.11 Angular Magnification and the Magnifying Glass

**76.** A spectator, seated in the left field stands, is watching a 1.9-m-tall baseball player who is 75 m away. On a TV screen, located 3.0 m from a person watching the game at home, the same player has a 0.12-m image. Find the angular size of the player as seen by (a) the spectator watching the game live and (b) the TV viewer. (c) To whom does the player appear to be larger?

**77. ssm** A quarter (diameter = 2.4 cm) is held at arms length (70.0 cm). The sun has a diameter of $1.39 \times 10^9$ m and is $1.50 \times 10^{11}$ m from the earth. What is the ratio of the angular size of the quarter to that of the sun?

**78.** An object has an angular size of 0.0150 rad when placed at the near point (21.0 cm) of an eye. When the eye views this object using a magnifying glass, the largest possible angular size of the image is 0.0380 rad. What is the focal length of the magnifying glass?

**79.** A magnifying glass is held next to the eye, above a magazine. The image formed by the magnifying glass is located at the near point of the eye. The near point is 0.30 m away from the eye, and the angular magnification is 3.4. Find the focal length of the magnifying glass.

**80.** The angular magnification of a magnifying glass ($f =$ 22 cm) used as in Figure 26.40*b* is 2.5. The person using it has a near point that is 36 cm from his eyes. What is the image distance for the object being examined?

***81. ssm** A person using a magnifying glass as in Figure 26.40*b* observes that for clear vision its maximum angular magnification is 1.25 times as large as its minimum angular magnification. Assuming that the person has a near point located 25 cm from her eye, what is the focal length of the magnifying glass?

****82.** A farsighted person can read printing as close as 25.0 cm when she wears contacts that have a focal length of 45.4 cm. One day, however, she forgets her contacts and uses a magnifying glass, as in Figure 26.40*b*. It has a maximum angular magnification of 7.50 for a young person with a normal near point of 25.0 cm. What is the maximum angular magnification that the magnifying glass can provide for her?

### Section 26.12 The Compound Microscope

**83.** A microscope for viewing blood cells has an objective with a focal length of 0.50 cm and an eyepiece with a focal length of 2.5 cm. The distance between the objective and eyepiece is 14.0 cm. If a blood cell subtends an angle of $2.1 \times 10^{-5}$ rad when viewed with the naked eye at a near point of 25.0 cm, what angle (magnitude only) does it subtend when viewed through the microscope?

**84.** The distance between the lenses in a microscope is 18 cm. The focal length of the objective is 1.5 cm. If the microscope is to provide an angular magnification of $-83$ when used by a person with a normal near point (25 cm from the eye), what must be the focal length of the eyepiece?

**85. ssm** A compound microscope has a barrel whose length is 16.0 cm and an eyepiece whose focal length is 1.4 cm. The viewer has a near point located 25 cm from his eyes. What focal length must the objective have so the angular magnification of the microscope is $-320$?

**86.** An anatomist is viewing heart muscle cells with a microscope that has two selectable objectives with refracting powers of

100 and 300 diopters. When she uses the 100-diopter objective, the image of a cell subtends an angle of $3 \times 10^{-3}$ rad with the eye. What angle is subtended when she uses the 300-diopter objective?

*87. The maximum angular magnification of a magnifying glass is 12.0 when a person uses it who has a near point that is 25.0 cm from his eyes. The same person finds that a microscope, using this magnifying glass as the eyepiece, has an angular magnification of −525. The separation between the eyepiece and the objective of the microscope is 23.0 cm. Obtain the focal length of the objective.

*88. In a compound microscope, the focal length of the objective is 3.50 cm and that of the eyepiece is 6.50 cm. The distance between the lenses is 26.0 cm. (a) What is the angular magnification of the microscope if the person using it has a near point of 35.0 cm? (b) If, as normal, the first image lies just inside the focal point of the eyepiece (see Figure 26.33), how far is the object from the objective? (c) What is the magnification (not the angular magnification) of the objective?

### Section 26.13 The Telescope

89. **ssm** An astronomical telescope has an angular magnification of −184 and uses an objective with a focal length of 48.0 cm. What is the focal length of the eyepiece?

90. An astronomical telescope for hobbyists has an angular magnification of −155. The eyepiece has a focal length of 5.00 mm. (a) Determine the focal length of the objective. (b) About how long is the telescope?

91. Mars subtends an angle of $8.0 \times 10^{-5}$ rad at the unaided eye. An astronomical telescope has an eyepiece with a focal length of 0.032 m. When Mars is viewed using this telescope, it subtends an angle of $2.8 \times 10^{-3}$ rad. Find the focal length of the telescope's objective lens.

92. A telescope has an objective and an eyepiece that have refractive powers of 1.25 diopters and 250 diopters, respectively. Find the angular magnification of the telescope.

93. **ssm** An amateur astronomer decides to build a telescope from a discarded pair of eyeglasses. One of the lenses has a refractive power of 11 diopters, while the other has a refractive power of 1.3 diopters. (a) Which lens should be the objective? (b) How far apart should the lenses be separated? (c) What is the angular magnification of the telescope?

*94. The objective and eyepiece of an astronomical telescope are 1.25 m apart, and the eyepiece has a focal length of 5.0 cm. What is the angular magnification of the telescope?

*95. The telescope at Yerkes Observatory in Wisconsin has an objective whose focal length is 19.4 m. Its eyepiece has a focal length of 10.0 cm. (a) What is the angular magnification of the telescope? (b) If the telescope is used to look at a lunar crater (diameter = 1500 m), what is the size of the first image, assuming the surface of the moon is $3.77 \times 10^8$ m from the surface of the earth? (c) How close does the crater appear to be when seen through the telescope?

**96. An astronomical telescope is being used to examine a relatively close object that is only 114.00 m away from the objective of the telescope. The objective and eyepiece have focal lengths of 1.500 and 0.070 m, respectively. Noting that the expression $M \approx -f_o/f_e$ is no longer applicable because the object is so close, use the thin-lens and magnification equations to find the angular magnification of this telescope. *(Hint: See Figure 26.42 and note that the focal points $F_o$ and $F_e$ are so close together that the distance between them may be ignored.)*

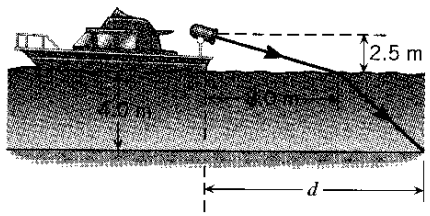
## ADDITIONAL PROBLEMS

97. **ssm** An object is located 9.0 cm in front of a converging lens ($f = 6.0$ cm). Using an accurately drawn ray diagram, determine where the image is located.

98. An insect subtends an angle of only $4.0 \times 10^{-3}$ rad at the unaided eye when placed at the near point. What is the angular size (magnitude only) when the insect is viewed through a microscope whose angular magnification has a magnitude of 160?

99. A glass block ($n = 1.60$) is immersed in a liquid. A ray of light within the glass hits a glass–liquid surface at a 65.0° angle of incidence. Some of the light enters the liquid. What is the smallest possible refractive index for the liquid?

100. A spotlight on a boat is 2.5 m above the water, and the light strikes the water at a point that is 8.0 m horizontally displaced from the spotlight (see the drawing). The depth of the water is 4.0 m. Determine the distance $d$, which locates the point where the light strikes the bottom.




101. **ssm** A nearsighted person has a far point located only 220 cm from his eyes. Determine the focal length of contact lenses that will enable him to see distant objects clearly.

102. Amber ($n = 1.546$) is a transparent brown-yellow fossil resin. An insect, trapped and preserved within the amber, appears to be 2.5 cm beneath the surface, when viewed directly from above. How far below the surface is the insect actually located?

103. A tourist takes a picture of a mountain 14 km away using a camera that has a lens with a focal length of 50 mm. She then takes a second picture when the mountain is only 5.0 km away. What is the ratio of the height of the mountain's image on the film for the second picture to its height on the film for the first picture?

104. A diverging lens has a focal length of −32 cm. An object is placed 19 cm in front of this lens. Calculate (a) the image distance and (b) the magnification. Is the image (c) real or virtual, (d) upright or inverted, and (e) enlarged or reduced in size?

105. **ssm** A light ray in air is incident on a water surface at a 43° angle of incidence. Find (a) the angle of reflection and (b) the angle of refraction.

**106.** A jeweler whose near point is 72 cm from his eye uses a magnifying glass as in Figure 26.40*b* to examine a watch. The watch is held 4.0 cm from the magnifying glass. Find the angular magnification of the magnifying glass.

**107. ssm** An optometrist prescribes contact lenses that have a focal length of 55.0 cm. (a) Are the lenses converging or diverging, and (b) is the person who wears them nearsighted or farsighted? (c) Where is the unaided near point of the person located, if the lenses are designed so that objects no closer than 35.0 cm can be seen clearly?

**108.** A ray of light traveling in material $A$ strikes the interface between materials $A$ and $B$ at an angle of incidence of 72°. The angle of refraction is 56°. Find the ratio $n_A/n_B$ of the refractive indices of the two materials.

**109.** A camper is trying to start a fire by focusing sunlight onto a piece of paper. The diameter of the sun is $1.39 \times 10^9$ m, and its mean distance from the earth is $1.50 \times 10^{11}$ m. The camper is using a converging lens whose focal length is 10.0 cm. (a) What is the area of the sun's image on the paper? (b) If 0.530 W of sunlight pass through the lens, what is the intensity of the sunlight at the paper?

**110.** (a) For a diverging lens ($f = -20.0$ cm), construct a ray diagram to scale and find the image distance for an object that is 20.0 cm from the lens. (b) Determine the magnification of the lens from the diagram.

***111. ssm** An office copier uses a lens to place an image of a document onto a rotating drum. The copy is made from this image. (a) What kind of lens is used? If the document and its copy are to have the same size, but are inverted with respect to one another, (b) how far from the document is the lens located and (c) how far from the lens is the image located? Express your answers in terms of the focal length $f$ of the lens.

***112.** A stamp collector is viewing a stamp with a magnifying glass held next to her eye. Her near point is 25 cm from her eye. (a) What is the refractive power of a magnifying glass that has an angular magnification of 6.0 when the image of the stamp is located at the near point? (b) What is the angular magnification when the image of the stamp is 45 cm from the eye?

***113. ssm** At age forty, a man requires contact lenses ($f = 65.0$ cm) to read a book held 25.0 cm from his eyes. At age forty-five, he finds that while wearing these contacts he must now hold a book 29.0 cm from his eyes. (a) By what distance has his near point *changed?* (b) What focal length lenses does he require at age forty-five to read a book at 25.0 cm?

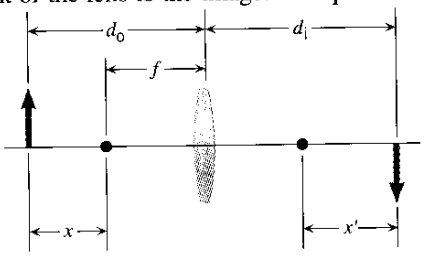
***114.** An object is in front of a converging lens ($f = 0.30$ m). The magnification of the lens is $m = 4.0$. (a) Relative to the lens, in what direction should the object be moved so that the magnification changes to $m = -4.0$? (b) Through what distance should the object be moved?

****115. ssm** The angular magnification of a telescope is 32 800 times as large when you look through the correct end of the telescope than when you look through the wrong end. What is the angular magnification of the telescope?

****116.** The equation

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

is called the *Gaussian* form of the thin-lens equation. The drawing shows the variables $d_o$, $d_i$, and $f$. The drawing also shows the distances $x$ and $x'$, which are, respectively, the distance from the object to the focal point on the left of the lens and the distance from the focal point on the right of the lens to the image. An equivalent form of the thin-lens equation, involving $x$, $x'$, and $f$, is called the *Newtonian* form. Show that the Newtonian form of the thin-lens equation can be written as $xx' = f^2$.




****117.** The contacts worn by a farsighted person allow her to see objects clearly that are as close as 25.0 cm, even though her uncorrected near point is 79.0 cm from her eyes. When she is looking at a poster, the contacts form an image of the poster at a distance of 217 cm from her eyes. (a) How far away is the poster actually located? (b) If the poster is 0.350 m tall, how tall is the image formed by the contacts?

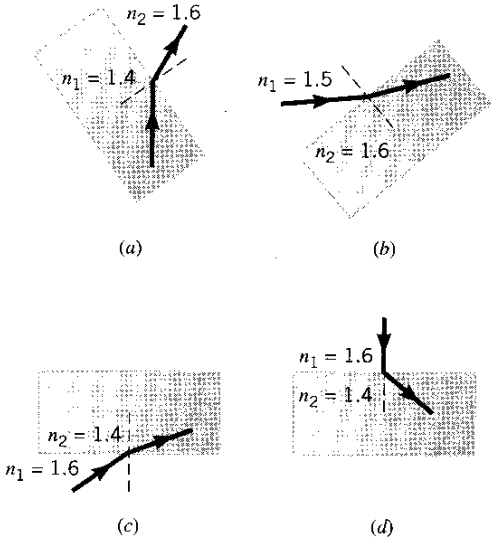
## CONCEPTS & CALCULATIONS

## GROUP LEARNING PROBLEMS

*Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on the concepts with which the problems deal. Recognizing the concepts is the essential initial step in any problem-solving technique.*

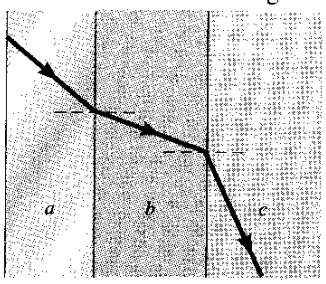
**118. Concept Questions** The drawing shows four different situations in which a light ray is traveling from one medium into another. Without doing any calculations, but taking note of the relative sizes of the angles of incidence and refraction, decide which situations (if any) show a refraction that is physically possible. Provide a reason as to why the refraction is possible or impossible.

**Problem** For the first three cases, the angle of incidence is 55°; for the fourth case, the angle of incidence is 0°. For each case, determine the actual angle of refraction. Check to be sure that your answers are consistent with your answers to the Concept Questions.



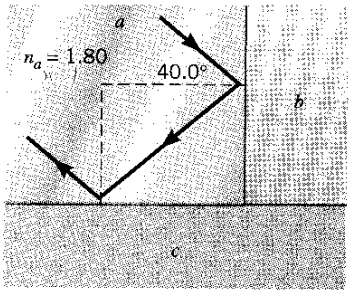

**119. Concept Question** The drawing shows a ray of light traveling through three materials whose surfaces are parallel to each other. The refracted rays (but not the reflected rays) are shown as the light passes through each material. Taking into account the relative sizes of the angles of incidence and refraction, rank the materials according to their indices of refraction, greatest first. Provide reasons for your ranking.

**Problem** A ray of light strikes the $a-b$ interface at a 50.0° angle of incidence. The index of refraction of material $a$ is $n_a = 1.20$. The angles of refraction in materials $b$ and $c$ are, respectively, 45.0° and 56.7°. Find the indices of refraction in these two media. Verify that your answers are consistent with your answers to the Concept Question.




**120. Concept Question** The drawing shows three materials, $a$, $b$, and $c$. A ray of light strikes the $a-b$ interface at its critical angle. The reflected ray then strikes the $a-c$ interface at its critical angle. Rank the three materials according to their indices of refraction, largest first.

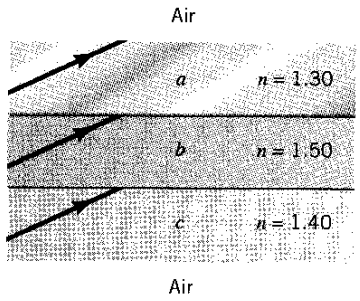
**Problem** A ray of light is incident at the $a-b$ interface with an angle of incidence equal to the critical angle, $\theta_c = 40.0°$. The index of refraction of material $a$ is $n_a = 1.80$. Find the indices of refraction for the two other materials. Be sure your ranking of the indices is consistent with that determined in the Concept Question.




**121. Concept Question** The drawing shows three layers of different materials, with air above and below the layers. The interfaces between the layers are parallel. The index of refraction of each layer is given in the drawing. Identical rays of light are sent into the layers, and each ray zigzags through the layer, reflecting from the top and bottom surfaces. Fill in the table below, specifying a "yes" or "no" as to whether total internal reflection is possible from the top and bottom surfaces of each layer. Provide a reason for each of your answers.

| | Is total internal reflection possible? | |
|---|---|---|
| Layer | Top surface of layer | Bottom surface of layer |
| a | | |
| b | | |
| c | | |

**Problem** For each layer, the ray of light has an angle of incidence of 75.0°. For the cases where total internal reflection is possible from either the top or bottom surface of a layer, determine the amount by which the angle of incidence exceeds the critical angle.




**122. Concept Questions** An object is placed to the left of a lens, and a real image is formed to the right of the lens. The image is inverted relative to the object and is one-half the size of the object. (a) What kind of lens, converging or diverging, is used to produce this image? (b) How is the height $h_i$ of the image related to the height $h_o$ of the object? Don't forget to take into account the fact that the image is inverted relative to the object. (c) What is the ratio $d_i/d_o$ of the image distance to the object distance?

**Problem** For the situation described in the Concept Questions, the distance between the object and the image is 90.0 cm. (a) How far from the lens is the object? (b) What is the focal length of the lens?

**123. Concept Question** Two systems are formed from a converging lens and a diverging lens, as shown in parts $a$ and $b$ of the drawing. (The point labeled "F" is the focal point of the converging lens.) An object is placed inside the focal point of lens 1. Without doing any calculations, determine for each system whether the final image lies to the left or to the right of lens 2. Provide a reason for each answer.

**Problem** The focal lengths of the converging and diverging lenses are 15.00 and −20.0 cm, respectively. The distance between the lenses is 50.0 cm, and an object is placed 10.00 cm to the left of lens 1. Determine the final image distance for each system, measured with respect to lens 2. Check to be sure your answers are consistent with your answers to the Concept Question.