Problems & Exercises

25.1 The Ray Aspect of Light

1.

Suppose a man stands in front of a mirror as shown in Figure 25.48. His eyes are 1.65 m above the floor, and the top of his head is 0.13 m higher. Find the height above the floor of the top and bottom of the smallest mirror in which he can see both the top of his head and his feet. How is this distance related to the man's height?

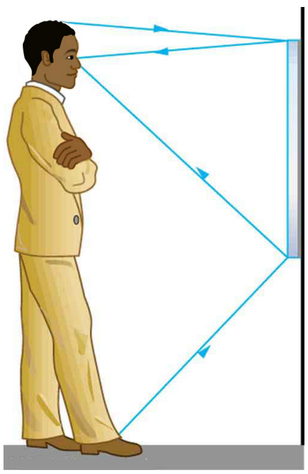

Figure 25.48 A full-length mirror is one in which you can see all of yourself. It need not be as big as you, and its size is independent of your distance from it.

25.2 The Law of Reflection

2.

Show that when light reflects from two mirrors that meet each other at a right angle, the outgoing ray is parallel to the incoming ray, as illustrated in the following figure.

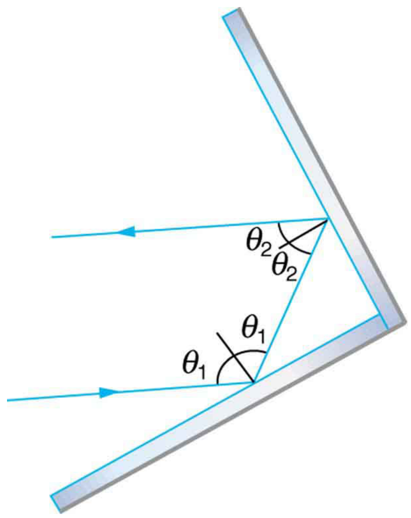

Figure 25.49 A corner reflector sends the reflected ray back in a direction parallel to the incident ray, independent of incoming direction.

3.

Light shows staged with lasers use moving mirrors to swing beams and create colorful effects. Show that a light ray reflected from a mirror changes direction by 2θ when the mirror is rotated by an angle θ.

4.

A flat mirror is neither converging nor diverging. To prove this, consider two rays originating from the same point and diverging at an angle θ. Show that after striking a plane mirror, the angle between their directions remains θ.

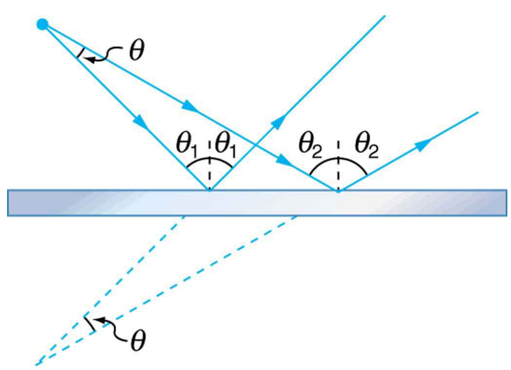

Figure 25.50 A flat mirror neither converges nor diverges light rays. Two rays continue to diverge at the same angle after reflection.

25.3 The Law of Refraction

5.

What is the speed of light in water? In glycerine?

6.

What is the speed of light in air? In crown glass?

7.

Calculate the index of refraction for a medium in which the speed of light is 2.012×10^8 m/s, and identify the most likely substance based on Table 25.1.

8.

In what substance in Table 25.1 is the speed of light 2.290×10^8 m/s?

9.

There was a major collision of an asteroid with the Moon in medieval times. It was described by monks at Canterbury Cathedral in England as a red glow on and around the Moon. How long after the asteroid hit the Moon, which is 3.84×10^5 km away, would the light first arrive on Earth?

10.

A scuba diver training in a pool looks at his instructor as shown in Figure 25.51. What angle does the ray from the instructor's face make with the perpendicular to the water at the point where the ray enters? The angle between the ray in the water and the perpendicular to the water is 25.0.

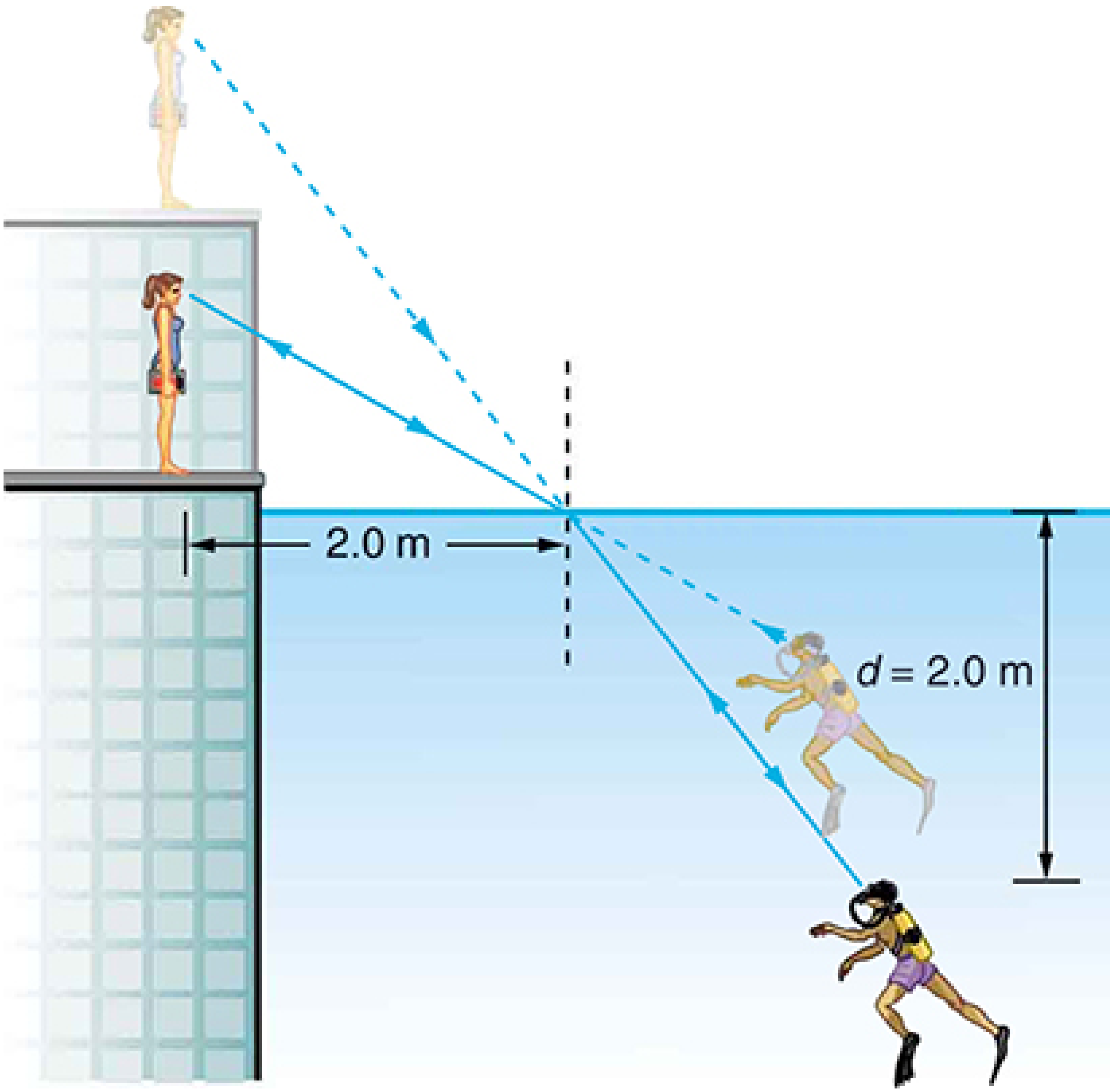

Figure 25.51 A scuba diver in a pool and his trainer look at each other.

11.

Components of some computers communicate with each other through optical fibers having an index of refraction $n = 1.55$. What time in nanoseconds is required for a signal to travel 0.200 m through such a fiber?

12.

(a) Given that the angle between the ray in the water and the perpendicular to the water is 25.0, and using information in Figure 25.51, find the height of the instructor's head above the water, noting that you will first have to calculate the angle of refraction. (b) Find the apparent depth of the diver's head below water as seen by the instructor. Assume the diver and the diver's image are the same horizontal distance from the normal.

13.

Suppose you have an unknown clear substance immersed in water, and you wish to identify it by finding its index of refraction. You arrange to have a beam of light enter it at an angle of 45.0, and you observe the angle of refraction to be 40.3. What is the index of refraction of the substance and its likely identity?

14.

On the Moon's surface, lunar astronauts placed a corner reflector, off which a laser beam is periodically reflected. The distance to the Moon is calculated from the round-trip time. What percent correction is needed to account for the delay in time due to the slowing of light in Earth's atmosphere? Assume the distance to the Moon is precisely 3.84×10^8 m, and Earth's atmosphere (which varies in density with altitude) is equivalent to a layer 30.0 km thick with a constant index of refraction $n = 1.000293$.

15.

Suppose Figure 25.52 represents a ray of light going from air through crown glass into water, such as going into a fish tank. Calculate the amount the ray is displaced by the glass (Δx), given that the incident angle is 40.0 and the glass is 1.00 cm thick.

16.

Figure 25.52 shows a ray of light passing from one medium into a second and then a third. Show that θ_3 is the same as it would be if the second medium were not present (provided total internal reflection does not occur).

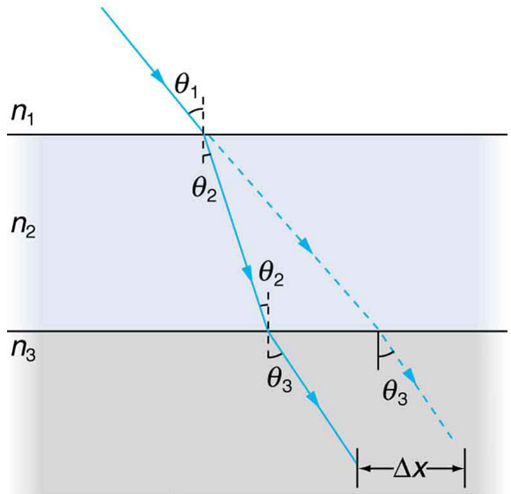

Figure 25.52 A ray of light passes from one medium to a third by traveling through a second. The final direction is the same as if the second medium were not present, but the ray is displaced by Δx (shown exaggerated).

17.

Unreasonable Results

Suppose light travels from water to another substance, with an angle of incidence of 10.0 and an angle of refraction of 14.9. (a) What is the index of refraction of the other substance? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent?

18.

Construct Your Own Problem

Consider sunlight entering the Earth's atmosphere at sunrise and sunset—that is, at a 90º incident angle. Taking the boundary between nearly empty space and the atmosphere to be sudden, calculate the angle of refraction for sunlight. This lengthens the time the Sun appears to be above the horizon, both at sunrise and sunset. Now construct a problem in which you determine the angle of refraction for different models of the atmosphere, such as various layers of varying density. Your instructor may wish to guide you on the level of complexity to consider and on how the index of refraction varies with air density.

19.

Unreasonable Results

Light traveling from water to a gemstone strikes the surface at an angle of 80.0 and has an angle of refraction of 15.2. (a) What is the speed of light in the gemstone? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent?

25.4 Total Internal Reflection

20.

Verify that the critical angle for light going from water to air is 48.6^{o}, as discussed at the end of Example 25.4, regarding the critical angle for light traveling in a polystyrene (a type of plastic) pipe surrounded by air.

21.

(a) At the end of Example 25.4, it was stated that the critical angle for light going from diamond to air is 24.4. Verify this. (b) What is the critical angle for light going from zircon to air?

22.

An optical fiber uses flint glass clad with crown glass. What is the critical angle?

23.

At what minimum angle will you get total internal reflection of light traveling in water and reflected from ice?

24.

Suppose you are using total internal reflection to make an efficient corner reflector. If there is air outside and the incident angle is 45.0, what must be the minimum index of refraction of the material from which the reflector is made?

25.

You can determine the index of refraction of a substance by determining its critical angle. (a) What is the index of refraction of a substance that has a critical angle of 68.4 when submerged in water? What is the substance, based on Table 25.1? (b) What would the critical angle be for this substance in air?

26.

A ray of light, emitted beneath the surface of an unknown liquid with air above it, undergoes total internal reflection as shown in Figure 25.53. What is the index of refraction for the liquid and its likely identification?

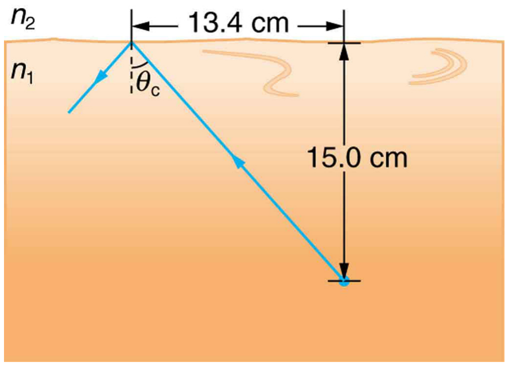

Figure 25.53 A light ray inside a liquid strikes the surface at the critical angle and undergoes total internal reflection.

27.

A light ray entering an optical fiber surrounded by air is first refracted and then reflected as shown in Figure 25.54. Show that if the fiber is made from crown glass, any incident ray will be totally internally reflected.

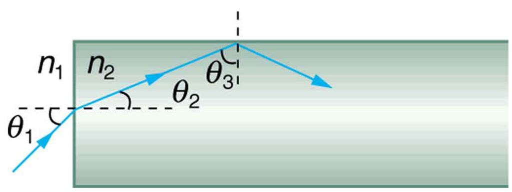

Figure 25.54 A light ray enters the end of a fiber, the surface of which is perpendicular to its sides. Examine the conditions under which it may be totally internally reflected.

25.5 Dispersion: The Rainbow and Prisms

28.

(a) What is the ratio of the speed of red light to violet light in diamond, based on Table 25.2? (b) What is this ratio in polystyrene? (c) Which is more dispersive?

29.

A beam of white light goes from air into water at an incident angle of 75.0. At what angles are the red (660 nm) and violet (410 nm) parts of the light refracted?

30.

By how much do the critical angles for red (660 nm) and violet (410 nm) light differ in a diamond surrounded by air?

31.

(a) A narrow beam of light containing yellow (580 nm) and green (550 nm) wavelengths goes from polystyrene to air, striking the surface at a 30.0 incident angle. What is the angle between the colors when they emerge? (b) How far would they have to travel to be separated by 1.00 mm?

32.

A parallel beam of light containing orange (610 nm) and violet (410 nm) wavelengths goes from fused quartz to water, striking the surface between them at a 60.0 incident angle. What is the angle between the two colors in water?

33.

A ray of 610 nm light goes from air into fused quartz at an incident angle of 55.0. At what incident angle must 470 nm light enter flint glass to have the same angle of refraction?

34.

A narrow beam of light containing red (660 nm) and blue (470 nm) wavelengths travels from air through a 1.00 cm thick flat piece of crown glass and back to air again. The beam strikes at a 30.0 incident angle. (a) At what angles do the two colors emerge? (b) By what distance are the red and blue separated when they emerge?

35.

A narrow beam of white light enters a prism made of crown glass at a 45.0 incident angle, as shown in Figure 25.55. At what angles, θ_R and θ_V, do the red (660 nm) and violet (410 nm) components of the light emerge from the prism?

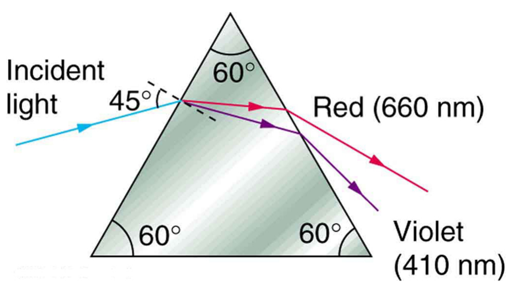

Figure 25.55 This prism will disperse the white light into a rainbow of colors. The incident angle is 45.0, and the angles at which the red and violet light emerge are θ_R and θ_V.

25.6 Image Formation by Lenses

36.

What is the power in diopters of a camera lens that has a 50.0 mm focal length?

37.

Your camera's zoom lens has an adjustable focal length ranging from 80.0 to 200 mm. What is its range of powers?

38.

What is the focal length of 1.75 D reading glasses found on the rack in a pharmacy?

39.

You note that your prescription for new eyeglasses is –4.50 D. What will their focal length be?

40.

How far from the lens must the film in a camera be, if the lens has a 35.0 mm focal length and is being used to photograph a flower 75.0 cm away? Explicitly show how you follow the steps in the Problem-Solving Strategy for lenses.

41.

A certain slide projector has a 100 mm focal length lens. (a) How far away is the screen, if a slide is placed 103 mm from the lens and produces a sharp image? (b) If the slide is 24.0 by 36.0 mm, what are the dimensions of the image? Explicitly show how you follow the steps in the Problem-Solving Strategy for lenses.

42.

A doctor examines a mole with a 15.0 cm focal length magnifying glass held 13.5 cm from the mole (a) Where is the image? (b) What is its magnification? (c) How big is the image of a 5.00 mm diameter mole?

43.

How far from a piece of paper must you hold your father's 2.25 D reading glasses to try to burn a hole in the paper with sunlight?

44.

A camera with a 50.0 mm focal length lens is being used to photograph a person standing 3.00 m away. (a) How far from the lens must the film be? (b) If the film is 36.0 mm high, what fraction of a 1.75 m tall person will fit on it? (c) Discuss how reasonable this seems, based on your experience in taking or posing for photographs.

45.

A camera lens used for taking close-up photographs has a focal length of 22.0 mm. The farthest it can be placed from the film is 33.0 mm. (a) What is the closest object that can be photographed? (b) What is the magnification of this closest object?

46.

Suppose your 50.0 mm focal length camera lens is 51.0 mm away from the film in the camera. (a) How far away is an object that is in focus? (b) What is the height of the object if its image is 2.00 cm high?

47.

(a) What is the focal length of a magnifying glass that produces a magnification of 3.00 when held 5.00 cm from an object, such as a rare coin? (b) Calculate the power of the magnifier in diopters. (c) Discuss how this power compares to those for store-bought reading glasses (typically 1.0 to 4.0 D). Is the magnifier's power greater, and should it be?

48.

What magnification will be produced by a lens of power –4.00 D (such as might be used to correct myopia) if an object is held 25.0 cm away?

49.

In Example 25.7, the magnification of a book held 7.50 cm from a 10.0 cm focal length lens was found to be 4.00. (a) Find the magnification for the book when it is held 8.50 cm from the magnifier. (b) Do the same for when it is held 9.50 cm from the magnifier. (c) Comment on the trend in m as the object distance increases as in these two calculations.

50.

Suppose a 200 mm focal length telephoto lens is being used to photograph mountains 10.0 km away. (a) Where is the image? (b) What is the height of the image of a 1000 m high cliff on one of the mountains?

51.

A camera with a 100 mm focal length lens is used to photograph the sun and moon. What is the height of the image of the sun on the film, given the sun is 1.40×10^6 km in diameter and is 1.50×10^8 km away?

52.

Combine thin lens equations to show that the magnification for a thin lens is determined by its focal length and the object distance and is given by $m = f/(f - d_o)$.

25.7 Image Formation by Mirrors

53.

What is the focal length of a makeup mirror that has a power of 1.50 D?

54.

Some telephoto cameras use a mirror rather than a lens. What radius of curvature mirror is needed to replace a 800 mm focal length telephoto lens?

55.

(a) Calculate the focal length of the mirror formed by the shiny back of a spoon that has a 3.00 cm radius of curvature. (b) What is its power in diopters?

56.

Find the magnification of the heater element in Example 25.9. Note that its large magnitude helps spread out the reflected energy.

57.

What is the focal length of a makeup mirror that produces a magnification of 1.50 when a person's face is 12.0 cm away? Explicitly show how you follow the steps in the Problem-Solving Strategy for Mirrors.

58.

A shopper standing 3.00 m from a convex security mirror sees his image with a magnification of 0.250. (a) Where is his image? (b) What is the focal length of the mirror? (c) What is its radius of curvature? Explicitly show how you follow the steps in the Problem-Solving Strategy for Mirrors.

59.

An object 1.50 cm high is held 3.00 cm from a person's cornea, and its reflected image is measured to be 0.167 cm high. (a) What is the magnification? (b) Where is the image? (c) Find the radius of curvature of the convex mirror formed by the cornea. (Note that this technique is used by optometrists to measure the curvature of the cornea for contact lens fitting. The instrument used is called a keratometer, or curve measurer.)

60.

Ray tracing for a flat mirror shows that the image is located a distance behind the mirror equal to the distance of the object from the mirror. This is stated $d_{\mathrm{i}} = -d_{\mathrm{o}}$, since this is a negative image distance (it is a virtual image). (a) What is the focal length of a flat mirror? (b) What is its power?

61.

Show that for a flat mirror $h_{\mathrm{i}} = h_{\mathrm{o}}$, knowing that the image is a distance behind the mirror equal in magnitude to the distance of the object from the mirror.

62.

Use the law of reflection to prove that the focal length of a mirror is half its radius of curvature. That is, prove that $f = R/2$. Note this is true for a spherical mirror only if its diameter is small compared with its radius of curvature.

63.

Referring to the electric room heater considered in the first example in this section, calculate the intensity of IR radiation in $\mathrm{W/m^2}$ projected by the concave mirror on a person 3.00 m away. Assume that the heating element radiates 1500 W and has an area of 100 cm^2, and that half of the radiated power is reflected and focused by the mirror.

64.

Consider a 250-W heat lamp fixed to the ceiling in a bathroom. If the filament in one light burns out then the remaining three still work. Construct a problem in which you determine the resistance of each filament in order to obtain a certain intensity projected on the bathroom floor. The ceiling is 3.0 m high. The problem will need to involve concave mirrors behind the filaments. Your instructor may wish to guide you on the level of complexity to consider in the electrical components.

65.

Critical Thinking Light composed of multiple frequencies passes through crown glass. (a) How much faster does the violet component of the light with a wavelength of 410 nm travel in the crown glass than the component of orange light with a wavelength of 610 nm? (b) In a mechanical situation with friction, the longer one surface moves relative to the other, the more the friction acts, slowing the relative motion during the process. Is this the same for light in a medium? (c) In a mechanical situation, it is possible for friction to stop the motion if it occurs over a long enough path. Is this the same for light in a medium? (d) In a mechanical friction situation, once the object slows it will not increase in speed once the friction no longer acts unless another force is present. If a light ray exits a medium into a vacuum, will it go back to a speed of c even though that would be an increase in speed not caused by an additional force?