2013 assignment

Mirrors:
1,3,7,9,10,12,15,22

Refraction:
24,26,28,30,31,36,39

Lenses:
43,45,48,52,53

* 23–10 Lensmaker's Equation

A useful equation, known as the **lensmaker's equation**, relates the focal length of a lens to the radii of curvature R_1 and R_2 of its two surfaces and its index of refraction n:

$$\frac{1}{f} = (n - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right). \tag{23–10}$$

If both surfaces are convex, R_1 and R_2 are considered positive.[†] For a concave surface, the radius must be considered *negative*.

Notice that Eq. 23–10 is symmetrical in R_1 and R_2. Thus, if a lens is turned around so that light impinges on the other surface, the focal length is the same even if the two lens surfaces are different.

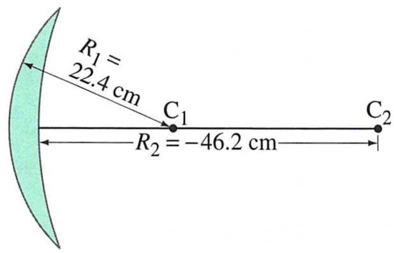

FIGURE 23–43 Example 23–14.

EXAMPLE 23–14 Calculating *f* for a converging lens. A convex meniscus lens (Figs. 23–29a and 23–43) is made from glass with $n = 1.50$. The radius of curvature of the convex surface is 22.4 cm, and that of the concave surface is 46.2 cm. What is the focal length?

APPROACH We use the lensmaker's equation, Eq. 23–10, to find f.

SOLUTION $R_1 = 22.4$ cm and $R_2 = -46.2$ cm (concave surface). Then

$$\frac{1}{f} = (1.50 - 1.00)\left(\frac{1}{22.4\text{ cm}} - \frac{1}{46.2\text{ cm}}\right) = 0.0115\text{ cm}^{-1}.$$

So

$$f = \frac{1}{0.0115\text{ cm}^{-1}} = 87\text{ cm},$$

and the lens is converging since $f > 0$.

NOTE If we turn the lens around so that $R_1 = -46.2$ cm and $R_2 = +22.4$ cm, we get the same result.

[†]Some books use a different convention—for example, R_1 and R_2 are considered positive if their centers of curvature are to the right of the lens, in which case a minus sign replaces the + sign in their equivalent of Eq. 23–10.

Summary

Light appears to travel in straight-line paths, called **rays**, at a speed v that depends on the **index of refraction**, n, of the material; that is

$$n = \frac{c}{v}, \tag{23–4}$$

where c is the speed of light in vacuum.

When light reflects from a flat surface, the *angle of reflection equals the angle of incidence*. This **law of reflection** explains why mirrors can form **images**.

In a **plane mirror**, the image is virtual, upright, the same size as the object, and is as far behind the mirror as the object is in front.

A **spherical mirror** can be concave or convex. A **concave** spherical mirror focuses parallel rays of light (light from a very distant object) to a point called the **focal point**. The distance of this point from the mirror is the **focal length** f of the mirror and

$$f = \frac{r}{2}, \tag{23–1}$$

where r is the radius of curvature of the mirror.

Parallel rays falling on a **convex mirror** reflect from the mirror as if they diverged from a common point behind the mirror. The distance of this point from the mirror is the focal length and is considered negative for a convex mirror.

For a given object, the approximate position and size of the image formed by a mirror can be found by ray tracing. Algebraically, the relation between image and object distances, d_i and d_o, and the focal length f, is given by the **mirror equation:**

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}. \tag{23–2}$$

The ratio of image height h_i to object height h_o, which equals the magnification m of a mirror, is

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}. \tag{23–3}$$

If the rays that converge to form an image actually pass through the image, so the image would appear on film or a screen placed there, the image is said to be a **real image**. If the light rays do not actually pass through the image, the image is a **virtual image**.

When light passes from one transparent medium into another, the rays bend or refract. The **law of refraction** (**Snell's law**) states that

$$n_1 \sin\theta_1 = n_2 \sin\theta_2, \tag{23–5}$$

where n_1 and θ_1 are the index of refraction and angle with the normal to the surface for the incident ray, and n_2 and θ_2 are for the refracted ray.

When light rays reach the boundary of a material where the index of refraction decreases, the rays will be **totally internally reflected** if the incident angle, θ_1, is such that Snell's law would predict $\sin\theta_2 > 1$. This occurs if θ_1 exceeds the critical angle θ_C given by

$$\sin\theta_C = \frac{n_2}{n_1}. \tag{23–6}$$

A lens uses refraction to produce a real or virtual image. Parallel rays of light are focused to a point, called the **focal point**, by a **converging** lens. The distance of the focal point from the lens is called the **focal length** f of the lens.

After parallel rays pass through a **diverging** lens, they appear to diverge from a point, its focal point; and the corresponding focal length is considered negative.

The **power** P of a lens, which is $P = 1/f$ (Eq. 23–7), is given in diopters, which are units of inverse meters (m^{-1}).

For a given object, the position and size of the image formed by a lens can be found approximately by ray tracing. Algebraically, the relation between image and object distances, d_i and d_o, and the focal length f, is given by the **thin lens equation**:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}. \tag{23–8}$$

The ratio of image height to object height, which equals the magnification m for a lens, is

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}. \tag{23–9}$$

When using the various equations of geometrical optics, it is important to remember the **sign conventions** for all quantities involved: carefully review them (pages 641 and 651) when doing Problems.

[* When two (or more) thin lenses are used in combination to produce an image, the thin lens equation can be used for each lens in sequence. The image produced by the first lens acts as the object for the second lens. The **lensmaker's equation** relates the radii of curvature of the lens surfaces and the lens' index of refraction to the focal length of the lens.]

Questions

1. What would be the appearance of the Moon if it had (*a*) a rough surface; (*b*) a polished mirrorlike surface?
2. Archimedes is said to have burned the whole Roman fleet in the harbor of Syracuse by focusing the rays of the Sun with a huge spherical mirror. Is this reasonable?
3. Although a plane mirror appears to reverse left and right, it doesn't reverse up and down. Explain.
4. If a concave mirror produces a real image, is the image necessarily inverted? Explain.
5. An object is placed along the principal axis of a spherical mirror. The magnification of the object is −3.0. Is the image real or virtual, inverted or upright? Is the mirror concave or convex? On which side of the mirror is the image located?
6. Using the rules for the three rays discussed with reference to Fig. 23–13, draw ray 2 for Fig. 23–17b.
7. What is the focal length of a plane mirror? What is the magnification of a plane mirror?
8. When you look at the Moon's reflection from a ripply sea, it appears elongated (Fig. 23–44). Explain.

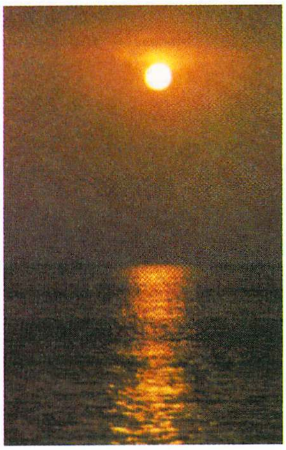

FIGURE 23–44 Question 8.

9. What is the angle of refraction when a light ray meets the boundary between two materials perpendicularly?
10. How might you determine the speed of light in a solid, rectangular, transparent object?
11. When you look down into a swimming pool or a lake, are you likely to underestimate or overestimate its depth? Explain. How does the apparent depth vary with the viewing angle? (Use ray diagrams.)
12. Draw a ray diagram to show why a stick looks bent when part of it is under water (Fig. 23–21).
13. Your eye looks into an aquarium and views a fish inside. One ray of light that emerges from the tank is shown in Fig. 23–45, as well as the apparent position of the fish. In the drawing, indicate the approximate position of the actual fish. Briefly justify your answer.

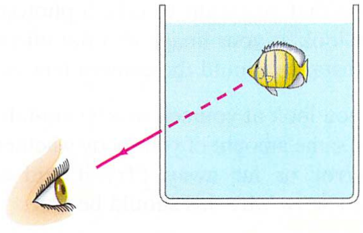

FIGURE 23–45 Question 13.

14. How can you "see" a round drop of water on a table even though the water is transparent and colorless?
15. When you look up at an object in air from beneath the surface in a swimming pool, does the object appear to be the same size as when you see it directly in air? Explain.
16. How can a spherical mirror have a negative object distance?

17. Light rays from stars (including our Sun) always bend toward the vertical direction as they pass through the Earth's atmosphere. (*a*) Why does this make sense? (*b*) What can you conclude about the apparent positions of stars as viewed from Earth?

18. Where must the film be placed if a camera lens is to make a sharp image of an object very far away?

19. What type of mirror is shown in Fig. 23–46? Explain.

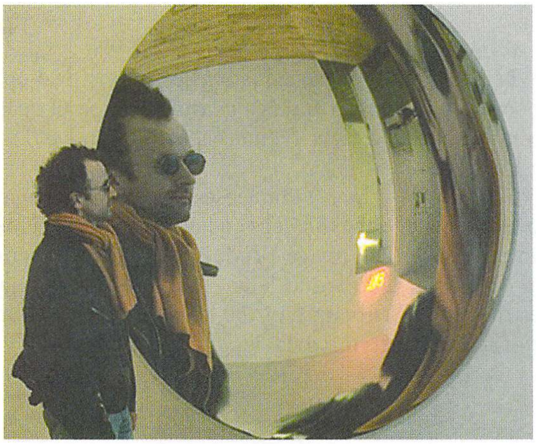

FIGURE 23–46 Question 19.

20. A photographer moves closer to his subject and then refocuses. Does the camera lens move farther from or closer to the film? Explain.

21. Can a diverging lens form a real image under any circumstances? Explain.

22. Use ray diagrams to show that a real image formed by a thin lens is always inverted, whereas a virtual image is always upright if the object is real.

23. Light rays are said to be "reversible." Is this consistent with the thin lens equation? Explain.

24. Can real images be projected on a screen? Can virtual images? Can either be photographed? Discuss carefully.

25. A thin converging lens is moved closer to a nearby object. Does the real image formed change (*a*) in position, (*b*) in size? If yes, describe how.

26. A lens is made of a material with an index of refraction $n = 1.30$. In air, it is a converging lens. Will it still be a converging lens if placed in water? Explain, using a ray diagram.

27. A dog with its tail in the air stands facing a converging lens. If the nose and the tail are each focused on a screen in turn, which will have the greater magnification?

28. A cat with its tail in the air stands facing a converging lens. Under what circumstances (if any) would the image of the nose be virtual and the image of the tail be real? Where would the image of the rest of the cat be?

* 29. Why, in Example 23–13, must the converging lens have a shorter focal length than the diverging lens if the latter's focal length is to be determined by combining them?

* 30. Explain how you could have a virtual object.

* 31. An unsymmetrical lens (say, planoconvex) forms an image of a nearby object. Does the image point change if the lens is turned around?

* 32. The thicker a double convex lens is in the center as compared to its edges, the shorter its focal length for a given lens diameter. Explain.

* 33. Consider two converging lenses separated by some distance. An object is placed so that the image from the first lens lies exactly at the focal point of the second lens. Will this combination produce an image? If so, where? If not, why not?

Problems

23–2 Reflection; Plane Mirrors

1. (I) Suppose that you want to take a photograph of yourself as you look at your image in a flat mirror 2.5 m away. For what distance should the camera lens be focused?

2. (I) When you look at yourself in a 60-cm-tall plane mirror, you see the same amount of your body whether you are close to the mirror or far away. (Try it and see.) Use ray diagrams to show why this should be true.

3. (II) Two mirrors meet at a 135° angle, Fig. 23–47. If light rays strike one mirror at 40° as shown, at what angle ϕ do they leave the second mirror?

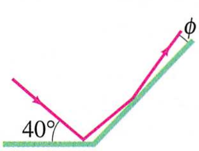

FIGURE 23–47 Problem 3.

4. (II) A person whose eyes are 1.68 m above the floor stands 2.20 m in front of a vertical plane mirror whose bottom edge is 43 cm above the floor, Fig. 23–48. What is the horizontal distance x to the base of the wall supporting the mirror of the nearest point on the floor that can be seen reflected in the mirror?

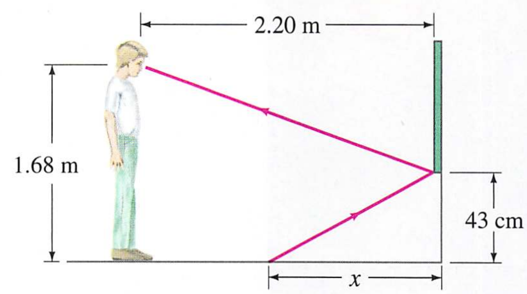

FIGURE 23–48 Problem 4.

5. (II) Suppose you are 90 cm from a plane mirror. What area of the mirror is used to reflect the rays entering one eye from a point on the tip of your nose if your pupil diameter is 5.5 mm?

6. (III) Show that if two plane mirrors meet at an angle ϕ, a single ray reflected successively from both mirrors is deflected through an angle of 2ϕ independent of the incident angle. Assume $\phi < 90°$ and that only two reflections, one from each mirror, take place.

23–3 Spherical Mirrors

7. (I) A solar cooker, really a concave mirror pointed at the Sun, focuses the Sun's rays 18.0 cm in front of the mirror. What is the radius of the spherical surface from which the mirror was made?

8. (I) How far from a concave mirror (radius 23.0 cm) must an object be placed if its image is to be at infinity?

9. (II) If you look at yourself in a shiny Christmas tree ball with a diameter of 9.0 cm when your face is 30.0 cm away from it, where is your image? Is it real or virtual? Is it upright or inverted?

10. (II) A mirror at an amusement park shows an upright image of any person who stands 1.4 m in front of it. If the image is three times the person's height, what is the radius of curvature?

11. (II) A dentist wants a small mirror that, when 2.20 cm from a tooth, will produce a 4.5× upright image. What kind of mirror must be used and what must its radius of curvature be?

12. (II) Some rearview mirrors produce images of cars behind you that are smaller than they would be if the mirror were flat. Are the mirrors concave or convex? What is a mirror's radius of curvature if cars 20.0 m away appear 0.33× their normal size?

13. (II) A luminous object 3.0 mm high is placed 20.0 cm from a convex mirror of radius of curvature 20.0 cm. (*a*) Show by ray tracing that the image is virtual, and estimate the image distance. (*b*) Show that the (negative) image distance can be computed from Eq. 23–2 using a focal length of −10.0 cm. (*c*) Compute the image size, using Eq. 23–3.

14. (II) You are standing 3.0 m from a convex security mirror in a store. You estimate the height of your image to be half of your actual height. Estimate the radius of curvature of the mirror.

15. (II) (*a*) Where should an object be placed in front of a concave mirror so that it produces an image at the same location as the object? (*b*) Is the image real or virtual? (*c*) Is the image inverted or upright? (*d*) What is the magnification of the image?

16. (II) The image of a distant tree is virtual and very small when viewed in a curved mirror. The image appears to be 18.0 cm behind the mirror. What kind of mirror is it, and what is its radius of curvature?

17. (II) Use two different techniques, (*a*) a ray diagram, and (*b*) the mirror equation, to show that the magnitude of the magnification of a concave mirror is less than 1 if the object is beyond the center of curvature C $(d_o > r)$, and is greater than 1 if the object is within C $(d_o < r)$.

18. (II) Show, using a ray diagram, that the magnification m of a convex mirror is $m = -d_i/d_o$, just as for a concave mirror. [*Hint*: consider a ray from the top of the object that reflects at the center of the mirror.]

19. (II) Use ray diagrams to show that the mirror equation, Eq. 23–2, is valid for a convex mirror as long as f is considered negative.

20. (II) The magnification of a convex mirror is +0.65× for objects 2.2 m from the mirror. What is the focal length of this mirror?

21. (III) A 4.5-cm-tall object is placed 28 cm in front of a spherical mirror. It is desired to produce a virtual image that is upright and 3.5 cm tall. (*a*) What type of mirror should be used? (*b*) Where is the image located? (*c*) What is the focal length of the mirror? (*d*) What is the radius of curvature of the mirror?

22. (III) A shaving/makeup mirror is designed to magnify your face by a factor of 1.33 when your face is placed 20.0 cm in front of it. (*a*) What type of mirror is it? (*b*) Describe the type of image that it makes of your face. (*c*) Calculate the required radius of curvature for the mirror.

23–4 Index of Refraction

23. (I) What is the speed of light in (*a*) crown glass, (*b*) Lucite, and (*c*) ethyl alcohol?

24. (I) The speed of light in ice is 2.29×10^8 m/s. What is the index of refraction of ice?

25. (II) The speed of light in a certain substance is 89% of its value in water. What is the index of refraction of this substance?

23–5 Refraction: Snell's Law

26. (I) A flashlight beam strikes the surface of a pane of glass ($n = 1.58$) at a 63° angle to the normal. What is the angle of refraction?

27. (I) A diver shines a flashlight upward from beneath the water at a 42.5° angle to the vertical. At what angle does the light leave the water?

28. (I) A light beam coming from an underwater spotlight exits the water at an angle of 66.0° to the vertical. At what angle of incidence does it hit the air–water interface from below the surface?

29. (I) Rays of the Sun are seen to make a 31.0° angle to the vertical beneath the water. At what angle above the horizon is the Sun?

30. (II) An aquarium filled with water has flat glass sides whose index of refraction is 1.52. A beam of light from outside the aquarium strikes the glass at a 43.5° angle to the perpendicular (Fig. 23–49). What is the angle of this light ray when it enters (*a*) the glass, and then (*b*) the water? (*c*) What would be the refracted angle if the ray entered the water directly?

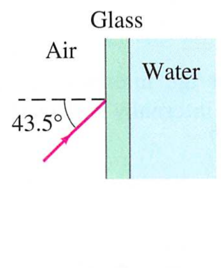

FIGURE 23–49
Problem 30.

31. (II) In searching the bottom of a pool at night, a watchman shines a narrow beam of light from his flashlight, 1.3 m above the water level, onto the surface of the water at a point 2.7 m from the edge of the pool (Fig. 23–50). Where does the spot of light hit the bottom of the pool, measured from the wall beneath his foot, if the pool is 2.1 m deep?

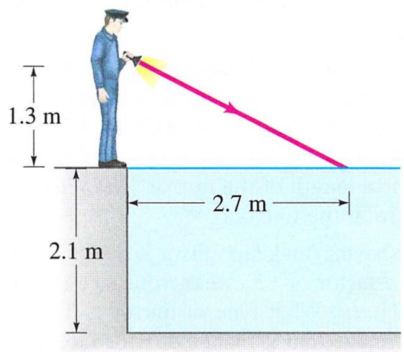

FIGURE 23–50 Problem 31.

32. (II) Light is incident on an equilateral glass prism at a 45.0° angle to one face, Fig. 23–51. Calculate the angle at which light emerges from the opposite face. Assume that $n = 1.58$.

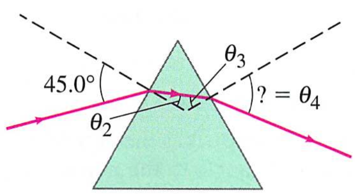

FIGURE 23–51 Problems 32 and 40.

33. (II) A beam of light in air strikes a slab of glass ($n = 1.52$) and is partially reflected and partially refracted. Find the angle of incidence if the angle of reflection is twice the angle of refraction.

34. (III) Prove in general that for a light beam incident on a uniform layer of transparent material, as in Fig. 23–22, the direction of the emerging beam is parallel to the incident beam, independent of the incident angle θ. Assume air on both sides of the glass.

35. (III) A light ray is incident on a flat piece of glass with index of refraction n as in Fig. 23–22. Show that if the incident angle θ is small, the emerging ray is displaced a distance $d = t\theta(n - 1)/n$ from the incident ray, where t is the thickness of the glass and θ is in radians. [*Hint*: for small θ, $\sin\theta \approx \tan\theta \approx \theta$ in radians.]

23–6 Total Internal Reflection

36. (I) What is the critical angle for the interface between water and Lucite? To be totally internally reflected, the light must start in which material?

37. (I) The critical angle for a certain liquid–air surface is 47.7°. What is the index of refraction of the liquid?

38. (II) A beam of light is emitted in a pool of water from a depth of 62.0 cm. Where must it strike the air–water interface, relative to the spot directly above it, in order that the light does *not* exit the water?

39. (II) A beam of light is emitted 8.0 cm beneath the surface of a liquid and strikes the surface 7.0 cm from the point directly above the source. If total internal reflection occurs, what can you say about the index of refraction of the liquid?

40. (III) Suppose a ray strikes the left face of the prism in Fig. 23–51 at 45.0° as shown, but is totally internally reflected at the opposite side. If the prism apex angle (at the top) is $\phi = 75.0°$, what can you say about the index of refraction of the prism?

41. (III) A beam of light enters the end of an optic fiber as shown in Fig. 23–52. Show that we can guarantee total internal reflection at the side surface of the material (at point a), if the index of refraction is greater than about 1.42. In other words, regardless of the angle α, the light beam reflects back into the material at point a.

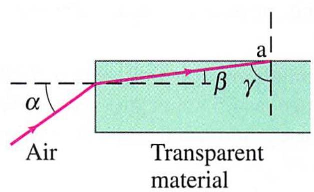

FIGURE 23–52 Problem 41.

42. (III) (*a*) What is the minimum index of refraction for a glass or plastic prism to be used in binoculars (Fig. 23–26) so that total internal reflection occurs at 45°? (*b*) Will binoculars work if its prisms (assume $n = 1.50$) are immersed in water? (*c*) What minimum n is needed if the prisms are immersed in water?

23–7 and 23–8 Thin Lenses

43. (I) A sharp image is located 78.0 mm behind a 65.0-mm-focal-length converging lens. Find the object distance (*a*) using a ray diagram, (*b*) by calculation.

44. (I) Sunlight is observed to focus at a point 18.5 cm behind a lens. (*a*) What kind of lens is it? (*b*) What is its power in diopters?

45. (I) A certain lens focuses light from an object 2.75 m away as an image 48.3 cm on the other side of the lens. What type of lens is it and what is its focal length? Is the image real or virtual?

46. (I) (*a*) What is the power of a 20.5-cm-focal-length lens? (*b*) What is the focal length of a −6.25-diopter lens? (*c*) Are these lenses converging or diverging?

47. (II) A stamp collector uses a converging lens with focal length 24 cm to view a stamp 18 cm in front of the lens. (*a*) Where is the image located? (*b*) What is the magnification?

48. (II) A −5.5-D lens is held 14.0 cm from an object 4.0 mm high. What are the position, type, and height of the image?

49. (II) An 80-mm-focal-length lens is used to focus an image on the film of a camera. The maximum distance allowed between the lens and the film plane is 120 mm. (*a*) How far ahead of the film should the lens be if the object to be photographed is 10.0 m away? (*b*) 3.0 m away? (*c*) 1.0 m away? (*d*) What is the closest object this lens could photograph sharply?

50. (II) It is desired to magnify reading material by a factor of 2.5× when a book is placed 8.0 cm behind a lens. (*a*) Draw a ray diagram and describe the type of image this would be. (*b*) What type of lens is needed? (*c*) What is the power of the lens in diopters?

51. (II) An object is located 1.5 m from an 8.0-D lens. By how much does the image move if the object is moved (*a*) 1.0 m closer to the lens, and (*b*) 1.0 m farther from the lens?

52. (II) How far from a converging lens with a focal length of 25 cm should an object be placed to produce a real image which is the same size as the object?

53. (II) (*a*) How far from a 50.0-mm-focal-length lens must an object be placed if its image is to be magnified 2.00× and be real? (*b*) What if the image is to be virtual and magnified 2.00×?

54. (II) Repeat Problem 53 for a −50.0-mm-focal-length lens. [*Hint*: consider objects real or virtual (formed by some other piece of optics).]

55. (II) (*a*) A 2.00-cm-high insect is 1.20 m from a 135-mm-focal-length lens. Where is the image, how high is it, and what type is it? (*b*) What if $f = -135$ mm?

56. (III) How far apart are an object and an image formed by a 75-cm-focal-length converging lens if the image is 2.5× larger than the object and is real?

57. (III) A bright object and a viewing screen are separated by a distance of 66.0 cm. At what location(s) between the object and the screen should a lens of focal length 12.5 cm be placed in order to produce a crisp image on the screen? [*Hint*: first draw a diagram.]

* 23–9 Lens Combinations

* 58. (II) Two 28.0-cm-focal-length converging lenses are placed 16.5 cm apart. An object is placed 36.0 cm in front of one lens. Where will the final image formed by the second lens be located? What is the total magnification?

* 59. (II) A diverging lens with $f = -31.5$ cm is placed 14.0 cm behind a converging lens with $f = 20.0$ cm. Where will an object at infinity be focused?

* 60. (II) A 31.0-cm-focal-length converging lens is 21.0 cm behind a diverging lens. Parallel light strikes the diverging lens. After passing through the converging lens, the light is again parallel. What is the focal length of the diverging lens? [*Hint*: first draw a ray diagram.]

* 61. (II) The two converging lenses of Example 23–12 are now placed only 20.0 cm apart. The object is still 60.0 cm in front of the first lens as in Fig. 23–41. In this case, determine (*a*) the position of the final image, and (*b*) the overall magnification. (*c*) Sketch the ray diagram for this system.

* 62. (II) Two converging lenses are placed 30.0 cm apart. The focal length of the lens on the right is 20.0 cm, and the focal length of the lens on the left is 15.0 cm. An object is placed to the left of the 15.0-cm-focal-length lens. A final image from both lenses is inverted and located halfway between the two lenses. How far to the left of the 15.0-cm-focal-length lens is the original object?

* 63. (II) A diverging lens with a focal length of −14 cm is placed 12 cm to the right of a converging lens with a focal length of 18 cm. An object is placed 33 cm to the left of the converging lens. (*a*) Where will the final image be located? (*b*) Where will the image be if the diverging lens is 38 cm from the converging lens?

* 64. (II) Two lenses, one converging with focal length 20.0 cm and one diverging with focal length −10.0 cm, are placed 25.0 cm apart. An object is placed 60.0 cm in front of the converging lens. Determine (*a*) the position and (*b*) the magnification of the final image formed. (*c*) Sketch a ray diagram for this system.

* 65. (III) A diverging lens is placed next to a converging lens of focal length f_C, as in Fig. 23–42. If f_T represents the focal length of the combination, show that the focal length of the diverging lens, f_D, is given by

$$\frac{1}{f_D} = \frac{1}{f_T} - \frac{1}{f_C}.$$

* 23–10 Lensmaker's Equation

* 66. (I) A double concave lens has surface radii of 34.2 cm and 23.8 cm. What is the focal length if $n = 1.52$?

* 67. (I) Both surfaces of a double convex lens have radii of 31.0 cm. If the focal length is 28.9 cm, what is the index of refraction of the lens material?

* 68. (II) A planoconcave lens ($n = 1.50$) has a focal length of −23.4 cm. What is the radius of the concave surface?

* 69. (II) A Lucite planoconcave lens (see Fig. 23–29b) has one flat surface and the other has $R = -18.4$ cm. What is the focal length?

* 70. (II) A symmetric double convex lens with a focal length of 25.0 cm is to be made from glass with an index of refraction of 1.52. What should be the radius of curvature for each surface?

* 71. (II) A prescription for a corrective lens calls for +1.50 D. The lensmaker grinds the lens from a "blank" with $n = 1.56$ and a preformed convex front surface of radius of curvature of 40.0 cm. What should be the radius of curvature of the other surface?

General Problems

72. Two plane mirrors face each other 2.0 m apart as in Fig. 23–53. You stand 1.5 m away from one of these mirrors and look into it. You will see multiple images of yourself. (*a*) How far away from you are the first three images in the mirror in front of you? (*b*) Are these first three images facing toward you or away from you?

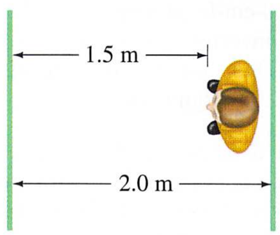

FIGURE 23–53 Problem 72.

73. We wish to determine the depth of a swimming pool filled with water. We measure the width ($x = 5.50$ m) and then note that the bottom edge of the pool is just visible at an angle of 14.0° above the horizontal as shown in Fig. 23–54. Calculate the depth of the pool.

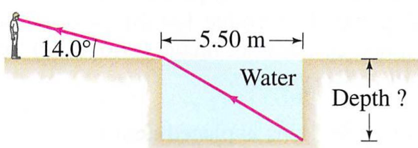

FIGURE 23–54 Problem 73.

74. The critical angle of a certain piece of plastic in air is $\theta_C = 37.3°$. What is the critical angle of the same plastic if it is immersed in water?

75. (*a*) A plane mirror can be considered a limiting case of a spherical mirror. Specify what this limit is. (*b*) Determine an equation that relates the image and object distances in this limit of a plane mirror. (*c*) Determine the magnification of a plane mirror in this same limit. (*d*) Are your results in parts (*b*) and (*c*) consistent with the discussion of Section 23–2 on plane mirrors?

76. Stand up two plane mirrors so they form a 90° angle as in Fig. 23–55. When you look into this double mirror, you see yourself as others see you, instead of reversed as in a single mirror. Make a careful ray diagram to show how this occurs.

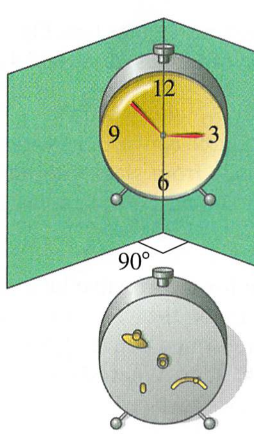

FIGURE 23–55 Problem 76.

77. Show analytically that a diverging lens can never form a real image of a real object. Can you describe a situation in which a diverging lens can form a real image?

78. Each student in a physics lab is assigned to find the location where a bright object may be placed in order that a concave mirror with radius of curvature $r = 40$ cm will produce an image three times the size of the object. Two students complete the assignment at different times using identical equipment, but when they compare notes later, they discover that their answers for the object distance are not the same. Explain why they do not necessarily need to repeat the lab, and justify your response with a calculation.

79. If the apex angle of a prism is $\phi = 72°$ (see Fig. 23–56), what is the minimum incident angle for a ray if it is to emerge from the opposite side (i.e., not be totally internally reflected), given $n = 1.50$?

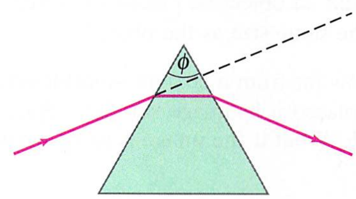

FIGURE 23–56 Problem 79.

80. The end faces of a cylindrical glass rod ($n = 1.54$) are perpendicular to the sides. Show that a light ray entering an end face at any angle will be totally internally reflected inside the rod when the ray strikes the sides. Assume the rod is in air. What if it were in water?

* 81. A lighted candle is placed 33 cm in front of a converging lens of focal length $f_1 = 15$ cm, which in turn is 55 cm in front of another converging lens of focal length $f_2 = 12$ cm (see Fig. 23–57). (*a*) Draw a ray diagram and estimate the location and the relative size of the final image. (*b*) Calculate the position and relative size of the final image.

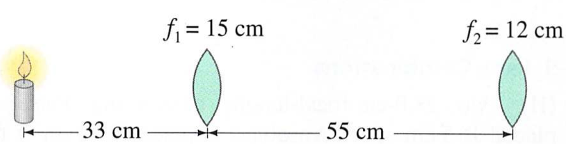

FIGURE 23–57 Problem 81.

82. A bright object is placed on one side of a converging lens of focal length f, and a white screen for viewing the image is on the opposite side. The distance $d_T = d_i + d_o$ between the object and the screen is kept fixed, but the lens can be moved. (*a*) Show that if $d_T > 4f$, there will be two positions where the lens can be placed and a sharp image will be produced on the screen. (*b*) If $d_T < 4f$, show that there will be no lens position where a sharp image is formed. (*c*) Determine a formula for the distance between the two lens positions in part (*a*), and the ratio of the image sizes.

83. In a slide or movie projector, the film acts as the object whose image is projected on a screen (Fig. 23–58). If a 105-mm-focal-length lens is to project an image on a screen 8.00 m away, how far from the lens should the slide be? If the slide is 36 mm wide, how wide will the picture be on the screen?

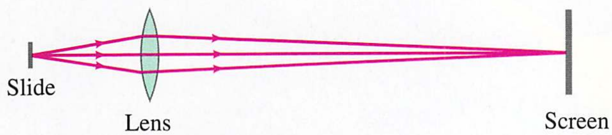

FIGURE 23–58 Problem 83.

84. A 35-mm slide (picture size is actually 24 by 36 mm) is to be projected on a screen 1.80 m by 2.70 m placed 7.50 m from the projector. What focal-length lens should be used if the image is to cover the screen?

85. Show analytically that the image formed by a converging lens is real and inverted if the object is beyond the focal point ($d_o > f$), and is virtual and upright if the object is within the focal point ($d_o < f$). Describe the image if the object is itself an image, formed by another lens, so its position is beyond the lens, for which $-d_o > f$, and for which $0 < -d_o < f$.

86. A movie star catches a reporter shooting pictures of her at home. She claims the reporter was trespassing. To prove her point, she gives as evidence the film she seized. Her 1.75-m height is 8.25 mm high on the film, and the focal length of the camera lens was 210 mm. How far away from the subject was the reporter standing?

87. How large is the image of the Sun on film used in a camera with (*a*) a 28-mm-focal-length lens, (*b*) a 50-mm-focal-length lens, and (*c*) a 135-mm-focal-length lens? (*d*) If the 50-mm lens is considered normal for this camera, what relative magnification does each of the other two lenses provide? The Sun has diameter 1.4×10^6 km, and it is 1.5×10^8 km away.

88. (*a*) An object 34.5 cm in front of a certain lens is imaged 8.20 cm in front of that lens (on the same side as the object). What type of lens is this, and what is its focal length? Is the image real or virtual? (*b*) If the image were located, instead, 41.5 cm in front of the lens, what type of lens would it be and what focal length would it have?

89. When an object is placed 60.0 cm from a certain converging lens, it forms a real image. When the object is moved to 40.0 cm from the lens, the image moves 10.0 cm farther from the lens. Find the focal length of this lens.

90. A small object is 25.0 cm from a diverging lens as shown in Fig. 23–59. A converging lens with a focal length of 12.0 cm is 30.0 cm to the right of the diverging lens. The two-lens system forms a real inverted image 17.0 cm to the right of the converging lens. What is the focal length of the diverging lens?

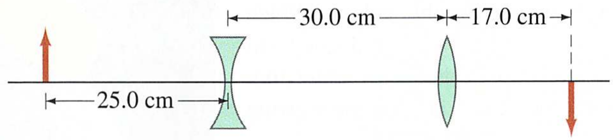

FIGURE 23–59 Problem 90.

91. An object is placed 15 cm from a certain mirror. The image is half the size of the object, inverted, and real. How far is the image from the mirror, and what is the radius of curvature of the mirror?

92. (*a*) Show that the lens equation can be written in the *Newtonian form*

$$xx' = f^2,$$

where x is the distance of the object from the focal point on the front side of the lens, and x' is the distance of the image to the focal point on the other side of the lens. Calculate the location of an image if the object is placed 45.0 cm in front of a convex lens with a focal length f of 32.0 cm using (*b*) the standard form of the thin lens equation, and (*c*) the Newtonian form, stated above.

* 93. A converging lens with focal length of 10.0 cm is placed in contact with a diverging lens with a focal length of −20.0 cm. What is the focal length of the combination, and is the combination converging or diverging?

* 94. (*a*) Show that if two thin lenses of focal lengths f_1 and f_2 are placed in contact with each other, the focal length of the combination is given by $f_T = f_1 f_2/(f_1 + f_2)$. (*b*) Show that the power P of the combination of two lenses is the sum of their separate powers, $P = P_1 + P_2$.

Answers to Exercises

A: No.
B: Yes; for a plane mirror, $r = \infty$, so $f = \infty$; then Eq. 23–2 gives $1/d_o + 1/d_i = 0$, or $d_i = -d_o$.
C: Toward.
D: None.
E: 1.414.
F: No total internal reflection, $\theta_C > 45°$.
G: Closer to it.
H: (*a*) Virtual; (*b*) virtual.
I: −97.5 cm (that is, 97.5 cm in front of lens).