Physics 123, Spring 2009
Homework #6
Due in P123 homework locker 4pm, Friday, March 20, 2009

Feel free to discuss the problems with me and/or each other. Each student must write up his/her own solutions separately.
Unless otherwise indicated, problems are from Giancoli, 4th edition.

Note: If you don't have a copy of volume II of Giancoli, you can find the following questions and problems on the appended pages.

1. Giancoli, chapter 32, **question** 18, page 859.
2. Giancoli, chapter 32, problem 55, page 862.
3. Giancoli, chapter 32, problem 61, page 863.
4. Giancoli, chapter 33, **question** 8, page 893.
5. Giancoli, chapter 33, problem 4, page 894.
6. Giancoli, chapter 33, problem 11, page 894.
7. Giancoli, chapter 33, problem 16, page 895.

The frequency or wavelength of light determines its color. The **visible spectrum** in air extends from about 400 nm (violet) to about 750 nm (red).

Glass prisms break white light down into its constituent colors because the index of refraction varies with wavelength, a phenomenon known as **dispersion**.

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

$$\sin\theta_C = \frac{n_2}{n_1}. \qquad \text{(32–7)}$$

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. What is the focal length of a plane mirror? What is the magnification of a plane mirror?
4. 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?
5. Using the rules for the three rays discussed with reference to Fig. 32–15, draw ray 2 for Fig. 32–19b.
6. Does the mirror equation, Eq. 32–2, hold for a plane mirror? Explain.
7. If a concave mirror produces a real image, is the image necessarily inverted?
8. How might you determine the speed of light in a solid, rectangular, transparent object?
9. When you look at the Moon's reflection from a ripply sea, it appears elongated (Fig. 32–41). Explain.

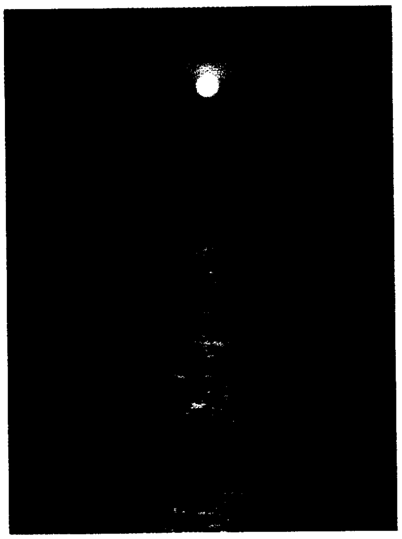


FIGURE 32–41 Question 9.

10. How can a spherical mirror have a negative object distance?
11. What is the angle of refraction when a light ray is incident perpendicular to the boundary between two transparent materials?
12. When you look down into a swimming pool or a lake, are you likely to overestimate or underestimate its depth? Explain. How does the apparent depth vary with the viewing angle? (Use ray diagrams.)
13. Draw a ray diagram to show why a stick or straw looks bent when part of it is under water (Fig. 32–23).

†Students at MIT did a feasibility study. See www.mit.edu.

14. When a wide beam of parallel light enters water at an angle, the beam broadens. Explain.
15. You look into an aquarium and view a fish inside. One ray of light from the fish as it emerges from the tank is shown in Fig. 32–42. The apparent position of the fish is also shown. In the drawing, indicate the approximate position of the actual fish. Briefly justify your answer.

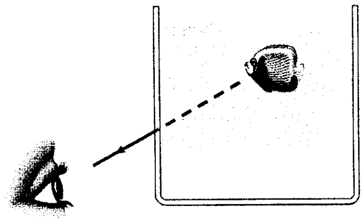


FIGURE 32–42 Question 15.

16. How can you "see" a round drop of water on a table even though the water is transparent and colorless?
17. A ray of light is refracted through three different materials (Fig. 32–43). Rank the materials according to their index of refraction, least to greatest.

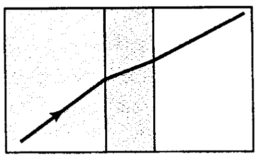


FIGURE 32–43 Question 17.

18. Can a light ray traveling in air be totally reflected when it strikes a smooth water surface if the incident angle is chosen correctly? Explain.
19. 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.
20. What type of mirror is shown in Fig. 32–44?

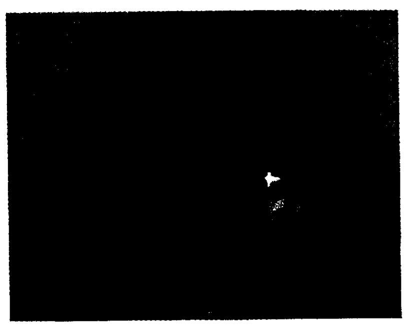


FIGURE 32–44 Question 20.

21. 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?

46. (II) The block of glass ($n = 1.5$) shown in cross section in Fig. 32–51 is surrounded by air. A ray of light enters the block at its left-hand face with incident angle θ_1 and reemerges into the air from the right-hand face directed parallel to the block's base. Determine θ_1.

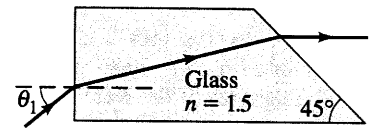


FIGURE 32–51 Problem 46.

47. (II) A laser beam of diameter $d_1 = 3.0\,\text{mm}$ in air has an incident angle $\theta_1 = 25°$ at a flat air–glass surface. If the index of refraction of the glass is $n = 1.5$, determine the diameter d_2 of the beam after it enters the glass.

48. (II) Light is incident on an equilateral glass prism at a 45.0° angle to one face, Fig. 32–52. Calculate the angle at which light emerges from the opposite face. Assume that $n = 1.54$.

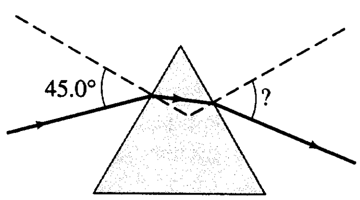


FIGURE 32–52 Problems 48 and 65.

49. (II) A triangular prism made of crown glass ($n = 1.52$) with base angles of 30.0° is surrounded by air. If parallel rays are incident normally on its base as shown in Fig. 32–53, what is the angle ϕ between the two emerging rays?

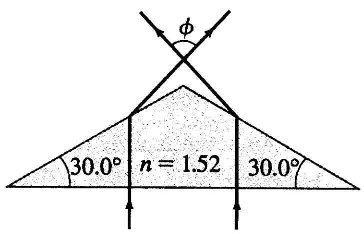


FIGURE 32–53 Problem 49.

50. (II) Show in general that for a light beam incident on a uniform layer of transparent material, as in Fig. 32–24, the direction of the emerging beam is parallel to the incident beam, independent of the incident angle θ. Assume the air on the two sides of the transparent material is the same.

51. (III) A light ray is incident on a flat piece of glass with index of refraction n as in Fig. 32–24. Show that if the incident angle θ is small, the emerging ray is displaced a distance $d = t\theta(n-1)/n$, where t is the thickness of the glass, θ is in radians, and d is the perpendicular distance between the incident ray and the (dashed) line of the emerging ray (Fig. 32–24).

32–6 Visible Spectrum; Dispersion

52. (I) By what percent is the speed of blue light (450 nm) less than the speed of red light (680 nm), in silicate flint glass (see Fig. 32–28)?

53. (I) A light beam strikes a piece of glass at a 60.00° incident angle. The beam contains two wavelengths, 450.0 nm and 700.0 nm, for which the index of refraction of the glass is 1.4831 and 1.4754, respectively. What is the angle between the two refracted beams?

54. (II) A parallel beam of light containing two wavelengths, $\lambda_1 = 465\,\text{nm}$ and $\lambda_2 = 652\,\text{nm}$, enters the silicate flint glass of an equilateral prism as shown in Fig. 32–54. At what angle does each beam leave the prism (give angle with normal to the face)? See Fig. 32–28.

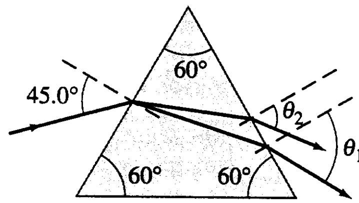


FIGURE 32–54 Problem 54.

55. (III) A ray of light with wavelength λ is incident from air at precisely 60° ($= \theta$) on a spherical water drop of radius r and index of refraction n (which depends on λ). When the ray reemerges into the air from the far side of the drop, it has been deflected an angle ϕ from its original direction as shown in Fig. 32–55. By how much does the value of ϕ for violet light ($n = 1.341$) differ from the value for red light ($n = 1.330$)?

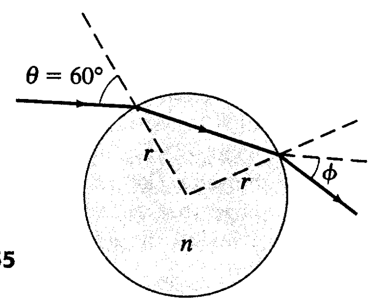


FIGURE 32–55 Problem 55.

56. (III) For visible light, the index of refraction n of glass is roughly 1.5, although this value varies by about 1% across the visible range. Consider a ray of white light incident from air at angle θ_1 onto a flat piece of glass. (*a*) Show that, upon entering the glass, the visible colors contained in this incident ray will be dispersed over a range $\Delta\theta_2$ of refracted angles given approximately by

$$\Delta\theta_2 \approx \frac{\sin\theta_1}{\sqrt{n^2 - \sin^2\theta_1}}\,\frac{\Delta n}{n}.$$

[*Hint*: For x in radians, $(d/dx)(\sin^{-1}x) = 1/\sqrt{1-x^2}$.] (*b*) If $\theta_1 = 0°$, what is $\Delta\theta_2$ in degrees? (*c*) If $\theta_1 = 90°$, what is $\Delta\theta_2$ in degrees?

32–7 Total Internal Reflection

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

58. (I) The critical angle for a certain liquid–air surface is 49.6°. What is the index of refraction of the liquid?

59. (II) A beam of light is emitted in a pool of water from a depth of 72.0 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?

60. (II) A ray of light, after entering a light fiber, reflects at an angle of 14.5° with the long axis of the fiber, as in Fig. 32–56. Calculate the distance along the axis of the fiber that the light ray travels between successive reflections off the sides of the fiber. Assume that the fiber has an index of refraction of 1.55 and is 1.40×10^{-4} m in diameter.

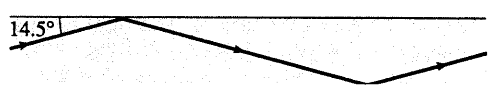
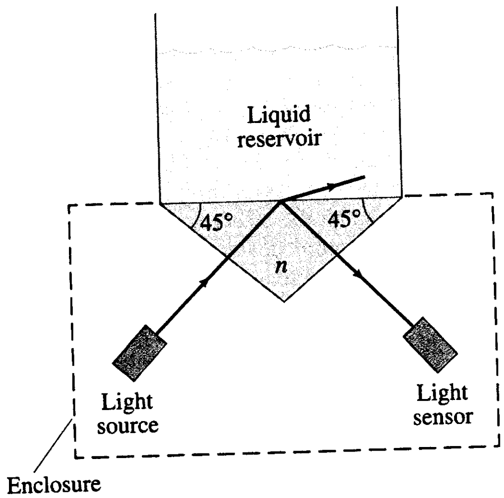


FIGURE 32–56 Problem 60.

61. (II) A beam of light is emitted 8.0 cm beneath the surface of a liquid and strikes the surface 7.6 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?

62. (II) Figure 32–57 shows a liquid-detecting prism device that might be used inside a washing machine or other liquid-containing appliance. If no liquid covers the prism's hypotenuse, total internal reflection of the beam from the light source produces a large signal in the light sensor. If liquid covers the hypotenuse, some light escapes from the prism into the liquid and the light sensor's signal decreases. Thus a large signal from the light sensor indicates the absence of liquid in the reservoir. If this device is designed to detect the presence of water, determine the allowable range for the prism's index of refraction n. Will the device work properly if the prism is constructed from (inexpensive) lucite? For lucite, $n = 1.5$.

FIGURE 32–57 Problem 62.



63. (II) Two rays A and B travel down a cylindrical optical fiber of diameter $d = 75.0\,\mu\text{m}$, length $\ell = 1.0\,\text{km}$, and index of refraction $n_1 = 1.465$. Ray A travels a straight path down the fiber's axis, whereas ray B propagates down the fiber by repeated reflections at the critical angle each time it impinges on the fiber's boundary. Determine the extra time Δt it takes for ray B to travel down the entire fiber in comparison with ray A (Fig. 32–58), assuming (*a*) the fiber is surrounded by air, (*b*) the fiber is surrounded by a cylindrical glass "cladding" with index of refraction $n_2 = 1.460$.

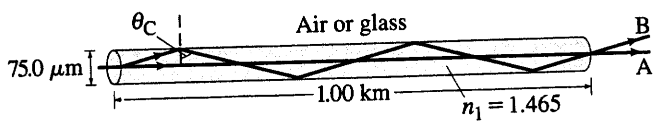


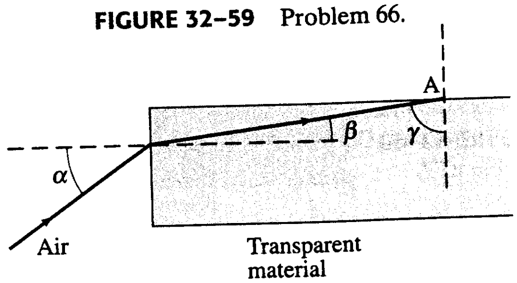
FIGURE 32–58 Problem 63.

64. (II) (*a*) What is the minimum index of refraction for a glass or plastic prism to be used in binoculars (Fig. 32–33) so that total internal reflection occurs at 45°? (*b*) Will binoculars work if their prisms (assume $n = 1.58$) are immersed in water? (*c*) What minimum n is needed if the prisms are immersed in water?

65. (III) Suppose a ray strikes the left face of the prism in Fig. 32–52 at 45.0° as shown, but is totally internally reflected at the opposite side. If the apex angle (at the top) is $\theta = 60.0°$, what can you say about the index of refraction of the prism?

66. (III) A beam of light enters the end of an optic fiber as shown in Fig. 32–59. (*a*) 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, assuming air outside.

FIGURE 32–59 Problem 66.



*32–8 Refraction at Spherical Surface

***67.** (II) A 13.0-cm-thick plane piece of glass ($n = 1.58$) lies on the surface of a 12.0-cm-deep pool of water. How far below the top of the glass does the bottom of the pool seem, as viewed from directly above?

***68.** (II) A fish is swimming in water inside a thin spherical glass bowl of uniform thickness. Assuming the radius of curvature of the bowl is 28.0 cm, locate the image of the fish if the fish is located: (*a*) at the center of the bowl; (*b*) 20.0 cm from the side of the bowl between the observer and the center of the bowl. Assume the fish is small.

***69.** (III) In Section 32–8, we derived Eq. 32–8 for a convex spherical surface with $n_2 > n_1$. Using the same conventions and using diagrams similar to Fig. 32–37, show that Eq. 32–8 is valid also for (*a*) a convex spherical surface with $n_2 < n_1$, (*b*) a concave spherical surface with $n_2 > n_1$, and (*c*) a concave spherical surface with $n_2 < n_1$.

***70.** (III) A coin lies at the bottom of a 0.75-m-deep pool. If a viewer sees it at a 45° angle, where is the image of the coin, relative to the coin? [*Hint*: The image is found by tracing back to the intersection of two rays.]

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**:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}. \qquad (33\text{–}2)$$

The ratio of image height to object height, which equals the **lateral magnification** m, is

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}. \qquad (33\text{–}3)$$

When using the various equations of geometric optics, it is important to remember the **sign conventions** for all quantities involved: carefully review them (page 871) 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 len's index of refraction to the focal length of the lens.]

A **camera** lens forms an image on film, or on an electronic sensor (CCD or CMOS) in a digital camera, by allowing light in through a shutter. The image is focused by moving the lens relative to the film, and the ***f*-stop** (or lens opening) must be adjusted for the brightness of the scene and the chosen shutter speed. The f-stop is defined as the ratio of the focal length to the diameter of the lens opening.

The human **eye** also adjusts for the available light—by opening and closing the iris. It focuses not by moving the lens, but by adjusting the shape of the lens to vary its focal length. The image is formed on the retina, which contains an array of receptors known as rods and cones.

Diverging eyeglass or contact lenses are used to correct the defect of a nearsighted eye, which cannot focus well on distant objects. Converging lenses are used to correct for defects in which the eye cannot focus on close objects.

A **simple magnifier** is a converging lens that forms a virtual image of an object placed at (or within) the focal point. The **angular magnification**, when viewed by a relaxed normal eye, is

$$M = \frac{N}{f}, \qquad (33\text{–}6a)$$

where f is the focal length of the lens and N is the near point of the eye (25 cm for a "normal" eye).

An **astronomical telescope** consists of an **objective** lens or mirror, and an **eyepiece** that magnifies the real image formed by the objective. The **magnification** is equal to the ratio of the objective and eyepiece focal lengths, and the image is inverted:

$$M = -\frac{f_o}{f_e}. \qquad (33\text{–}7)$$

[*A compound **microscope** also uses objective and eyepiece lenses, and the final image is inverted. The total magnification is the product of the magnifications of the two lenses and is approximately

$$M \approx \frac{N\ell}{f_e f_o}, \qquad (33\text{–}10b)$$

where ℓ is the distance between the lenses, N is the near point of the eye, and f_o and f_e are the focal lengths of objective and eyepiece, respectively.]

[*Microscopes, telescopes, and other optical instruments are limited in the formation of sharp images by **lens aberrations**. These include **spherical aberration**, in which rays passing through the edge of a lens are not focused at the same point as those that pass near the center; and **chromatic aberration**, in which different colors are focused at different points. Compound lenses, consisting of several elements, can largely correct for aberrations.]

Questions

1. Where must the film be placed if a camera lens is to make a sharp image of an object far away?
2. A photographer moves closer to his subject and then refocuses. Does the camera lens move farther away from or closer to the sensor? Explain.
3. Can a diverging lens form a real image under any circumstances? Explain.
4. 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.
5. Light rays are said to be "reversible." Is this consistent with the thin lens equation? Explain.
6. Can real images be projected on a screen? Can virtual images? Can either be photographed? Discuss carefully.
7. 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.
8. Compare the mirror equation with the thin lens equation. Discuss similarities and differences, especially the sign conventions for the quantities involved.
9. 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.
10. Explain how you could have a virtual object.
11. 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?
12. 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?
13. Why, in Example 33–6, 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?
14. 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.
15. Does the focal length of a lens depend on the fluid in which it is immersed? What about the focal length of a spherical mirror? Explain.

16. An underwater lens consists of a carefully shaped thin-walled plastic container filled with air. What shape should it have in order to be (*a*) converging (*b*) diverging? Use ray diagrams to support your answer.

17. 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?

18. Will a nearsighted person who wears corrective lenses in her glasses be able to see clearly underwater when wearing those glasses? Use a diagram to show why or why not.

19. You can tell whether people are nearsighted or farsighted by looking at the width of their face through their glasses. If a person's face appears narrower through the glasses, (Fig. 33–45), is the person farsighted or nearsighted?

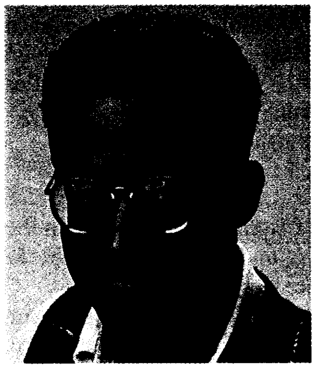


FIGURE 33–45 Question 19.

20. The human eye is much like a camera—yet, when a camera shutter is left open and the camera is moved, the image will be blurred. But when you move your head with your eyes open, you still see clearly. Explain.

21. In attempting to discern distant details, people will sometimes squint. Why does this help?

22. Is the image formed on the retina of the human eye upright or inverted? Discuss the implications of this for our perception of objects.

23. Reading glasses use converging lenses. A simple magnifier is also a converging lens. Are reading glasses therefore magnifiers? Discuss the similarities and differences between converging lenses as used for these two different purposes.

24. Why must a camera lens be moved farther from the film to focus on a closer object?

*25. Spherical aberration in a thin lens is minimized if rays are bent equally by the two surfaces. If a planoconvex lens is used to form a real image of an object at infinity, which surface should face the object? Use ray diagrams to show why.

*26. For both converging and diverging lenses, discuss how the focal length for red light differs from that for violet light.

Problems

33–1 and 33–2 Thin Lenses

1. (I) A sharp image is located 373 mm behind a 215-mm-focal-length converging lens. Find the object distance (*a*) using a ray diagram, (*b*) by calculation.

2. (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?

3. (I) (*a*) What is the power of a 23.5-cm-focal-length lens? (*b*) What is the focal length of a −6.75-D lens? Are these lenses converging or diverging?

4. (II) A certain lens focuses an object 1.85 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?

5. (II) A 105-mm-focal-length lens is used to focus an image on the sensor of a camera. The maximum distance allowed between the lens and the sensor plane is 132 mm. (*a*) How far ahead of the sensor 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?

6. (II) A stamp collector uses a converging lens with focal length 28 cm to view a stamp 18 cm in front of the lens. (*a*) Where is the image located? (*b*) What is the magnification?

7. (II) It is desired to magnify reading material by a factor of 2.5× when a book is placed 9.0 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?

8. (II) A −8.00-D lens is held 12.5 cm from an ant 1.00 mm high. Describe the position, type, and height of the image.

9. (II) An object is located 1.50 m from an 8.0-D lens. By how much does the image move if the object is moved (*a*) 0.90 m closer to the lens, and (*b*) 0.90 m farther from the lens?

10. (II) (*a*) How far from a 50.0-mm-focal-length lens must an object be placed if its image is to be magnified 2.50× and be real? (*b*) What if the image is to be virtual and magnified 2.50×?

11. (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?

12. (II) (*a*) A 2.80-cm-high insect is 1.30 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?

13. (II) A bright object and a viewing screen are separated by a distance of 86.0 cm. At what location(s) between the object and the screen should a lens of focal length 16.0 cm be placed in order to produce a sharp image on the screen? [*Hint*: first draw a diagram.]

14. (II) How far apart are an object and an image formed by an 85-cm-focal-length converging lens if the image is 2.95× larger than the object and is real?

15. (II) Show analytically that the image formed by a converging lens (*a*) is real and inverted if the object is beyond the focal point $(d_o > f)$, and (*b*) is virtual and upright if the object is within the focal point $(d_o < f)$. Next, describe the image if the object is itself an image (formed by another lens), and its position is on the opposite side of the lens from the incoming light, (*c*) for $-d_o > f$, and (*d*) for $0 < -d_o < f$.

16. (II) A converging lens has focal length f. When an object is placed a distance $d_o > f$ from this lens, a real image with magnification m is formed. (*a*) Show that $m = f/(f - d_o)$. (*b*) Sketch m vs. d_o over the range $f < d_o < \infty$ where $f =$ 0.45 cm. (*c*) For what value of d_o will the real image have the same (lateral) size as the object? (*d*) To obtain a real image that is much larger than the object, in what general region should the object be placed relative to the lens?

17. (II) In a slide or movie projector, the film acts as the object whose image is projected on a screen (Fig. 33–46). If a 105-mm-focal-length lens is to project an image on a screen 6.50 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?

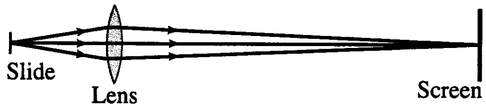


FIGURE 33–46 Slide projector, Problem 17.

18. (III) 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.

19. (III) (*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 48.0 cm in front of a convex lens with a focal length of 38.0 cm using (*b*) the standard form of the thin lens formula, and (*c*) the Newtonian form, derived above.

33–3 Lens Combinations

20. (II) A diverging lens with $f = -33.5$ cm is placed 14.0 cm behind a converging lens with $f = 20.0$ cm. Where will an object at infinity be focused?

21. (II) Two 25.0-cm-focal-length converging lenses are placed 16.5 cm apart. An object is placed 35.0 cm in front of one lens. Where will the final image formed by the second lens be located? What is the total magnification?

22. (II) A 34.0-cm-focal-length converging lens is 24.0 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.]

23. (II) The two converging lenses of Example 33–5 are now placed only 20.0 cm apart. The object is still 60.0 cm in front of the first lens as in Fig. 33–14. In this case, determine (*a*) the position of the final image, and (*b*) the overall magnification. (*c*) Sketch the ray diagram for this system.

24. (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?

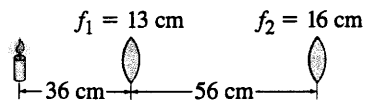
25. (II) Two lenses, one converging with focal length 20.0 cm and one diverging with focal length −10.0 cm, are placed 25.0 cm apart. An object is placed 60.0 cm in front of the converging lens. Determine (*a*) the position and (*b*) the magnification of the final image formed. (*c*) Sketch a ray diagram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

26. (II) A diverging lens is placed next to a converging lens of focal length f_C, as in Fig. 33–15. If f_T represents the focal length of the combination, show that the focal length of the diverging lens, f_D, is given by

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

27. (II) A lighted candle is placed 36 cm in front of a converging lens of focal length $f_1 = 13$ cm, which in turn is 56 cm in front of another converging lens of focal length $f_2 = 16$ cm (see Fig. 33–47). (*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 33–47 Problem 27.



*33–4 Lensmaker's Equation

*28. (I) A double concave lens has surface radii of 33.4 cm and 28.8 cm. What is the focal length if $n = 1.58$?

*29. (I) Both surfaces of a double convex lens have radii of 31.4 cm. If the focal length is 28.9 cm, what is the index of refraction of the lens material?

*30. (I) Show that if the lens of Example 33–7 is reversed, the focal length is unchanged.

*31. (I) A planoconvex lens (Fig. 33–2a) is to have a focal length of 18.7 cm. If made from fused quartz, what must be the radius of curvature of the convex surface?

*32. (II) An object is placed 90.0 cm from a glass lens ($n = 1.52$) with one concave surface of radius 22.0 cm and one convex surface of radius 18.5 cm. Where is the final image? What is the magnification?

*33. (II) A prescription for a corrective lens calls for +3.50 diopters. The lensmaker grinds the lens from a "blank" with $n = 1.56$ and convex front surface of radius of curvature of 30.0 cm. What should be the radius of curvature of the other surface?

33–5 Camera

34. (I) A properly exposed photograph is taken at $f/16$ and $\frac{1}{120}$ s. What lens opening is required if the shutter speed is $\frac{1}{1000}$ s?

35. (I) A television camera lens has a 17-cm focal length and a lens diameter of 6.0 cm. What is its f-number?

36. (II) A "pinhole" camera uses a tiny pinhole instead of a lens. Show, using ray diagrams, how reasonably sharp images can be formed using such a pinhole camera. In particular, consider two point objects 2.0 cm apart that are 1.0 m from a 1.0-mm-diameter pinhole. Show that on a piece of film 7.0 cm behind the pinhole the two objects produce two separate circles that do not overlap.

37. (II) Suppose that a correct exposure is $\frac{1}{250}$ s at $f/11$. Under the same conditions, what exposure time would be needed for a pinhole camera (Problem 36) if the pinhole diameter is 1.0 mm and the film is 7.0 cm from the hole?