

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  $135^\circ$  angle, Fig. 23–47. If light rays strike one mirror at  $40^\circ$  as shown, at what angle  $\phi$  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?

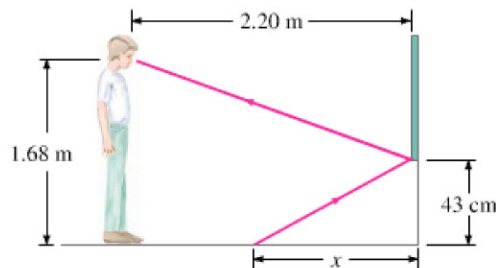


FIGURE 23–48 Problem 4.