TRY IT

FOR SECTION 3.5D
Aberrations of a magnifying glass

You will need a focusing lens, such as a magnifying glass, preferably of large diameter. Image the grid of a window with sunlight shining through onto a piece of paper. Can you get every point of the window grid in focus at once, or does one position of the paper provide a better focus for some parts, and other positions for others? What aberration is this? Do straight lines of the grid image as straight lines? If not, what type of distortion do you have? Does twisting the lens slightly affect the aberrations? Why should it?

Make a point source by covering a light source with aluminum foil that has a pinhole in it. Image this source on a piece of paper. How sharp an image can you make? Is there spherical aberration? Can you see any colors around the image? What happens to the image when you twist the lens? What kind of aberration can you see?

Look through the lens at the lines on a piece of ruled paper. The lens should be just far enough from the paper (somewhat beyond a focal length) so that the image is inverted. Your eye must be far enough from the lens so that the image is in focus for you. What kind of distortion do you see? Now move the lens closer to the paper (a little less than a focal length away) and examine the distortion again (also see Fig. 3.42).

How can there be distortion without any stop evident? The answer is that the pupil of your eye is usually the stop when you are looking through the lens. Because of this stop, a lens sometimes gives a better image when you look through it than when you use it to project an image. You can see this effect best with a large lens. Try it!

SUMMARY

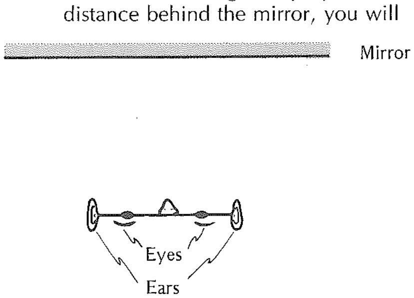
Lenses and ***mirrors*** form ***images*** depending on the relative location of the object. The images are located using the *rules* of ***ray tracing.*** Light actually passes through ***real images,*** but only seems to come from ***virtual images.*** A plane mirror produces virtual images behind its surface. *Multiple reflections* may produce many images, for example, in a ***kaleidoscope.***

Both *spherical* lenses and mirrors are characterized by their ***focal lengths*** *(f)*. A spherical *mirror* has only one ***focal point*** *(F)*; it is midway between the mirror and its *center of curvature (C). Lenses* have two *focal points (F,F')*. For a *thin lens* they are on opposite sides and equidistant from the lens. *Positive* focal length lenses are ***converging*** lenses, while *negative* focal length lenses are ***diverging*** lenses. Converging lenses can be used to produce a *retroreflector* ***(heiligenschein). Fresnel lenses*** are made thin by eliminating much of the glass (or plastic). The ***power*** (in ***diopters*** = $1/f$, f in meters) of a compound lens, made of two or more thin lenses in *contact,* is equal to the *sum of the powers* of its component lenses.

Aberrations are imperfections of the image produced by a lens or mirror. ***Chromatic aberration*** in lenses results from dispersion and can be corrected using an ***achromatic doublet. Spherical aberration*** can be corrected by using a lens or a mirror of nonspherical shape, or by allowing, through the use of ***stops,*** only ***paraxial*** rays (near the axis and nearly parallel to it) to be focused by the lens or mirror. A *parabolic mirror* has no aberrations for distant on-axis sources. ***Off-axis aberrations*** in lenses ***(curvature of field, coma, distortion*** such as ***pincushion*** or ***barrel distortion)*** can be reduced by proper placement of stops. They depend on the lens shape (***double-convex, plano-convex, meniscus,*** etc.).

PROBLEMS

P1 Copy the figure, which shows a top view of a (flat) face looking in a mirror. (a) By drawing rays, show where the image of the right ear is. To locate the image the proper distance behind the mirror, you will need two rays from the right ear that obey the law of reflection. (b) Complete the image and use it to draw the ray from each ear to the right eye. (c) The person with this flat face wants to mark the outline of her face on the steamed-up mirror. She closes her left eye and, using only her right eye, writes an *R* where she sees her right ear and an *L* where she sees her left ear. Clearly indicate where she writes those letters on the mirror.

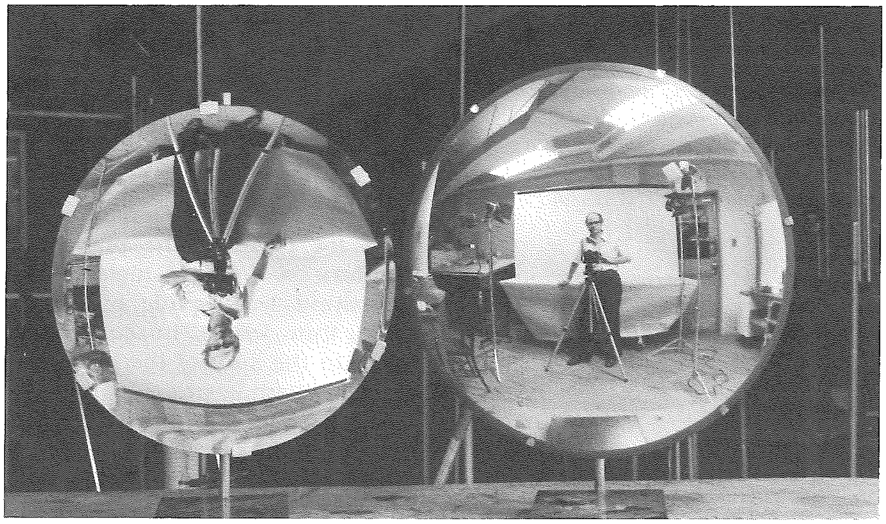


P2 An arrow is viewed through a kaleidoscope that has an angle of 45° between its mirrors. Draw two lines meeting at a 45° angle to represent the mirrors, and, between them, an arrow pointing at one of them. Sketch all the images of the arrow.

P3 (a) Use ray tracing to find the image of a 2-cm arrow in a concave mirror of focal length 2 cm, when the arrow is 6 cm in front of the mirror and perpendicular to the axis. (b) Is the image real or virtual? Upright or inverted? Larger or smaller than the object?

P4 Repeat Problem P3, but with the object a 1-cm arrow, only 1 cm in front of the mirror.

P5 Repeat Problem P3 for a convex mirror of focal length 2 cm, with the object 2 cm in front of the mirror.



P6 In the photograph, identify which mirror is convex and which is concave.

P7 (a) When you use a lens as a burning glass, it forms a small bright spot. Is the lens then forming an image, and if so, of what? (b) Why does it burn? (c) What would the bright spot look like during a partial solar eclipse?

P8 Here is a problem that occurs almost every day. You are stranded on a sunny desert isle with only a standard flashlight but no batteries. How could you use some part of the flashlight to ignite a small dry leaf, and thus start a fire?

P9 (a) Use ray tracing to find the image of a 2-cm arrow due to a converging lens of focal length 5 cm, when the arrow is 10 cm in front of the lens and perpendicular to the axis. (b) Is the image real or virtual? Upright or inverted? Larger, smaller, or the same size as the object?

P10 Repeat Problem P9, but with the object only 2.5 cm in front of the lens.

P11 Repeat Problem P9, but for a diverging lens of focal length -5 cm, with the object 10 cm in front of the lens.

P12 The word "LIGHT" appears as shown in the figure, when viewed through a lens. What kind of distortion is this? Where was the stop, probably?

P13 Do front surface mirrors have chromatic aberration?

P14 Images in a very thick glass mirror may be slightly colored by dispersion. Draw two vertical lines, separated by about 2 cm, to represent the front (glass) surface and the rear (silver) surface of the mirror. About 2 cm in front of the mirror, draw the object—a white *point* source. (a) Carefully draw red and blue rays to represent the red and blue light. Show that there are separate red and blue images, and indicate their locations. (Hint: To locate each image you'll need two rays. Choose as one the ray perpendicular to the mirror.)
(b) Where would the image be if the glass were removed, but the silver and everything else remained in the same positions? Would the image be colored in this case?

P15 A certain thin lens has an extremely large amount of chromatic aberration. Its focal length is 3 cm for blue light and 4 cm for red light. A 2-cm arrow is 8 cm in front of the lens and is illuminated with white light. (a) By ray tracing construct the images for red and blue light.
(b) Draw a sketch indicating what you would see on a screen that is placed at the red image.

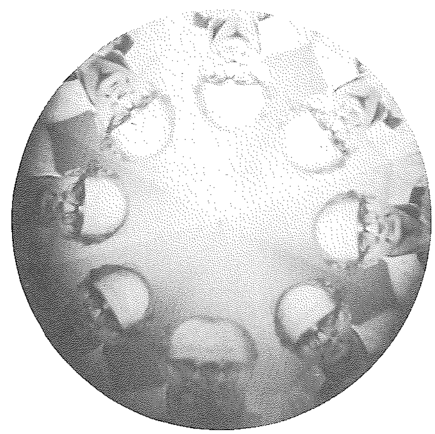
P16 An object (the usual arrow) is located at the focal plane of a thin lens of focal length f. On the other side of the lens, at a distance $\frac{1}{2}f$ from the lens and parallel to it, is a plane mirror. (a) Use ray tracing to find two rays leaving the lens. (b) Use the law of reflection to determine how these rays are reflected. (c) Use ray tracing again to follow the reflected rays back through the lens, and thus find the final image.

P17 In *Tess of the D'Urbervilles,* Thomas Hardy writes:
Then these children of the open air, whom every excess of alcohol could scarce injure permanently, betook themselves to the field-path; and as they went there moved onward with them, around the shadow of each one's head, a circle of opalized light, formed by the moon's rays upon the glistening sheet of dew. Each pedestrian could see no halo but his or her own, which never deserted the head shadow, whatever its vulgar unsteadiness might be; but adhered to it; and persistently beautified it, till the erratic motions seemed an inherent part of the irradiation, and the fumes of their breathing a component of the night's mist; and the spirit of the scene, and of the moonlight, and of Nature, seemed harmoniously to mingle with the spirit of the wine.
Explain the phenomenon Hardy describes.

HARDER PROBLEMS

PH1 (a) What is the maximum number of images of himself that can be seen by the man in Problem P13 of Chapter 2? (b) If the man raises his right hand, which of these images will raise their right hands, and which their left?

PH2 How was this photo taken? Discuss in detail how many mirrors were used, at what angles, the unequal brightness of the images, which image was formed by direct light (without mirror reflection), and the reason for the double image at the bottom.



PH3 A shaving or makeup mirror is a large concave mirror. In terms of its focal length f, what is the *range* of distances from the mirror at which you can put your face and get an enlarged image in the mirror?

PH4 Will an underwater air pocket in the shape of a plano-convex lens act like a converging or like a diverging lens?

PH5 When you wear goggles underwater, objects usually appear larger than normal. Trace rays from the top and bottom of an object PQ to an eye to verify this statement. Draw a vertical line to represent the front of the goggles, with the eye on one side of the line, and water and the object on