UNIVERSITY PHYSICS

Chapter 2 GEOMETRIC OPTICS AND IMAGE FORMATION

PowerPoint Image Slideshow

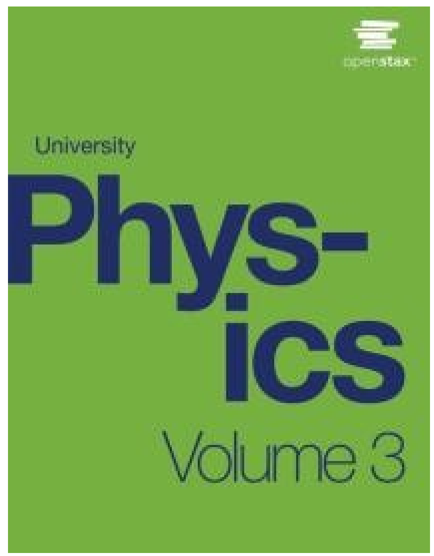

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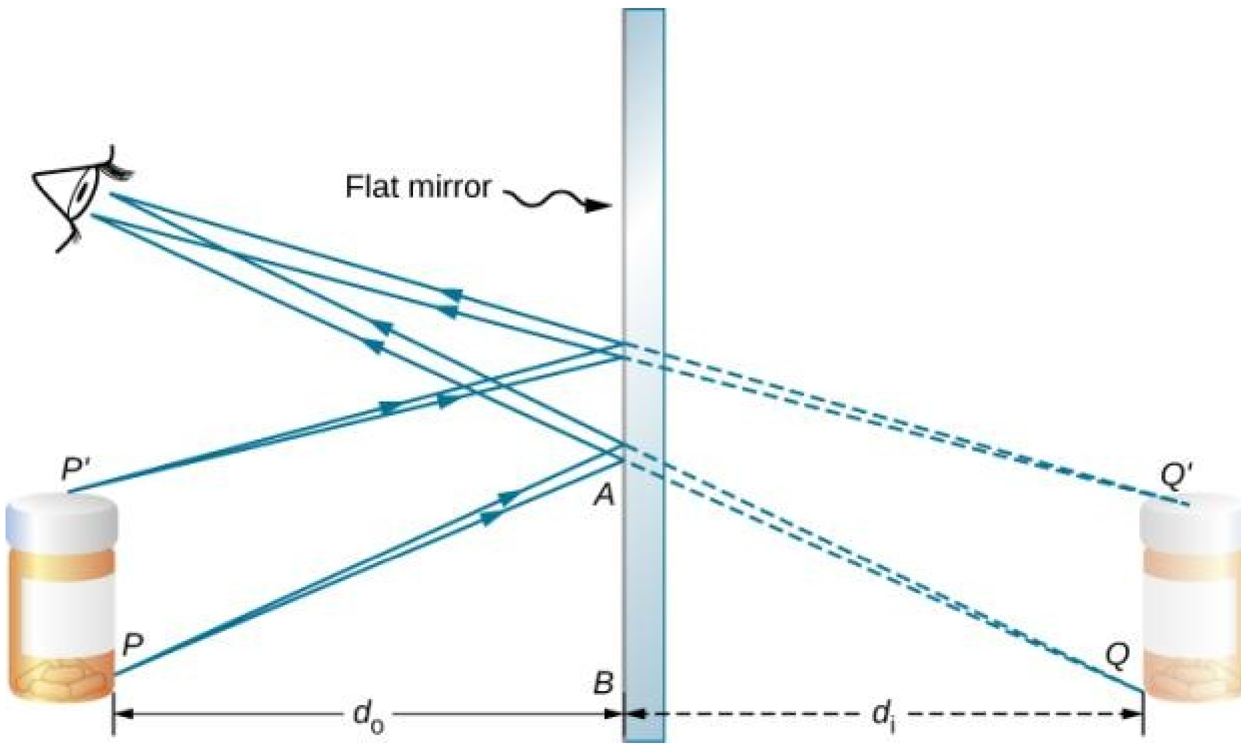
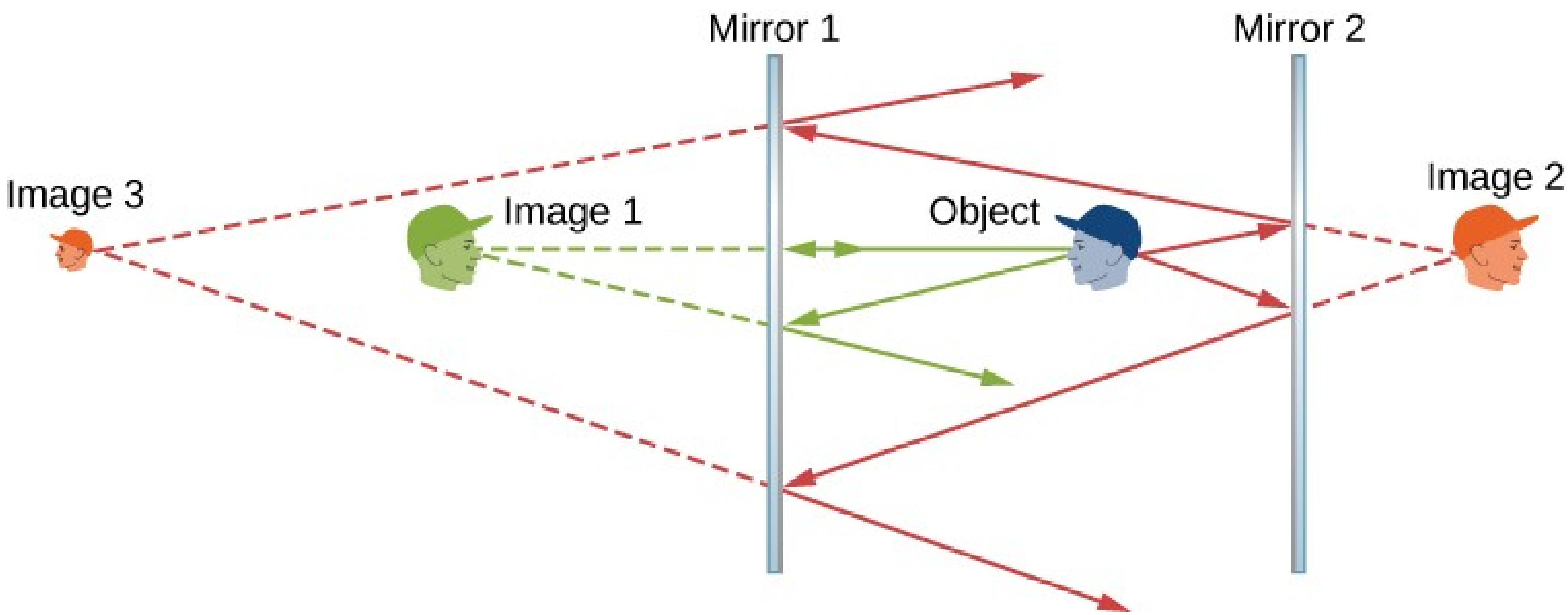
Image formation by plane mirrors

FIGURE 2.2



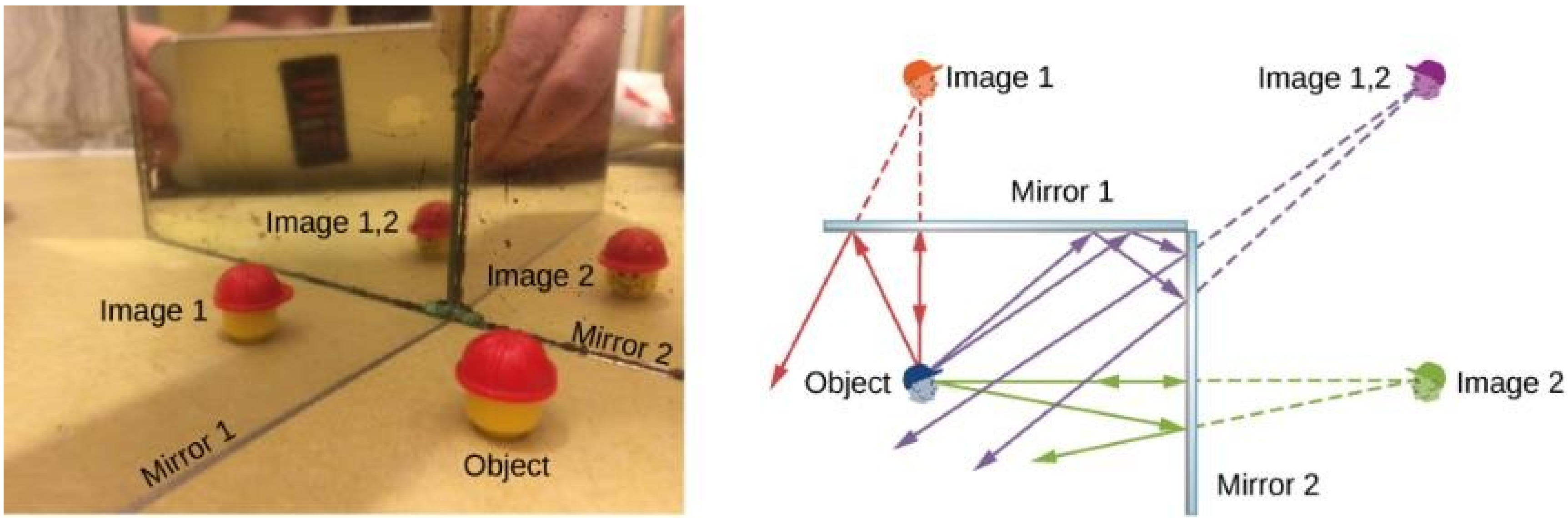
Two light rays originating from point *P* on an object are reflected by a flat mirror into the eye of an observer. The reflected rays are obtained by using the law of reflection. Extending these reflected rays backward, they seem to come from point *Q* behind the mirror, which is where the virtual image is located. Repeating this process for point *P′* gives the image point *Q′*. The image height is thus the same as the object height, the image is upright, and the object distance d_o is the same as the image distance d_i. (credit: modification of work by Kevin Dufendach)

FIGURE 2.3



Two parallel mirrors can produce, in theory, an infinite number of images of an object placed off center between the mirrors. Three of these images are shown here. The front and back of each image is inverted with respect to its object. Note that the colors are only to identify the images. For normal mirrors, the color of an image is essentially the same as that of its object.

FIGURE 2.4



(a) (b)

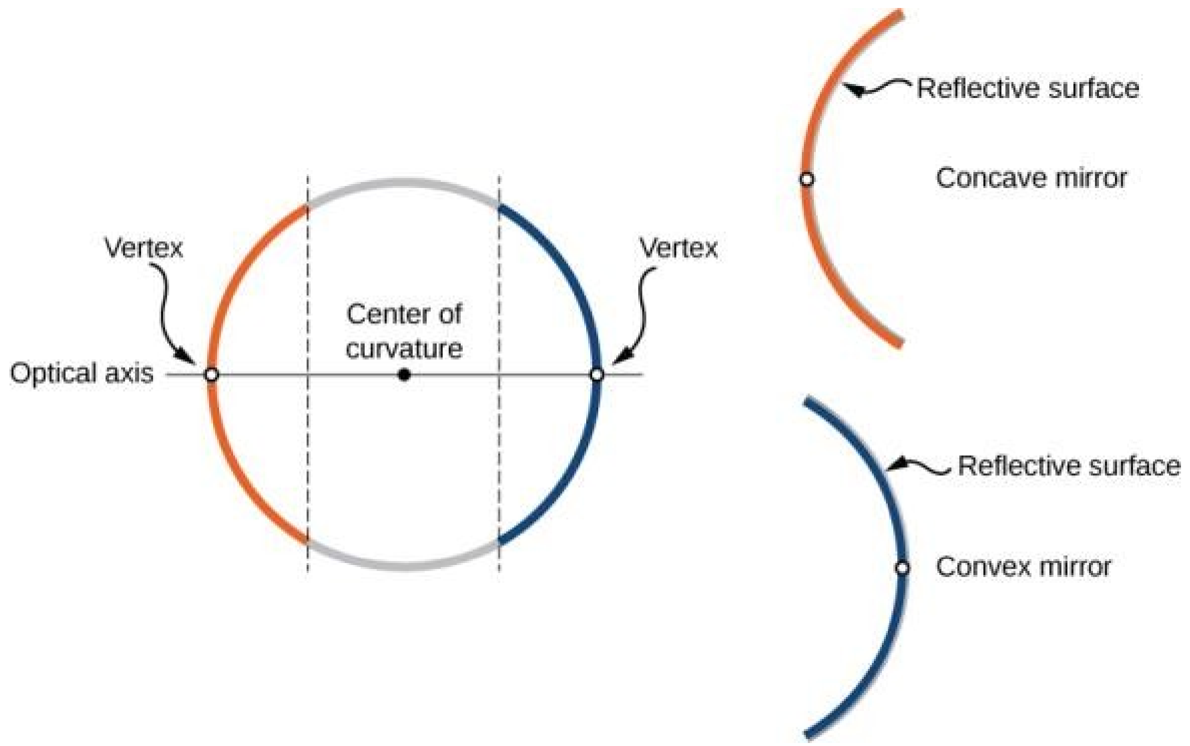
Two mirrors can produce multiple images.

a) Three images of a plastic head are visible in the two mirrors at a right angle.

b) A single object reflecting from two mirrors at a right angle can produce three images, as shown by the green, purple, and red images.

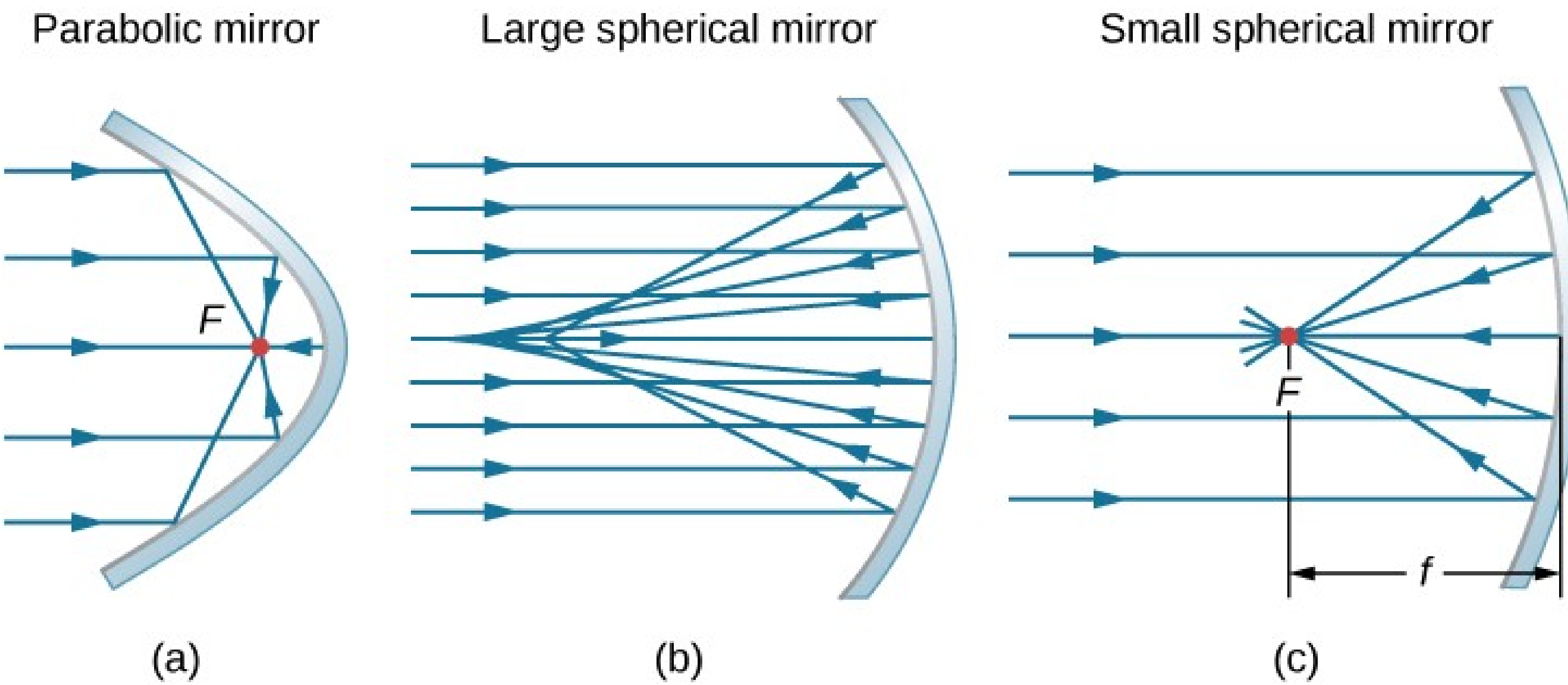
Image formation by spherical mirrors

FIGURE 2.5



A spherical mirror is formed by cutting out a piece of a sphere and silvering either the inside or outside surface. A concave mirror has silvering on the interior surface (think “cave”), and a convex mirror has silvering on the exterior surface.

FIGURE 2.6

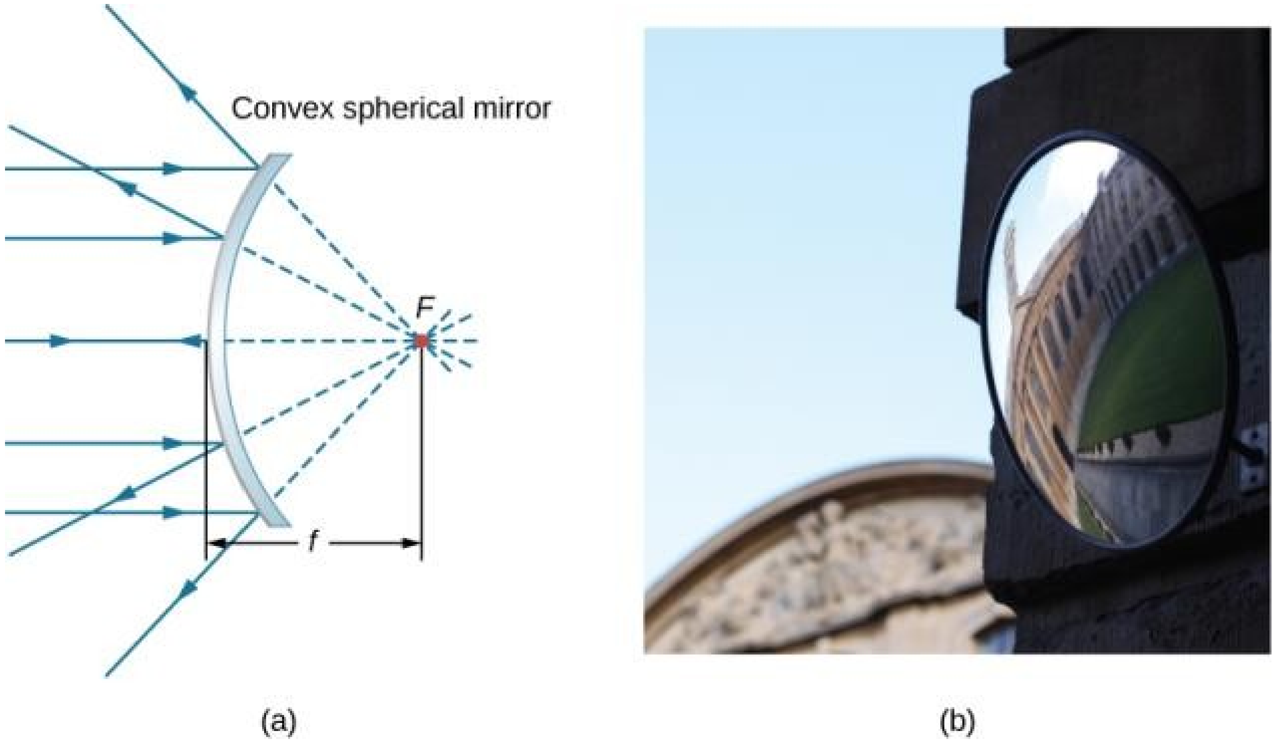


a) Parallel rays reflected from a parabolic mirror cross at a single point called the focal point *F*.

b) Parallel rays reflected from a large spherical mirror do not cross at a common point.

c) If a spherical mirror is small compared with its radius of curvature, it better approximates the central part of a parabolic mirror, so parallel rays essentially cross at a common point. The distance along the optical axis from the mirror to the focal point is the focal length *f* of the mirror.

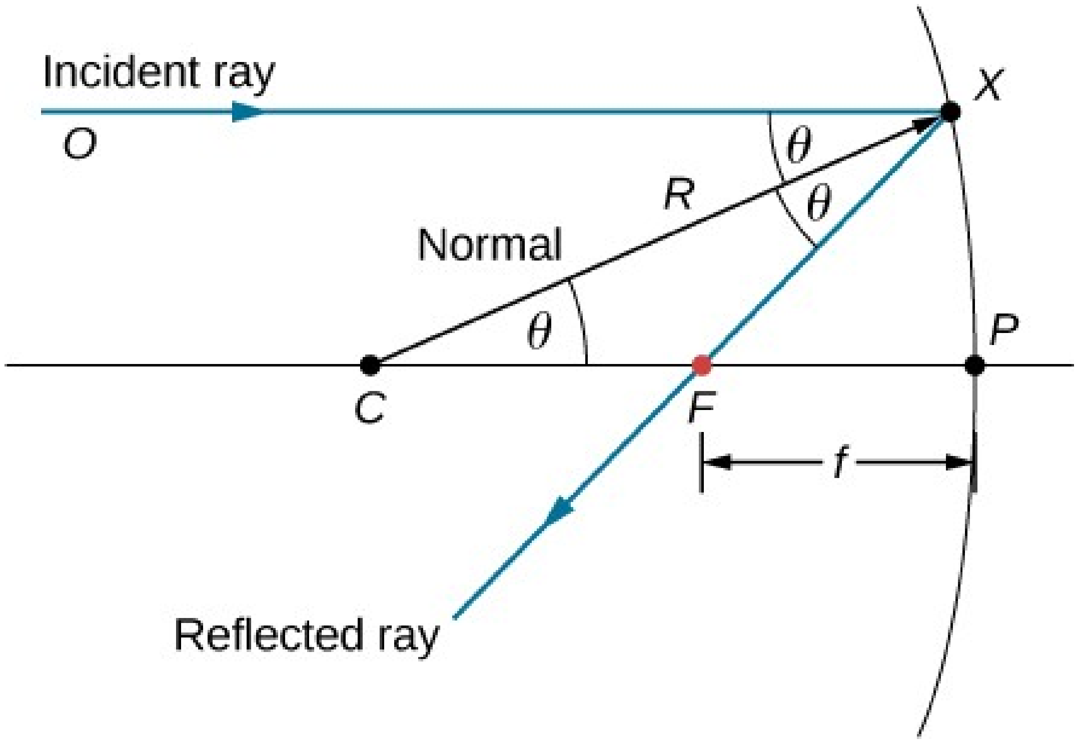
FIGURE 2.7



a) Rays reflected by a convex spherical mirror: Incident rays of light parallel to the optical axis are reflected from a convex spherical mirror and seem to originate from a well-defined focal point at focal distance *f* on the opposite side of the mirror. The focal point is virtual because no real rays pass through it.

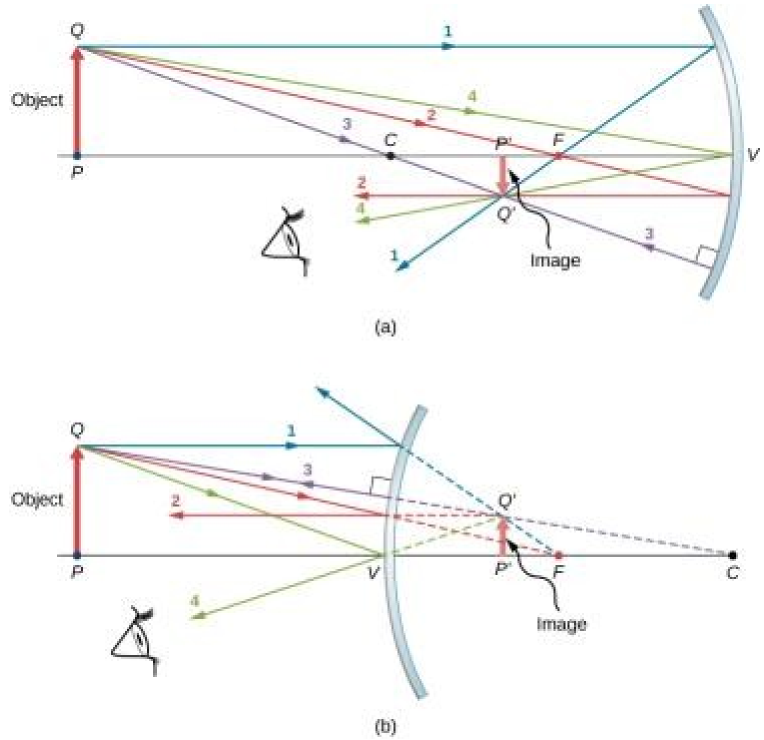
b) Photograph of a virtual image formed by a convex mirror. (credit b: modification of work by Jenny Downing)

FIGURE 2.8



Reflection in a concave mirror. In the small-angle approximation, a ray that is parallel to the optical axis *CP* is reflected through the focal point *F* of the mirror.

FIGURE 2.9



The four principal rays shown for both (a) a concave mirror and (b) a convex mirror. The image forms where the rays intersect (for real images) or where their backward extensions intersect (for virtual images).

FIGURE 2.10

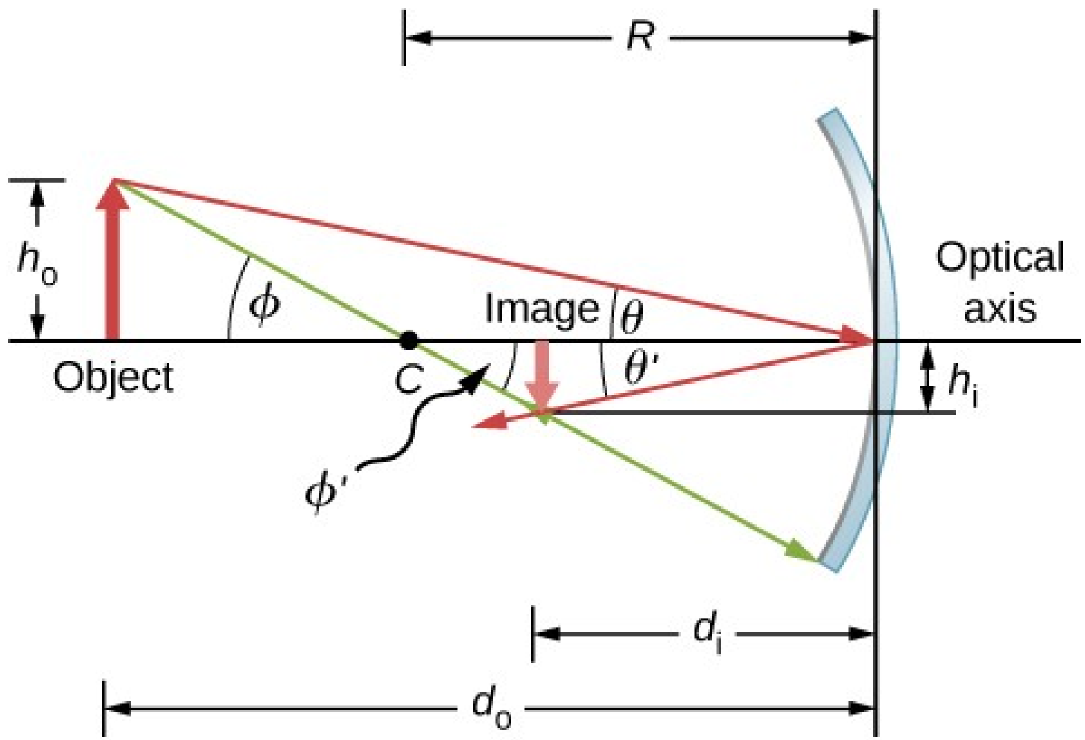
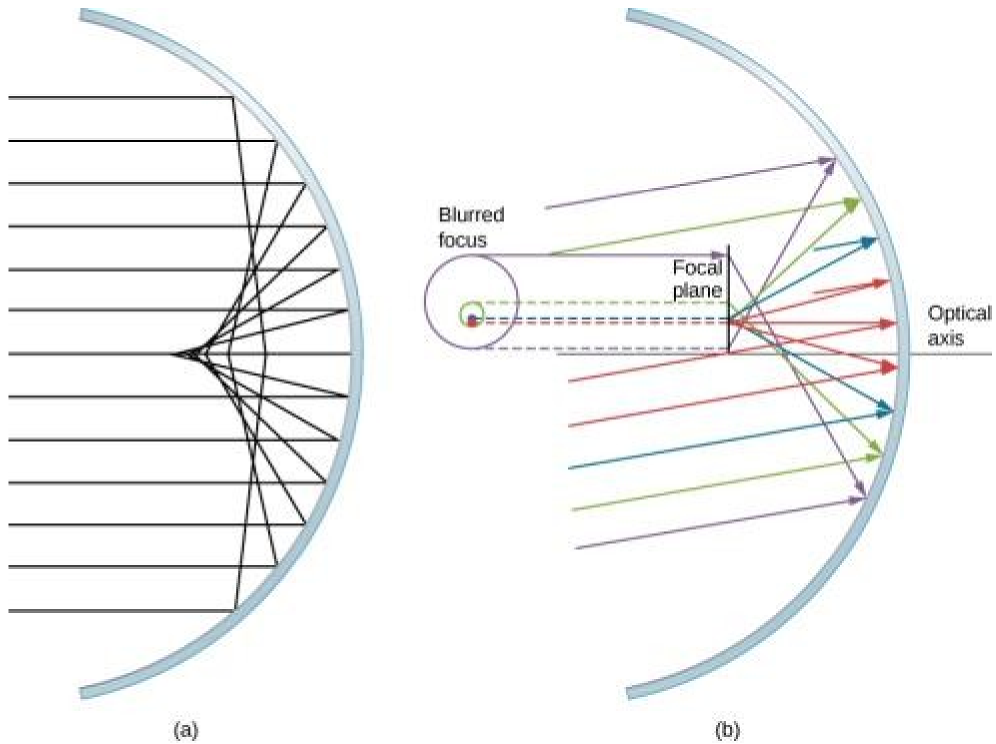


Image formed by a concave mirror.

FIGURE 2.12

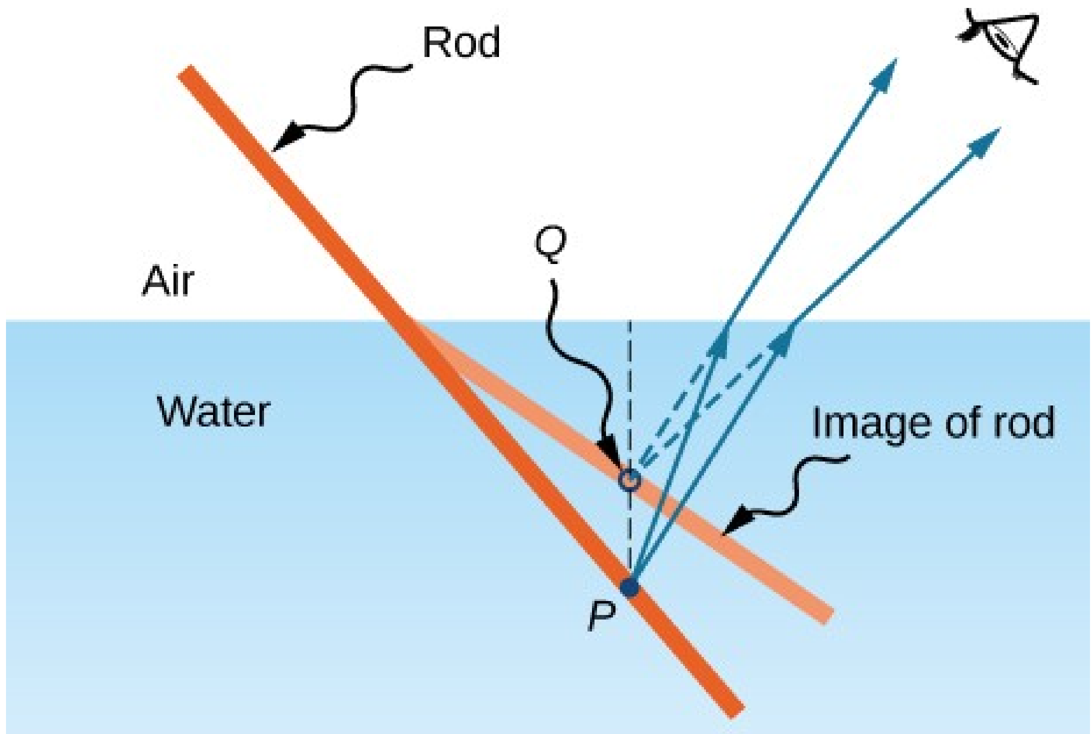


a) With spherical aberration, the rays that are farther from the optical axis and the rays that are closer to the optical axis are focused at different points. Notice that the aberration gets worse for rays farther from the optical axis.

b) For comatic aberration, parallel rays that are not parallel to the optical axis are focused at different heights and at different focal lengths, so the image contains a “tail” like a comet (which is “coma” in Latin). Note that the colored rays are only to facilitate viewing; the colors do not indicate the color of the light.

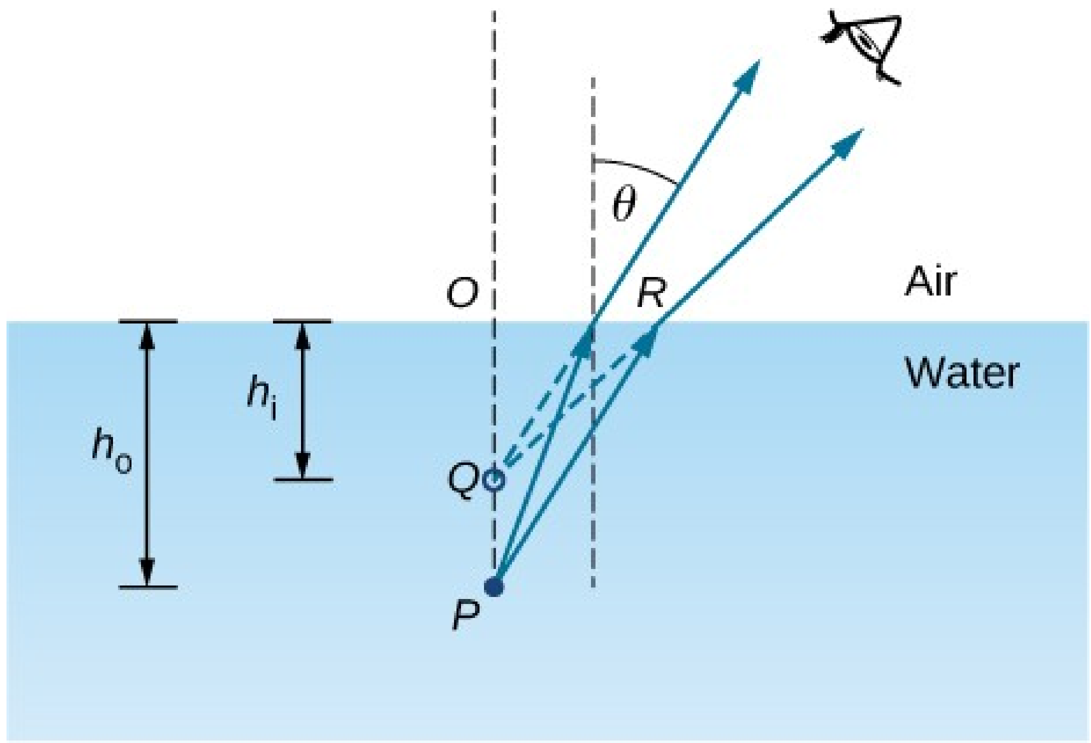
Image formation by refraction

FIGURE 2.13



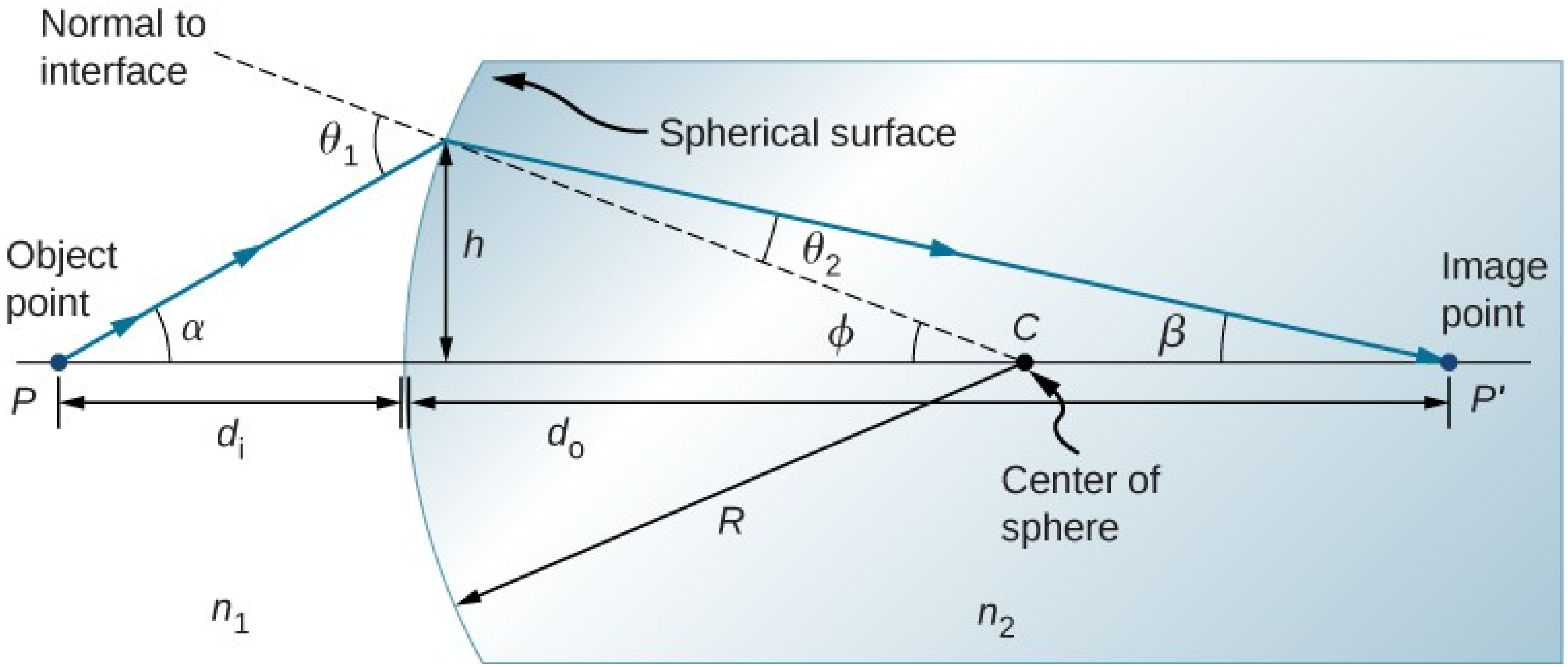
Bending of a rod at a water-air interface. Point *P* on the rod appears to be at point *Q*, which is where the image of point *P* forms due to refraction at the air-water interface.

FIGURE 2.14



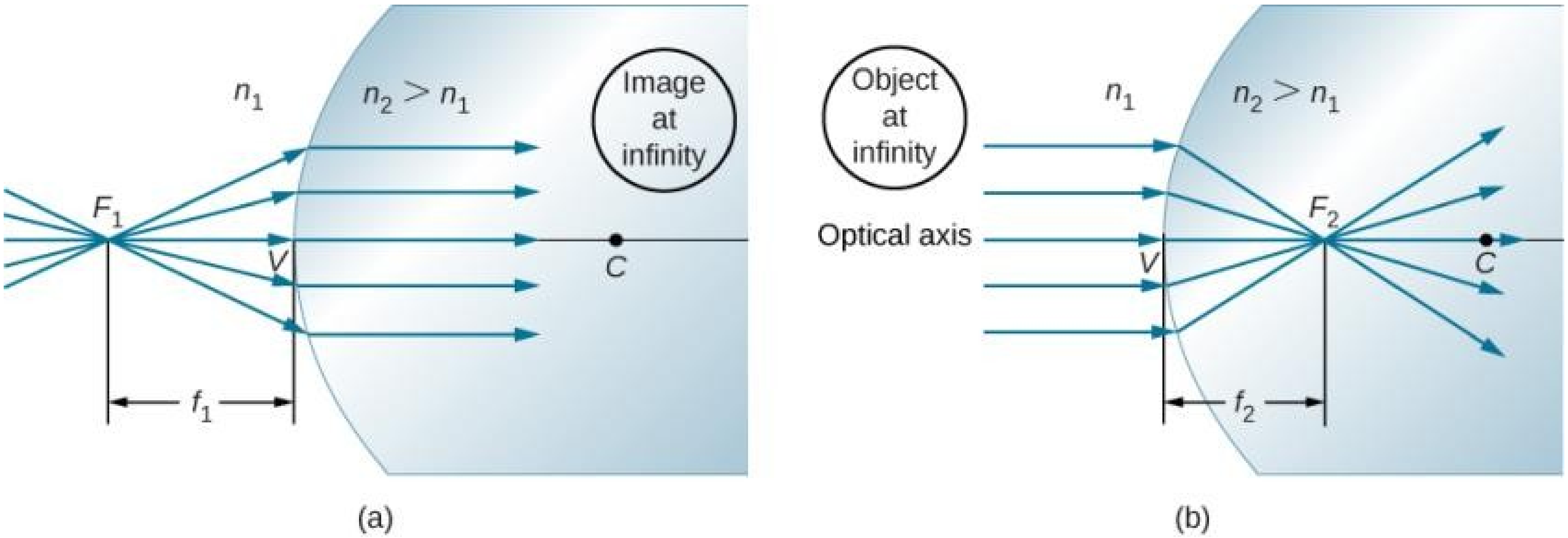
Apparent depth due to refraction. The real object at point *P* creates an image at point *Q*. The image is not at the same depth as the object, so the observer sees the image at an "apparent depth."

FIGURE 2.15



Refraction at a convex surface ($n_2 > n_1$).

FIGURE 2.16

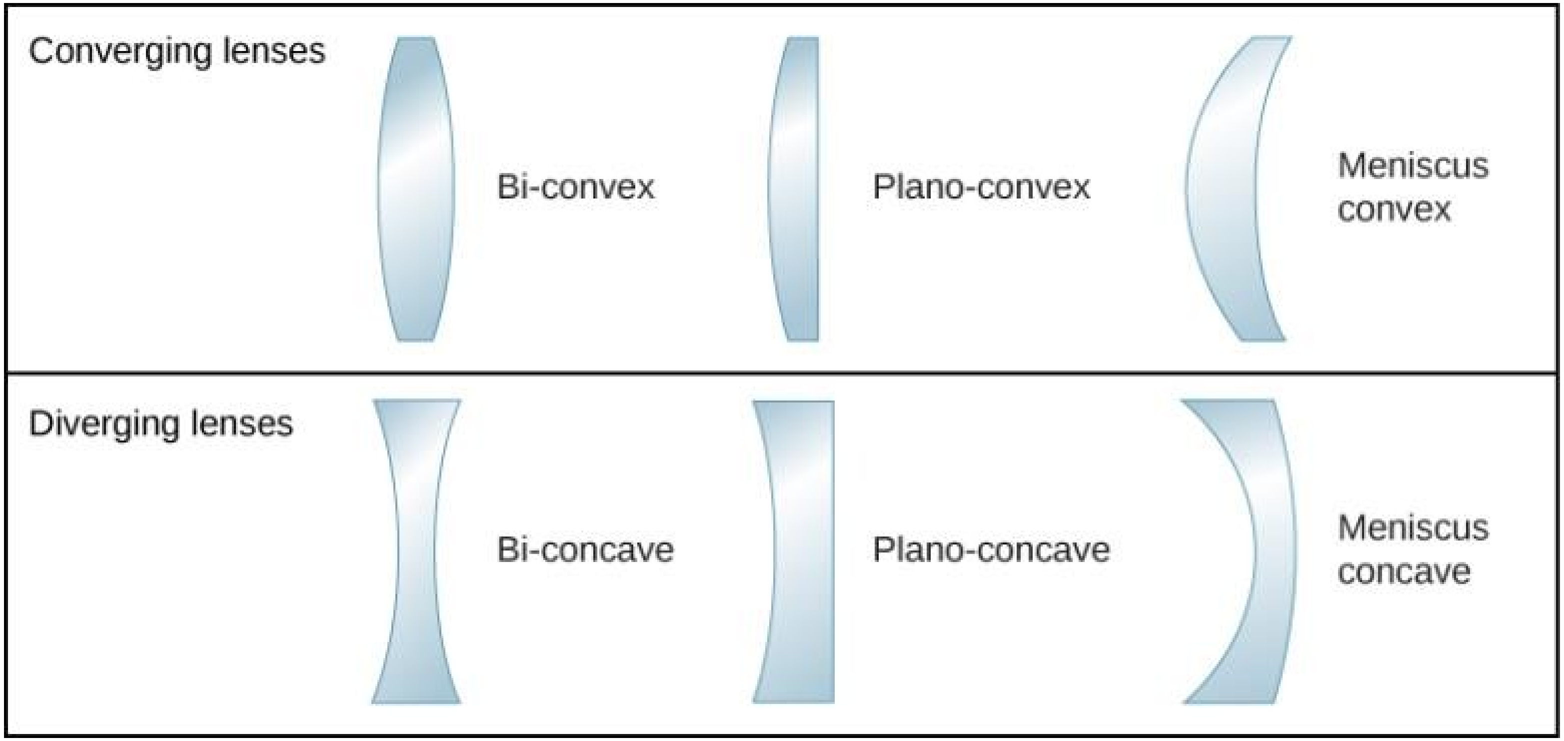


a) First focus (called the “object focus”) for refraction at a convex surface.

b) Second focus (called “image focus”) for refraction at a convex surface.

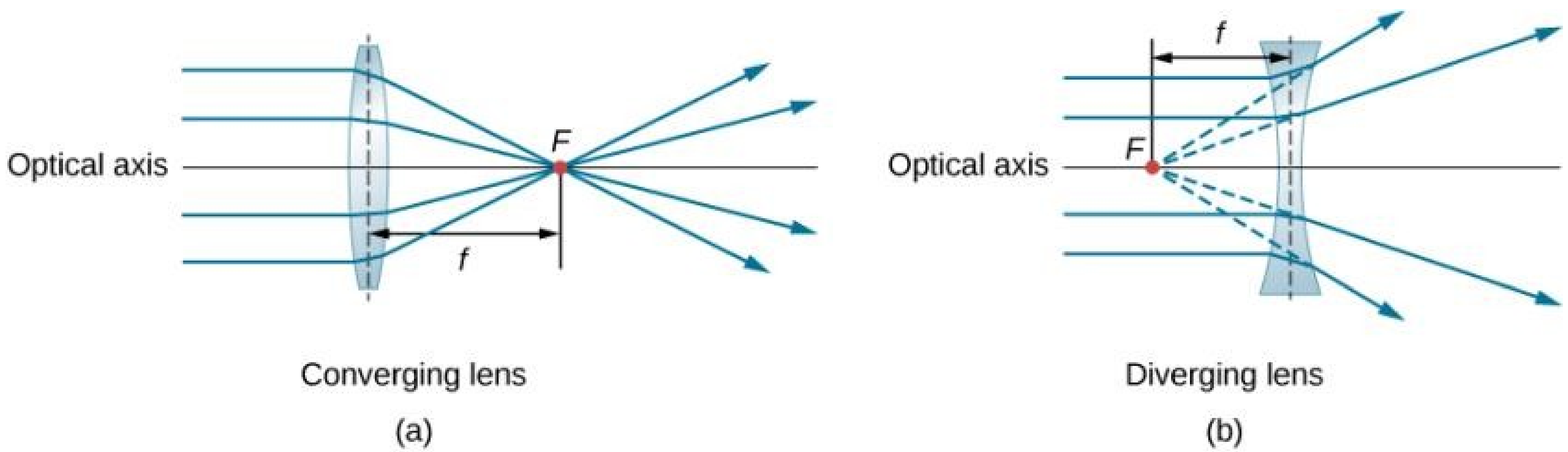
Image formation by lenses

FIGURE 2.17



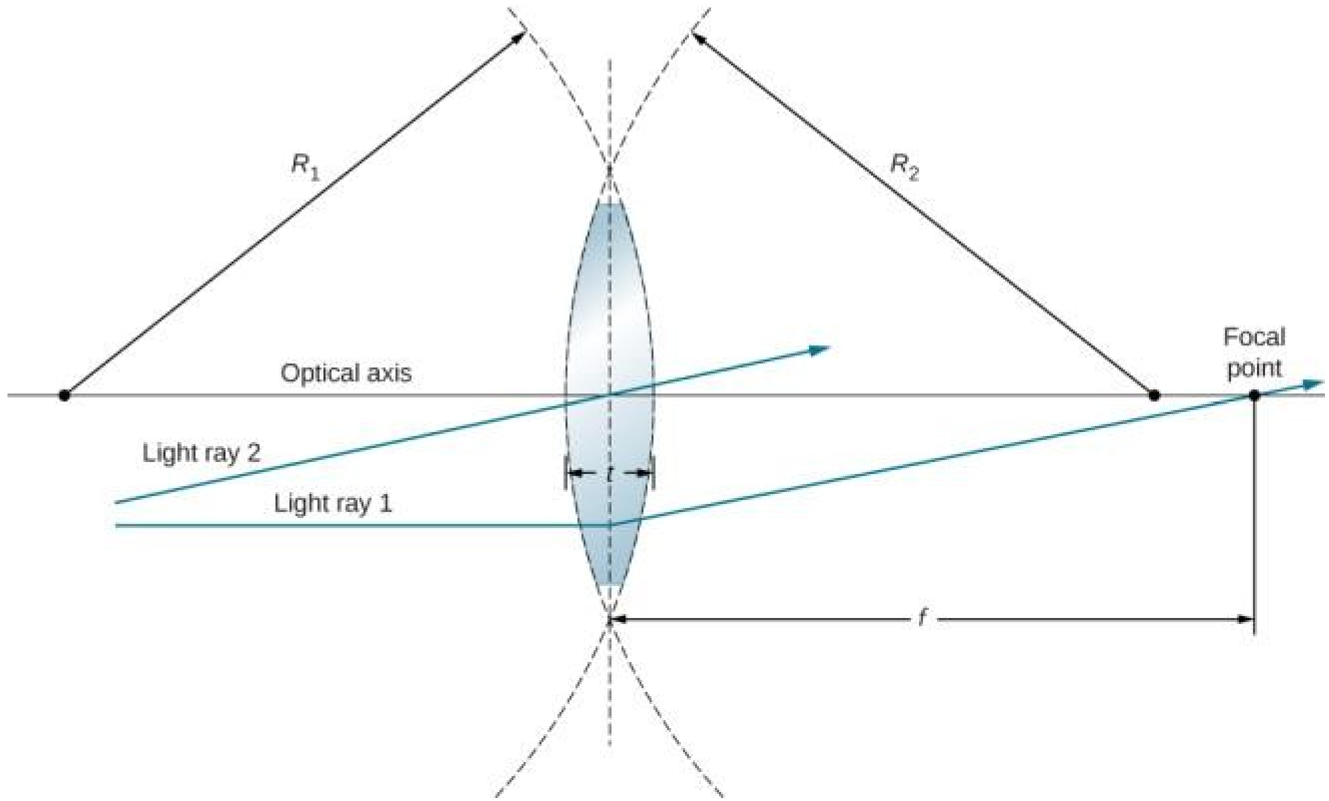
Various types of lenses: Note that a converging lens has a thicker “waist,” whereas a diverging lens has a thinner waist.

FIGURE 2.18



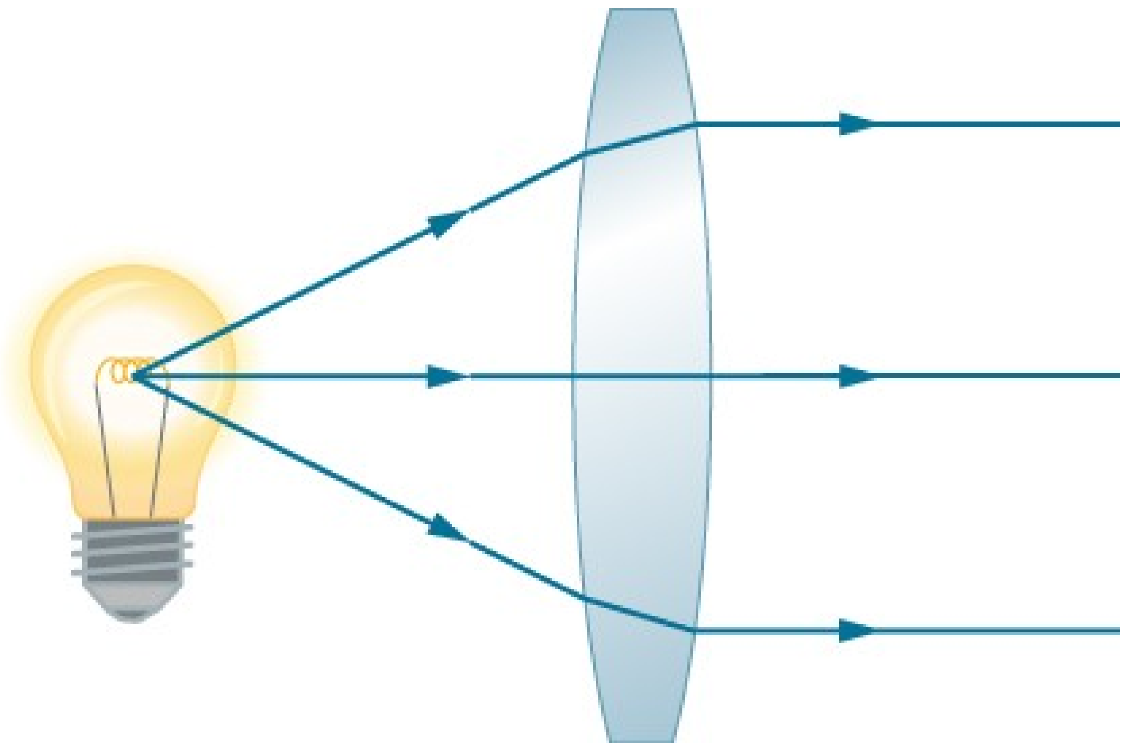
Rays of light entering (a) a converging lens and (b) a diverging lens, parallel to its axis, converge at its focal point *F*. The distance from the center of the lens to the focal point is the lens's focal length *f*. Note that the light rays are bent upon entering and exiting the lens, with the overall effect being to bend the rays toward the optical axis.

FIGURE 2.19



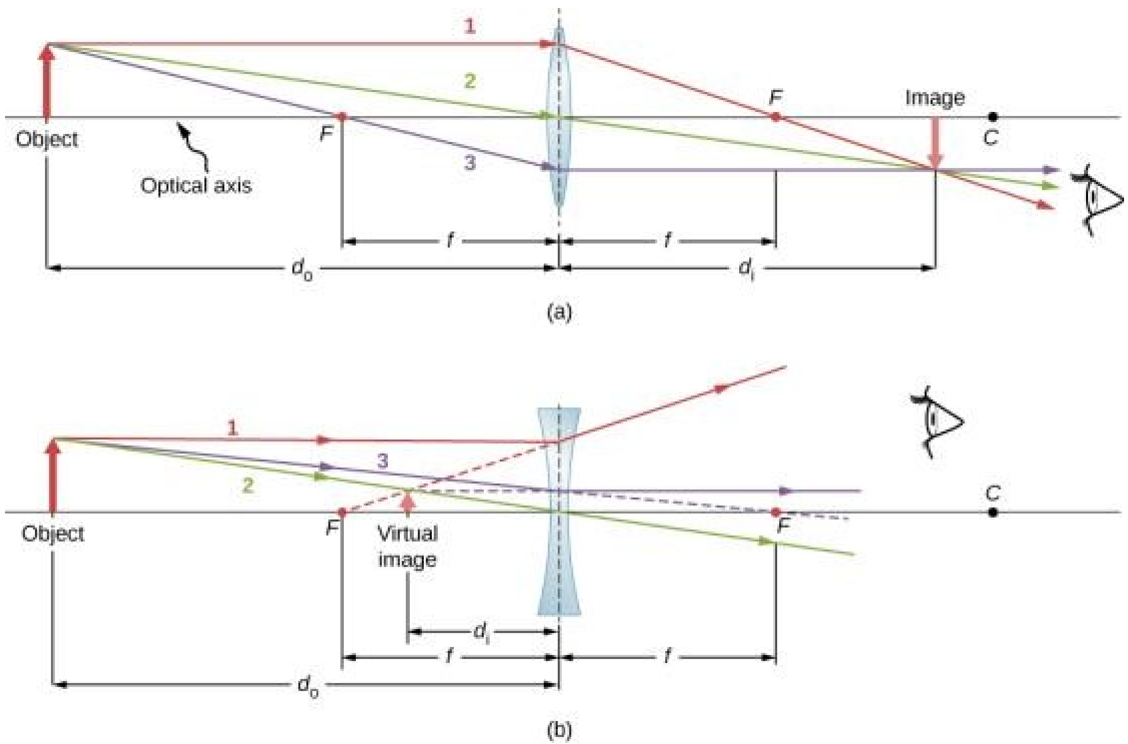
In the thin-lens approximation, the thickness *d* of the lens is much, much less than the radii R_1 and R_2 of curvature of the surfaces of the lens. Light rays are considered to bend at the center of the lens, such as light ray 1. Light ray 2 passes through the center of the lens and is undeviated in the thin-lens approximation.

FIGURE 2.20



A small light source, like a light bulb filament, placed at the focal point of a convex lens results in parallel rays of light emerging from the other side. The paths are exactly the reverse of those shown in Figure 2.18 in converging and diverging lenses. This technique is used in lighthouses and sometimes in traffic lights to produce a directional beam of light from a source that emits light in all directions.

FIGURE 2.21

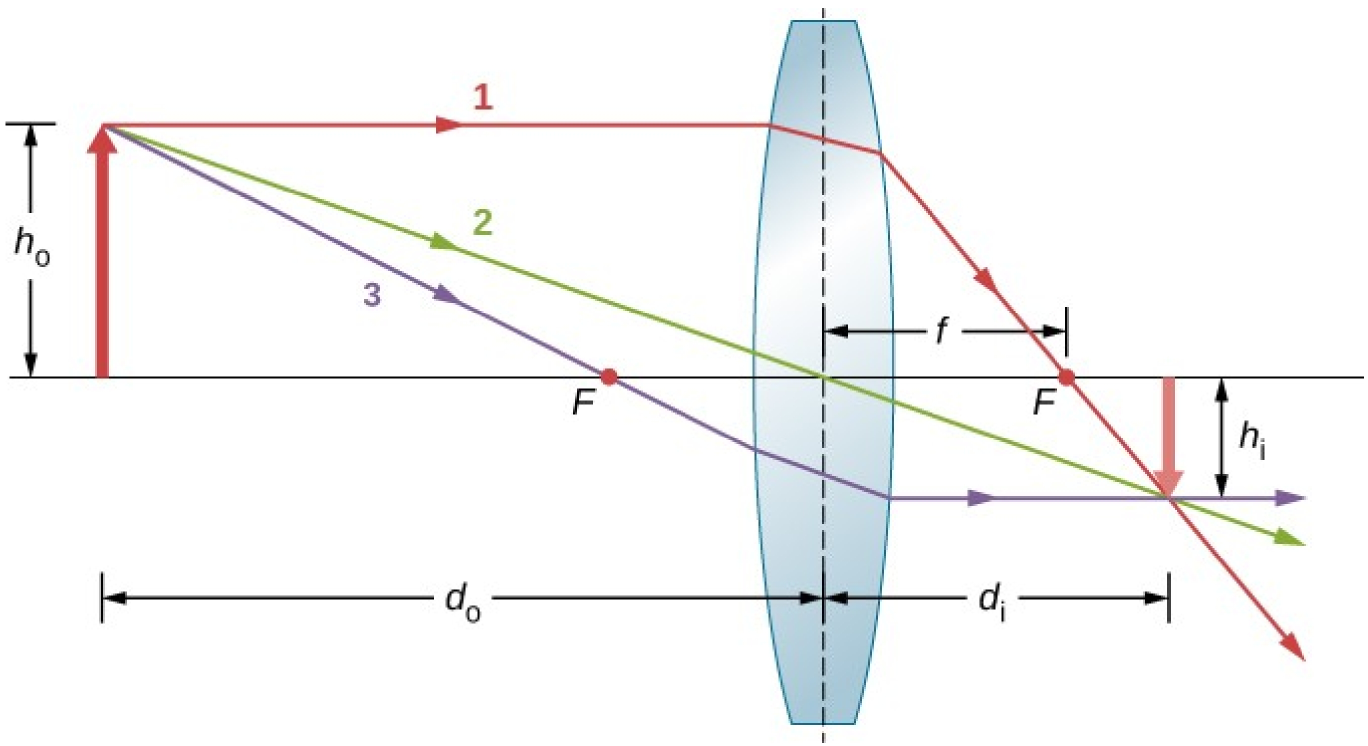


Thin lenses have the same focal lengths on either side.

a) Parallel light rays from the object toward a converging lens.

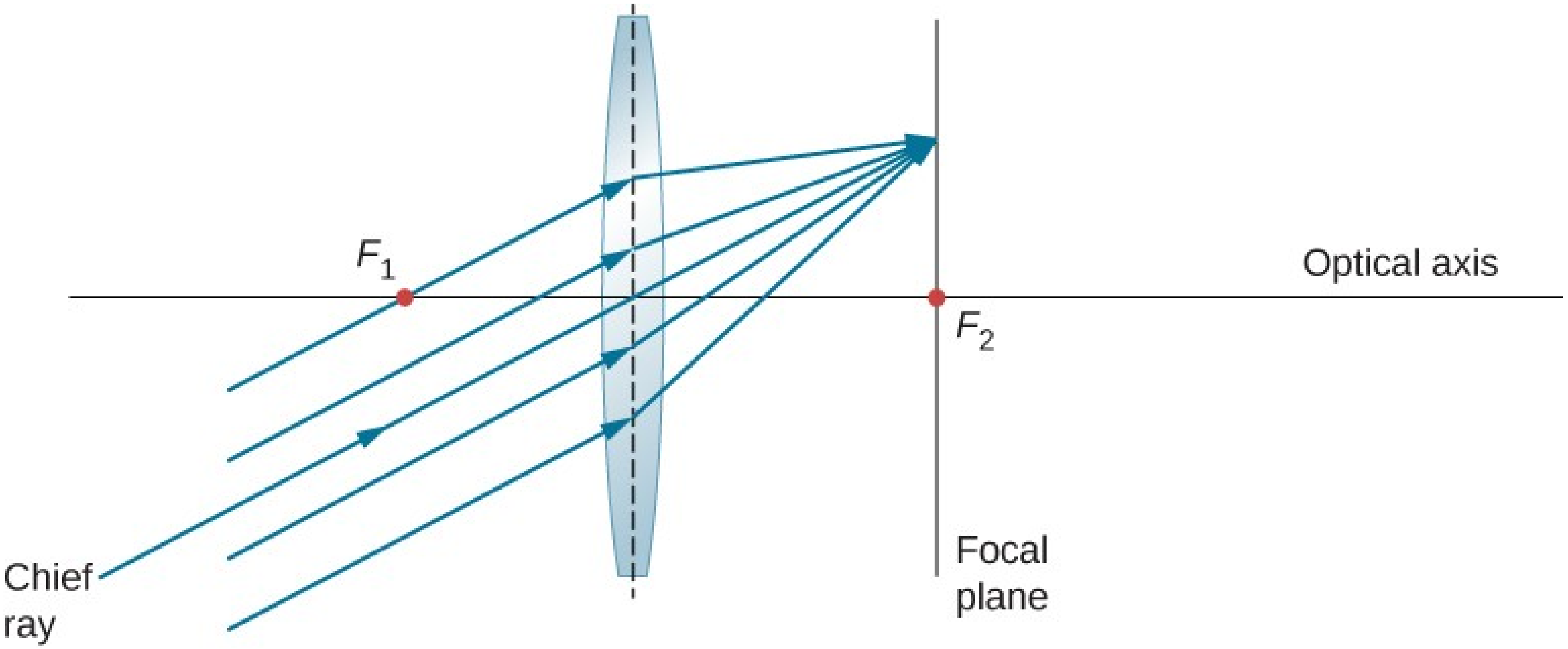
b) Parallel light rays from the object entering a diverging lens from the left seem to come from the focal point on the left.

FIGURE 2.22



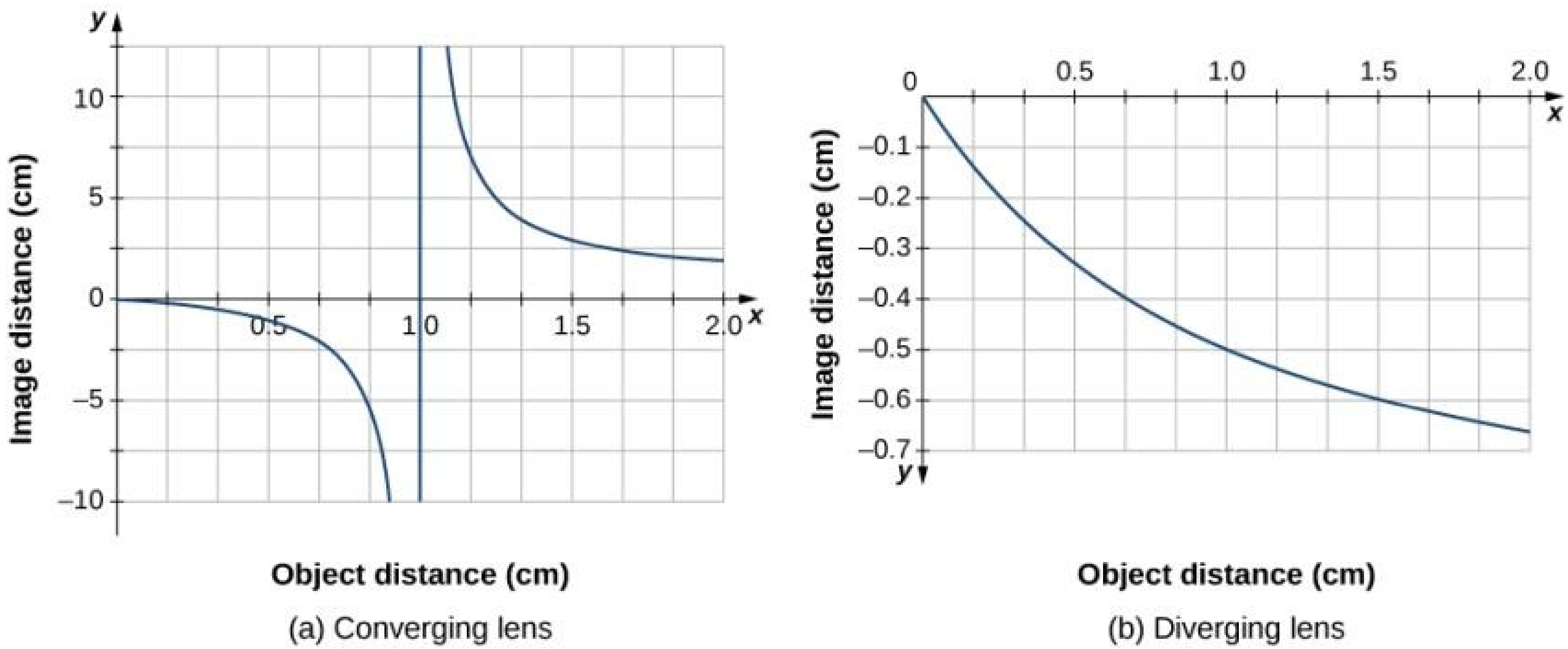
Ray tracing is used to locate the image formed by a lens. Rays originating from the same point on the object are traced—the three chosen rays each follow one of the rules for ray tracing, so that their paths are easy to determine. The image is located at the point where the rays cross. In this case, a real image—one that can be projected on a screen—is formed.

FIGURE 2.23



Parallel oblique rays focus on a point in a focal plane.

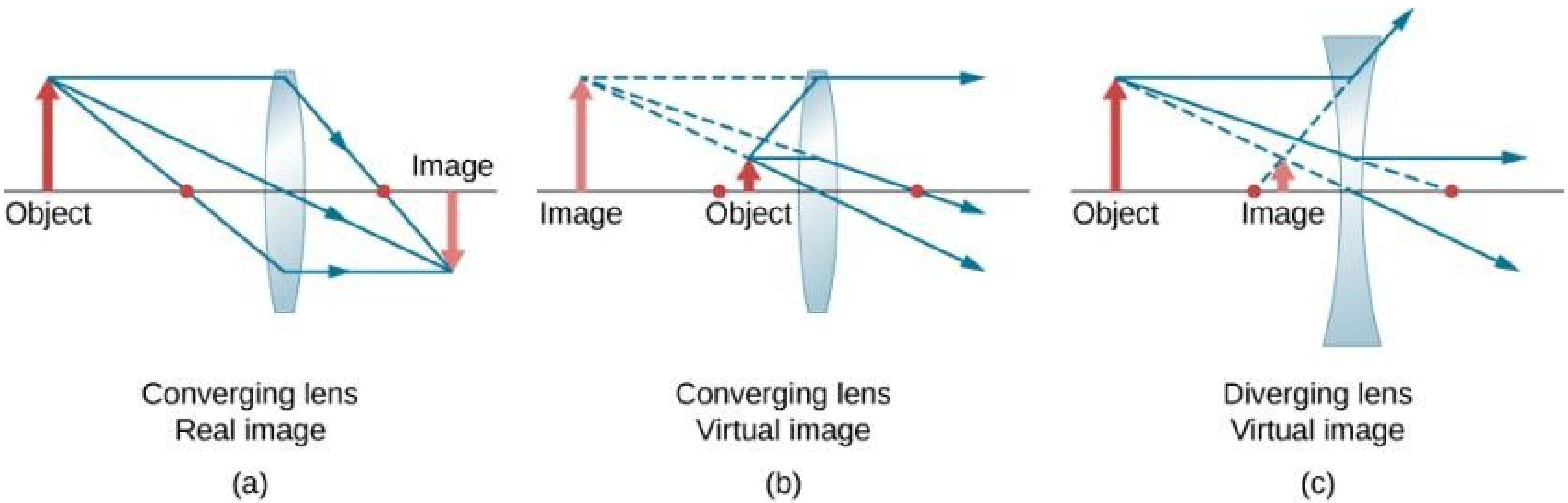
FIGURE 2.25



a) Image distance for a thin converging lens with $f = 1.0$ cm as a function of object distance.

b) Same thing but for a diverging lens with $f = -1.0$ cm.

FIGURE 2.26



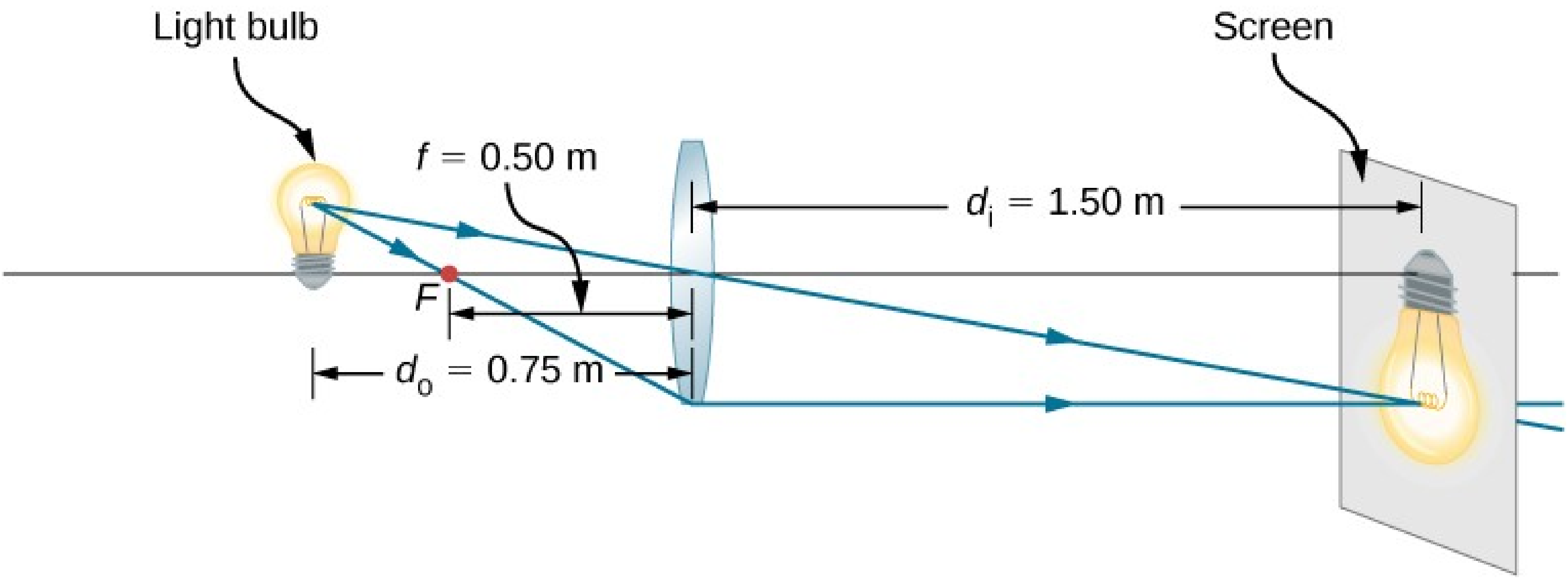
The red dots show the focal points of the lenses.

a) A real, inverted image formed from an object that is farther than the focal length from a converging lens.

b) A virtual, upright image formed from an object that is closer than a focal length from the lens.

c) A virtual, upright image formed from an object that is farther than a focal length from a diverging lens.

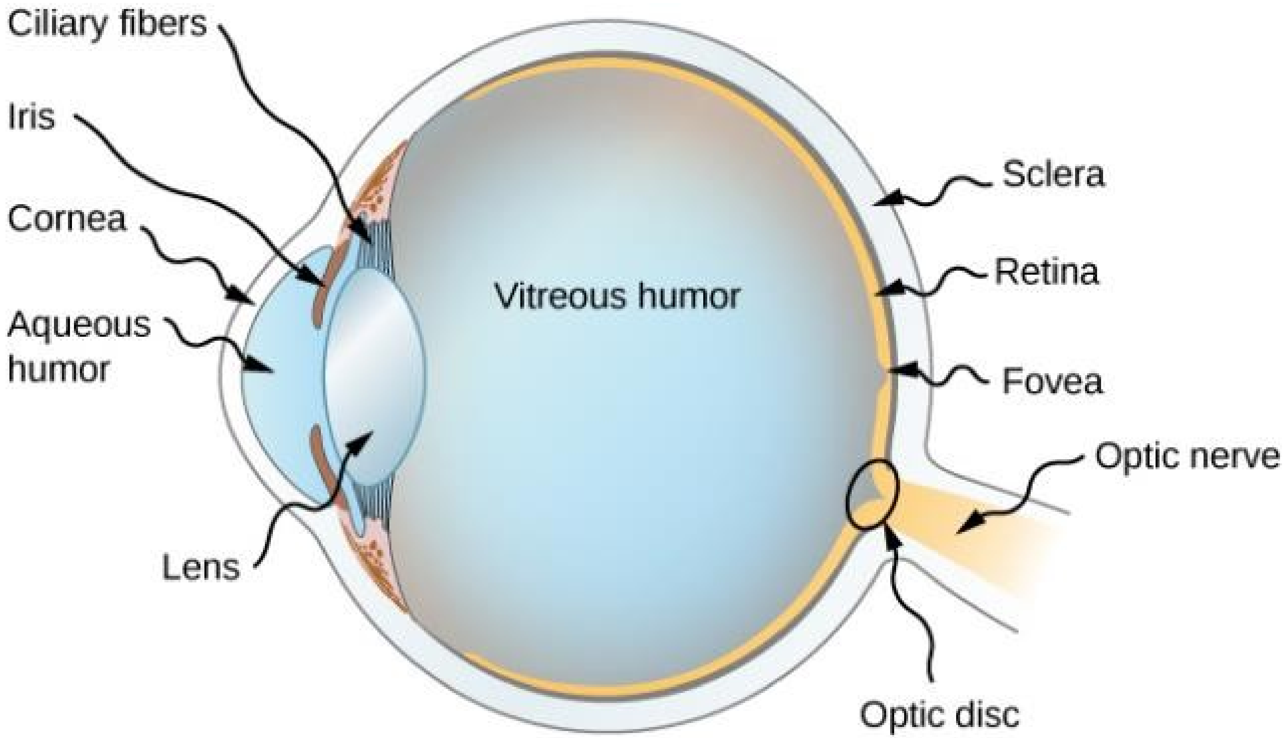
FIGURE 2.28



A light bulb placed 0.75 m from a lens having a 0.50-m focal length produces a real image on a screen, as discussed in the example. Ray tracing predicts the image location and size.

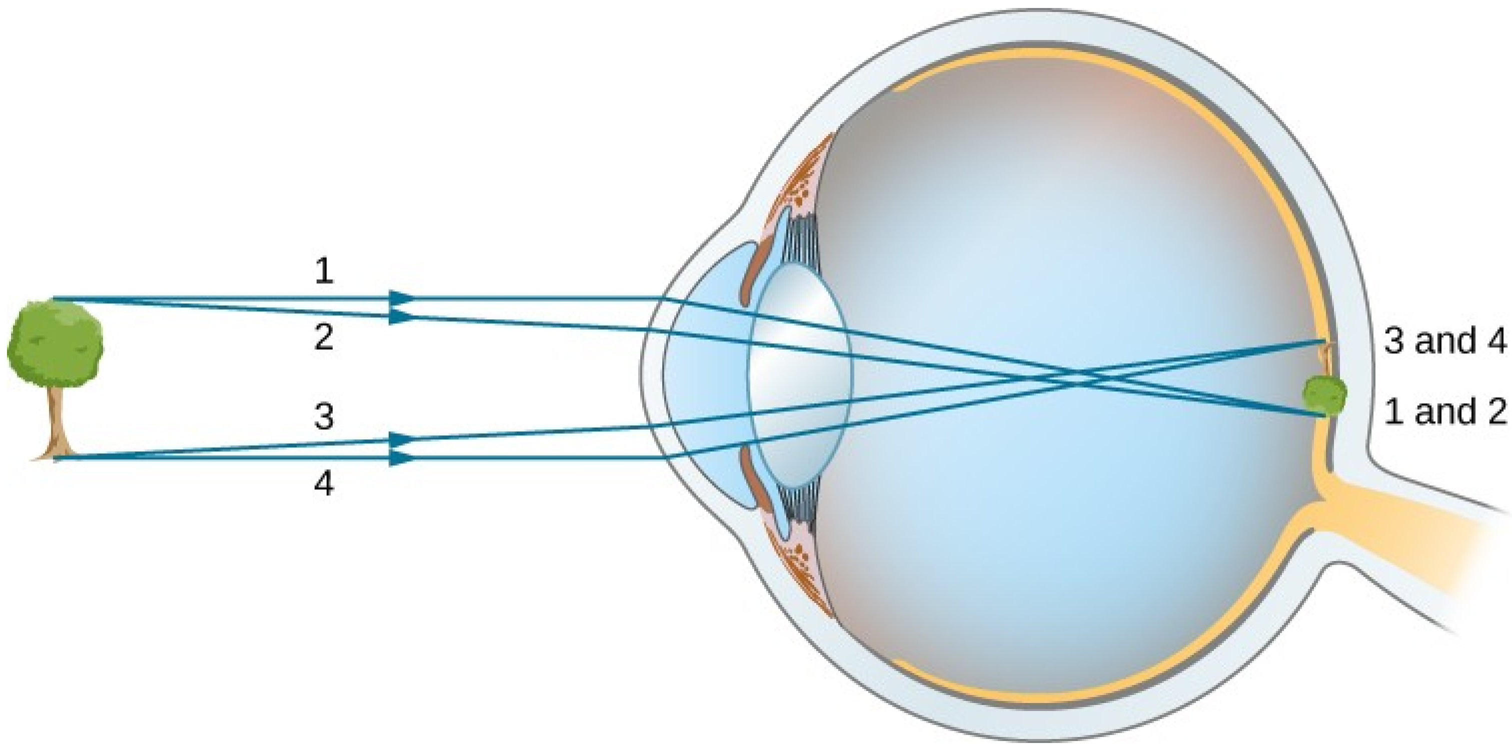
Applications – the eye

FIGURE 2.29



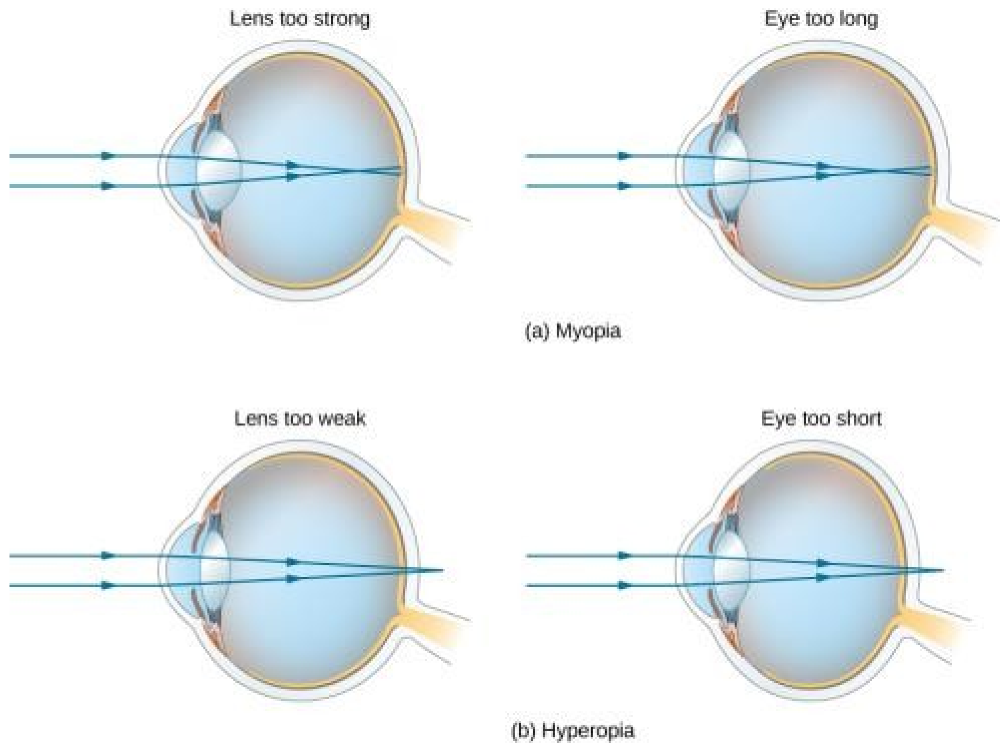
The cornea and lens of the eye act together to form a real image on the light-sensing retina, which has its densest concentration of receptors in the fovea and a blind spot over the optic nerve. The radius of curvature of the lens of an eye is adjustable to form an image on the retina for different object distances. Layers of tissues with varying indices of refraction in the lens are shown here. However, they have been omitted from other pictures for clarity.

FIGURE 2.30



In the human eye, an image forms on the retina. Rays from the top and bottom of the object are traced to show how a real, inverted image is produced on the retina. The distance to the object is not to scale.

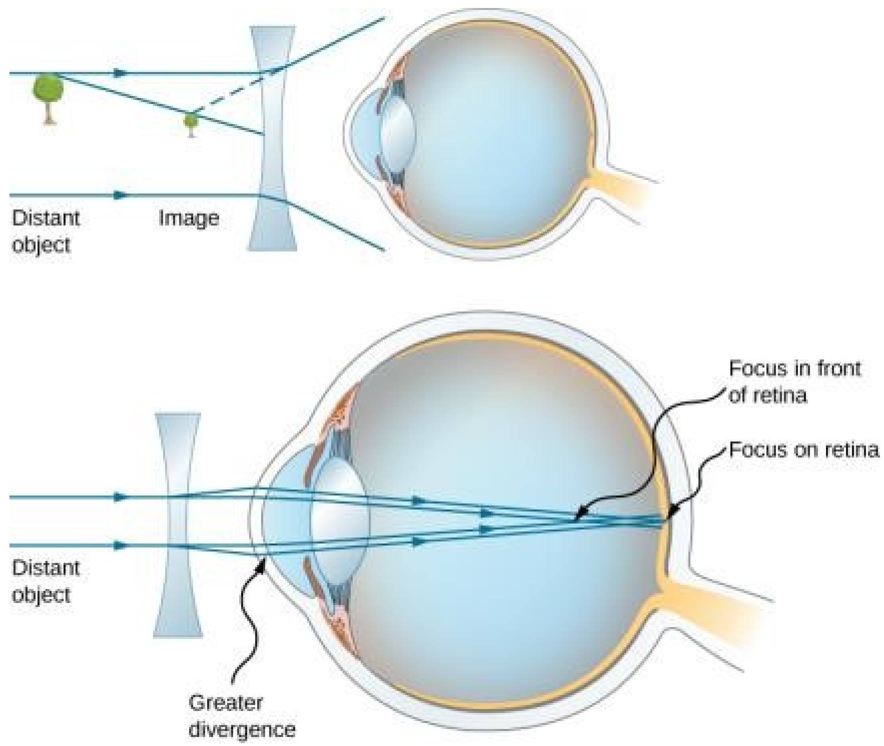
FIGURE 2.31



a) The nearsighted (myopic) eye converges rays from a distant object in front of the retina, so they have diverged when they strike the retina, producing a blurry image. An eye lens that is too powerful can cause nearsightedness, or the eye may be too long.

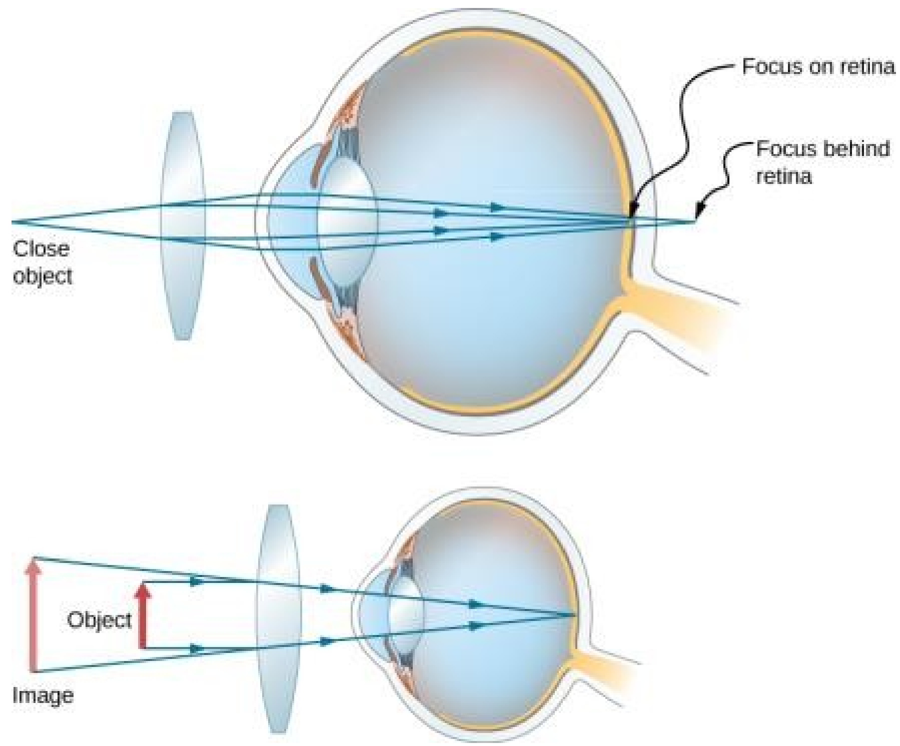
b) The farsighted (hyperopic) eye is unable to converge the rays from a close object on the retina, producing blurry near-field vision. An eye lens with insufficient optical power or an eye that is too short can cause farsightedness.

FIGURE 2.32



Correction of nearsightedness requires a diverging lens that compensates for overconvergence by the eye. The diverging lens produces an image closer to the eye than the physical object. This image serves as the optical object for the eye, and the nearsighted person can see it clearly because it is closer than their far point.

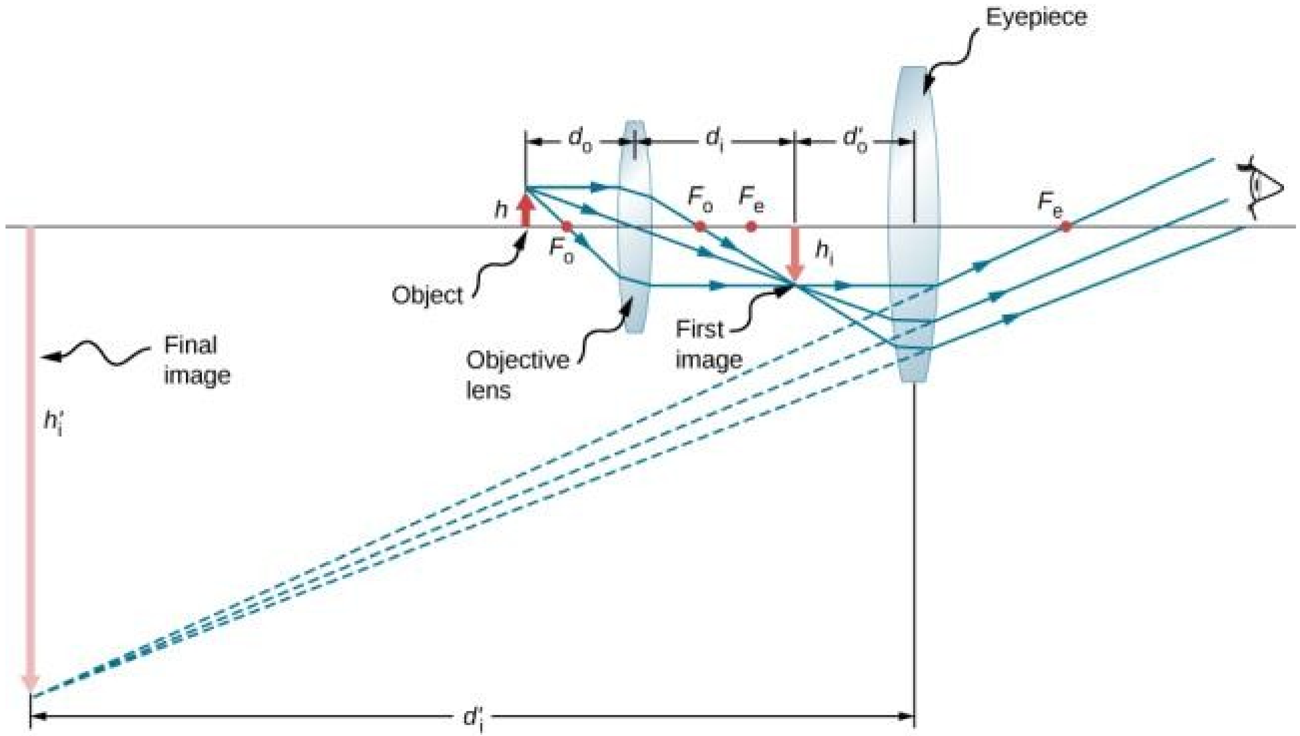
FIGURE 2.33



Correction of farsightedness uses a converging lens that compensates for the underconvergence by the eye. The converging lens produces an image farther from the eye than the object, so that the farsighted person can see it clearly.

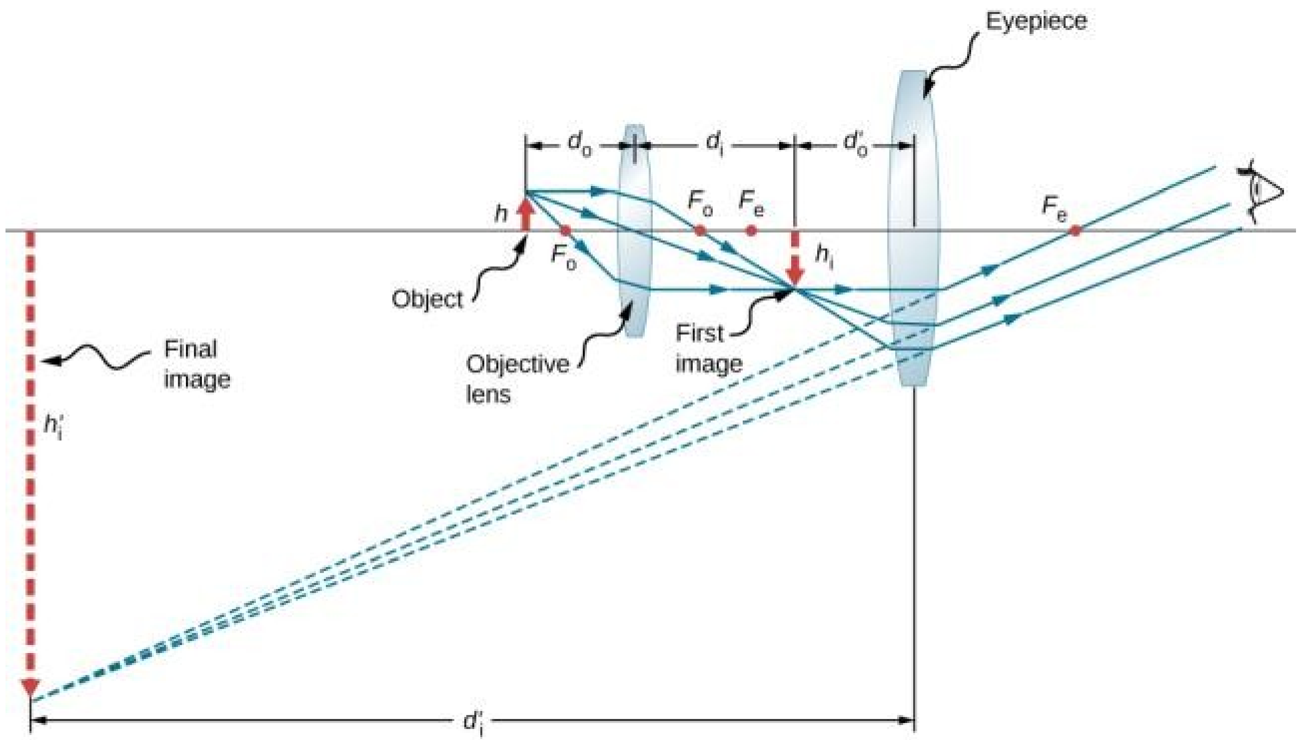
Microscope

FIGURE 2.38



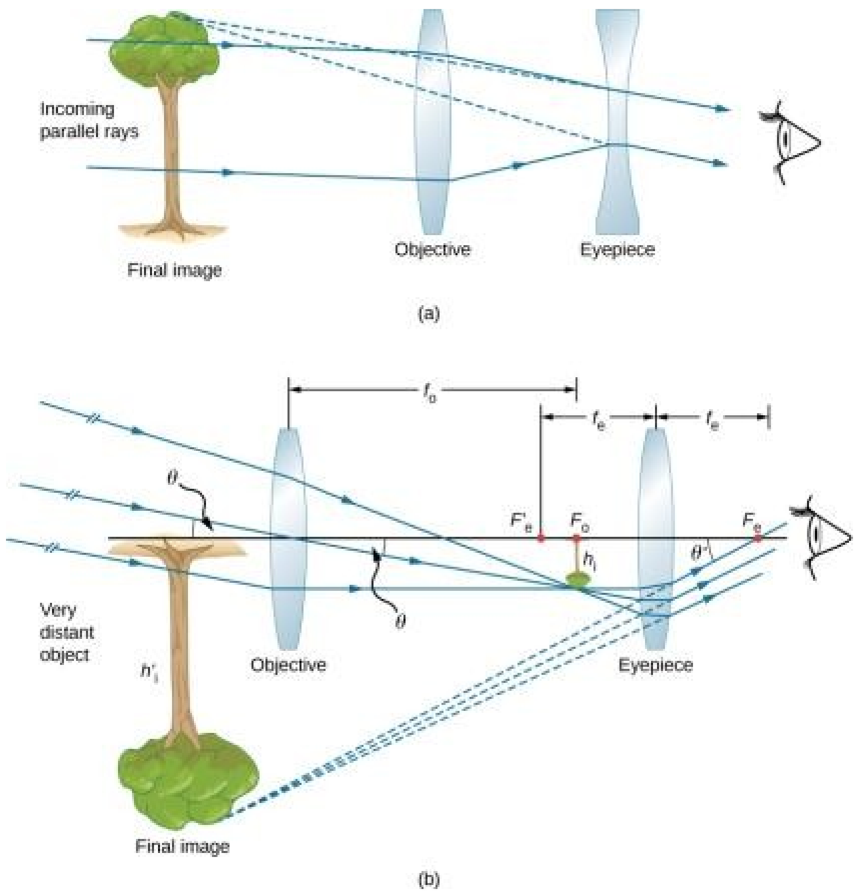
A compound microscope is composed of two lenses: an objective and an eyepiece. The objective forms the first image, which is larger than the object. This first image is inside the focal length of the eyepiece and serves as the object for the eyepiece. The eyepiece forms final image that is further magnified. The d_o and d_i shown will be discussed with superscripts "obj" below to denote they are measured from the objective lens, while the eye piece variables will have superscripts of "eye" to denote this lens.

FIGURE 2.39



A compound microscope with the image created at infinity.

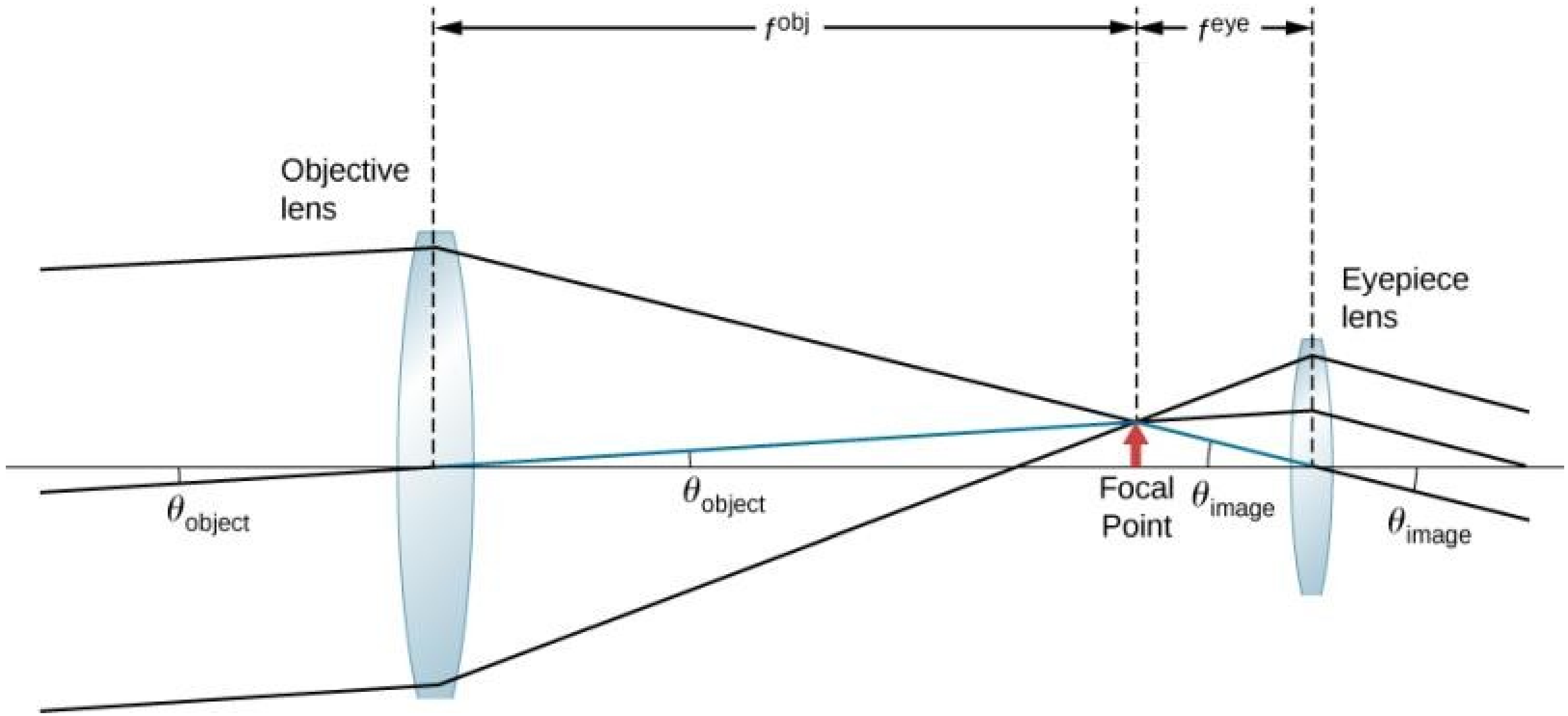
FIGURE 2.40



a) Galileo made telescopes with a convex objective and a concave eyepiece. These produce an upright image and are used in spyglasses.

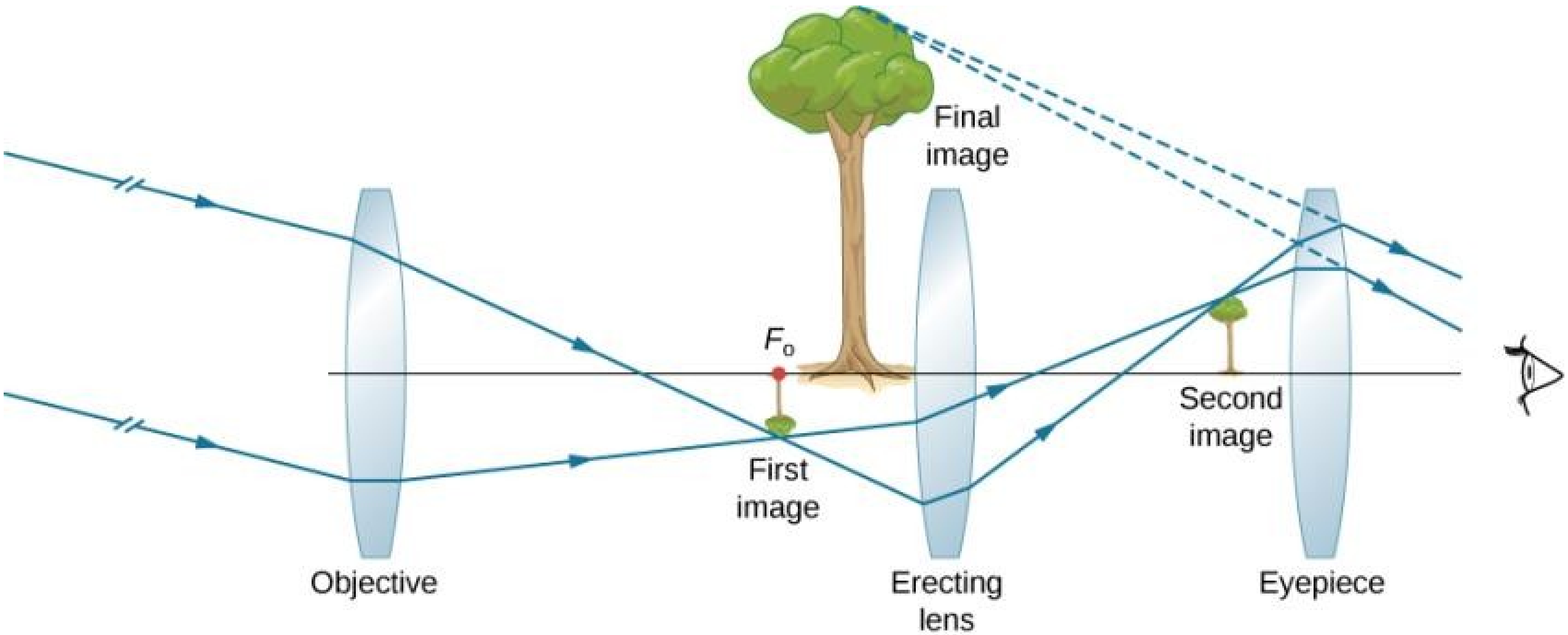
b) Most simple refracting telescopes have two convex lenses. The objective forms a real, inverted image at (or just within) the focal plane of the eyepiece. This image serves as the object for the eyepiece. The eyepiece forms a virtual, inverted image that is magnified.

FIGURE 2.41



The focal plane of the objective lens of a telescope is very near to the focal plane of the eyepiece. The angle θ_{image} subtended by the image viewed through the eyepiece is larger than the angle θ_{object} subtended by the object when viewed with the unaided eye.

FIGURE 2.42



This arrangement of three lenses in a telescope produces an upright final image. The first two lenses are far enough apart that the second lens inverts the image of the first. The third lens acts as a magnifier and keeps the image upright and in a location that is easy to view.

Examples

Examples of ray diagrams

Exercise 59

A camera with a 100 mm-focal length lens is used to photograph the sun. What is the height of the image of the sun on the film, given the sun is in diameter and is away?