Chapter 34

Images

Checkpoint 3

A bee is hovering in front of the concave spherical refracting surface of a glass sculpture. (a) Which part of Fig. 34-12 is like this situation? (b) Is the image produced by the surface real or virtual, and (c) is it on the same side as the bee or the opposite side?

(a) *e*; (b) virtual, same

Sample Problem 34.02 Image produced by a refracting surface

A Jurassic mosquito is discovered embedded in a chunk of amber, which has index of refraction 1.6. One surface of the amber is spherically convex with radius of curvature 3.0 mm (Fig. 34-13). The mosquito's head happens to be on the central axis of that surface and, when viewed along the axis, appears to be buried 5.0 mm into the amber. How deep is it really?

KEY IDEAS

The head appears to be 5.0 mm into the amber only because the light rays that the observer intercepts are bent by refraction at the convex amber surface. The image distance i differs from the object distance p according to Eq. 34-8. To use that equation to find the object distance, we first note:

1. Because the object (the head) and its image are on the same side of the refracting surface, the image must be virtual and so $i = -5.0$ mm.
2. Because the object is always taken to be in the medium of index of refraction n_1, we must have $n_1 = 1.6$ and $n_2 = 1.0$.
3. Because the *object* faces a concave refracting surface, the radius of curvature r is negative, and so $r = -3.0$ mm.

Calculations: Making these substitutions in Eq. 34-8,

$$\frac{n_1}{p} + \frac{n_2}{i} = \frac{n_2 - n_1}{r},$$

yields

$$\frac{1.6}{p} + \frac{1.0}{-5.0\ \text{mm}} = \frac{1.0 - 1.6}{-3.0\ \text{mm}}$$

and

$$p = 4.0\ \text{mm}. \qquad \text{(Answer)}$$

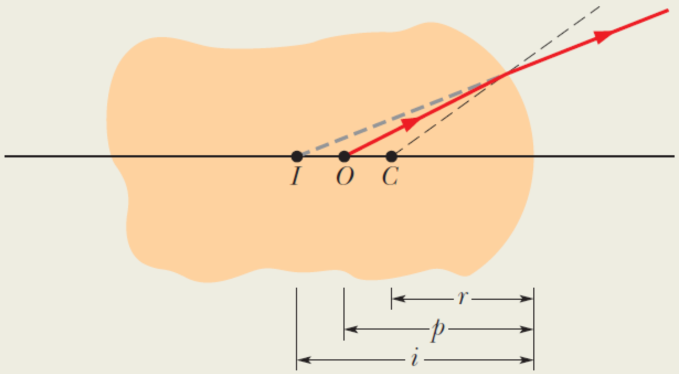


Figure 34-13 A piece of amber with a mosquito from the Jurassic period, with the head buried at point O. The spherical refracting surface at the right end, with center of curvature C, provides an image I to an observer intercepting rays from the object at O.

34-4 Thin Lenses

For an object in front of a lens, object distance *p* and image distance *i* are related to the lens's focal length *f*, index of refraction *n*, and radii of curvature r_1 and r_2 by

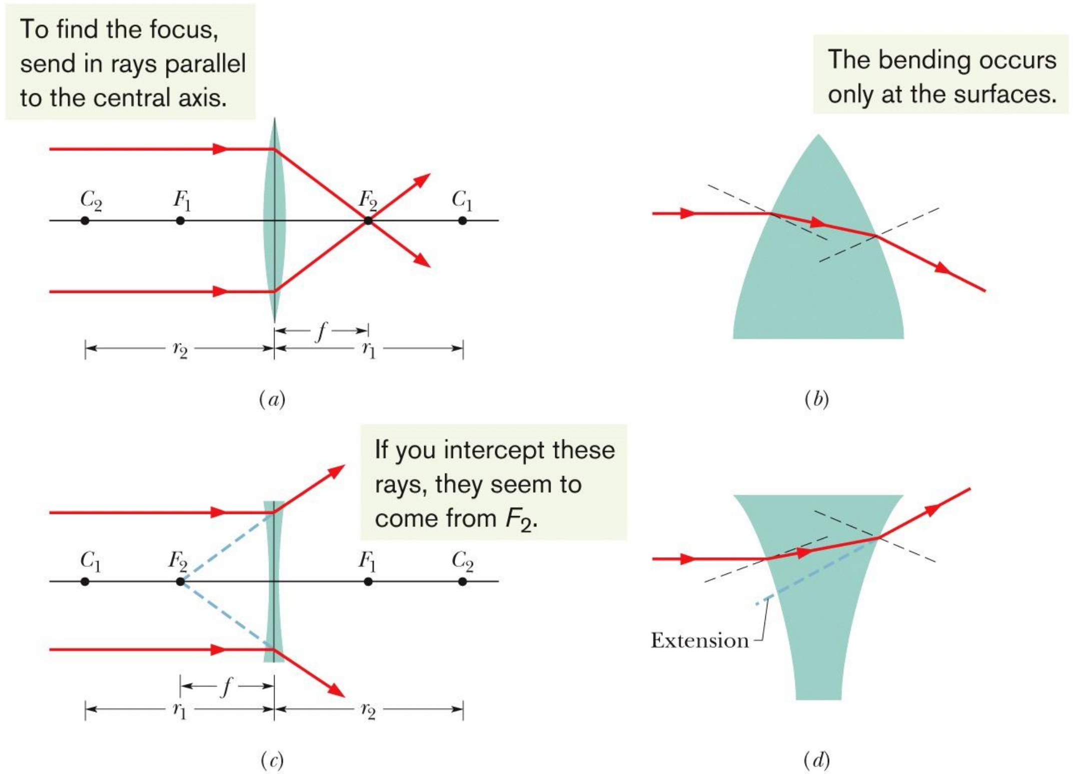
$$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \quad \text{(thin lens in air),}$$

which is often called the **lens maker's** equation. Here r_1 is the radius of curvature of the lens surface nearer the object and r_2 is that of the other surface. If the lens is surrounded by some medium other than air (say, corn oil) with index of refraction n_{medium}, we replace n in above Eq. with n/n_{medium}.

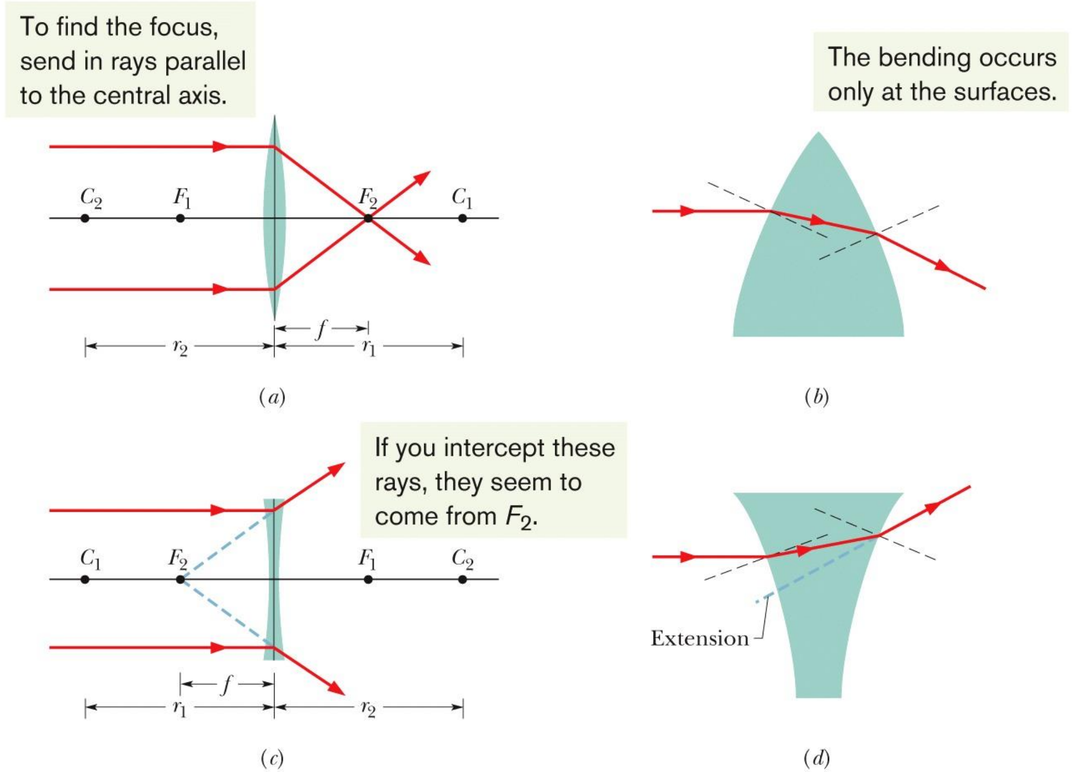
A lens can produce an image of an object only because the lens can bend light rays, but it can bend light rays only if its index of refraction differs from that of the surrounding medium.

34-4 Thin Lenses

Forming a Focus. Figure (a) shows a thin lens with convex refracting surfaces, or sides. When rays that are parallel to the central axis of the lens are sent through the lens, they refract twice, as is shown enlarged in Fig.(b). This double refraction causes the rays to converge and pass through a common point F_2 at a distance f from the center of the lens. Hence, this lens is a converging lens; further, a real focal point (or focus) exists at F_2 (because the rays really do pass through it), and the associated focal length is f. When rays parallel to the central axis are sent in the opposite direction through the lens, we find another real focal point at F_1 on the other side of the lens. For a thin lens, these two focal points are equidistant from the lens.



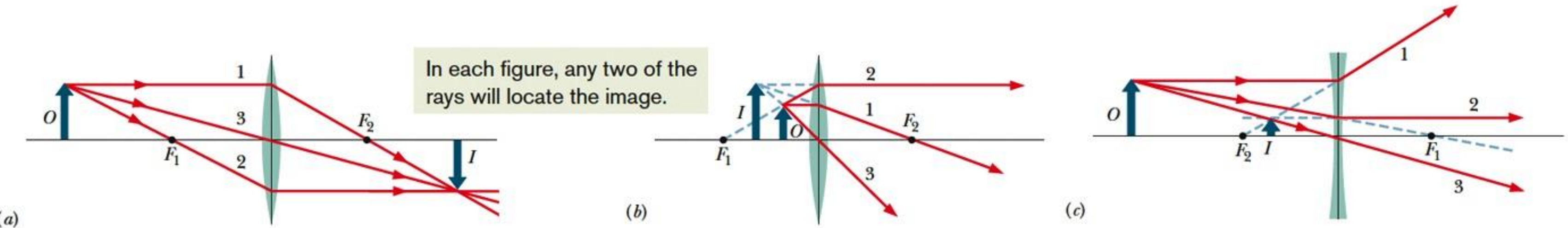
34-4 Thin Lenses



Forming a Focus. Figure (c) shows a thin lens with concave sides. When rays that are parallel to the central axis of the lens are sent through this lens, they refract twice, as is shown enlarged in Fig. (d); these rays diverge, never passing through any common point, and so this lens is a diverging lens. However, extensions of the rays do pass through a common point F_2 at a distance f from the center of the lens. Hence, the lens has a virtual focal point at F_2. (If your eye intercepts some of the diverging rays, you perceive a bright spot to be at F_2, as if it is the source of the light.) Another virtual focus exists on the opposite side of the lens at F_1, symmetrically placed if the lens is thin. Because the focal points of a diverging lens are virtual, we take the focal length f to be negative.

34-4 Thin Lenses

Locating Images of Extended Objects by Drawing Rays

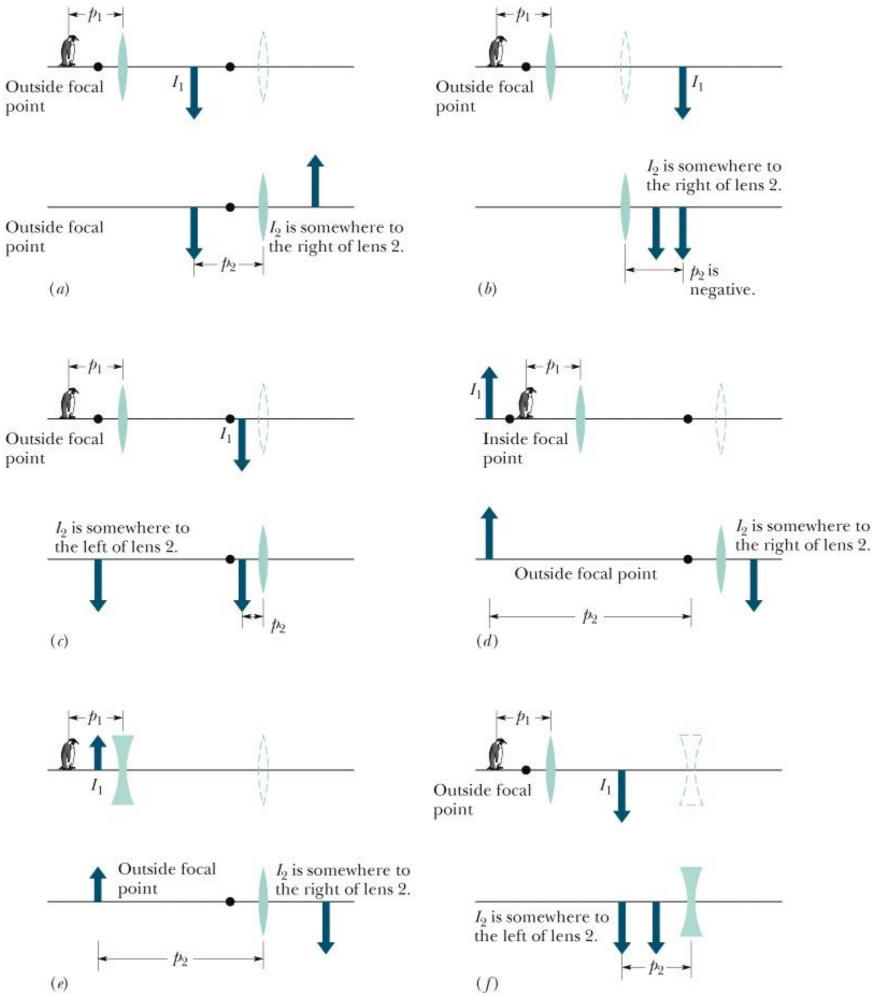


1. A ray that is initially parallel to the central axis of the lens will pass through focal point F_2 (ray 1 in Fig. a).
2. A ray that initially passes through focal point F_1 will emerge from the lens parallel to the central axis (ray 2 in Fig. a).
3. A ray that is initially directed toward the center of the lens will emerge from the lens with no change in its direction (ray 3 in Fig. a) because the ray encounters the two sides of the lens where they are almost parallel.

Figure b shows how the extensions of the three special rays can be used to locate the image of an object placed inside focal point F_1 of a converging lens. Note that the description of ray 2 requires modification (it is now a ray whose backward extension passes through F_1).You need to modify the descriptions of rays 1 and 2 to use them to locate an image placed (anywhere) in front of a diverging lens. In Fig. c, for example, we find the point where ray 3 intersects the backward extensions of rays 1 and 2.

34-4 Thin Lenses

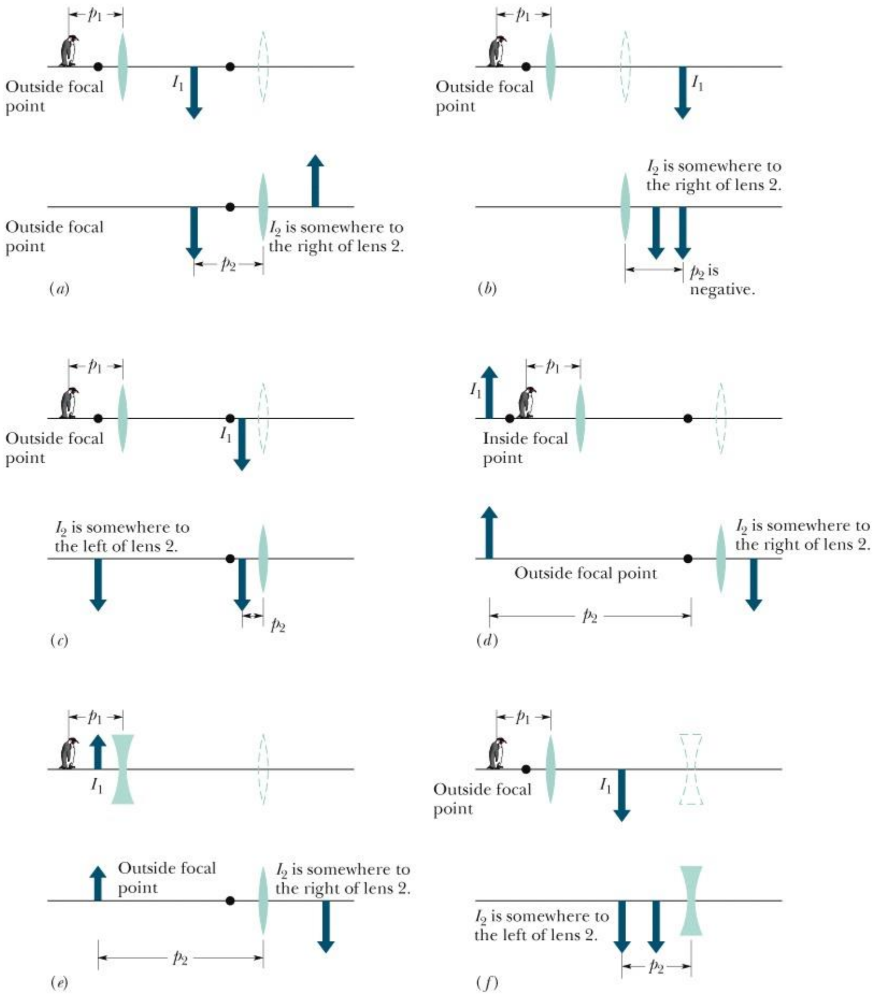
Two Lens System



Here we consider an object sitting in front of a system of two lenses whose central axes coincide. Some of the possible two-lens systems are sketched in the figure (left) , but the figures are not drawn to scale. In each, the object sits to the left of lens 1 but can be inside or outside the focal point of the lens. Although tracing the light rays through any such two-lens system can be challenging, we can use the following simple two-step solution:

34-4 Thin Lenses

Two Lens System



Step 1: Neglecting lens *2*, use thin lens equation to locate the image I_1 produced by lens *1*. Determine whether the image is on the left or right side of the lens, whether it is real or virtual, and whether it has the same orientation as the object. Roughly sketch I_1. The top part of Fig. (a) gives an example.

Step 2: Neglecting lens *1*, treat I_1 as though it is the object for lens *2*. Use thin lens equation to locate the image I_2 produced by lens *2*. This is the final image of the system. Determine whether the image is on the left or right side of the lens, whether it is real or virtual, and whether it has the same orientation as the object for lens *2*. Roughly sketch I_2 . The bottom part of Fig. (a) gives an example.

Checkpoint 4

A thin symmetric lens provides an image of a fingerprint with a magnification of $+0.2$ when the fingerprint is 1.0 cm farther from the lens than the focal point of the lens. What are the (a) type and (b) orientation of the image, and (c) what is the type of lens?

virtual, same as object, diverging