EXAMPLE 23–10 **Object close to converging lens.** An object is placed 10 cm from a 15-cm-focal-length converging lens. Determine the image position and size (*a*) analytically, and (*b*) using a ray diagram.

APPROACH We first use Eqs. 23–8 and 23–9 to obtain an analytic solution, and then confirm with a ray diagram using the special rays 1, 2, and 3 for a single object point.

SOLUTION (*a*) Given $f = 15\text{ cm}$ and $d_o = 10\text{ cm}$, then

$$\frac{1}{d_i} = \frac{1}{15\text{ cm}} - \frac{1}{10\text{ cm}} = -\frac{1}{30\text{ cm}},$$

and $d_i = -30\text{ cm}$. (Remember to take the reciprocal!) Because d_i is negative, the image must be virtual and on the same side of the lens as the object. The magnification

$$m = -\frac{d_i}{d_o} = -\frac{-30\text{ cm}}{10\text{ cm}} = 3.0.$$

The image is three times as large as the object and is upright. This lens is being used as a simple magnifying glass, which we discuss in more detail in Section 25–3.

(*b*) The ray diagram is shown in Fig. 23–40 and confirms the result in part (*a*). We choose point O′ on the top of the object and draw ray 1, which is easy. But ray 2 may take some thought: if we draw it heading toward F′, it is going the wrong way—so we have to draw it as if coming from F′ (and so dashed), striking the lens, and then going out parallel to the lens axis. We project it backward with a dashed line, as we must do also for ray 1, in order to find where they cross. Ray 3 is drawn through the lens center, and it crosses the other two rays at the image point, I′.

NOTE From Fig. 23–40 we can see that, whenever an object is placed between a converging lens and its focal point, the image is virtual.

CAUTION
Don't forget to take the reciprocal

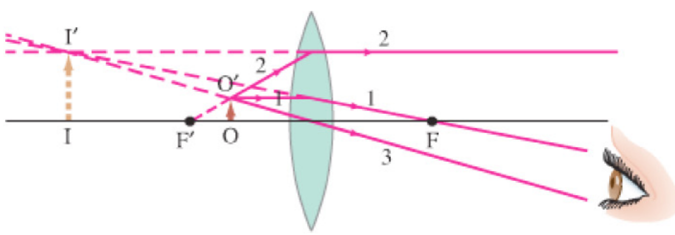

FIGURE 23–40 An object placed within the focal point of a converging lens produces a virtual image. Example 23–10.

EXAMPLE 23–11 **Diverging lens.** Where must a small insect be placed if a 25-cm-focal-length diverging lens is to form a virtual image 20 cm in front of the lens?

APPROACH The ray diagram is basically that of Fig. 23–38 because our lens here is diverging and our image is in front of the lens within the focal distance. (It would be a valuable exercise to draw the ray diagram to scale, precisely, now.) The insect's distance, d_o, can be calculated using the thin lens equation.

SOLUTION The lens is diverging, so f is negative: $f = -25\text{ cm}$. The image distance must be negative too because the image is in front of the lens (sign conventions), so $d_i = -20\text{ cm}$. Equation 23–8 gives

$$\frac{1}{d_o} = \frac{1}{f} - \frac{1}{d_i} = -\frac{1}{25\text{ cm}} + \frac{1}{20\text{ cm}} = \frac{-4+5}{100\text{ cm}} = \frac{1}{100\text{ cm}}.$$

So the object must be 100 cm in front of the lens.

EXERCISE H An object is placed 12 cm from a lens with 15-cm focal length. Will the image be real or virtual if the lens is (*a*) converging or (*b*) diverging?

EXERCISE I Determine the position of the image produced by a 15.0-cm-focal-length converging lens when an object is placed 13.0 cm in front of it.