be careful about the signs of all quantities in Eqs. 23–2 and 23–3. Sign conventions are chosen so as to give the correct locations and orientations of images, as predicted by ray diagrams. The sign conventions we use are: the image height h_i is positive if the image is upright, and negative if inverted, relative to the object (assuming h_o is taken as positive); d_i or d_o is positive if image or object is in front of the mirror (as in Fig. 23–14); if either image or object is behind the mirror, the corresponding distance is negative (an example can be seen in Fig. 23–16, Example 23–3). Thus the magnification (Eq. 23–3) is positive for an upright image and negative for an inverted image (upside down). We summarize sign conventions more fully after discussing convex mirrors later in this Section.

CAUTION
Sign conventions

EXERCISE B Does the mirror equation, Eq. 23–2, hold for a plane mirror? Explain.

Concave Mirror Examples

EXAMPLE 23–2 **Image in a concave mirror.** A 1.50-cm-high diamond ring is placed 20.0 cm from a concave mirror with radius of curvature 30.0 cm. Determine (*a*) the position of the image, and (*b*) its size.

APPROACH We determine the focal length from the radius of curvature (Eq. 23–1), $f = r/2 = 15.0\,\text{cm}$. The ray diagram is basically like that shown in Fig. 23–13 or Fig. 23–14, since the object is between F and C. The position and size of the image are found from Eqs. 23–2 and 23–3.

SOLUTION Referring to Fig. 23–14, we have $\text{CA} = r = 30.0\,\text{cm}$, $\text{FA} = f = 15.0\,\text{cm}$, and $\text{OA} = d_o = 20.0\,\text{cm}$.

(*a*) From Eq. 23–2,

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} = \frac{1}{15.0\,\text{cm}} - \frac{1}{20.0\,\text{cm}} = 0.0167\,\text{cm}^{-1}.$$

So $d_i = 1/(0.0167\,\text{cm}^{-1}) = 60.0\,\text{cm}$. Because d_i is positive, the image is 60.0 cm in front of the mirror, on the same side as the object.

CAUTION
Remember to take the reciprocal

(*b*) From Eq. 23–3, the magnification is

$$m = -\frac{d_i}{d_o} = -\frac{60.0\,\text{cm}}{20.0\,\text{cm}} = -3.00.$$

The image height is 3.0 times the object height, and is

$$h_i = mh_o = (-3.00)(1.5\,\text{cm}) = -4.5\,\text{cm}.$$

The minus sign reminds us that the image is inverted, as in Fig. 23–14.

NOTE When an object is beyond the focal point of a concave mirror, we can see from Fig. 23–13 or 23–14 that the image is always inverted and real.

For a person's eye to see a sharp image, the eye must be at a place where it intercepts diverging rays from points on the image, as is the case for the eye's position in Figs. 23–13 and 23–14. Our eyes are made to see normal objects, which always means the rays are diverging toward the eye as shown in Fig. 23–1. (Or, for very distant objects like stars, the rays become essentially parallel—see Fig. 23–10.) If you placed your eye between points O and I in Fig. 23–14, for example, *converging* rays from the object OO′ would enter your eye and the lens of your eye could not bring them to a focus; you would see a blurry image. We will discuss the eye more in Chapter 25.

If *you* are the object OO′ in Fig. 23–14, situated between F and C, and are trying to see yourself in the mirror, you would see a blur; but the person whose eye is shown in Fig. 23–14 can see you clearly. You can see yourself clearly, but upside down, if you are to the left of C in Fig. 23–14, so $d_o > 2f$. Why? Because then the rays reflected from the image will be *diverging* at your position as shown in Fig. 23–15, and your eye can focus them. You can also see yourself clearly, and right-side up, if you are closer to the mirror than its focal point $(d_o < f)$, as we will see in Example 23–3, Fig. 23–16.

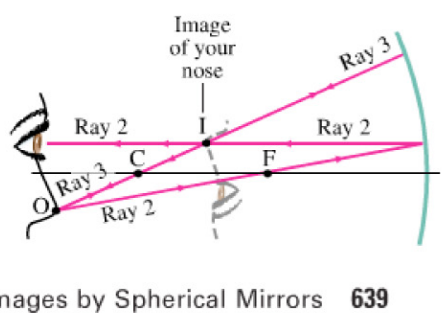

FIGURE 23–15 You can see a clear inverted image of your face when you are beyond C $(d_o > 2f)$, because the rays that arrive at your eye are diverging. Standard rays 2 and 3 are shown leaving point O on your nose. Ray 2 (and other nearby rays) enters your eye. Notice that rays are diverging as they move to the left of image point I.