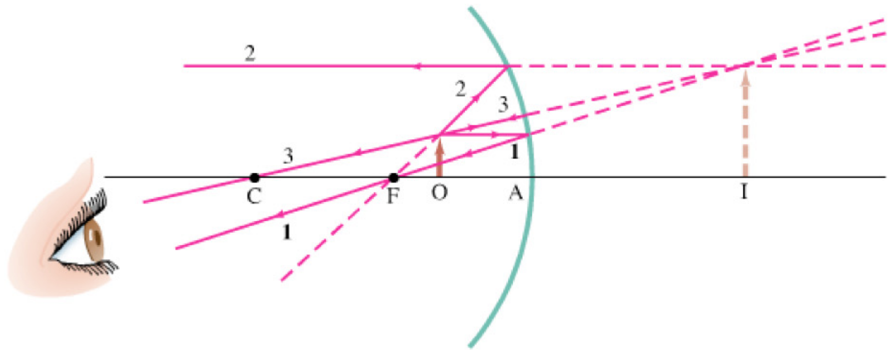

FIGURE 23–16 Object placed within the focal point F. The image is *behind* the mirror and is *virtual*, Example 23–3. [Note that the vertical scale (height of object = 1.0 cm) is different from the horizontal (OA = 10.0 cm) for ease of drawing, and affects the precision of the drawing.]

EXAMPLE 23–3 **Object closer to concave mirror.** A 1.00-cm-high object is placed 10.0 cm from a concave mirror whose radius of curvature is 30.0 cm. (*a*) Draw a ray diagram to locate (approximately) the position of the image. (*b*) Determine the position of the image and the magnification analytically.

APPROACH We draw the ray diagram using the rays of Fig. 23–13. An analytic solution uses Eqs. 23–1, 23–2, and 23–3.

SOLUTION (*a*) Since $f = r/2 = 15.0\text{ cm}$, the object is between the mirror and the focal point. We draw the three rays as described earlier (Fig. 23–13); they are shown leaving the tip of the object in Fig. 23–16. Ray 1 leaves the tip of our object heading toward the mirror parallel to the axis, and reflects through F. Ray 2 cannot head toward F because it would not strike the mirror; so ray 2 must point as if it started at F (dashed line) and heads to the mirror, and then is reflected parallel to the principal axis. Ray 3 is perpendicular to the mirror, as before. The rays reflected from the mirror diverge and so never meet at a point. They appear, however, to be coming from a point behind the mirror. This point locates the image of the tip of the arrow. The image is thus behind the mirror and *virtual*. (Why?)
(*b*) We use Eq. 23–2 to find d_i when $d_o = 10.0\text{ cm}$:

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} = \frac{1}{15.0\text{ cm}} - \frac{1}{10.0\text{ cm}} = \frac{2-3}{30.0\text{ cm}} = -\frac{1}{30.0\text{ cm}}.$$

Therefore, $d_i = -30.0\text{ cm}$. The minus sign means the image is behind the mirror. The magnification is $m = -d_i/d_o = -(-30.0\text{ cm})/(10.0\text{ cm}) = +3.00$. So the image is 3.00 times larger than the object. The plus sign indicates that the image is upright (same as object), which is consistent with the ray diagram, Fig. 23–16).

NOTE The image distance cannot be obtained accurately by measuring on Fig. 23–16, because our diagram violates the paraxial ray assumption (so as to make all rays clearly visible).]

Seeing yourself upright and magnified in a concave mirror

NOTE When the object is located inside the focal point of a concave mirror $(d_o < f)$, the image is always upright and vertical. And if the object O in Fig. 23–16 is you, you see yourself clearly, because the reflected rays at O are diverging. Your image is upright and enlarged.

PHYSICS APPLIED
Magnifying mirror (shaving/cosmetic)

It is useful to compare Figs. 23–13 and 23–16. We can see that if the object is within the focal point $(d_o < f)$, as in Fig. 23–16, the image is virtual, upright, and magnified. This is how a shaving or cosmetic mirror is used—you must place your head closer to the mirror than the focal point if you are to see yourself right-side up (Fig. 23–9a). If the object is *beyond* the focal point, as in Fig. 23–13, the image is real and inverted (upside down—and hard to use!). Whether the magnification is greater or less than 1.0 in the latter case depends on the position of the object relative to the center of curvature, point C.