9. **THINK** A concave mirror has a positive value of focal length.

EXPRESS For spherical mirrors, the focal length f is related to the radius of curvature r by $f = r/2$. The object distance p, the image distance i, and the focal length f are related by Eq. 34-4:

$$\frac{1}{p}+\frac{1}{i}=\frac{1}{f}.$$

The value of i is positive for a real images, and negative for virtual images.

The corresponding lateral magnification is $m = -i/p$. The value of m is positive for upright (not inverted) images, and negative for inverted images. Real images are formed on the same side as the object, while virtual images are formed on the opposite side of the mirror.

ANALYZE (a) With f = +12 cm and p = +18 cm, the radius of curvature is r = 2f = 2(12 cm) = + 24 cm.

(b) The image distance is $i = \frac{pf}{p-f} = \frac{(18\text{ cm})(12\text{ cm})}{18\text{ cm} - 12\text{ cm}} = 36\text{ cm}.$

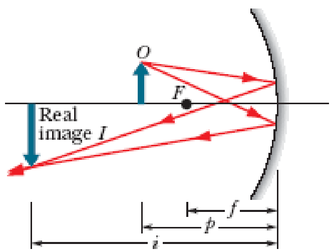
(c) The lateral magnification is $m = -i/p = -$ (36 cm)/(18 cm) = –2.0.

(d) Since the image distance i is positive, the image is real (R).

(e) Since the magnification m is negative, the image is inverted (I).

(f) A real image is formed on the same side as the object.

LEARN The situation in this problem is similar to that illustrated in Fig. 34-10(c). The object is outside the focal point, and its image is real and inverted.



11. **THINK** A convex mirror has a negative value of focal length.

EXPRESS For spherical mirrors, the focal length *f* is related to the radius of curvature *r* by $f = r/2$. The object distance *p*, the image distance *i*, and the focal length *f* are related by Eq. 34-4:

$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f}.$$

The value of *i* is positive for a real images, and negative for virtual images.

The corresponding lateral magnification is

$$m = -\frac{i}{p}.$$

The value of *m* is positive for upright (not inverted) images, and negative for inverted images. Real images are formed on the same side as the object, while virtual images are formed on the opposite side of the mirror.

ANALYZE (a) With f = –10 cm and p = +8 cm, the radius of curvature is $r = 2f$ = –20 cm.

(b) The image distance is $i = \frac{pf}{p-f} = \frac{(8\text{ cm})(-10\text{ cm})}{8\text{ cm} - (-10)\text{ cm}} = -4.44\text{ cm}.$

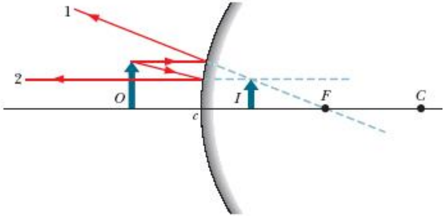
(c) The lateral magnification is $m = -i/p = -(-4.44\text{ cm})/(8.0\text{ cm}) = +0.56$.

(d) Since the image distance is negative, the image is virtual (V).

(e) The magnification *m* is positive, so the image is upright [not inverted] (NI).

(f) A virtual image is formed on the opposite side of the mirror from the object.

LEARN The situation in this problem is similar to that illustrated in Fig. 34-11(c). The mirror is convex, and its image is virtual and upright.



45. Let the diameter of the Sun be d_s and that of the image be d_i. Then, Eq. 34-5 leads to

$$d_i = |m| d_s = \left(\frac{i}{p} \right) d_s \approx \left(\frac{f}{p} \right) d_s = \frac{\left(20.0 \times 10^{-2}\ \text{m}\right)(2)\left(6.96 \times 10^{8}\ \text{m}\right)}{1.50 \times 10^{11}\ \text{m}} = 1.86 \times 10^{-3}\ \text{m} = 1.86\ \text{mm}.$$

47. **THINK** Our lens is of double-convex type. We apply lens maker's equation to analyze the problem.

EXPRESS The lens maker's equation is given by Eq. 34-10:

$$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

where f is the focal length, n is the index of refraction, r_1 is the radius of curvature of the first surface encountered by the light and r_2 is the radius of curvature of the second surface. Since one surface has twice the radius of the other and since one surface is convex to the incoming light while the other is concave, set $r_2 = -2r_1$ to obtain

$$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} + \frac{1}{2r_1}\right) = \frac{3(n-1)}{2r_1}.$$

ANALYZE (a) We solve for the smaller radius r_1:

$$r_1 = \frac{3(n-1)f}{2} = \frac{3(1.5-1)(60 \text{ mm})}{2} = 45 \text{ mm}.$$

(b) The magnitude of the larger radius is $|r_2| = 2r_1 = 90$ mm.

LEARN An image of an object can be formed with a lens because it can bend the light rays, but the bending is possible only if the index of refraction of the lens is different from that of its surrounding medium.

91. **THINK** This problem is about human eyes. We model the cornea and eye lens as a single effective thin lens, with image formed at the retina.

EXPRESS When the eye is relaxed, its lens focuses far-away objects on the retina, a distance i behind the lens. We set $p = \infty$ in the thin lens equation to obtain $1/i = 1/f$, where f is the focal length of the relaxed effective lens. Thus, $i = f = 2.50$ cm. When the eye focuses on closer objects, the image distance i remains the same but the object distance and focal length change.

ANALYZE (a) If p is the new object distance and $f\,'$ is the new focal length, then

$$\frac{1}{p}+\frac{1}{i}=\frac{1}{f\,'}.$$

We substitute $i = f$ and solve for $f\,'$: $f\,'=\dfrac{pf}{f+p}=\dfrac{(40.0\text{ cm})(2.50\text{ cm})}{40.0\text{ cm}+2.50\text{ cm}}=2.35\text{ cm}.$

(b) Consider the lens maker's equation

$$\frac{1}{f}=(n-1)\left(\frac{1}{r_1}-\frac{1}{r_2}\right)$$

where r_1 and r_2 are the radii of curvature of the two surfaces of the lens and n is the index of refraction of the lens material. For the lens pictured in Fig. 34-46, r_1 and r_2 have about the same magnitude, r_1 is positive, and r_2 is negative. Since the focal length decreases, the combination $(1/r_1) - (1/r_2)$ must increase. This can be accomplished by decreasing the magnitudes of both radii.

LEARN When focusing on an object near the eye, the lens bulges a bit (smaller radius of curvature), and its focal length decreases.