Chapter 23

9. The ball is a convex mirror with a focal length

$$f = \frac{r}{2} = \frac{(-4.5\,\text{cm})}{2} = -2.25\,\text{cm}.$$

We locate the image from

$$\left(\frac{1}{d_o}\right) + \left(\frac{1}{d_i}\right) = \frac{1}{f};$$

$$\left[\frac{1}{(30.0\,\text{cm})}\right] + \left(\frac{1}{d_i}\right) = \frac{1}{(-2.25\,\text{cm})},\ \text{which gives } d_i = -2.09\,\text{cm}.$$

The image is **2.09 cm behind the surface, virtual.**

The magnification is

$$m = -\frac{d_i}{d_o} = \frac{-(-2.09\,\text{cm})}{(30.0\,\text{cm})} = +0.070.$$

Because the magnification is positive, the image is **upright.**

12. We find the image distance from the magnification:

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}.$$

$$+0.33 = \frac{-d_i}{(20.0\,\text{m})}\ \text{which gives } d_i = -6.60\,\text{m}.$$

We find the focal length from

$$\left(\frac{1}{d_o}\right) + \left(\frac{1}{d_i}\right) = \frac{1}{f};$$

$$\left[\frac{1}{(20.0\,\text{m})}\right] + \left[\frac{1}{(-6.60\,\text{m})}\right] = \frac{1}{f},\ \text{which gives } f = -9.85\,\text{m}.$$

Because the focal length is negative, the mirror is **convex**. (Only convex mirrors produce images that are right-side-up and smaller than the object. See also Example 23-4.) The radius is

$$r = 2f = 2(-9.85\,\text{m}) = \boxed{-19.7\,\text{m}.}$$

15. (*a*) With $d_i = d_o$, we locate the object from

$$\left(\frac{1}{d_o}\right) + \left(\frac{1}{d_i}\right) = \frac{1}{f};$$

$$\left(\frac{1}{d_o}\right) + \left(\frac{1}{d_o}\right) = \frac{1}{f},\ \text{which gives } d_o = 2f = r.$$

The object should be placed at the **center of curvature.**

(*b*) Because the image is in front of the mirror, $d_i > 0$, it is **real.**

(*c*) The magnification is

$$m = \frac{-d_i}{d_o} = \frac{-d_o}{d_o} = -1.$$

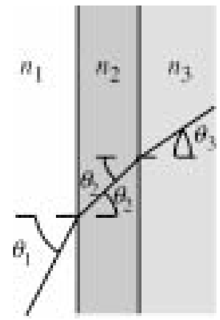
Because the magnification is negative, the image is **inverted.**

(*d*) As found in part (*c*), $m = \boxed{-1.}$

30. (*a*) We find the angle in the glass from the refraction at the air–glass surface:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2;$$

$$(1.00)\sin 43.5° = (1.52)\sin\theta_2, \text{which gives } \theta_2 = \boxed{26.9°.}$$



(*b*) Because the surfaces are parallel, the refraction angle from the first surface is the incident angle at the second surface. We find the angle in the water from the refraction at the glass–water surface:

$$n_2 \sin\theta_2 = n_3 \sin\theta_3;$$

$$(1.52)\sin 26.9° = (1.33)\sin\theta_3, \text{ which gives } \theta_3 = \boxed{31.2°.}$$

(*c*) If there were no glass, we would have

$$n_1 \sin\theta_1 = n_3 \sin\theta_3';$$

$$(1.00)\sin 43.5° = (1.33)\sin\theta_3', \text{ which gives } \theta_3' = \boxed{31.2°.}$$

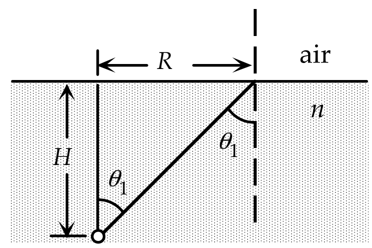
38. We find the critical angle for light leaving the water:

$$n \sin\theta_1 = \sin\theta_2;$$

$$(1.33)\sin\theta_C = \sin 90°, \text{ which gives } \theta_C = 48.8°.$$

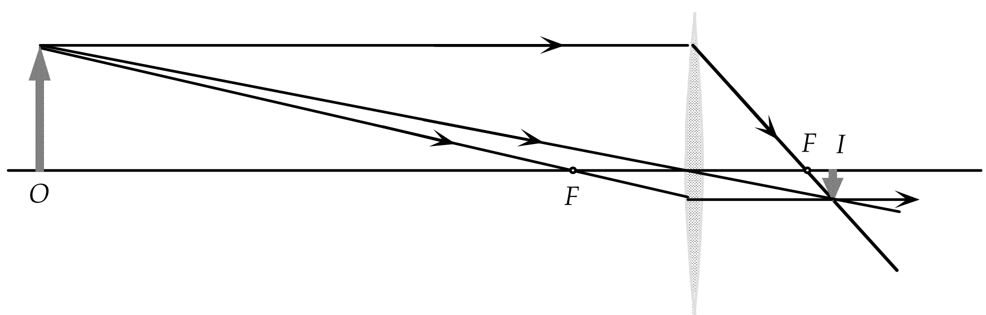
If the light is incident at a greater angle than this, it will totally reflect. We see from the diagram that

$$R > H \tan\theta_C = (62.0\,\text{cm})\tan 48.8° = \boxed{70.7\,\text{cm.}}$$



sin 45

43. (*a*) From the ray diagram, the object distance is about six focal lengths, or $\boxed{390 \text{ mm.}}$



(*b*) We find the object distance from

$$\left(\frac{1}{d_o}\right) + \left(\frac{1}{d_i}\right) = \frac{1}{f};$$

$$\left(\frac{1}{d_o}\right) + \left(\frac{1}{78.0\,\text{mm}}\right) = \frac{1}{65.0\,\text{mm}}, \text{ which gives } d_o = 390\,\text{mm} = \boxed{39.0\,\text{cm.}}$$

47. (*a*) We locate the image from

$$\left(\frac{1}{d_o}\right) + \left(\frac{1}{d_i}\right) = \frac{1}{f};$$

$$\left(\frac{1}{18\,\text{cm}}\right) + \left(\frac{1}{d_i}\right) = \frac{1}{24\,\text{cm}}, \text{ which gives } d_i = -72\,\text{cm}.$$

The negative sign means the image is 72 cm behind the lens (virtual).

(*b*) We find the magnification from

$$m = \frac{-d_i}{d_o} = -\frac{(-72\,\text{cm})}{(18\,\text{cm})} = \boxed{+4.0.}$$

53. We can relate the image and object distance from the magnification:

$$m = \frac{-d_i}{d_o}, \text{ or } d_o = \frac{-d_i}{m}.$$

We use this in the lens equation:

$$\left(\frac{1}{d_o}\right) + \left(\frac{1}{d_i}\right) = \frac{1}{f};$$

$$-\left(\frac{m}{d_i}\right) + \left(\frac{1}{d_i}\right) = \frac{1}{f}, \text{ which gives } d_i = (1 - m)f.$$

(*a*) If the image is real, $d_i > 0$. With $f > 0$, we see that $m < 1$; thus $m = -2.00$. The image distance is

$$d_i = [1 - (-2.00)](50.0\,\text{mm}) = 150\,\text{mm}.$$

The object distance is

$$d_o = \frac{-d_i}{m} = \frac{-(150\,\text{mm})}{(-2.00)} = \boxed{75.0\,\text{mm}.}$$

(*b*) If the image is virtual, $d_i < 0$. With $f > 0$, we see that $m > 1$; thus $m = +2.00$. The image distance is

$$d_i = [1 - (+2.00)](50.0\,\text{mm}) = -50\,\text{mm}.$$

The object distance is

$$d_o = \frac{-d_i}{m} = \frac{-(-50\,\text{mm})}{(+2.00)} = \boxed{25.0\,\text{mm}.}$$