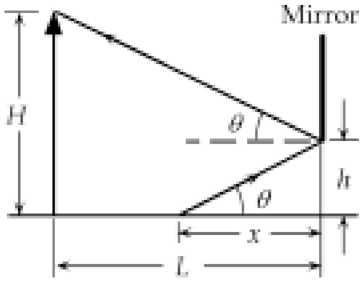
4. The angle of incidence is the angle of reflection. Thus we have



$$\tan\theta = \frac{(H-h)}{L} = \frac{h}{x};$$
$$\frac{(1.68\text{ m} - 0.43\text{ m})}{(2.20\text{ m})} = \frac{(0.43\text{ m})}{x},$$

which gives $x = 0.76\text{ m} = \boxed{76\text{ cm.}}$

11. We find the image distance from the magnification:

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o};$$
$$+4.5 = \frac{-d_i}{(2.20\text{ cm})}, \text{ which gives } d_i = -9.90\text{ cm.}$$

We find the focal length from

$$\left(\frac{1}{d_o}\right) + \left(\frac{1}{d_i}\right) = \frac{1}{f};$$
$$\left[\frac{1}{(2.20\text{ cm})}\right] + \left[\frac{1}{(-9.90\text{ cm})}\right] = \frac{1}{f}, \text{ which gives } f = 2.83\text{ cm.}$$

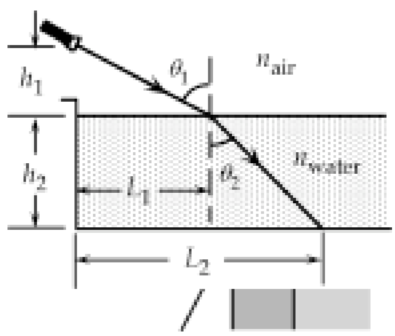
Because the focal length is positive, the mirror is $\boxed{\text{concave}}$ with a radius of $r = 2f = 2(2.83\text{ cm}) = \boxed{5.7\text{ cm.}}$

16. We take the object distance to be ∞, and find the focal length from

$$\left(\frac{1}{d_o}\right) + \left(\frac{1}{d_i}\right) = \frac{1}{f};$$
$$\left(\frac{1}{\infty}\right) + \left[\frac{1}{(-18.0\text{ cm})}\right] = \frac{1}{f}, \text{ which gives } f = -18.0\text{ cm.}$$

The focal length is negative, so the mirror is convex. The radius is $r = 2f = 2(-18.0\text{ cm}) = \boxed{-36.0\text{ cm.}}$

31. We find the angle of incidence from the distances:



$$\tan\theta_1 = \frac{L_1}{h_1} = \frac{(2.7\text{ m})}{(1.3\text{ m})} = 2.076, \text{ so } \theta_1 = 64.3°.$$

For the refraction from air into water, we have

$$n_{air}\sin\theta_1 = n_{water}\sin\theta_2;$$
$$(1.00)\sin 64.3° = (1.33)\sin\theta_2, \text{ which gives } \theta_2 = 42.6°.$$

We find the horizontal distance from the edge of the pool from

$$L = L_1 + L_2 = L_1 + h_2\tan\theta_2$$
$$= 2.7\text{ m} + (2.1\text{ m})\tan 42.6° = \boxed{4.6\text{ m.}}$$

33. The angle of reflection is equal to the angle of incidence: $\theta_{ref1} = \theta_1 = 2\theta_2$.

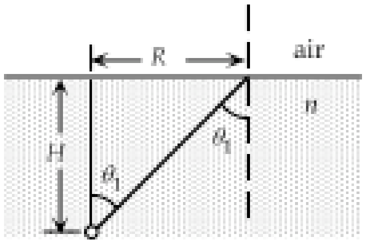
For the refraction we have
$$n_{air} \sin\theta_1 = n_{glass} \sin\theta_2;$$
$$(1.00) \sin 2\theta_2 = (1.52) \sin\theta_2.$$

We use a trigonometric identity for the left-hand side:

$$\sin 2\theta_2 = 2\sin\theta_2 \cos\theta_2 = (1.52) \sin\theta_2, \text{ or } \cos\theta_2 = 0.760, \text{ so } \theta_2 = 40.5°.$$

Thus the angle of incidence is $\theta_1 = 2\theta_2 = \boxed{81.0°.}$

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

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

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 $\boxed{\text{72 cm behind the lens (virtual).}}$

(*b*) We find the magnification from

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

55. (*a*) We find the image distance from

$$\left(\frac{1}{d_o}\right) + \left(\frac{1}{d_i}\right) = \frac{1}{f};$$
$$\left(\frac{1}{1.20 \times 10^3 \text{ mm}}\right) + \left(\frac{1}{d_i}\right) = \frac{1}{135 \text{ mm}}, \text{ which gives } d_i = \boxed{152 \text{ mm (real, behind the lends).}}$$

We find the height of the image from

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o};$$
$$\frac{h_i}{2.00 \text{ cm}} = \frac{-(152 \text{ mm})}{(1.20 \times 10^3 \text{ mm})}, \text{ which gives } h_i = \boxed{-0.254 \text{ cm (inverted).}}$$

(*b*) We find the image distance from
$$\left(\frac{1}{d_o}\right) + \left(\frac{1}{d_i}\right) = \frac{1}{f};$$
$$\left(\frac{1}{1.20 \times 10^3 \text{ mm}}\right) + \left(\frac{1}{d_i}\right) = \frac{1}{(-135 \text{ mm})},$$

which gives $d_i = \boxed{-121\text{ mm (virtual, in front of the lens).}}$

We find the height of the image from

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

$$\frac{h_i}{(2.00\text{ cm})} = \frac{-(-121\text{ mm})}{(1.20\times 10^3\text{ mm})}, \text{ which gives } h_i = \boxed{+0.202\text{ cm (upright).}}$$

58. We find the image formed by the refraction of the first lens:

$$\left(\frac{1}{d_{o1}}\right) + \left(\frac{1}{d_{i1}}\right) = \frac{1}{f_1};$$

$$\left(\frac{1}{36.0\text{ cm}}\right) + \left(\frac{1}{d_{i1}}\right) = \frac{1}{28.0\text{ cm}}; \text{ which gives } d_{i1} = +126\text{ cm.}$$

This image is the object for the second lens. Because it is beyond the second lens, it has a negative object distance: $d_{o2} = 16.5\text{ cm} - 126\text{ cm} = -109.5\text{ cm.}$

We find the image formed by the refraction of the second lens:

$$\left(\frac{1}{d_{o2}}\right) + \left(\frac{1}{d_{i2}}\right) = \frac{1}{f_2};$$

$$\left[\frac{1}{(-109.5\text{ cm})}\right] + \left(\frac{1}{d_{i2}}\right) = \frac{1}{28.0\text{ cm}}, \text{ which gives } d_{i2} = +22.3\text{ cm.}$$

Thus the final image is $\boxed{\text{real, 22.3 cm beyond second lens.}}$

The total magnification is the product of the magnifications for the two lenses:

$$m = m_1 m_2 = \left(-\frac{d_{i1}}{d_{o1}}\right)\left(-\frac{d_{i2}}{d_{o2}}\right) = \frac{d_{i1}d_{i2}}{d_{o1}d_{o2}}$$

$$= \frac{(+126\text{ cm})(+22.3\text{ cm})}{(+36.0\text{ cm})(-109.5\text{ cm})} = \boxed{-0.713\text{ (inverted).}}$$

63. We find the image formed by the converging lens:

$$\frac{1}{d_{o1}} + \frac{1}{d_{i1}} = \frac{1}{f_1};$$

$$\frac{1}{33\text{ cm}} + \frac{1}{d_{i1}} = \frac{1}{18\text{ cm}}, \text{ which gives } d_{i1} = 39.6\text{ cm.}$$

(*a*) The image from the first lens becomes the object for the second lens, with

$d_{o2} = 12\text{ cm} - 39.6\text{ cm} = -27.6\text{ cm}$ (27.6 cm to the right of the second lens). Now we find the image

formed by the second lens: $\frac{1}{d_{o2}} + \frac{1}{d_{i2}} = \frac{1}{f_2};$

$\frac{1}{-27.6\text{ cm}} + \frac{1}{d_{i2}} = \frac{1}{-14\text{ cm}}$ gives $d_{i2} = -28.4\text{ cm},$ which means that the final image is 28 cm to the left of the second lens, or $28\text{ cm} - 12\text{ cm} = \boxed{16\text{ cm to the left of the converging lens.}}$

(*b*) Now $d_{o2} = 38\text{ cm} - 39.6\text{ cm} = -1.6\text{ cm},$ and

$$\frac{1}{d_{o2}} + \frac{1}{d_{i2}} = \frac{1}{f_2} \text{ yields}$$

$$\frac{1}{-1.6\text{ cm}} + \frac{1}{d_{i2}} = \frac{1}{-14\text{ cm}}, \text{ which gives } d_{i2} = 1.8\text{ cm.}$$

Now the final image is $\boxed{\text{1.8 cm to the right of the diverging lens.}}$

66. We find the focal length of the lens from

$$\frac{1}{f} = (n-1)\left[\left(\frac{1}{R_1}\right) + \left(\frac{1}{R_2}\right)\right]$$
$$= (1.52-1)\left\{\left[\frac{1}{-34.2\text{ cm}}\right] + \left[\frac{1}{(-23.8\text{ cm})}\right]\right\}, \text{ which gives } \boxed{f = -27.0\text{ cm.}}$$

69. We find the focal length from the lensmaker's equation, using $n = 1.51$ for Lucite:

$$\frac{1}{f} = (n-1)\left[\left(\frac{1}{R_1}\right) + \left(\frac{1}{R_2}\right)\right];$$
$$\frac{1}{f} = (1.51-1)\left[\left(\frac{1}{\infty}\right) + \left(\frac{1}{-18.4\text{ cm}}\right)\right], \text{ which gives } f = \boxed{-36.1\text{ cm.}}$$

90. Working backwards, we use

$\frac{1}{d_{o2}} + \frac{1}{d_{i2}} = \frac{1}{f_2}$ with $d_{i2} = 17.0\text{ cm}$ and $f_2 = 12.0\text{ cm}$:

$$\frac{1}{d_{o2}} + \frac{1}{17.0\text{ cm}} = \frac{1}{12.0\text{ cm}} \text{ gives } d_{o2} = 40.8\text{ cm.}$$

This means that $d_{i1} = 30.0\text{ cm} - 40.8\text{ cm} = -10.8\text{ cm}$ (10.8 to the left of the diverging lens). So for the diverging lens,

$$\left[\frac{1}{d_{o1}} + \frac{1}{d_{i1}} = \frac{1}{f_1};\right]$$
$$\frac{1}{25.0\text{ cm}} + \frac{1}{-10.8\text{ cm}} = \frac{1}{f_1}, \text{ which gives } f_1 = \boxed{19\text{ cm.}}$$