3. Since the incident beam travels from one corner of the tank to the opposite corner, the angle of incidence is given by $\tan\theta_1 = w/h$, where w and h are the width and height of the tank. Thus,

$$\theta_1 = \tan^{-1}\left(\frac{w}{h}\right) = \tan^{-1}\left(\frac{1.10\text{ m}}{0.850\text{ m}}\right) = 52.3°.$$

The angle of refraction is $\theta_2 = 90°$, so the index of refraction of the liquid is

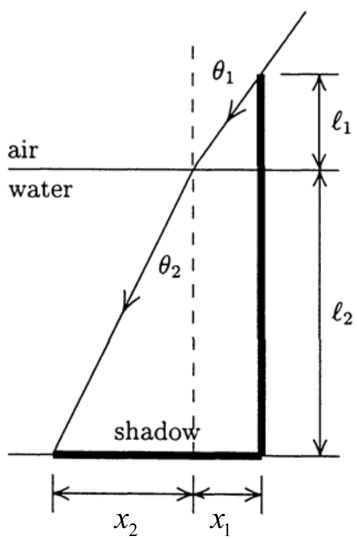
$$n_1 = n_2\frac{\sin\theta_2}{\sin\theta_1} = (1.00)\left(\frac{\sin 90°}{\sin 52.3°}\right) = 1.26.$$

5. Consider a ray that grazes the top of the pole, as shown in the diagram that follows. Here $\theta_1 = 35.0°$, $\ell_1 = 0.500\text{m}$, and $\ell_2 = 1.50$ m. From Snell's law,

$$\theta_2 = \sin^{-1}(n_1\sin\theta_1/n_2) = \sin^{-1}(\sin 35.0°/1.33) = 25.5°.$$

The length of the shadow is

$$x_1 + x_2 = \ell_1\tan\theta_1 + \ell_2\tan\theta_2 = (0.500\text{m})(\tan 35.0°) + (1.50\text{m})(\tan 25.5°) = 1.07\text{m}.$$



7. If the light enters the glass at an incident angle θ, it passes through the glass at an angle $\theta_2 = \sin^{-1}((\sin\theta)/n)$. Since the plate's faces are parallel, this is the angle of incidence for the second refraction as the light leaves the glass. The transmission angle as the light leaves the glass is

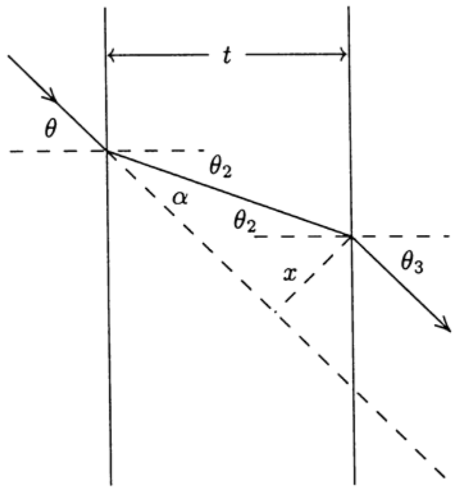
$$\theta_3 = \sin^{-1}(n\sin\theta_2) = \sin^{-1}\left(n\sin\left[\sin^{-1}((\sin\theta)/n)\right]\right) = \sin^{-1}\left(n((\sin\theta)/n)\right) = \sin^{-1}(\sin\theta) = \theta.$$

This demonstrates that the light leaves the glass parallel to its initial direction. From the diagram below, we note that the light travels a distance $t/\cos\theta_2$ in the glass. With $\alpha = \theta - \theta_2$, the distance x is

$$x = \frac{t\sin(\theta - \theta_2)}{\cos\theta_2}.$$

If all these angles are small, then $\theta_2 \approx \theta/n$, $\sin(\theta - \theta_2) \approx \theta - \theta_2$, and $\cos\theta_2 \approx 1$. Hence, we write the distance the beam is displaced as

$$x = t(\theta - \theta/n) = t\theta\frac{n-1}{n}.$$



13. (a) No refraction occurs at the surface *ab*, so the angle of incidence at surface *ac* is $\theta_1 = 90° - \phi$. For total internal reflection at the second surface, we must have

$$\theta_1 = 90° - \phi \geq \sin^{-1}\left(\frac{n_{\text{outside}}}{n_{\text{glass}}}\right) \quad \Rightarrow \quad \phi \leq 90° - \sin^{-1}\left(\frac{n_{\text{outside}}}{n_{\text{glass}}}\right).$$

When the material outside the prism is air, this leads to

$$\phi \leq 90° - \sin^{-1}\left(\frac{1}{1.52}\right) = 48.9°.$$

(b) When the material outside the prism is water, this leads to

$$\phi \leq 90° - \sin^{-1}\left(\frac{1.33}{1.52}\right) = 29.0°.$$

26. When *S* is barely able to see *B* the light rays from *B* must reflect to *S* off the edge of the mirror. The angle of reflection in this case is 45°, since a line drawn from *S* to the mirror's edge makes a 45° angle relative to the wall. If light from the burglar strikes the edge of the mirror at a 45° when the burglar is a distance x away from the mirror, then

$$\frac{x}{d/2} = \tan 45° = 1 \quad \Rightarrow \quad x = \frac{d}{2} = \frac{3.0\,\text{m}}{2} = 1.5\,\text{m}.$$

47. With an object distance of $o_1 = 40\text{cm}$ and a focal length of $f_1 = +20$ cm, we use Eq. 35-18 to located the image formed by the converging lens:

$$\frac{1}{o_1} + \frac{1}{i_1} = \frac{1}{f_1} \quad \Rightarrow \quad i_1 = \frac{o_1 f_1}{o_1 - f_1} = \frac{(40\text{cm})(20\text{cm})}{(40\text{cm} - (20\text{cm}))} = 40 \text{ cm}.$$

This image will be the object for the second lens, with an object distance of $o_2 = 10 \text{ cm} - 40 \text{ cm} = -30 \text{ cm}.$ The focal length of the second lens is $f_2 = -15$ cm. Now, Eq. 35-9 leads to

$$\frac{1}{o_2} + \frac{1}{i_2} = \frac{1}{f_2} \quad \Rightarrow \quad i_2 = \frac{o_2 f_2}{o_2 - f_2} = \frac{(-30\text{cm})(-15\text{cm})}{((-30\text{cm}) - (-15\text{cm}))} = -30 \text{ cm}.$$

So the final image is produced 30 cm in front of the second lens, for a total distance of 20 cm from the object. The image is virtual since i_2 is negative. The magnification due to the first lens is $m_1 = -i_1/o_1 = -40\text{cm}/40\text{cm} = -1.0.$ That of the second lens is $m_2 = -i_2/o_2 = -(-30\text{cm})/(-30\text{cm}) = -1.0.$ The total magnification is $m = m_1 m_2 = 1.0,$ so the image is the same size as the object and has the same orientation.

55. (a) When the eye is relaxed, its lens focuses far-away objects on the retina, a distance *i* behind the lens. We set the object distance to infinity in the thin lens equation to obtain $i = f = 2.50$ cm. When the eye focuses on closer objects, the image distance *i* remains the same but the object distance and focal length change. If $o = 40.0$ cm is the new object distance and f' is the new focal length, then

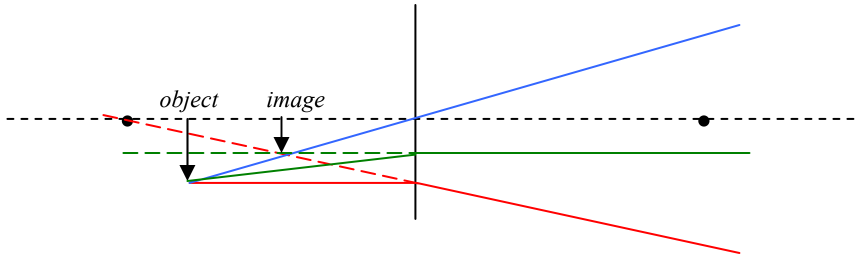
$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f'} \quad \Rightarrow \quad f' = \frac{io}{i+o} = \frac{fo}{f+o} = \frac{(2.50 \text{ cm})(40.0 \text{ cm})}{2.50 \text{ cm} + 40.0 \text{ cm}} = 2.35 \text{ cm}.$$

(b) Consider the lens maker's equation. For the type of lens shown, $r_1 > 0$ and $r_2 < 0$. Hence, we can write the lens maker's equation as

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

The only way to decrease the focal length is to decrease the radii of curvature.

64. (a) See below…



(b) Using $\frac{1}{d_i}+\frac{1}{d_o}=\frac{1}{f}\Rightarrow\frac{1}{d_i}=\frac{1}{f}-\frac{1}{d_o}=\frac{1}{-8cm}-\frac{1}{6cm}$ we find that d_o = -3.42 cm. (Right where is should be according to our picture.)
(c) $m=-d_i/d_o$ = 3.42/6 = 0.57, or just over half as tall. (Again, this matches the picture.)
(d) This is a virtual image. We know this for two ways. First, from the picture, we see that no real light rays converge at any location on the image, so we must extrapolate the refracted rays back to where they seem to come from. Second, from the equation above, $d_o < 0$, which implies the image is virtual.
(e) You must be on the opposite side of the lens from the object, looking at the lens. This is the only way for the refracted rays to get into your eye.