P35.8  (a) The dashed lines are parallel, and alternate interior angles are equal between parallel lines, so the angle of refraction law at the air-oil interface is 20.0°. Applying Snell’s law,

\[ n_{\text{air}} \sin \theta = n_{\text{oil}} \sin \alpha \]

\[ 1.00 \sin \theta = 1.48 \sin 20.0° \]

yields \[ \theta = 30.4° \].

(b) The angle of incidence \( \alpha = 20.0° \). Applying Snell’s law at the oil-water interface,

\[ n_{\text{water}} \sin \theta' = n_{\text{oil}} \sin \alpha \]

\[ 1.33 \sin \theta' = 1.48 \sin 20.0° \]

yields \[ \theta' = 22.3° \].

P35.22  (a) At entry, \( n_1 \sin \theta_1 = n_2 \sin \theta_2 \),

or \[ 1.00 \sin 30.0° = 1.50 \sin \theta_2 \],

which gives \( \theta_2 = 19.5° \).

The distance \( h \) the light travels in the medium is given by

\[ \cos \theta_2 = \frac{2.00 \text{ cm}}{h} \]

or \[ h = \frac{2.00 \text{ cm}}{\cos 19.5°} = 2.12 \text{ cm} \].
The angle of deviation upon entry is
\[ \alpha = \theta_1 - \theta_2 = 30.0^\circ - 19.5^\circ = 10.5^\circ \]

The offset distance comes from \( \sin \alpha = \frac{d}{h} \):
\[ d = (2.12 \text{ cm}) \sin 10.5^\circ = 0.387 \text{ cm} \]

(b) The speed of light in the material is
\[ v = \frac{c}{n} = \frac{3.00 \times 10^8 \text{ m/s}}{1.50} = 2.00 \times 10^8 \text{ m/s} \]

The distance \( h \) traveled by the light is \( h = 2.12 \text{ cm} \). The time interval is
\[ \Delta t = \frac{h}{v} = \frac{2.12 \times 10^{-2} \text{ m}}{2.00 \times 10^8 \text{ m/s}} = 1.06 \times 10^{-10} \text{ s} = 106 \text{ ps} \]

P35.23 From Table 35.1, the index of refraction of ice is 1.309. The pulses are in step with each other until one enters the ice, then that pulse slows down. The difference in the times of arrival of the pulses is
\[ \Delta t = \frac{L}{v_{\text{ice}}} - \frac{L}{v_{\text{air}}} = \frac{L}{c/n_{\text{ice}}} - \frac{L}{c/n_{\text{air}}} = \left(n_{\text{ice}} - n_{\text{air}}\right) \frac{L}{c} \]
\[ \Delta t = (1.309 - 1.000) \frac{6.20 \text{ m}}{3.00 \times 10^8 \text{ m/s}} = 6.39 \times 10^{-9} \text{ s} = 6.39 \text{ ns} \]
P35.33 Since the light ray strikes the first surface at normal incidence, it passes into the prism without deviation. Thus, the angle of incidence at the second surface (hypotenuse of the triangular prism) is $\theta_1 = 45.0^\circ$ as shown in the sketch at the right. The angle of refraction is

$$\theta_2 = 45.0^\circ + 15.0^\circ = 60.0^\circ$$

and Snell's law gives the index of refraction of the prism material as

$$n_1 = \frac{n_2 \sin \theta_2}{\sin \theta_1} = \frac{(1.00) \sin(60.0^\circ)}{\sin(45.0^\circ)} = 1.22$$

ANS. FIG. P35.33

P35.39 For the incoming ray, $\sin \theta_2 = \frac{\sin \theta_1}{n}$.

Using ANS. FIG. P35.39,

$$\left(\theta_2\right)_{\text{violet}} = \sin^{-1}\left(\frac{\sin 50.0^\circ}{1.66}\right) = 27.48^\circ$$

$$\left(\theta_2\right)_{\text{red}} = \sin^{-1}\left(\frac{\sin 50.0^\circ}{1.62}\right) = 28.22^\circ$$

For the outgoing ray,

$$\left(90.0^\circ - \theta_2\right) + \left(90.0^\circ - \theta_3\right) + 60.0^\circ = 180.0^\circ$$

$$\theta_3 = 60.0^\circ - \theta_2$$

and

$$\sin \theta_4 = n \sin \theta_3$$

$$\left(\theta_4\right)_{\text{violet}} = \sin^{-1}[1.66 \sin 32.52^\circ] = 63.17^\circ$$

$$\left(\theta_4\right)_{\text{red}} = \sin^{-1}[1.62 \sin 31.78^\circ] = 58.56^\circ$$

The angular dispersion is the difference

$$\Delta \theta_4 = \left(\theta_4\right)_{\text{violet}} - \left(\theta_4\right)_{\text{red}} = 63.17^\circ - 58.56^\circ = 4.61^\circ$$
At the upper surface,

\[
\sin \theta_c = \frac{n_{\text{air}}}{n_{\text{pipe}}} = \frac{1.00}{1.36} = 0.735 \quad \rightarrow \quad \theta_c = 47.3^\circ
\]

Geometry shows that the angle of refraction at the end is

\[\phi = 90.0^\circ - \theta_c = 90.0^\circ - 47.3^\circ = 42.7^\circ\]

Then, by Snell’s law at the end,

\[1.00 \sin \theta = 1.36 \sin 42.7^\circ \]

gives \[\theta = 67.2^\circ\].

The 2-\(\mu\)m diameter is unnecessary information.

\[\text{ANS. FIG. P35.45}\]

\[\sin \theta_2 \quad \frac{v_2}{v_1} \quad \text{and} \quad \theta_2 = 90.0^\circ \quad \text{at the critical angle.}\]

\[
\sin 90.0^\circ = \frac{1.850 \text{ m/s}}{343 \text{ m/s}} \quad \text{so} \quad \theta_c = \sin^{-1}(0.185) = 10.7^\circ.
\]

(b) Sound can be totally reflected if it is traveling in the medium where it travels slower: \[\text{air}\].

(c) Sound in air falling on the wall from most directions is 100% reflected, so the wall is a good mirror.