21.49 From $Intensity = \frac{E_{max} B_{max}}{2\mu_0}$ and $\frac{E_{max}}{B_{max}} = c$, we find $Intensity = \frac{cB_{max}^2}{2\mu_0}$

Thus,

$$B_{max} = \sqrt{\frac{2\mu_0}{c}(Intensity)} = \sqrt{\frac{2\left(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A}\right)}{3.00\times10^{8}\ \text{m/s}}\left(1\,340\ \text{W/m}^2\right)} = \boxed{3.35\times10^{-6}\ \text{T}}$$

and $$E_{max} = B_{max}c = \left(3.35\times10^{-6}\ \text{T}\right)\left(3.00\times10^{8}\ \text{m/s}\right) = \boxed{1.01\times10^{3}\ \text{V/m}}$$

21.50 $$\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\ \text{m/s}}{27.33\times10^{6}\ \text{Hz}} = \boxed{11.0\ \text{m}}$$

21.51 (a) For the AM band,

$$\lambda_{min} = \frac{c}{f_{max}} = \frac{3.00\times10^{8}\ \text{m/s}}{1\,600\times10^{3}\ \text{Hz}} = \boxed{188\ \text{m}}$$

$$\lambda_{max} = \frac{c}{f_{min}} = \frac{3.00\times10^{8}\ \text{m/s}}{540\times10^{3}\ \text{Hz}} = \boxed{556\ \text{m}}$$

(b) For the FM band,

$$\lambda_{min} = \frac{c}{f_{max}} = \frac{3.00\times10^{8}\ \text{m/s}}{108\times10^{6}\ \text{Hz}} = \boxed{2.78\ \text{m}}$$

$$\lambda_{max} = \frac{c}{f_{min}} = \frac{3.00\times10^{8}\ \text{m/s}}{88\times10^{6}\ \text{Hz}} = \boxed{3.4\ \text{m}}$$

21.52 The transit time for the radio wave is

$$t_R = \frac{d_R}{c} = \frac{100\times10^{3}\ \text{m}}{3.00\times10^{8}\ \text{m/s}} = 3.33\times10^{-4}\ \text{s} = 0.333\ \text{ms}$$

and that for the sound wave is

$$t_s = \frac{d_s}{v_{sound}} = \frac{3.0\ \text{m}}{343\ \text{m/s}} = 8.7\times10^{-3}\ \text{s} = 8.7\ \text{ms}$$

Thus, $\boxed{\text{the radio listeners hear the news 8.4 ms before the studio audience}}$ because radio waves travel so much faster than sound waves.

21.63 (a) $\frac{E_{\max}}{B_{\max}} = c$, so

$$B_{\max} = \frac{E_{\max}}{c} = \frac{0.20\times10^{-6}\ \text{V/m}}{3.00\times10^{8}\ \text{m/s}} = \boxed{6.7\times10^{-16}\ \text{T}}$$

(b) $\textit{Intensity} = \frac{E_{\max}B_{\max}}{2\mu_0}$

$$= \frac{\left(0.20\times10^{-6}\ \text{V/m}\right)\left(6.7\times10^{-16}\ \text{T}\right)}{2\left(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A}\right)} = \boxed{5.3\times10^{-17}\ \text{W/m}^2}$$

(c) $\mathcal{P}_{\text{av}} = (\textit{Intensity})\cdot A = (\textit{Intensity})\left[\frac{\pi d^2}{4}\right]$

$$= \left(5.3\times10^{-17}\ \text{W/m}^2\right)\left[\frac{\pi(20.0\ \text{m})^2}{4}\right] = \boxed{1.7\times10^{-14}\ \text{W}}$$

22.4 (a) The time for the light to travel to the stationary mirror and back is

$$\Delta t = \frac{2d}{c} = \frac{2\left(35.0\times10^{3}\ \text{m}\right)}{3.00\times10^{8}\ \text{m/s}} = 2.33\times10^{-4}\ \text{s}$$

At the lowest angular speed, the octagonal mirror will have rotated $1/8$ rev in this time, so

$$\omega_{\min} = \frac{\Delta\theta}{\Delta t} = \frac{1/8\ \text{rev}}{2.33\times10^{-4}\ \text{s}} = \boxed{536\ \text{rev/s}}$$

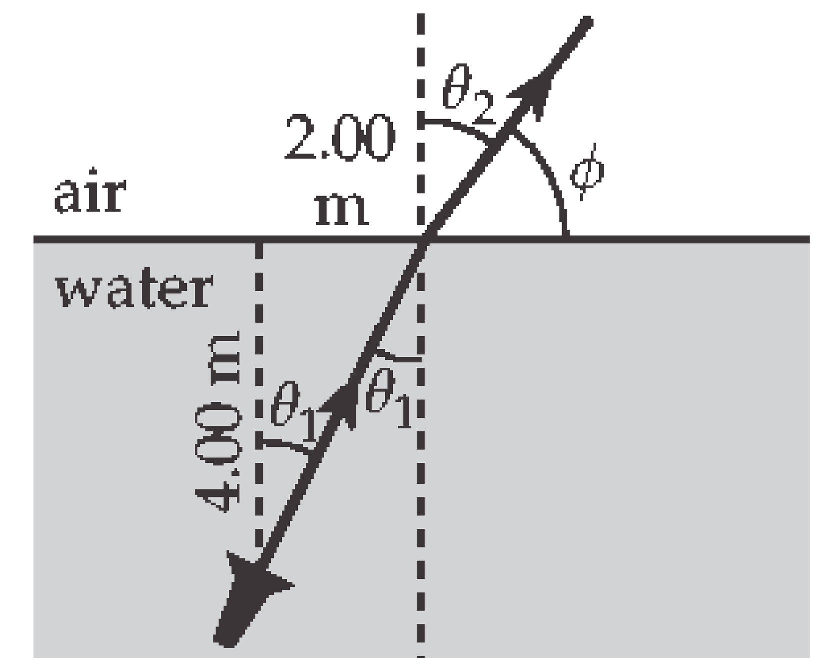
(b) At the next higher angular speed, the mirror will have rotated $2/8$ rev in the elapsed time, or

$$\omega_2 = 2\omega_{\min} = 2\left(536\ \text{rev/s}\right) = \boxed{1.07\times10^{3}\ \text{rev/s}}$$

22.12 (a) $\lambda_{water} = \frac{\lambda_0}{n_{water}} = \frac{436\ \text{nm}}{1.333} = \boxed{327\ \text{nm}}$

(b) $\lambda_{glass} = \frac{\lambda_0}{n_{\substack{crown\\glass}}} = \frac{436\ \text{nm}}{1.52} = \boxed{287\ \text{nm}}$

22.16 The angle of incidence is



$$\theta_1 = \tan^{-1}\left[\frac{2.00 \text{ m}}{4.00 \text{ m}}\right] = 26.6°$$

Therefore, Snell's law gives

$$\theta_2 = \sin^{-1}\left[\frac{n_1 \sin\theta_1}{n_2}\right]$$

$$= \sin^{-1}\left[\frac{(1.333)\sin 26.6°}{1.00}\right] = 36.6°$$

and the angle the refracted ray makes with the surface is

$$\phi = 90.0° - \theta_2 = 90.0° - 36.6° = \boxed{53.4°}$$

22.18 At the first surface, the angle of incidence is $\theta_1 = \boxed{30.0°}$, and Snell's law gives

$$\theta_2 = \sin^{-1}\left[\frac{n_{air} \sin\theta_1}{n_{glass}}\right] = \sin^{-1}\left[\frac{(1.00)\sin 30.0°}{1.50}\right] = \boxed{19.5°}$$

Since the second surface is parallel to the first, the angle of incidence at the second surface is $\theta_1 = 19.5°$ and the angle of refraction is

$$\theta_2 = \sin^{-1}\left[\frac{n_{glass} \sin\theta_{glass}}{n_{air}}\right] = \sin^{-1}\left[\frac{(1.50)\sin 19.5°}{1.00}\right] = \boxed{30.0°}$$

Thus, the light emerges traveling parallel to the incident beam.

22.20 The distance h the light travels in the glass is

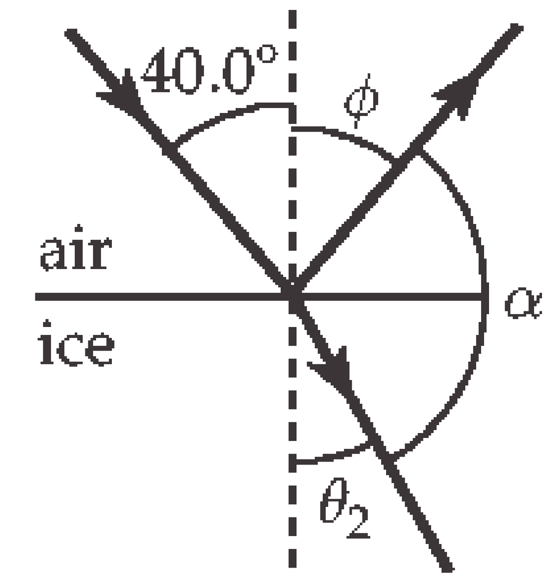
$$h = \frac{2.00 \text{ cm}}{\cos 19.5°} = 2.12 \text{ cm}$$

The speed of light in the glass is

$$v = \frac{c}{n_{glass}} = \frac{3.00\times10^{8} \text{ m/s}}{1.50} = 2.00\times10^{8} \text{ m/s}$$

Therefore, $t = \frac{h}{v} = \frac{2.12\times10^{-2} \text{ m}}{2.00\times10^{8} \text{ m/s}} = \boxed{1.06\times10^{-10} \text{ s}}$

22.13 From Snell's law,



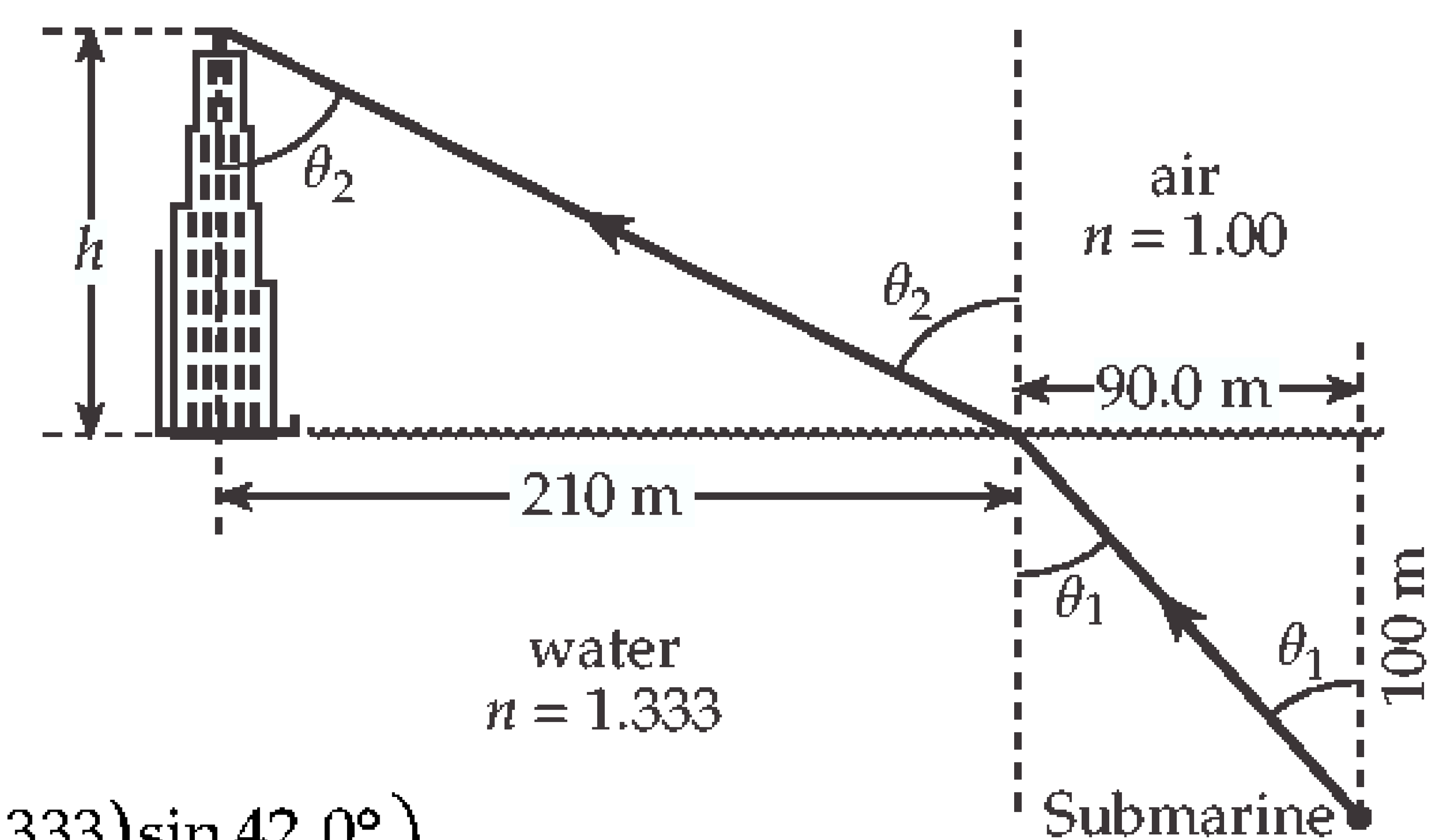
$$\theta_2 = \sin^{-1}\left[\frac{n_1 \sin\theta_1}{n_2}\right] = \sin^{-1}\left[\frac{(1.00)\sin 40.0°}{1.309}\right] = 29.4°$$

and from the law of reflection, $\phi = \theta_1 = 40.0°$

Hence, the angle between the reflected and refracted rays is

$$\alpha = 180° - \theta_2 - \phi = 180° - 29.4° - 40.0° = \boxed{111°}$$

22.22 The angle of incidence at the water surface is



$$\theta_1 = \tan^{-1}\left(\frac{90.0 \text{ m}}{100 \text{ m}}\right) = 42.0°$$

Then, Snell's law gives the angle of refraction as

$$\theta_2 = \sin^{-1}\left(\frac{n_{water} \sin\theta_1}{n_{air}}\right) = \sin^{-1}\left(\frac{(1.333)\sin 42.0°}{1.00}\right) = 63.1°$$

so the height of the building is $h = \dfrac{210 \text{ m}}{\tan\theta_2} = \dfrac{210 \text{ m}}{\tan 63.1°} = \boxed{107 \text{ m}}$

22.30 The angles of refraction for the two wavelengths are

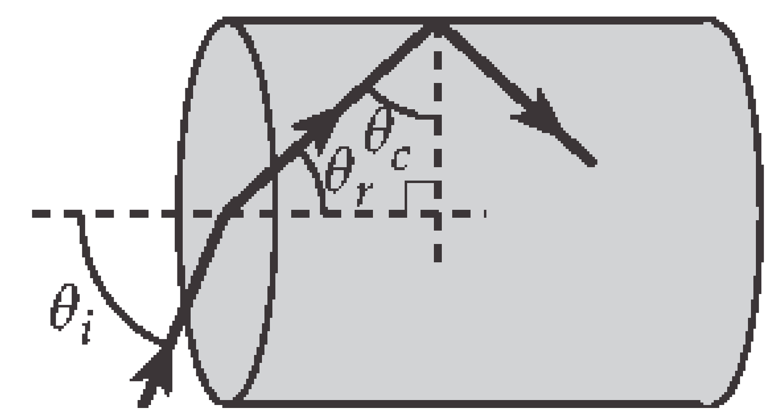
$$\theta_{red} = \sin^{-1}\left(\frac{n_{air} \sin\theta_i}{n_{red}}\right) = \sin^{-1}\left(\frac{(1.00\,0)\sin 30.00°}{1.615}\right) = 18.04°$$

and $$\theta_{blue} = \sin^{-1}\left(\frac{n_{air} \sin\theta_i}{n_{blue}}\right) = \sin^{-1}\left(\frac{(1.00\,0)\sin 30.00°}{1.650}\right) = 17.64°$$

Thus, the angle between the two refracted rays is

$$\Delta\theta = \theta_{red} - \theta_{blue} = 18.04° - 17.64° = \boxed{0.40°}$$

22.38 The critical angle for this material in air is

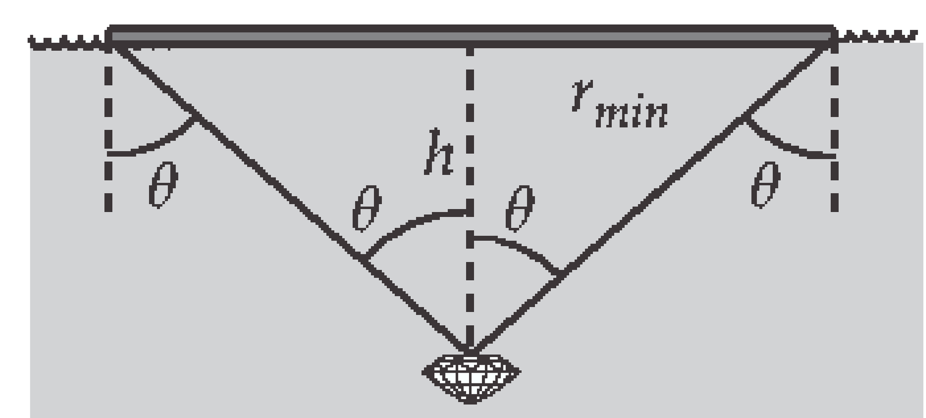


$$\theta_c = \sin^{-1}\left(\frac{n_{air}}{n_{pipe}}\right) = \sin^{-1}\left(\frac{1.00}{1.36}\right) = 47.3°$$

Thus, $\theta_r = 90.0° - \theta_c = 42.7°$ and from Snell's law,

$$\theta_i = \sin^{-1}\left(\frac{n_{pipe}\sin\theta_r}{n_{air}}\right) = \sin^{-1}\left(\frac{(1.36)\sin 42.7°}{1.00}\right) = \boxed{67.2°}$$

22.40 The circular raft must cover the area of the surface through which light from the diamond could emerge. Thus, it must form the base of a cone (with apex at the diamond) whose half angle is θ, where θ is greater than or equal to the critical angle.



The critical angle at the water-air boundary is

$$\theta_c = \sin^{-1}\left(\frac{n_{air}}{n_{water}}\right) = \sin^{-1}\left(\frac{1.00}{1.333}\right) = 48.6°$$

Thus, the minimum diameter of the raft is

$$2r_{min} = 2h\tan\theta_{min} = 2h\tan\theta_c = 2(2.00\text{ m})\tan 48.6° = \boxed{4.54\text{ m}}$$

23.3 (1) The first image in the left-hand mirror is 5.00 ft behind the mirror, or $\boxed{\text{10.0 ft from the person}}$

(2) The first image in the right-hand mirror serves as an object for the left-hand mirror. It is located 10.0 ft behind the right-hand mirror, which is 25.0 ft from the left-hand mirror. Thus, the second image in the left-hand mirror is 25.0 ft behind the mirror, or $\boxed{\text{30.0 ft from the person}}$

(3) The first image in the left-hand mirror serves as an object for the right-hand mirror. It is located 20.0 ft in front of the right-hand mirror and forms an image 20.0 ft behind that mirror. This image then serves as an object for the left-hand mirror. The distance from this object to the left-hand mirror is 35.0 ft. Thus, the third image in the left-hand mirror is 35.0 ft behind the mirror, or $\boxed{\text{40.0 ft from the person}}$

23.7 The radius of curvature of a concave mirror is positive, so $R = +20.0\text{ cm}$. The mirror equation then gives

$$\frac{1}{q} = \frac{2}{R} - \frac{1}{p} = \frac{1}{10.0\text{ cm}} - \frac{1}{p} = \frac{p - 10.0\text{ cm}}{(10.0\text{ cm})p}\text{, or } q = \frac{(10.0\text{ cm})p}{p - 10.0\text{ cm}}$$

(a) If $p = 40.0\text{ cm}$, $q = +13.3\text{ cm}$ and $M = -\frac{q}{p} = -\frac{13.3\text{ cm}}{40.0\text{ cm}} = \boxed{-0.333}$

The image is $\boxed{\text{13.3 cm in front of the mirror, real, and inverted}}$

(b) When $p = 20.0\text{ cm}$, $q = +20.0\text{ cm}$ and $M = -\frac{q}{p} = -\frac{20.0\text{ cm}}{20.0\text{ cm}} = \boxed{-1.00}$

The image is $\boxed{\text{20.0 cm in front of the mirror, real, and inverted}}$

(c) If $p = 10.0\text{ cm}$, $q = \frac{(10.0\text{ cm})(10.0\text{ cm})}{10.0\text{ cm} - 10.0\text{ cm}} \to \infty$

and $\boxed{\text{no image is formed. Parallel rays leave the mirror}}$

23.10 The image was initially upright but became inverted when Dina was more than 30 cm from the mirror. From this information, we know that the mirror must be $\boxed{\text{concave}}$ because a convex mirror will form only upright, virtual images of real objects.

When the object is located at the focal point of a concave mirror, the rays leaving the mirror are parallel, and no image is formed. Since Dina observed that her image disappeared when she was about 30 cm from the mirror, we know that the focal length must be $\boxed{f \approx 30\text{ cm}}$. Also, for spherical mirrors, $R = 2f$. Thus, the radius of curvature of this concave mirror must be $\boxed{R \approx 60\text{ cm}}$.

23.11 The *magnified*, *virtual* images formed by a concave mirror are upright, so $M > 0$.

Thus, $M = -\dfrac{q}{p} = \dfrac{h'}{h} = \dfrac{5.00 \text{ cm}}{2.00 \text{ cm}} = +2.50$, giving

$$q = -2.50p = -2.50(+3.00 \text{ cm}) = -7.50 \text{ cm}$$

The mirror equation then gives,

$$\frac{1}{f} = \frac{2}{R} = \frac{1}{p} + \frac{1}{q} = \frac{1}{3.00 \text{ cm}} - \frac{1}{7.50 \text{ cm}} = \frac{2.50 - 1}{7.50 \text{ cm}}$$

or $$f = \frac{7.50 \text{ cm}}{1.50} = 5.00 \text{ cm}$$

23.13 The image is upright, so $M > 0$, and we have

$$M = -\frac{q}{p} = +2.0, \text{ or } q = -2.0p = -2.0(25 \text{ cm}) = -50 \text{ cm}$$

The radius of curvature is then found to be

$$\frac{2}{R} = \frac{1}{p} + \frac{1}{q} = \frac{1}{25 \text{ cm}} - \frac{1}{50 \text{ cm}} = \frac{2-1}{50 \text{ cm}}, \text{ or } R = 2\left(\frac{0.50 \text{ m}}{+1}\right) = \boxed{1.0 \text{ m}}$$