Chapter 17 Solutions

17.1 Since $v_{\text{light}} >> v_{\text{sound}}$, $d \approx (343\text{ m/s})(16.2\text{ s}) = \boxed{5.56\text{ km}}$

<u>Goal Solution</u>

G: There is a common rule of thumb that lightning is about a mile away for every 5 seconds of delay between the flash and thunder (or ~3 s/km). Therefore, this lightning strike is about 3 miles (~5 km) away.

O: The distance can be found from the speed of sound and the elapsed time. The time for the light to travel to the observer will be much less than the sound delay, so the speed of light can be ignored.

A: Assuming that the speed of sound is constant through the air between the lightning strike and the observer,

$$v_s = \frac{d}{\Delta t} \quad \text{or} \quad d = v_s\,\Delta t = (343\text{ m/s})(16.2\text{ s}) = 5.56\text{ km}$$

L: Our calculated answer is consistent with our initial estimate, but we should check the validity of our assumption that the speed of light could be ignored. The time delay for the light is

$$t_{\text{light}} = \frac{d}{c} = \frac{5560\text{ m}}{3.00 \times 10^8\text{ m/s}} = 1.85 \times 10^{-5}\text{ s}$$

and $\Delta t = t_{\text{sound}} - t_{\text{light}} = 16.2\text{ s} - 1.85 \times 10^{-5}\text{ s} \approx 16.2\text{ s}$ (when properly rounded)

Since the travel time for the light is much smaller than the uncertainty in the time of 16.2 s, t_{light} can be ignored without affecting the distance calculation. However, our assumption of a constant speed of sound in air is probably not valid due to local variations in air temperature during a storm. We must assume that the given speed of sound in air is an accurate *average* value for the conditions described.

17.2 $v = \sqrt{\frac{B}{\rho}} = \sqrt{\frac{2.80 \times 10^{10}}{13.6 \times 10^3}} = \boxed{1.43\text{ km/s}}$

17.3 Sound takes this time to reach the man:

$$\frac{(20.0\text{ m} - 1.75\text{ m})}{343\text{ m/s}} = 5.32 \times 10^{-2}\text{ s}$$

so the warning should be shouted no later than

$$0.300\text{ s} + 5.32 \times 10^{-2}\text{ s} = 0.353\text{ s} \quad \text{before the pot strikes.}$$

Since the whole time of fall is given by

$$y = \frac{1}{2}\,gt^2 \qquad 18.25\text{ m} = \frac{1}{2}(9.80\text{ m/s}^2)\,t^2$$

$$t = 1.93\text{ s}$$

the warning needs to come 1.93 s – 0.353 s = 1.58 s

into the fall, when the pot has fallen $\frac{1}{2}(9.80\text{ m/s}^2)(1.58\text{ s})^2 = 12.2\text{ m}$

to be above the ground by 20.0 m – 12.2 m = $\boxed{7.82\text{ m}}$

17.4 $v(\text{air}) = 343\text{ m/s}$ and $v(\text{salt water}) = 1533\text{ m/s}$

Let d = width of inlet $t = \dfrac{d}{v_w}$; $t + 4.50 = \dfrac{d}{v_a}$, so $\dfrac{d}{v_w} + 4.50 = \dfrac{d}{v_a}$

$$d = \frac{4.50 v_w v_a}{v_w - v_a} = \frac{(4.50)(1533)(343)}{1533 - 343} = \boxed{1.99\text{ km}}$$

17.5 (a) At 9000 m, $\Delta T = \left(\dfrac{9000}{150}\right)(-1.00°\text{C}) = -60.0°\text{C}$ so $T = -30.0°\text{C}$

Using the chain rule:

$$\frac{dv}{dt} = \frac{dv}{dT}\frac{dT}{dx}\frac{dx}{dt} = v\frac{dv}{dT}\frac{dT}{dx} = v(0.607)\left(\frac{1}{150}\right) = \frac{v}{247}, \text{ so } dt = (247\text{ s})\frac{dv}{v}$$

$$\int_0^t dt = (247\text{ s})\int_{v_i}^{v_f}\frac{dv}{v}$$

$$t = (247\text{ s})\ln\left(\frac{v_f}{v_i}\right) = (247\text{ s})\ln\left[\frac{331.5 + 0.607(30.0)}{331.5 + 0.607(-30.0)}\right]$$

$t = \boxed{27.2\text{ s}}$ for sound to reach ground

(b) $$t = \frac{h}{v} = \frac{9000}{[331.5 + 0.607(30.0)]} = \boxed{25.7\text{ s}}$$

It takes longer when the air cools off than if it were at a uniform temperature.

17.6 From $\lambda = \dfrac{v}{f}$, we get: $\lambda = \dfrac{340\text{ m/s}}{60.0 \times 10^3\text{ s}^{-1}} = \boxed{5.67\text{ mm}}$

17.7 It is easiest to solve part (b) first:

(b) The distance the sound travels to the plane is $d_s = \sqrt{h^2 + (h/2)^2} = h\sqrt{5}/2$

The sound travels this distance in 2.00 s, so

$$d_s = \frac{h\sqrt{5}}{2} = (343 \text{ m/s})(2.00 \text{ s}) = 686 \text{ m}$$

giving the altitude of the plane as $h = \dfrac{2(686 \text{ m})}{\sqrt{5}} = \boxed{614 \text{ m}}$

(a) The distance the plane has traveled in 2.00 s is $v(2.00 \text{ s}) = h/2 = 307$ m

Thus, the speed of the plane is: $v = \dfrac{307 \text{ m}}{2.00 \text{ s}} = \boxed{153 \text{ m/s}}$

17.8 $\Delta P_{\max} = \rho v \omega s_{\max}$

$$s_{\max} = \frac{\Delta P_{\max}}{\rho v \omega} = \frac{(4.00 \times 10^{-3} \text{ N/m}^2)}{(1.20 \text{ kg/m}^3)(343 \text{ m/s})(2\pi)(10.0 \times 10^3 \text{ s}^{-1})} = \boxed{1.55 \times 10^{-10} \text{ m}}$$

17.9 (a) $A = \boxed{2.00\ \mu\text{m}}$ $\lambda = \dfrac{2\pi}{15.7} = 0.400 \text{ m} = \boxed{40.0 \text{ cm}}$

$$v = \frac{\omega}{k} = \frac{858}{157} = \boxed{54.6 \text{ m/s}}$$

(b) $s = 2.00 \cos[(15.7)(0.0500) - (858)(3.00 \times 10^{-3})] = \boxed{-0.433 \mu\text{m}}$

(c) $v_{\max} = A\omega = (2.00\ \mu\text{m})(858 \text{ s}^{-1}) = \boxed{1.72 \text{ mm/s}}$

17.10 (a) $\Delta P = (1.27 \text{ Pa})\sin(\pi x/\text{m} - 340\pi t/\text{s})$ (SI units)

The pressure amplitude is: $\Delta P_{\max} = \boxed{1.27 \text{ Pa}}$

(b) $\omega = 2\pi f = 340\pi/\text{s}$, so $f = \boxed{170 \text{ Hz}}$

(c) $k = \dfrac{2\pi}{\lambda} = \pi/\text{m}$, giving $\lambda = \boxed{2.00 \text{ m}}$

(d) $v = \lambda f = (2.00 \text{ m})(170 \text{ Hz}) = \boxed{340 \text{ m/s}}$

17.11 $k = \frac{2\pi}{\lambda} = \frac{2\pi}{(0.100 \text{ m})} = 62.8 \text{ m}^{-1}$

$\omega = \frac{2\pi v}{\lambda} = \frac{2\pi(343 \text{ m/s})}{(0.100 \text{ m})} = 2.16 \times 10^4 \text{ s}^{-1}$

Therefore, $\boxed{\Delta P = (0.200 \text{ Pa}) \sin[62.8x/\text{m} - 2.16 \times 10^4 t/\text{s}]}$

17.12 $\omega = 2\pi f = \frac{2\pi v}{\lambda} = \frac{2\pi(343 \text{ m/s})}{(0.100 \text{ m})} = 2.16 \times 10^4 \text{ rad/s}$

$s_{max} = \frac{\Delta P_{max}}{\rho v \omega} = \frac{(0.200 \text{ Pa})}{(1.20 \text{ kg/m}^3)(343 \text{ m/s})(2.16 \times 10^4 \text{ s}^{-1})} = 2.25 \times 10^{-8} \text{ m}$

$k = \frac{2\pi}{\lambda} = \frac{2\pi}{(0.100 \text{ m})} = 62.8 \text{ m}^{-1}$

Therefore, $\boxed{s = s_{max} \cos(kx - \omega t) = (2.25 \times 10^{-8} \text{ m}) \cos(62.8x/\text{m} - 2.16 \times 10^4 t/\text{s})}$

17.13 (a) The sound "pressure" is extra tensile stress for one-half of each cycle. When it becomes $(0.500\%)(13.0 \times 10^{10} \text{ Pa}) = 6.50 \times 10^8 \text{ Pa}$, the rod will break.

Then, $\Delta P_{max} = \rho v \omega s_{max}$

$$s_{max} = \frac{\Delta P_{max}}{\rho v \omega} = \frac{6.50 \times 10^8 \text{ N/m}^2}{(8.92 \times 10^3 \text{ kg/m}^3)(3560 \text{ m/s})(2\pi 500/\text{s})} = \boxed{6.52 \text{ mm}}$$

(b) From $s = s_{max} \cos(kx - \omega t)$

$$v = \frac{\partial s}{\partial t} = -\omega s_{max} \sin(kx - \omega t)$$

$$v_{max} = \omega s_{max} = (2\pi\, 500/\text{s})(6.52 \text{ mm}) = \boxed{20.5 \text{ m/s}}$$

17.14 $\Delta P_{max} = \rho \omega v s_{max} = (1.20 \text{ kg/m}^3)[2\pi(2000 \text{ s}^{-1})](343 \text{ m/s})(2.00 \times 10^{-8} \text{ m})$

$\Delta P_{max} = \boxed{0.103 \text{ Pa}}$

17.15 $\Delta P_{max} = \rho v \omega s_{max} = \rho v \left(\frac{2\pi v}{\lambda}\right) s_{max}$

$\lambda = \frac{2\pi \rho v^2 s_{max}}{\Delta P_{max}}$

$\lambda = \frac{2\pi(1.20)(343)^2(5.50 \times 10^{-6})}{0.840} = \boxed{5.81 \text{ m}}$

17.16 (a) $\Delta P = \Delta P_{max} \sin [kx - \omega t + \phi]$ with $\Delta P_{max} = 4.00$ Pa

$\Delta P(0, 0) = \Delta P_{max} \sin \phi = 0 \Rightarrow \phi = 0$

$\omega = 2\pi f = 2\pi(5000 \text{ s}^{-1}) = \pi \times 10^4 \text{ s}^{-1}$

Therefore, $\Delta P = (4.00 \text{ Pa}) \sin (kx - \pi \times 10^4\, t/\text{s})$

At $x = 0$, $t = 2.00 \times 10^{-4}$ s, $\Delta P = (4.00 \text{ Pa}) \sin (0 - 2.00\pi) = \boxed{0}$

(b) $k = \dfrac{2\pi}{\lambda} = \dfrac{\omega}{v} = \dfrac{\pi \times 10^4 \text{ s}^{-1}}{343 \text{ m/s}} = 91.5 \text{ m}^{-1}$

At $x = 0.0200$ m, $t = 0$, $\Delta P = (4.00 \text{ Pa}) \sin [(91.5 \text{ m}^{-1})(0.0200 \text{ m}) - 0]$

$\Delta P = \boxed{3.87 \text{ Pa}}$

17.17 $\beta = 10 \log\left(\dfrac{I}{I_0}\right) = 10 \log\left(\dfrac{4.00 \times 10^{-6}}{1.00 \times 10^{-12}}\right) = \boxed{66.0 \text{ dB}}$

17.18 (a) $70.0 \text{ dB} = 10 \log\left(\dfrac{I}{1.00 \times 10^{-12} \text{ W/m}^{-2}}\right)$

Therefore, $I = (1.00 \times 10^{-12} \text{ W/m}^{-2})10^{(70.0/10)} = \boxed{1.00 \times 10^{-5} \text{ W/m}^2}$

(b) $I = \Delta P_{max}^2 / 2\rho v$, so

$\Delta P_{max} = \sqrt{2\rho v I} = \sqrt{2(1.20 \text{ kg/m}^3)(343 \text{ m/s})(1.00 \times 10^{-5} \text{ W/m}^2)}$

$\Delta P_{max} = \boxed{90.7 \text{ mPa}}$

17.19 $I = \dfrac{1}{2} \rho \omega^2 s_{max}^2 v$

(a) At $f = 2500$ Hz, the frequency is increased by a factor of 2.50, so the intensity (at constant s_{max}) increases by $(2.50)^2 = 6.25$.

Therefore, $6.25(0.600) = \boxed{3.75 \text{ W/m}^2}$

(b) $\boxed{0.600 \text{ W/m}^2}$

17.20 The original intensity is $I_1 = \frac{1}{2}\rho\omega^2 s_{max}^2 v = 2\pi^2\rho v f^2 s_{max}^2$

(a) If the frequency is increased to $f\,'$ while a constant displacement amplitude is maintained, the new intensity is

$$I_2 = 2\pi^2\rho v(f\,')^2 s_{max}^2 \quad \text{so} \quad \frac{I_2}{I_1} = \frac{2\pi^2\rho v(f\,')s_{max}^2}{2\pi^2\rho v f^2 s_{max}^2} = \left(\frac{f\,'}{f}\right)^2 \quad \text{or} \quad \boxed{I_2 = \left(\frac{f\,'}{f}\right)^2 I_1}$$

(b) If the frequency is reduced to $f\,' = f/2$ while the displacement amplitude is doubled, the new intensity is

$$I_2 = 2\pi^2\rho v\left(\frac{f}{2}\right)^2(2s_{max})^2 = 2\pi^2\rho v f^2 s_{max}^2 = I_1$$

or the $\boxed{\text{intensity is unchanged}}$.

17.21 (a) $I_1 = (1.00 \times 10^{-12}\ \text{W/m}^2)10^{(\beta_1/10)} = (1.00 \times 10^{-12}\ \text{W/m}^2)10^{80.0/10}$

or $I_1 = 1.00 \times 10^{-4}\ \text{W/m}^2$

$I_2 = (1.00 \times 10^{-12}\ \text{W/m}^2)10^{(\beta_2/10)} = (1.00 \times 10^{-12}\ \text{W/m}^2)10^{75.0/10}$

or $I_2 = 1.00 \times 10^{-4.5}\ \text{W/m}^2 = 31.6 \times 10^{-5}\ \text{W/m}^2$

When both sounds are present, the total intensity is

$$I = I_1 + I_2 = 1.00 \times 10^{-4}\ \text{W/m}^2 + 31.6 \times 10^{-5}\ \text{W/m}^2 = \boxed{1.32 \times 10^{-4}\ \text{W/m}^2}$$

(b) The decibel level for the combined sounds is

$$\beta = 10 \log\left(\frac{1.32 \times 10^{-4}\ \text{W/m}^2}{1.00 \times 10^{-12}\ \text{W/m}^2}\right) = 10 \log(1.32 \times 10^8) = \boxed{81.2\ \text{db}}$$

17.22 We begin with $\beta_2 = 10 \log\left(\frac{I_2}{I_0}\right)$, and $\beta_1 = 10 \log\left(\frac{I_1}{I_0}\right)$, so

$$\beta_2 - \beta_1 = 10 \log\left(\frac{I_2}{I_1}\right)$$

Also, $I_2 = \frac{\wp}{4\pi r_2^2}$, and $I_1 = \frac{\wp}{4\pi r_1^2}$, giving $\frac{I_2}{I_1} = \left(\frac{r_1}{r_2}\right)^2$

Then, $\beta_2 - \beta_1 = 10 \log\left(\frac{r_1}{r_2}\right)^2 = \boxed{20 \log\left(\frac{r_1}{r_2}\right)}$

17.23 Since intensity is inversely proportional to the square of the distance,

$$I_4 = \frac{1}{100} I_{0.4} \quad \text{and} \quad I_{0.4} = \frac{\Delta P_{\max}^2}{2\rho v} = \frac{(10.0)^2}{2(1.20)(343)} = 0.121 \text{ W/m}^2$$

The difference in sound intensity level is

$$\Delta\beta = 10 \log\left(\frac{I_{4\text{ km}}}{I_{0.4\text{ km}}}\right) = 10(-200) = -20.0 \text{ dB}$$

At 0.400 km,

$$\beta_{0.4} = 10 \log\left(\frac{0.121 \text{ W/m}^2}{10^{-12} \text{ W/m}^2}\right) = 110.8 \text{ db}$$

At 4.00 km,

$$\beta_4 = \beta_{0.4} + \Delta\beta = (110.8 - 20.0) \text{ dB} = 90.8 \text{ dB}$$

Allowing for absorption of the wave over the distance traveled,

$$\beta_4' = \beta_4 - (7.00 \text{ dB/km})(3.60 \text{ km}) = \boxed{65.6 \text{ dB}}$$

This is equivalent to the sound intensity level of heavy traffic.

Goal Solution

G: At a distance of 4 km, an explosion should be audible, but probably not extremely loud. So based on the data in Table 17.2, we might expect the sound level to be somewhere between 50 and 100 dB.

O: From the sound pressure data given in the problem, we can find the intensity, which is used to find the sound level in dB. The sound intensity will decrease with increased distance from the source and from the absorption of the sound by the air.

A: At a distance of 400 m from the explosion, $\Delta P_{\max} = 10$ Pa.

At this point, $I_{\max} = \dfrac{(10 \text{ N/m}^2)^2}{2(1.20 \text{ kg/m}^3)(343 \text{ m/s})} = 0.121 \text{ W/m}^2$

Therefore, the maximum sound level is

$$\beta_{\max} = 10 \log\left(\frac{I_{\max}}{I_0}\right) = 10 \log\left(\frac{0.121 \text{ W/m}^2}{1.00 \times 10^{-12} \text{ W/m}^2}\right) = 111 \text{ dB}$$

From equations 17.8 and 17.7, we can calculate the intensity and decibel level (due to distance alone) 4 km away:

$$I' = \frac{I(400\text{ m})^2}{(4000\text{ m})^2} = 1.21 \times 10^{-3}\text{ W/m}^2 \quad \text{and} \quad \beta = 10\log\left(\frac{I}{I_0}\right) = 10\log\left(\frac{1.21 \times 10^{-3}}{1.00 \times 10^{-12}}\right) = 90.8\text{ dB}$$

At a distance of 4 km from the explosion, absorption from the air will have decreased the sound level by an additional $\Delta\beta = (7\text{ dB/km})(3.6\text{ km}) = 25.2\text{ dB}$

So at 4 km, the sound level will be $\beta_f = \beta - \Delta\beta = 90.8\text{ dB} - 25.2\text{ dB} = \boxed{65.6\text{ dB}}$

L: This sound level falls within our expected range. Evidently, this explosion is rather loud (about the same as a vacuum cleaner) even at a distance of 4 km from the source. It is interesting to note that the distance and absorption effects each reduce the sound level by about the same amount (~20 dB). If the explosion were at ground level, the sound level would be further reduced by reflection and absorption from obstacles between the source and observer, and the calculation would be much more complicated (if not impossible).

17.24 Let r_1 and r_2 be the distance from the speaker to the observer that hears 60.0 dB and 80.0 dB, respectively. Use the result of problem 22,

$$\beta_2 - \beta_1 = 20\log\left(\frac{r_1}{r_2}\right), \quad \text{to obtain} \quad 80.0 - 60.0 = 20\log\left(\frac{r_1}{r_2}\right)$$

Thus, $\log\left(\frac{r_1}{r_2}\right) = 1$, so $r_1 = 10.0 r_2$. Also: $r_1 + r_2 = 110\text{ m}$, so

$10.0 r_2 + r_2 = 110\text{ m}$ giving $\boxed{r_2 = 10.0\text{ m}}$, and $\boxed{r_1 = 100\text{ m}}$

17.25 We presume the speakers broadcast equally in all directions.

(a) $r_{AC} = \sqrt{3.00^2 + 4.00^2}\text{ m} = 5.00\text{ m}$

$I = \wp/4\pi r^2 = 1.00 \times 10^{-3}\text{ W}/4\pi(5.00\text{ m})^2 = 3.18 \times 10^{-6}\text{ W/m}^2$

$\beta = 10\text{ dB}\log(3.18 \times 10^{-6}\text{ W/m}^2/10^{-12}\text{ W/m}^2)$

$\beta = 10\text{ dB }6.50 = \boxed{65.0\text{ dB}}$

(b) $r_{BC} = 4.47\text{ m}$

$I = 1.50 \times 10^{-3}\text{ W}/4\pi(4.47\text{ m})^2 = 5.97 \times 10^{-6}\text{ W/m}^2$

$\beta = 10\text{ dB}\log(5.97 \times 10^{-6}/10^{-12})$

$\beta = \boxed{67.8\text{ dB}}$

(c) $I = 3.18\ \mu\text{W/m}^2 + 5.97\ \mu\text{W/m}^2$

$\beta = 10\text{ dB}\log(9.15\times10^{-6}/10^{-12}) = \boxed{69.6\text{ dB}}$

17.26 $I = \dfrac{\wp}{4\pi r^2}$, where $I = 1.20\text{ W/m}^2$

$\wp = 4\pi r^2 I = 4\pi(4.00)^2(1.20) = \boxed{241\text{ W}}$

17.27 $40.0\text{ dB} = 10\text{ dB}\log\left(\dfrac{I}{10^{-12}\text{ W/m}^2}\right)$

$4.00 = \log\dfrac{I}{10^{-12}}$

$I = 10^{-12}(1.00\times10^4) = 1.00\times10^{-8}\text{ W/m}^2$

$\wp = 4\pi r^2 I = (4\pi)(9.00)(1.00\times10^{-8}) = \boxed{1.13\ \mu\text{W}}$

***17.28** In $I = \dfrac{\wp}{4\pi r^2}$, intensity I is proportional to $\dfrac{1}{r^2}$,

so between locations 1 and 2: $\dfrac{I_2}{I_1} = \dfrac{r_1^2}{r_2^2}$

In $I = \dfrac{1}{2}\rho v(\omega s_{\max})^2$, intensity is proportional to $s_{\max}^2$, so $\dfrac{I_2}{I_1} = \dfrac{s_2^2}{s_1^2}$

Then, $\left(\dfrac{s_2}{s_1}\right)^2 = \left(\dfrac{r_1}{r_2}\right)^2$ or $\left(\dfrac{1}{2}\right)^2 = \left(\dfrac{r_1}{r_2}\right)^2$, giving $r_2 = 2r_1 = 2(50.0\text{ m}) = 100\text{ m}$

But, $r_2 = \sqrt{(50.0\text{ m})^2 + d^2}$ yields $d = \boxed{86.6\text{ m}}$

17.29 $\beta = 10\log\left(\dfrac{I}{10^{-12}}\right)$ $\quad I = [10^{(\beta/10)}](10^{-12})\text{W/m}^2$

$I_{(120\text{ dB})} = 1.00\text{ W/m}^2$; $I_{(100\text{ dB})} = 1.00\times10^{-2}\text{ W/m}^2$; $I_{(10\text{ dB})} = 1.00\times10^{-11}\text{ W/m}^2$

(a) $\wp = 4\pi r^2 I$ so that $r_1^2 I_1 = r_2^2 I_2$

$r_2 = r_1(I_1/I_2)^{1/2} = (3.00\text{ m})\sqrt{\dfrac{1.00}{1.00\times10^{-2}}} = \boxed{30.0\text{ m}}$

(b) $r_2 = r_1(I_1/I_2)^{1/2} = (3.00\text{ m})\sqrt{\dfrac{1.00}{1.00\times10^{-11}}} = \boxed{9.49\times10^5\text{ m}}$

17.30 (a) $E = \wp t = 4\pi r^2 It = 4\pi(100\text{ m})^2(7.00 \times 10^{-2}\text{ W/m}^2)(0.200\text{ s}) = \boxed{1.76\text{ kJ}}$

(b) $\beta = 10\log\left(\dfrac{7.00 \times 10^{-2}}{1.00 \times 10^{-12}}\right) = \boxed{108\text{ dB}}$

***17.31** (a) The sound intensity inside the church is given by

$$\beta = 10\ln(I/I_0)$$

$$101\text{ dB} = (10\text{ dB})\ln(I/10^{-12}\text{ W/m}^2)$$

$$I = 10^{10.1}(10^{-12}\text{ W/m}^2) = 10^{-1.90}\text{ W/m}^2 = 0.0126\text{ W/m}^2$$

We suppose that sound comes perpendicularly out through the windows and doors. Then, the radiated power is

$$\wp = IA = (0.0126\text{ W/m}^2)(22.0\text{ m}^2) = 0.277\text{ W}$$

Are you surprised by how small this is? The energy radiated in 20.0 minutes is

$$E = \wp t = (0.277\text{ J/s})(20.0\text{ min})(60.0\text{ s}/1.00\text{ min}) = \boxed{332\text{ J}}$$

(b) If the ground reflects all sound energy headed downward, the sound power, $\wp = 0.277$ W, covers the area of a hemisphere. One kilometer away, this area is $A = 2\pi r^2 = 2\pi(1000\text{ m})^2 = 2\pi \times 10^6\text{ m}^2$.

The intensity at this distance is

$$I = \frac{\wp}{A} = \frac{0.277\text{ W}}{2\pi \times 10^6\text{ m}^2} = 4.41 \times 10^{-8}\text{ W/m}^2$$

and the sound intensity level is

$$\beta = (10\text{ dB})\ln\left(\frac{4.41 \times 10^{-8}\text{ W/m}^2}{1.00 \times 10^{-12}\text{ W/m}^2}\right) = \boxed{46.4\text{ dB}}$$

17.32 (a) $\Delta P_{\max} = \dfrac{25.0}{r} = \dfrac{25.0}{4.00} = \boxed{6.25\text{ Pa}}$

(b) $v = \dfrac{\omega}{k} = \dfrac{1870}{1.25} = 1496\text{ m/s}$ so the material is $\boxed{\text{water}}$

(c) $I = \dfrac{\Delta P_{\max}^2}{2\rho v} = \dfrac{(6.25)^2}{(2)(1000)(1496)} = 1.31 \times 10^{-5}\text{ W/m}^2$

$$\beta = 10\log\left(\frac{1.31 \times 10^{-5}}{1.00 \times 10^{-12}}\right) = \boxed{71.2\text{ dB}}$$

(d) $\Delta P = \left(\frac{25.0}{5.00}\right) \sin\left[(1.25)(5.00) - (1870)(0.0800)\right] = \boxed{4.59\text{ Pa}}$

***17.33** (a) $f' = f\frac{v}{(v \pm v_S)}$

Approach: $f' = 320\frac{(343)}{(343 - 40.0)} = 362.2\text{ Hz}$

Receding: $f' = 320\frac{(343)}{(343 + 40.0)} = 286.5\text{ Hz}$

The *change* in frequency observed = 362 – 287 = $\boxed{75.7\text{ Hz}}$

(b) $\lambda = \frac{v}{f'} = \frac{343\text{ m/s}}{362\text{ Hz}} = \boxed{0.948\text{ m}}$

17.34 (a) $f' = \frac{f(v + v_O)}{(v + v_S)}$ where from observer to source is positive.

$f' = 2500\frac{(343 + 25.0)}{(343 - 40.0)} = \boxed{3.04\text{ kHz}}$

(b) $f' = 2500\frac{(343 - 25.0)}{(343 + 40.0)} = \boxed{2.08\text{ kHz}}$

(c) $f' = 2500\frac{(343 - 25.0)}{(343 - 40.0)} = \boxed{2.62\text{ kHz}}$ while police car overtakes

$f' = 2500\frac{(343 + 25.0)}{(343 + 40.0)} = \boxed{2.40\text{ kHz}}$ after police car passes

17.35 Approaching car

$$f' = \frac{f}{\left(1 - \frac{v_S}{v}\right)} \qquad \text{(Equation 17.14)}$$

Departing car

$$f'' = \frac{f}{\left(1 + \frac{v_S}{v}\right)} \qquad \text{(Equation 17.15)}$$

Since $f' = 560$ Hz and $f'' = 480$ Hz,

$$560\left(1 - \frac{v_S}{v}\right) = 480\left(1 + \frac{v_S}{v}\right)$$

$$1040\frac{v_S}{v} = 80.0$$

$$v_S = \frac{80.0(343)}{1040}\text{ m/s} = \boxed{26.4\text{ m/s}}$$

Goal Solution

G: We can assume that a police car with its siren on is in a hurry to get somewhere, and is probably traveling between 20 and 100 mph (~10 to 50 m/s), depending on the driving conditions.

O: We can use the equation for the Doppler effect to find the speed of the car.

A: Approaching car: $f' = \dfrac{f}{\left(\dfrac{v_s}{v}\right)}$ (Eq. 17.14)

Departing car: $f'' = \dfrac{f}{\left(1 + \dfrac{v_s}{v}\right)}$ (Eq. 17.15)

Where $f' = 560$ Hz and $f'' = 480$ Hz. Solving the two equations above for f and setting them equal gives:

$$f'\left(1 - \frac{v_s}{v}\right) = f''\left(1 + \frac{v_s}{v}\right) \quad\text{or}\quad f' - f'' = \frac{v_s}{v}(f' + f'')$$

so the speed of the source is $v_s = \dfrac{v(f' - f'')}{f' + f''} = \dfrac{(343\text{ m/s})(560\text{ Hz} - 480\text{ Hz})}{(560\text{ Hz} + 480\text{ Hz})} = \boxed{26.4\text{ m/s}}$

L: This seems like a reasonable speed (about 50 mph) for a police car, unless the street is crowded or the car is traveling on an open highway.

***17.36** (a) $\omega = 2\pi f = 2\pi\left(\dfrac{115/\text{min}}{60.0\text{ s/min}}\right) = 12.0\text{ rad/s}$

$$v_{max} = \omega A = (12.0\text{ rad/s})(1.80 \times 10^{-3}\text{ m}) = \boxed{0.0217\text{ m/s}}$$

(b) The heart wall is a moving observer.

$$f' = f\left(\frac{v + v_O}{v}\right) = (2{,}000{,}000\text{ Hz})\left(\frac{1500 + 0.0217}{1500}\right) = \boxed{2\,000\,028.9\text{ Hz}}$$

(c) Now the heart wall is a moving source.

$$f'' = f'\left(\frac{v}{v - v_s}\right) = (2{,}000{,}029\text{ Hz})\left(\frac{1500}{1500 - 0.0217}\right) = \boxed{2\ 000\ 057.8\text{ Hz}}$$

17.37 $f' = f\left(\frac{v}{v + v_S}\right)$

$$485 = 512\left(\frac{340}{340 + 9.80t_{\text{fall}}}\right)$$

$$485(340) + (485)(9.80t_f) = (512)(340)$$

$$t_f = \left(\frac{512 - 485}{485}\right)\frac{340}{9.80} = 1.93\text{ s}$$

$$d_1 = \frac{1}{2}\,g t_f^2 = 18.3\text{ m}$$

$t_{\text{return}} = \frac{18.3}{340} = 0.0538\text{ s}$ The fork continues to fall while the sound returns.

$$t_{\text{total fall}} = t_f + t_{\text{return}} = 1.93\text{ s} + 0.0538\text{ s} = 1.985\text{ s}$$

$$d_{\text{total}} = \frac{1}{2}\,g t_{\text{total fall}}^2 = \boxed{19.3\text{ m}}$$

17.38 (a) The maximum speed of the speaker is described by

$$\frac{1}{2}\,m v_{\max}^2 = \frac{1}{2}\,kA^2$$

$$v_{\max} = \sqrt{k/m}\,A = \sqrt{\frac{20.0\text{ N/m}}{5.00\text{ kg}}}(0.500\text{ m}) = 1.00\text{ m/s}$$

The frequencies heard by the stationary observer range from

$$f'_{\min} = f\left(\frac{v}{v + v_{\max}}\right) \quad \text{to} \quad f'_{\max} = f\left(\frac{v}{v - v_{\max}}\right)$$

where v is the speed of sound.

$$f'_{\min} = 440\text{ Hz}\left(\frac{343\text{ m/s}}{343\text{ m/s} + 1.00\text{ m/s}}\right) = \boxed{439\text{ Hz}}$$

$$f'_{\max} = 440\text{ Hz}\left(\frac{343\text{ m/s}}{343\text{ m/s} - 1.00\text{ m/s}}\right) = \boxed{441\text{ Hz}}$$

(b) $\beta = 10\text{ dB}\log(I/I_0) = 10\text{ dB}\log\left(\frac{\wp/4\pi r^2}{I_0}\right)$

The maximum intensity level (of 60.0 dB) occurs at $r = r_{min} = 1.00$ m. The minimum intensity level occurs when the speaker is farthest from the listener (i.e., when $r = r_{max} = r_{min} + 2A = 2.00$ m).

Thus, $\beta_{max} - \beta_{min} = 10\text{ dB}\log\left(\frac{\wp}{4\pi I_0 r_{min}^2}\right) - 10\text{ dB}\log\left(\frac{\wp}{4\pi I_0 r_{max}^2}\right)$

or $\beta_{max} - \beta_{min} = 10\text{ dB}\log\left(\frac{\wp}{4\pi I_0 r_{min}^2}\frac{4\pi I_0 r_{max}^2}{\wp}\right) = 10\text{ dB}\log\left(\frac{r_{max}^2}{r_{min}^2}\right)$

This gives: 60.0 dB – β_{min} = 10 dB log(4.00) = 6.02 dB, and β_{min} = $\boxed{54.0\text{ dB}}$

17.39 $f' = f\frac{(v \pm v_O)}{(v \pm v_S)}$

(a) $f' = 320\frac{(343 + 40.0)}{(343 + 20.0)} = \boxed{338\text{ Hz}}$

(b) $f' = 510\frac{(343 + 20.0)}{(343 + 40.0)} = \boxed{483\text{ Hz}}$

***17.40** (a) $v = (331\text{ m/s})\sqrt{1 + \frac{T}{273°\text{C}}} = (331\text{ m/s})\sqrt{1 + \frac{-10.0°\text{C}}{273°\text{C}}} = \boxed{325\text{ m/s}}$

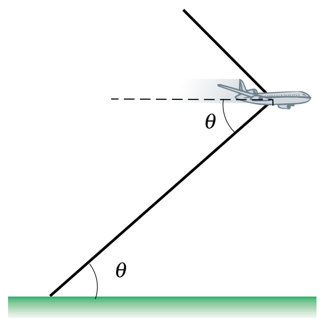
(b) Approaching the bell, the athlete hear a frequency of $f' = f\left(\frac{v + v_O}{v}\right)$

After passing the bell, she hears a lower frequency of $f'' = f\left(\frac{v - v_O}{v}\right)$

The ratio is $\frac{f''}{f'} = \frac{v - v_O}{v + v_O} = \frac{5}{6}$, which gives $6v - 6v_O = 5v + 5v_O$

or $v_O = \frac{v}{11} = \frac{325\text{ m/s}}{11} = \boxed{29.5\text{ m/s}}$

17.41 $\sin\theta = \dfrac{v_{\text{sound}}}{v_{\text{jet}}} = \dfrac{v_{\text{sound}}}{1.20 v_{\text{sound}}} = \dfrac{1}{1.20}$ $\qquad \theta = \boxed{56.4°}$



17.42 The *half angle* of the shock wave cone is given by $\sin\theta = \dfrac{v_{\text{light}}}{v_S}$

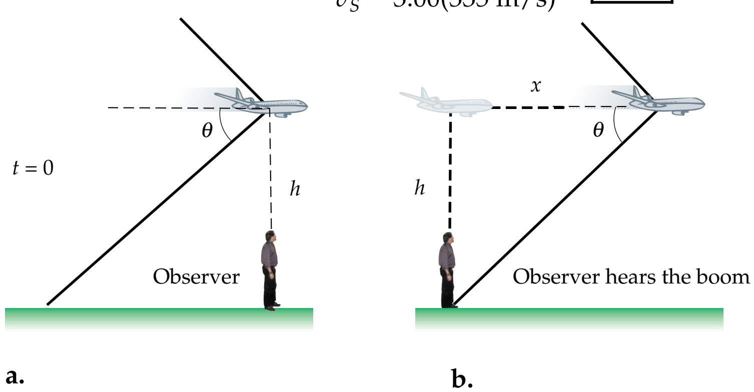
$$v_S = \frac{v_{\text{light}}}{\sin\theta} = \frac{2.25\times10^8\text{ m/s}}{\sin(53.0°)} = \boxed{2.82\times10^8\text{ m/s}}$$

17.43 (b) $\sin\theta = \dfrac{v}{v_S} = \dfrac{1}{3.00}$ $\qquad \theta = 19.5°$

$$\tan\theta = \frac{h}{x} \qquad x = \frac{h}{\tan\theta}$$

$$x = \frac{20000\text{ m}}{\tan 19.5°} = 5.66\times10^4\text{ m} = \boxed{56.6\text{ km}}$$

(a) It takes the plane $t = \dfrac{x}{v_S} = \dfrac{5.66\times10^4\text{ m}}{3.00(335\text{ m/s})} = \boxed{56.3\text{ s}}$ to travel this distance.



17.44 $\theta = \sin^{-1}\dfrac{v}{v_S} = \sin^{-1}\dfrac{1}{1.38} = \boxed{46.4°}$

17.45 Let d be the distance the stone drops.

$$t = \frac{d}{v_S} + \sqrt{\frac{2d}{g}}$$

$$d + \left(\sqrt{\frac{2}{g}}\ v_S\right)\sqrt{d} - v_S t = 0$$

$$\sqrt{d} = -\frac{1}{2}\left(\sqrt{\frac{2}{g}}\ v_S + \sqrt{\frac{2v_S^2}{g} + 4v_S t}\right)$$

$$\sqrt{d} = \frac{1}{2}(-155.0 \pm \sqrt{38\,000})$$

Choose the positive root so that $\sqrt{d} > 0$

$$\sqrt{d} = 20.0$$

$$d = \boxed{400 \text{ m}}$$

If the speed of sound is ignored,

$$t = \sqrt{\frac{2\,d'}{g}}$$

$$d = \frac{1}{2}\ gt^2 = 510 \text{ m}$$

The percentage error is given by

$$\frac{d' - d}{d} = 0.275 = \boxed{27.5\%}$$

***17.46** Model your loud, sharp sound impulse as a single narrow peak in a graph of air pressure versus time. It is a noise with no pitch, no frequency, wavelength, or period. It radiates away from you in all directions and some of it is incident on each one of the solid vertical risers of the bleachers. Suppose that, at the ambient temperature, sound moves at 340 m/s; and suppose that the horizontal width of each row of seats is 60 cm. Then there is a time delay of

$$\frac{0.6 \text{ m}}{(340 \text{ m/s})} \approx 0.002 \text{ s}$$

between your sound impulse reaching each riser and the next. Whatever its material, each will reflect much of the sound that reaches it. The reflected wave sounds very different from the sharp pop you made. If there are twenty rows of seats, you hear from the bleachers a tone with twenty crests, each separated from the next in time by

$$\frac{2(0.6 \text{ m})}{(340 \text{ m/s})} \approx 0.004 \text{ s}$$

This is the extra time for it to cross the width of one seat twice, once as an incident pulse and once again after its reflection. Thus, you hear a sound of definite pitch, with period about 0.004 s, frequency

$$\frac{1}{0.0035\text{ s}}\ \boxed{\sim 300\text{ Hz}}$$

wavelength

$$\lambda = \frac{v}{f} = \frac{(340\text{ m/s})}{(300/\text{s})} = 1.2\text{ m} \sim \boxed{10^0\text{ m}}$$

and duration

$$20(0.004\text{ s}) \sim \boxed{10^{-1}\text{ s}}$$

***17.47** (a) $\lambda = \frac{v}{f} = \frac{343\text{ m/s}}{1480\text{ s}^{-1}} = \boxed{0.232\text{ m}}$

(b) $\beta = 81.0\text{ dB} = 10\text{ dB}\log[I/(10^{-12}\text{ W/m}^2)]$

$$I = (10^{-12}\text{ W/m}^2)10^{8.10} = 10^{-3.90}\text{ W/m}^2 = 1.26\times10^{-4}\text{ W/m}^2 = \frac{1}{2}\rho v\omega^2 s_{max}^2$$

$$s_{max} = \sqrt{\frac{2I}{\rho v\omega^2}} = \sqrt{\frac{2(1.26\times10^{-4}\text{ W/m}^2)}{(1.20\text{ kg/m}^3)(343\text{ m/s})4\pi^2(1480\text{ s}^{-1})^2}} = \boxed{8.41\times10^{-8}\text{ m}}$$

(c) $\lambda' = \frac{v}{f'} = \frac{343\text{ m/s}}{1397\text{ s}^{-1}} = 0.246\text{ m}$ $\qquad \Delta\lambda = \lambda' - \lambda = \boxed{13.8\text{ mm}}$

17.48 Since $\cos^2\theta + \sin^2\theta = 1$ $\qquad \sin\theta = \pm(1-\cos^2\theta)^{1/2}$

each sign applying half the time.

$$\Delta P = \Delta P_{max}\sin(kx-\omega t)$$

$$= \pm\rho v\omega s_{max}[1-\cos^2(kx-\omega t)]^{1/2}$$

$$= \pm\rho v\omega[s_{max}^2 - s_{max}^2\cos^2(kx-\omega t)]^{1/2}$$

$$= \pm\rho v\omega(s_{max}^2 - s^2)^{1/2}$$

***17.49** The trucks form a train analogous to a wave train of crests with speed $v = 19.7$ m/s and unshifted frequency $f = \frac{2}{3.00\text{ min}} = 0.667/\text{min}$.

(a) The cyclist as observer measures a lower Doppler-shifted frequency:

$$f' = f\left(\frac{v - v_O}{v}\right) = (0.667/\text{min})\left(\frac{19.7 - 4.47}{19.7}\right) = \boxed{0.515/\text{min}}$$

(b) $f'' = f\left(\frac{v - v'_O}{v}\right) = (0.667/\text{min})\left(\frac{19.7 - 1.56}{19.7}\right) = \boxed{0.614/\text{min}}$

The cyclist's speed has decreased very significantly, but there is only a modest increase in the frequency of trucks passing him.

***17.50** $v = \frac{2d}{t}$

$$d = \frac{vt}{2} = \frac{1}{2}(6.50 \times 10^3 \text{ m/s})(1.85 \text{ s}) = \boxed{6.01 \text{ km}}$$

***17.51** Call d the distance to the reflection point. We have

$$2d = (6.20 \text{ km/s})t$$

and $2d = (3.20 \text{ km/s})(t + 2.40 \text{ s})$

To solve for d we eliminate t by substitution:

$$t = \frac{2d}{6.20 \text{ km/s}} \qquad 2d = (3.20 \text{ km/s})\left(\frac{2d \text{ s}}{6.20 \text{ km}} + 2.40 \text{ s}\right)$$

$$2d = 1.03d + 7.68 \text{ km}$$

$$d = \frac{7.68 \text{ km}}{0.968} = \boxed{7.94 \text{ km}}$$

***17.52** (a) From the equation given in Example 17.1, the speed of a compression wave in a bar is

$$v = \sqrt{Y/\rho} = \sqrt{(20.0 \times 10^{10} \text{ N/m}^2)/(7860 \text{ kg/m}^3)} = \boxed{5.04 \times 10^3 \text{ m/s}}$$

(b) The signal to stop passes between layers of atoms as a sound wave, reaching the back end of the bar in time

$$t = L/v = (0.800 \text{ m})/(5.04 \times 10^3 \text{ m/s}) = \boxed{1.59 \times 10^{-4} \text{ s}}$$

(c) As described by Newton's first law, the rearmost layer of steel has continued to move forward with its original speed v_i for this time, compressing the bar by

$$\Delta L = v_i t = (12.0 \text{ m/s})(1.59 \times 10^{-4} \text{ s}) = 1.90 \times 10^{-3} \text{ m} = \boxed{1.90 \text{ mm}}$$

(d) The strain in the rod is: $\Delta L/L = (1.90 \times 10^{-3} \text{ m})/(0.800 \text{ m}) = \boxed{2.38 \times 10^{-3}}$

(e) The stress in the rod is:

$$\sigma = Y(\Delta L/L) = (20.0 \times 10^{10} \text{ N/m}^2)(2.38 \times 10^{-3}) = \boxed{476 \text{ MPa}}$$

Since $\sigma > 400$ MPa, the rod will be permanently distorted.

(f) We go through the same steps as in parts (a) through (e), but use algebraic expressions rather than numbers:

The speed of sound in the rod is $v = \sqrt{Y/\rho}$.

The back end of the rod continues to move forward at speed v_i for a time of $t = L/v = L\sqrt{\rho/Y}$, traveling distance $\Delta L = v_i t$ after the front end hits the wall.

The strain in the rod is: $\Delta L/L = v_i t/L = v_i\sqrt{\rho/Y}$

The stress is then: $\sigma = Y(\Delta L/L) = Yv_i\sqrt{\rho/Y} = v_i\sqrt{\rho Y}$

For this to be less than the yield stress, σ_y, it is necessary that

$$v_i\sqrt{\rho Y} < \sigma_y \quad \text{or} \quad \boxed{v_i < \frac{\sigma_y}{\sqrt{\rho Y}}}$$

With the given numbers, this speed is 10.1 m/s. The fact that the length of the rod divides out means that the steel will start to bend right away at the front end of the rod. There it will yield enough so that eventually the remainder of the rod will experience only stress within the elastic range. You can see this effect when sledgehammer blows give a mushroom top to a rod used as a tent stake.

17.53 (a) $f' = f\dfrac{v}{(v - v_{\text{diver}})}$

so $\quad 1 - \dfrac{v_{\text{diver}}}{v} = \dfrac{f}{f'}$

$$\Rightarrow v_{\text{diver}} = v\left(1 - \frac{f}{f'}\right)$$

with $v = 343$ m/s, $f' = 1800$ Hz and $f = 2150$ Hz

we find

$$v_{\text{diver}} = 343\left(1 - \frac{1800}{2150}\right) = \boxed{55.8\text{ m/s}}$$

(b) If the waves are reflected, and the skydiver is moving into them, we have

$$f'' = f'\frac{(v + v_{\text{diver}})}{v} \Rightarrow f'' = f\left[\frac{v}{(v - v_{\text{diver}})}\right]\frac{(v + v_{\text{diver}})}{v}$$

so $\quad f'' = 1800\dfrac{(343 + 55.8)}{(343 - 55.8)} = \boxed{2500\text{ Hz}}$

<u>Goal Solution</u>

G: Sky divers typically reach a terminal speed of about 150 mph (~75 m/s), so this sky diver should also fall near this rate. Since her friend receives a higher frequency as a result of the Doppler shift, the sky diver should detect a frequency with twice the Doppler shift: $f' = 1800\text{ Hz} + 2(2150 - 1800)\text{ Hz} = 2500\text{ Hz}$.

O: We can use the equation for the Doppler effect to answer both parts of this problem.

A: Call $f_e = 1800$ Hz the emitted frequency; v_e, the speed of the sky diver; and $f_g = 2150$ Hz, the frequency of the wave crests reaching the ground.

(a) The sky diver source is moving toward the stationary ground, so we use the equation

$$f_g = f_s\left(\frac{v}{v - v_s}\right)$$

and $$v_e = v\left(1 - \frac{f_e}{f_g}\right) = (343\text{ m/s})\left(1 - \frac{1800\text{ Hz}}{2150\text{ Hz}}\right) = 55.8\text{ m/s}$$

(b) The ground now becomes a stationary source, reflecting crests with the 2150-Hz frequency at which they reach the ground, and sending them to a moving observer:

$$f_{e2} = f_g\left(\frac{v + v_e}{v}\right) = 2150\left(\frac{343\text{ m/s} + 55.8\text{ m/s}}{343\text{ m/s}}\right) = 2500\text{ Hz}$$

L: The answers appear to be consistent with our predictions, although the sky diver is falling somewhat slower than expected. The Doppler effect can be used to find the speed of many different types of moving objects, like raindrops (Doppler radar) and cars (police radar).

17.54 (a) $f' = \dfrac{fv}{v - u}$ $\qquad f'' = \dfrac{fv}{v + u}$

$$f' - f'' = fv\left(\frac{1}{v - u} - \frac{1}{v + u}\right)$$

$$\Delta f = \frac{fv(v + u - v + u)}{v^2 - u^2} = \frac{2uvf}{v^2\left(1 - \dfrac{u^2}{v^2}\right)}$$

$$\Delta f = \boxed{\frac{2(u/v)}{1 - (u^2/v^2)}f}$$

(b) 130 km/h = 36.1 m/s

$$\therefore \Delta f = \frac{2(36.1)(400)}{340\left[1 - \dfrac{(36.1)^2}{340^2}\right]} = \boxed{85.9\text{ Hz}}$$

17.55 Use the Doppler formula, and remember that the bat is a moving source.

If the velocity of the insect is v_x,

$$40.4 = 40.0\frac{(340 + 5.00)(340 - v_x)}{(340 - 5.00)(340 + v_x)}$$

Solving,

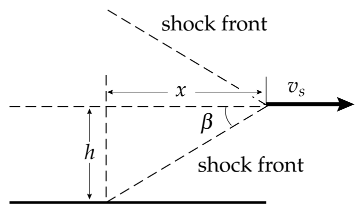
$$v_x = 3.31 \text{ m/s}$$

Therefore, $\boxed{\text{the bat is gaining on its prey at 1.69 m/s}}$

17.56 $\sin\beta = \frac{v}{v_S} = \frac{1}{N_M}$

$h = v(12.8 \text{ s})$

$x = v_S(10.0 \text{ s})$



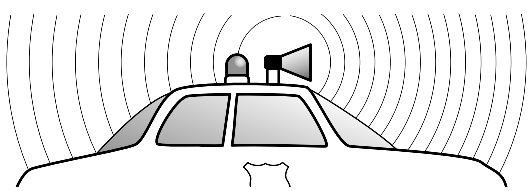
$\tan\beta = \frac{h}{x} = 1.28\frac{v}{v_S} = \frac{1.28}{N_M}$

$\cos\beta = \frac{\sin\beta}{\tan\beta} = \frac{1}{1.28}$

$\beta = 38.6°$

$N_M = \frac{1}{\sin\beta} = \boxed{1.60}$

***17.57** (a)



(b) $\lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{1000 \text{ s}^{-1}} = \boxed{0.343 \text{ m}}$

(c) $\lambda' = \frac{v}{f'} = \frac{v}{f}\left(\frac{v - v_S}{v}\right) = \frac{(343 - 40.0) \text{ m/s}}{1000 \text{ s}^{-1}} = \boxed{0.303 \text{ m}}$

(d) $\lambda'' = \frac{v}{f''} = = \frac{(343 + 40.0) \text{ m/s}}{1000 \text{ s}^{-1}} = \boxed{0.383 \text{ m}}$

(e) $f' = f\left(\frac{v - v_O}{v - v_S}\right) = (1000 \text{ Hz})\frac{(343 - 30.0) \text{ m/s}}{(343 - 40.0) \text{ m/s}} = \boxed{1.03 \text{ kHz}}$

17.58 $\Delta t = L\left(\frac{1}{v_{\text{air}}} - \frac{1}{v_{\text{cu}}}\right) = L\frac{v_{\text{cu}} - v_{\text{air}}}{v_{\text{air}}v_{\text{cu}}}$

$$L = \frac{v_{\text{air}}v_{\text{cu}}}{v_{\text{cu}} - v_{\text{air}}}\,\Delta t = \frac{(331\text{ m/s})(3.56\times 10^3\text{ m/s})}{(3560 - 331)\text{ m/s}}(6.40\times 10^{-3}\text{ s})$$

$$\boxed{L = 2.34\text{ m}}$$

17.59 (a) $120\text{ dB} = 10\text{ dB}\log\left[I/(10^{-12}\text{ W/m}^2)\right]$

$I = 1.00\text{ W/m}^2 = \wp/4\pi r^2$

$$r = \sqrt{\frac{\wp}{4\pi I}} = \sqrt{\frac{6.00\text{ W}}{4\pi(1.00\text{ W/m}^2)}} = \boxed{0.691\text{ m}}$$

We have assumed the speaker is an isotropic point source.

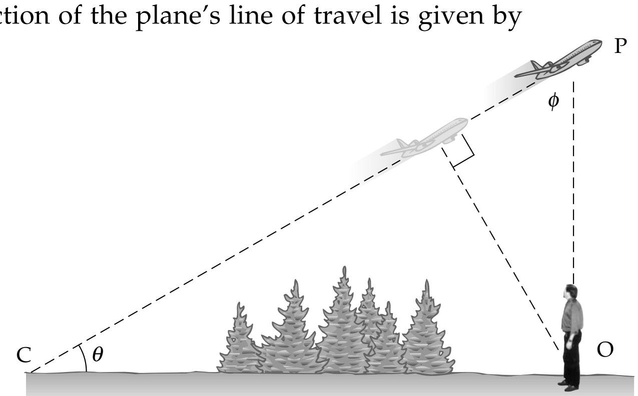
(b) $0\text{ dB} = 10\text{ dB}\log\left(I/10^{-12}\text{ W/m}^2\right)$

$I = 1.00\times 10^{-12}\text{ W/m}^2$

$$r = \sqrt{\frac{\wp}{4\pi I}} = \sqrt{\frac{6.00\text{ W}}{4\pi(1.00\times 10^{-12}\text{ W/m}^2)}} = \boxed{691\text{ km}}$$

We have assumed a uniform medium that absorbs no energy.

17.60 The shock wavefront connects all observers first hearing the plane, including our observer *O* and the plane *P*, so here it is vertical. The angle ϕ that the shock wavefront makes with the direction of the plane's line of travel is given by



$$\sin\phi = \frac{v}{v_S} = \frac{340\text{ m/s}}{1963\text{ m/s}} = 0.173$$

so $\phi = 9.97°$

Using the right triangle *CPO*, the angle θ is seen to be

$$\theta = 90.0° - \phi = 90.0° - 9.97° = \boxed{80.0°}$$

17.61 When observer is moving in front of and in the same direction as the source, $f' = f\frac{v - v_O}{v - v_S}$ where v_O and v_S are measured relative to the medium in which the sound is propagated. In this case the ocean current is opposite the direction of travel of the ships and

$$v_O = 45.0\text{ km/h} - (-10.0\text{ km/h}) = 55.0\text{ km/h} = 15.3\text{ m/s}, \quad \text{and}$$

$$v_S = 64.0\text{ km/h} - (-10.0\text{ km/h}) = 74.0\text{ km/h} = 20.55\text{ m/s}$$

Therefore, $f' = (1200.0\text{ Hz})\,\frac{1520\text{ m/s} - 15.3\text{ m/s}}{1520\text{ m/s} - 20.55\text{ m/s}} = \boxed{1204.2\text{ Hz}}$

17.62 We suppose the sound level is uniform over the outer surface of area

$$2(0.400\text{ m})(0.400\text{ m}) + 4(0.400\text{ m})(0.500\text{ m}) = 1.12\text{ m}^2$$

The intensity is given by

$$40.0\text{ dB} = 10\text{ dB}\log(I/10^{-12}\text{ W/m}^2)$$

$$I = 10^{-12+4}\text{ W/m}^2 = 10^{-8}\text{ W/m}^2$$

The sound power is

$$\wp = IA = 1.12 \times 10^{-8}\text{ W}$$

So the oven's energy efficiency as a sound source is

$$\wp / \wp_{\text{input}} = (1.12 \times 10^{-8}\text{ W})/(1.00 \times 10^3\text{ W}) = \boxed{1.12 \times 10^{-11}}$$

17.63 (a) $\theta = \sin^{-1}\left(\frac{v_{\text{sound}}}{v_{\text{obj}}}\right) = \sin^{-1}\left(\frac{331}{20.0 \times 10^3}\right) = \boxed{0.948^\circ}$

(b) $\theta' = \sin^{-1}\left(\frac{1533}{20.0 \times 10^3}\right) = \boxed{4.40^\circ}$

17.64 $\Delta P_{\text{max}} = \rho\omega v s_{\text{max}} = \rho\left(\frac{2\pi v}{\lambda}\right) v s_{\text{max}}$

Also, ΔP and s are 90° out of phase.

Therefore, $\Delta P = -\left(\frac{2\pi\rho v^2 s_{\text{max}}}{\lambda}\right)\cos(kx - \omega t)$

17.65 For the longitudinal wave $v_L = (Y/\rho)^{1/2}$

For the transverse wave $v_T = (T/\mu)^{1/2}$

If we require $\frac{v_L}{v_T} = 8.00$, we have $T = \frac{\mu Y}{64.0\rho}$ where $\mu = \frac{m}{L}$ and

$$\rho = \frac{\text{mass}}{\text{volume}} = \frac{m}{\pi r^2 L}$$

This gives $T = \frac{\pi r^2 Y}{64.0} = \frac{\pi(2.00 \times 10^{-3}\text{ m})^2(6.80 \times 10^{10}\text{ N/m}^2)}{64.0} = \boxed{1.34 \times 10^4\text{ N}}$

17.66 $\wp_2 = \frac{1}{20.0}\wp_1 \qquad \beta_1 - \beta_2 = 10\log\frac{\wp_1}{\wp_2}$

$80.0 - \beta_2 = 10\log 20.0 = +13.0$

$\beta_2 = \boxed{67.0\text{ dB}}$

17.67 $t = \frac{0.300 \times 10^3\text{ J}}{4\pi(500\text{ m})^2(10^{-12}\text{ W/m}^2)(10^6)} = \boxed{95.5\text{ s}}$

17.68 The total output sound energy is $eE = \wp t$, where $\wp$ is the power radiated.

Thus, $t = \frac{eE}{\wp} = \frac{eE}{IA} = \frac{eE}{(4\pi r^2)I}$

But, $\beta = 10\log\left(\frac{I}{I_0}\right)$. Therefore, $I = I_0(10^{\beta/10})$ and $t = \boxed{\frac{eE}{4\pi r^2 I_0(10^{\beta/10})}}$

17.69 (a) If the source and the observer are moving away from each other, we have: $\theta_S = \theta_O = 180°$, and since $\cos 180° = -1$, we get Equation 17.17 with the lower signs.

(b) If $v_O = 0$ m/s, then $f' = \frac{v}{v - v_S\cos\theta_S} f$

Also, when the train is 40.0 m from the intersection, and the car is 30.0 m from the intersection,

$\cos\theta_S = \frac{4}{5}$ so

$f' = \frac{343\text{ m/s}}{343\text{ m/s} - 0.800(25.0\text{ m/s})}(500\text{ Hz})$ or $f' = \boxed{531\text{ Hz}}$

Note that as the train approaches, passes, and departs from the intersection, θ_S varies from 0° to 180° and the frequency heard by the observer varies from:

$$f'_{max} = \frac{v}{v - v_S \cos 0°} f = \frac{343 \text{ m/s}}{343 \text{ m/s} - 25.0 \text{ m/s}} (500 \text{ Hz}) = 539 \text{ Hz}$$

$$f'_{min} = \frac{v}{v - v_S \cos 180°} f = \frac{343 \text{ m/s}}{343 \text{ m/s} + 25.0 \text{ m/s}} (500 \text{ Hz}) = 466 \text{ Hz}$$

***17.70** Let T represent the period of the source vibration, and E be the energy put into each wavefront. Then $\wp_{av} = E/T$. When the observer is at distance r in front of the source, he is receiving a spherical wavefront of radius vt, where t is the time since this energy was radiated, given by $vt - v_S t = r$. Then,

$$t = \frac{r}{v - v_S}$$

The area of the sphere is $4\pi(vt)^2 = \dfrac{4\pi v^2 r^2}{(v - v_S)^2}$. The energy per unit area over the spherical wavefront is uniform with the value $\dfrac{E}{A} = \dfrac{\wp_{av} T (v - v_S)^2}{4\pi v^2 r^2}$.

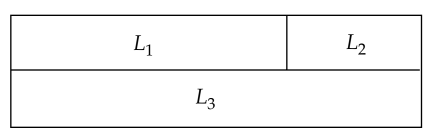
The observer receives parcels of energy with the Doppler shifted frequency $f' = f\left(\dfrac{v}{v - v_S}\right) = \dfrac{v}{T(v - v_S)}$, so the observer receives a wave with intensity

$$I = \left(\frac{E}{A}\right) f' = \left(\frac{\wp_{av} T (v - v_S)^2}{4\pi v^2 r^2}\right)\left(\frac{v}{T(v - v_S)}\right) = \boxed{\frac{\wp_{av}}{4\pi r^2}\left(\frac{v - v_S}{v}\right)}$$

17.71 (a) The time required for a sound pulse to travel distance L at speed v is given by $t = \dfrac{L}{v} = \dfrac{L}{\sqrt{Y/\rho}}$. Using this expression we find

$$t_1 = \frac{L_1}{\sqrt{Y_1/\rho_1}} = \frac{L_1}{\sqrt{(7.00 \times 10^{10} \text{ N/m}^2)/(2700 \text{ kg/m}^3)}} = (1.96 \times 10^{-4} L_1) \text{ s}$$

$$t_2 = \frac{1.50 \text{ m} - L_1}{\sqrt{Y_2/\rho_2}} = \frac{1.50 \text{ m} - L_1}{\sqrt{(1.60 \times 10^{10} \text{ N/m}^2)/(11.3 \times 10^3 \text{ kg/m}^3)}}$$



or $t_2 = (1.26 \times 10^{-3} - 8.40 \times 10^{-4} L_1) \text{ s}$

$$t_3 = \frac{1.50 \text{ m}}{\sqrt{(11.0 \times 10^{10} \text{ N/m}^3)/(8800 \text{ kg/m}^3)}}$$

$t_3 = 4.24 \times 10^{-4} \text{ s}$

We require $t_1 + t_2 = t_3$, or

$$1.96 \times 10^{-4} L_1 + 1.26 \times 10^{-3} - 8.40 \times 10^{-4} L_1 = 4.24 \times 10^{-4}$$

This gives $L_1 = 1.30$ m and $L_2 = 1.50 - 1.30 = 0.201$ m

The ratio of lengths is then $\dfrac{L_1}{L_2} = \boxed{6.45}$

(b) The ratio of lengths L_1/L_2 is adjusted in part (a) so that $t_1 + t_2 = t_3$. Sound travels the two paths in equal time and the phase difference, $\boxed{\Delta\phi = 0}$.

17.72 Let $\theta = \theta_0 \log R$, $I = kR$:

$$\beta = 10 \log\left(\frac{I}{I_0}\right) = 10 \log I - 10 \log I_0 = 10 \log kR - 10 \log I_0$$

or $$\beta = 10 \log R + 10(\log k - \log I_0) = 10\left(\frac{\theta}{\theta_0}\right) + 10(\log k - \log I_0)$$

$$\boxed{\beta = \left(\frac{10}{\theta_0}\right)\theta + 10 \log\left(\frac{k}{I_0}\right)} \leftarrow \text{the equation of a straight line. } [y = mx + b]$$

***17.73** To find the separation of adjacent molecules, use a model where each molecule occupies a sphere of radius r given by

$$\rho_{\text{air}} = \frac{\text{average mass per molecule}}{\frac{4}{3}\pi r^3}$$

or $$1.20 \text{ kg/m}^3 = \frac{4.82 \times 10^{-26} \text{ kg}}{\frac{4}{3}\pi r^3}, \quad r = \left[\frac{3(4.82 \times 10^{-26} \text{ kg})}{4\pi(1.20 \text{ kg/m}^3)}\right]^{1/3} = 2.12 \times 10^{-9} \text{ m}$$

Intermolecular separation is $2r = 4.25 \times 10^{-9}$ m, so the highest possible frequency sound wave is

$$f_{\max} = \frac{v}{\lambda_{\min}} = \frac{v}{2r} = \frac{343 \text{ m/s}}{4.25 \times 10^{-9} \text{ m}} = 8.03 \times 10^{10} \text{ Hz} \quad \boxed{\sim 10^{11} \text{ Hz}}$$