1. The time it takes for a soldier in the rear end of the column to switch from the left to the right foot to stride forward is t = 1 min/120 = 1/120 min = 0.50 s. This is also the time for the sound of the music to reach from the musicians (who are in the front) to the rear end of the column. Thus the length of the column is

$$l = vt = (343\,\text{m/s})(0.50\,\text{s}) = 1.7 \times 10^2\,\text{m}.$$

2. (a) When the speed is constant, we have $v = d/t$ where $v = 343$ m/s is assumed. Therefore, with $t = 15/2$ s being the time for sound to travel to the far wall we obtain $d = (343 \text{ m/s}) \times (15/2 \text{ s})$ which yields a distance of 2.6 km.

(b) Just as the $\frac{1}{2}$ factor in part (a) was $1/(n + 1)$ for $n = 1$ reflection, so also can we write

$$d = (343\,\text{m/s})\left(\frac{15\,\text{s}}{n+1}\right) \Rightarrow n = \frac{(343)(15)}{d} - 1$$

for multiple reflections (with d in meters). For $d = 25.7$ m, we find $n = 199 \approx 2.0\times10^2$.

3. (a) The time for the sound to travel from the kicker to a spectator is given by d/v, where d is the distance and v is the speed of sound. The time for light to travel the same distance is given by d/c, where c is the speed of light. The delay between seeing and hearing the kick is $\Delta t = (d/v) - (d/c)$. The speed of light is so much greater than the speed of sound that the delay can be approximated by $\Delta t = d/v$. This means $d = v\,\Delta t$. The distance from the kicker to spectator A is $d_A = v\,\Delta t_A = (343 \text{ m/s})(0.23 \text{ s}) = 79 \text{ m}$.

(b) The distance from the kicker to spectator B is $d_B = v\,\Delta t_B = (343 \text{ m/s})(0.12 \text{ s}) = 41 \text{ m}$.

(c) Lines from the kicker to each spectator and from one spectator to the other form a right triangle with the line joining the spectators as the hypotenuse, so the distance between the spectators is

$$D = \sqrt{d_A^2 + d_B^2} = \sqrt{(79\,\text{m})^2 + (41\,\text{m})^2} = 89\,\text{m}\,.$$

4. The density of oxygen gas is

$$\rho = \frac{0.0320\,\text{kg}}{0.0224\,\text{m}^3} = 1.43\,\text{kg/m}^3.$$

From $v = \sqrt{B/\rho}$ we find

$$B = v^2\rho = \left(317\,\text{m/s}\right)^2\left(1.43\,\text{kg/m}^3\right) = 1.44\times10^5\ \text{Pa}.$$

5. Let t_f be the time for the stone to fall to the water and t_s be the time for the sound of the splash to travel from the water to the top of the well. Then, the total time elapsed from dropping the stone to hearing the splash is $t = t_f + t_s$. If d is the depth of the well, then the kinematics of free fall gives $d = \frac{1}{2} g t_f^2$, or $t_f = \sqrt{2d/g}$. The sound travels at a constant speed v_s, so $d = v_s t_s$, or $t_s = d/v_s$. Thus the total time is $t = \sqrt{2d/g} + d/v_s$. This equation is to be solved for d. Rewrite it as $\sqrt{2d/g} = t - d/v_s$ and square both sides to obtain $2d/g = t^2 - 2(t/v_s)d + (1 + v_s^2)d^2$. Now multiply by $g v_s^2$ and rearrange to get

$$gd^2 - 2v_s(gt + v_s)d + g v_s^2 t^2 = 0.$$

This is a quadratic equation for d. Its solutions are

$$d = \frac{2v_s(gt + v_s) \pm \sqrt{4v_s^2(gt + v_s)^2 - 4g^2 v_s^2 t^2}}{2g}.$$

The physical solution must yield $d = 0$ for $t = 0$, so we take the solution with the negative sign in front of the square root. Once values are substituted the result $d = 40.7$ m is obtained.

6. Let ℓ be the length of the rod. Then the time of travel for sound in air (speed v_s) will be $t_s = \ell / v_s$. And the time of travel for compressional waves in the rod (speed v_r) will be $t_r = \ell / v_r$. In these terms, the problem tells us that

$$t_s - t_r = 0.12\,\text{s} = \ell\left(\frac{1}{v_s} - \frac{1}{v_r}\right).$$

Thus, with v_s = 343 m/s and $v_r = 15v_s$ = 5145 m/s, we find $\ell = 44\,\text{m}$.

7. If d is the distance from the location of the earthquake to the seismograph and v_s is the speed of the S waves then the time for these waves to reach the seismograph is $t_s. = d/v_s$. Similarly, the time for P waves to reach the seismograph is $t_p = d/v_p$. The time delay is

$$\Delta t = (d/v_s) - (d/v_p) = d(v_p - v_s)/v_s v_p,$$

so

$$d = \frac{v_s v_p \Delta t}{(v_p - v_s)} = \frac{(4.5\ \text{km/s})(8.0\,\text{km/s})(3.0\,\text{min})(60\,\text{s/min})}{8.0\,\text{km/s} - 4.5\,\text{km/s}} = 1.9 \times 10^3\ \text{km}.$$

We note that values for the speeds were substituted as given, in km/s, but that the value for the time delay was converted from minutes to seconds.

8. (a) The amplitude of a sinusoidal wave is the numerical coefficient of the sine (or cosine) function: p_m = 1.50 Pa.

(b) We identify $k = 0.9\pi$ and $\omega = 315\pi$ (in SI units), which leads to $f = \omega/2\pi$ = 158 Hz.

(c) We also obtain $\lambda = 2\pi/k$ = 2.22 m.

(d) The speed of the wave is $v = \omega/k$ = 350 m/s.

9. (a) Using $\lambda = v/f$, where v is the speed of sound in air and f is the frequency, we find

$$\lambda = \frac{343\,\text{m/s}}{4.50\times 10^{6}\ \text{Hz}} = 7.62\times 10^{-5}\ \text{m}.$$

(b) Now, $\lambda = v/f$, where v is the speed of sound in tissue. The frequency is the same for air and tissue. Thus

$$\lambda = (1500\ \text{m/s})/(4.50 \times 10^{6}\ \text{Hz}) = 3.33 \times 10^{-4}\ \text{m}.$$

10. Without loss of generality we take $x = 0$, and let $t = 0$ be when $s = 0$. This means the phase is $\phi = -\pi/2$ and the function is $s = (6.0 \text{ nm})\sin(\omega t)$ at $x = 0$. Noting that $\omega = 3000$ rad/s, we note that at $t = \sin^{-1}(1/3)/\omega = 0.1133$ ms the displacement is $s = +2.0$ nm. Doubling that time (so that we consider the excursion from –2.0 nm to +2.0 nm) we conclude that the time required is 2(0.1133 ms) = 0.23 ms.

11. (a) Consider a string of pulses returning to the stage. A pulse which came back just before the previous one has traveled an extra distance of $2w$, taking an extra amount of time $\Delta t = 2w/v$. The frequency of the pulse is therefore

$$f = \frac{1}{\Delta t} = \frac{v}{2w} = \frac{343\,\text{m/s}}{2(0.75\,\text{m})} = 2.3\times10^{2}\ \text{Hz}.$$

(b) Since $f \propto 1/w$, the frequency would be higher if w were smaller.

12. The problem says "At one instant.." and we choose that instant (without loss of generality) to be $t = 0$. Thus, the displacement of "air molecule A" at that instant is

$$s_A = +s_m = s_m\cos(kx_A - \omega t + \phi)|_{t=0} = s_m\cos(kx_A + \phi),$$

where $x_A = 2.00$ m. Regarding "air molecule B" we have

$$s_B = +\frac{1}{3}s_m = s_m\cos(kx_B - \omega t + \phi)|_{t=0} = s_m\cos(kx_B + \phi).$$

These statements lead to the following conditions:

$$kx_A + \phi = 0$$
$$kx_B + \phi = \cos^{-1}(1/3) = 1.231$$

where $x_B = 2.07$ m. Subtracting these equations leads to

$$k(x_B - x_A) = 1.231 \quad \Rightarrow \quad k = 17.6 \text{ rad/m}.$$

Using the fact that $k = 2\pi/\lambda$ we find $\lambda = 0.357$ m, which means

$$f = v/\lambda = 343/0.357 = 960 \text{ Hz}.$$

Another way to complete this problem (once k is found) is to use $kv = \omega$ and then the fact that $\omega = 2\pi f$.

13. (a) The period is $T = 2.0$ ms (or 0.0020 s) and the amplitude is $\Delta p_m = 8.0$ mPa (which is equivalent to 0.0080 N/m^2). From Eq. 17-15 we get

$$s_m = \frac{\Delta p_m}{v\rho\omega} = \frac{\Delta p_m}{v\rho(2\pi/T)} = 6.1 \times 10^{-9}\ \text{m}.$$

where $\rho = 1.21$ kg/m^3 and $v = 343$ m/s.

(b) The angular wave number is $k = \omega/v = 2\pi/vT = 9.2$ rad/m.

(c) The angular frequency is $\omega = 2\pi/T = 3142$ rad/s $\approx 3.1 \times 10^3$ rad/s.

The results may be summarized as $s(x, t) = (6.1\ \text{nm}) \cos[(9.2\ \text{m}^{-1})x - (3.1 \times 10^3\ \text{s}^{-1})t]$.

(d) Using similar reasoning, but with the new values for density ($\rho' = 1.35$ kg/m^3) and speed ($v' = 320$ m/s), we obtain

$$s_m = \frac{\Delta p_m}{v'\rho'\omega} = \frac{\Delta p_m}{v'\rho'(2\pi/T)} = 5.9 \times 10^{-9}\ \text{m}.$$

(e) The angular wave number is $k = \omega/v' = 2\pi/v'T = 9.8$ rad/m.

(f) The angular frequency is $\omega = 2\pi/T = 3142$ rad/s $\approx 3.1 \times 10^3$ rad/s.

The new displacement function is $s(x, t) = (5.9\ \text{nm}) \cos[(9.8\ \text{m}^{-1})x - (3.1 \times 10^3\ \text{s}^{-1})t]$.

14. Let the separation between the point and the two sources (labeled 1 and 2) be x_1 and x_2, respectively. Then the phase difference is

$$\Delta\phi = \phi_1 - \phi_2 = 2\pi\left(\frac{x_1}{\lambda} + ft\right) - 2\pi\left(\frac{x_2}{\lambda} + ft\right) = \frac{2\pi(x_1 - x_2)}{\lambda}$$

$$= \frac{2\pi(4.40\,\text{m} - 4.00\,\text{m})}{(330\,\text{m/s})/540\,\text{Hz}} = 4.12\,\text{rad}.$$

15. (a) The problem is asking at how many angles will there be "loud" resultant waves, and at how many will there be "quiet" ones? We note that at all points (at large distance from the origin) along the x axis there will be quiet ones; one way to see this is to note that the path-length difference (for the waves traveling from their respective sources) divided by wavelength gives the (dimensionless) value 3.5, implying a half-wavelength (180º) phase difference (destructive interference) between the waves. To distinguish the destructive interference along the $+x$ axis from the destructive interference along the $-x$ axis, we label one with +3.5 and the other –3.5. This labeling is useful in that it suggests that the complete enumeration of the quiet directions in the upper-half plane (including the x axis) is: –3.5, –2.5, –1.5, –0.5, +0.5, +1.5, +2.5, +3.5. Similarly, the complete enumeration of the loud directions in the upper-half plane is: –3, –2, –1, 0, +1, +2, +3. Counting also the "other" –3, –2, –1, 0, +1, +2, +3 values for the *lower*-half plane, then we conclude there are a total of 7 + 7 = 14 "loud" directions.

(b) The discussion about the "quiet" directions was started in part (a). The number of values in the list: –3.5, –2.5, –1.5, –0.5, +0.5, +1.5, +2.5, +3.5 along with –2.5, –1.5, –0.5, +0.5, +1.5, +2.5 (for the lower-half plane) is 14. There are 14 "quiet" directions.

16. At the location of the detector, the phase difference between the wave which traveled straight down the tube and the other one which took the semi-circular detour is

$$\Delta\phi = k\Delta d = \frac{2\pi}{\lambda}(\pi r - 2r).$$

For $r = r_{\min}$ we have $\Delta\phi = \pi$, which is the smallest phase difference for a destructive interference to occur. Thus

$$r_{\min} = \frac{\lambda}{2(\pi-2)} = \frac{40.0\,\text{cm}}{2(\pi-2)} = 17.5\,\text{cm}.$$

17. Let L_1 be the distance from the closer speaker to the listener. The distance from the other speaker to the listener is $L_2 = \sqrt{L_1^2 + d^2}$, where d is the distance between the speakers. The phase difference at the listener is $\phi = 2\pi(L_2 - L_1)/\lambda$, where λ is the wavelength.

For a minimum in intensity at the listener, $\phi = (2n + 1)\pi$, where n is an integer. Thus $\lambda = 2(L_2 - L_1)/(2n + 1)$. The frequency is

$$f = \frac{v}{\lambda} = \frac{(2n+1)v}{2\left(\sqrt{L_1^2 + d^2} - L_1\right)} = \frac{(2n+1)(343\,\text{m/s})}{2\left(\sqrt{(3.75\,\text{m})^2 + (2.00\,\text{m})^2} - 3.75\,\text{m}\right)} = (2n+1)(343\,\text{Hz}).$$

Now 20,000/343 = 58.3, so $2n + 1$ must range from 0 to 57 for the frequency to be in the audible range. This means n ranges from 0 to 28.

(a) The lowest frequency that gives minimum signal is (n = 0) $f_{\text{min},1} = 343$ Hz.

(b) The second lowest frequency is (n = 1) $f_{\text{min},2} = [2(1)+1]343\text{ Hz} = 1029\text{ Hz} = 3f_{\text{min},1}$. Thus, the factor is 3.

(c) The third lowest frequency is (n=2) $f_{\text{min},3} = [2(2)+1]343\text{ Hz} = 1715\text{ Hz} = 5f_{\text{min},1}$. Thus, the factor is 5.

For a maximum in intensity at the listener, $\phi = 2n\pi$, where n is any positive integer. Thus $\lambda = (1/n)\left(\sqrt{L_1^2 + d^2} - L_1\right)$ and

$$f = \frac{v}{\lambda} = \frac{nv}{\sqrt{L_1^2 + d^2} - L_1} = \frac{n(343\,\text{m/s})}{\sqrt{(3.75\,\text{m})^2 + (2.00\,\text{m})^2} - 3.75\,\text{m}} = n(686\,\text{Hz}).$$

Since 20,000/686 = 29.2, n must be in the range from 1 to 29 for the frequency to be audible.

(d) The lowest frequency that gives maximum signal is (n =1) $f_{\text{max},1} = 686$ Hz.

(e) The second lowest frequency is (n = 2) $f_{\text{max},2} = 2(686\text{ Hz}) = 1372\text{ Hz} = 2f_{\text{max},1}$. Thus, the factor is 2.

(f) The third lowest frequency is (n = 3) $f_{\text{max},3} = 3(686\text{ Hz}) = 2058\text{ Hz} = 3f_{\text{max},1}$. Thus, the factor is 3.

18. (a) The problem indicates that we should ignore the decrease in sound amplitude which means that all waves passing through point *P* have equal amplitude. Their superposition at *P* if $d = \lambda/4$ results in a net effect of zero there since there are four sources (so the first and third are $\lambda/2$ apart and thus interfere destructively; similarly for the second and fourth sources).

(b) Their superposition at *P* if $d = \lambda/2$ also results in a net effect of zero there since there are an even number of sources (so the first and second being $\lambda/2$ apart will interfere destructively; similarly for the waves from the third and fourth sources).

(c) If $d = \lambda$ then the waves from the first and second sources will arrive at *P* in phase; similar observations apply to the second and third, and to the third and fourth sources. Thus, four waves interfere constructively there with net amplitude equal to $4s_m$.

19. Building on the theory developed in §17 – 5, we set $\Delta L/\lambda = n - 1/2,\ n = 1, 2, \ldots$ in order to have destructive interference. Since $v = f\lambda$, we can write this in terms of frequency:

$$f_{\min,n} = \frac{(2n-1)v}{2\Delta L} = (n - 1/2)(286\ \text{Hz})$$

where we have used v = 343 m/s (note the remarks made in the textbook at the beginning of the exercises and problems section) and ΔL = (19.5 – 18.3) m = 1.2 m.

(a) The lowest frequency that gives destructive interference is (n = 1)

$$f_{\min,1} = (1 - 1/2)(286\ \text{Hz}) = 143\ \text{Hz}.$$

(b) The second lowest frequency that gives destructive interference is (n = 2)

$$f_{\min,2} = (2 - 1/2)(286\ \text{Hz}) = 429\ \text{Hz} = 3(143\ \text{Hz}) = 3 f_{\min,1}.$$

So the factor is 3.

(c) The third lowest frequency that gives destructive interference is (n = 3)

$$f_{\min,3} = (3 - 1/2)(286\ \text{Hz}) = 715\ \text{Hz} = 5(143\ \text{Hz}) = 5 f_{\min,1}.$$

So the factor is 5.

Now we set $\Delta L/\lambda = \frac{1}{2}$ (even numbers) — which can be written more simply as "(all integers n = 1, 2,…)" — in order to establish constructive interference. Thus,

$$f_{\max,n} = \frac{nv}{\Delta L} = n(286\ \text{Hz}).$$

(d) The lowest frequency that gives constructive interference is (n =1) $f_{\max,1} = (286\ \text{Hz})$.

(e) The second lowest frequency that gives constructive interference is (n = 2)

$$f_{\max,2} = 2(286\ \text{Hz}) = 572\ \text{Hz} = 2 f_{\max,1}.$$

Thus, the factor is 2.

(f) The third lowest frequency that gives constructive interference is (n = 3)

$$f_{\text{max},3} = 3(286\text{ Hz}) = 858\text{ Hz} = 3f_{\text{max},1}.$$

Thus, the factor is 3.

20. (a) If point P is infinitely far away, then the small distance d between the two sources is of no consequence (they seem effectively to be the same distance away from P). Thus, there is no perceived phase difference.

(b) Since the sources oscillate in phase, then the situation described in part (a) produces constructive interference.

(c) For finite values of x, the difference in source positions becomes significant. The path lengths for waves to travel from S_1 and S_2 become now different. We interpret the question as asking for the behavior of the absolute value of the phase difference $|\Delta\phi|$, in which case any change from zero (the answer for part (a)) is certainly an increase.

The path length difference for waves traveling from S_1 and S_2 is

$$\Delta\ell = \sqrt{d^2 + x^2} - x \qquad \text{for} \quad x > 0.$$

The phase difference in "cycles" (in absolute value) is therefore

$$|\Delta\phi| = \frac{\Delta\ell}{\lambda} = \frac{\sqrt{d^2 + x^2} - x}{\lambda}.$$

Thus, in terms of λ, the phase difference is identical to the path length difference: $|\Delta\phi| = \Delta\ell > 0$. Consider $\Delta\ell = \lambda/2$. Then $\sqrt{d^2 + x^2} = x + \lambda/2$. Squaring both sides, rearranging, and solving, we find

$$x = \frac{d^2}{\lambda} - \frac{\lambda}{4}.$$

In general, if $\Delta\ell = \xi\lambda$ for some multiplier $\xi > 0$, we find

$$x = \frac{d^2}{2\xi\lambda} - \frac{1}{2}\xi\lambda = \frac{64.0}{\xi} - \xi$$

where we have used $d = 16.0$ m and $\lambda = 2.00$ m.

(d) For $\Delta\ell = 0.50\lambda$, or $\xi = 0.50$, we have $x = (64.0/0.50 - 0.50)\text{ m} = 127.5\text{ m} \approx 128\text{ m}$.

(e) For $\Delta\ell = 1.00\lambda$, or $\xi = 1.00$, we have $x = (64.0/1.00 - 1.00)\text{ m} = 63.0\text{ m}$.

(f) For $\Delta\ell = 1.50\lambda$, or $\xi = 1.50$, we have $x = (64.0/1.50 - 1.50)\text{ m} = 41.2\text{ m}$.

Note that since whole cycle phase differences are equivalent (as far as the wave superposition goes) to zero phase difference, then the $\xi = 1, 2$ cases give constructive interference. A shift of a half-cycle brings "troughs" of one wave in superposition with "crests" of the other, thereby canceling the waves; therefore, the $\xi = \frac{1}{2}, \frac{3}{2}, \frac{5}{2}$ cases produce destructive interference.

21. The intensity is the rate of energy flow per unit area perpendicular to the flow. The rate at which energy flow across every sphere centered at the source is the same, regardless of the sphere radius, and is the same as the power output of the source. If P is the power output and I is the intensity a distance r from the source, then $P = IA = 4\pi r^2 I$, where A $(= 4\pi r^2)$ is the surface area of a sphere of radius r. Thus

$$P = 4\pi(2.50\text{ m})^2\,(1.91 \times 10^{-4}\text{ W/m}^2) = 1.50 \times 10^{-2}\text{ W}.$$

22. (a) Since intensity is power divided by area, and for an isotropic source the area may be written $A = 4\pi r^2$ (the area of a sphere), then we have

$$I = \frac{P}{A} = \frac{1.0\,\text{W}}{4\pi(1.0\,\text{m})^2} = 0.080\,\text{W/m}^2.$$

(b) This calculation may be done exactly as shown in part (a) (but with $r = 2.5$ m instead of $r = 1.0$ m), or it may be done by setting up a ratio. We illustrate the latter approach. Thus,

$$\frac{I'}{I} = \frac{P/4\pi(r')^2}{P/4\pi r^2} = \left(\frac{r}{r'}\right)^2$$

leads to $I' = (0.080\ \text{W/m}^2)(1.0/2.5)^2 = 0.013\ \text{W/m}^2$.

23. The intensity is given by $I = \frac{1}{2}\rho v \omega^2 s_m^2$, where ρ is the density of air, v is the speed of sound in air, ω is the angular frequency, and s_m is the displacement amplitude for the sound wave. Replace ω with $2\pi f$ and solve for s_m:

$$s_m = \sqrt{\frac{I}{2\pi^2 \rho v f^2}} = \sqrt{\frac{1.00\times10^{-6}\ \text{W/m}^2}{2\pi^2 (1.21\,\text{kg/m}^3)(343\,\text{m/s})(300\,\text{Hz})^2}} = 3.68\times10^{-8}\ \text{m}.$$

24. Sample Problem 17-5 shows that a decibel difference $\Delta\beta$ is directly related to an intensity ratio (which we write as $R = I'/I$). Thus,

$$\Delta\beta = 10\log(R) \Rightarrow R = 10^{\Delta\beta/10} = 10^{0.1} = 1.26.$$

25. (a) Let I_1 be the original intensity and I_2 be the final intensity. The original sound level is β_1 = (10 dB) log(I_1/I_0) and the final sound level is β_2 = (10 dB) log(I_2/I_0), where I_0 is the reference intensity. Since $\beta_2 = \beta_1$ + 30 dB which yields

$$(10\text{ dB})\log(I_2/I_0) = (10\text{ dB})\log(I_1/I_0) + 30\text{ dB},$$

or

$$(10\text{ dB})\log(I_2/I_0) - (10\text{ dB})\log(I_1/I_0) = 30\text{ dB}.$$

Divide by 10 dB and use $\log(I_2/I_0) - \log(I_1/I_0) = \log(I_2/I_1)$ to obtain $\log(I_2/I_1) = 3$. Now use each side as an exponent of 10 and recognize that $10^{\log(I_2/I_1)} = I_2/I_1$. The result is $I_2/I_1 = 10^3$. The intensity is increased by a factor of 1.0×10^3.

(b) The pressure amplitude is proportional to the square root of the intensity so it is increased by a factor of $\sqrt{1000} = 32$.

26. (a) The intensity is given by $I = P/4\pi r^2$ when the source is "point-like." Therefore, at r = 3.00 m,

$$I = \frac{1.00\times10^{-6}\ \text{W}}{4\pi(3.00\,\text{m})^2} = 8.84\times10^{-9}\ \text{W/m}^2.$$

(b) The sound level there is

$$\beta = 10\log\left(\frac{8.84\times10^{-9}\ \text{W/m}^2}{1.00\times10^{-12}\ \text{W/m}^2}\right) = 39.5\,\text{dB}.$$

27. (a) Eq. 17-29 gives the relation between sound level β and intensity I, namely

$$I = I_0 10^{(\beta/10\text{dB})} = (10^{-12}\ \text{W/m}^2)10^{(\beta/10\text{dB})} = 10^{-12+(\beta/10\text{dB})}\ \text{W/m}^2$$

Thus we find that for a $\beta = 70$ dB level we have a high intensity value of $I_{\text{high}} = 10\ \mu\text{W/m}^2$.

(b) Similarly, for $\beta = 50$ dB level we have a low intensity value of $I_{\text{low}} = 0.10\ \mu\text{W/m}^2$.

(c) Eq. 17-27 gives the relation between the displacement amplitude and I. Using the values for density and wave speed, we find $s_m = 70$ nm for the high intensity case.

(d) Similarly, for the low intensity case we have $s_m = 7.0$ nm.

We note that although the intensities differed by a factor of 100, the amplitudes differed by only a factor of 10.

28. (a) Since $\omega = 2\pi f$, Eq. 17-15 leads to

$$\Delta p_m = v\rho(2\pi f)s_m \quad \Rightarrow \quad s_m = \frac{1.13\times10^{-3}\text{ Pa}}{2\pi(1665\text{ Hz})(343\text{ m/s})(1.21\text{ kg/m}^3)}$$

which yields s_m = 0.26 nm. The nano prefix represents 10^{-9}. We use the speed of sound and air density values given at the beginning of the exercises and problems section in the textbook.

(b) We can plug into Eq. 17–27 or into its equivalent form, rewritten in terms of the pressure amplitude:

$$I = \frac{1}{2}\frac{(\Delta p_m)^2}{\rho v} = \frac{1}{2}\frac{(1.13\times10^{-3}\text{ Pa})^2}{(1.21\text{kg/m}^3)(343\text{ m/s})} = 1.5\ \text{ nW/m}^2.$$

29. Combining Eqs.17-28 and 17-29 we have $\beta = 10\log\left(\frac{P}{I_o 4\pi r^2}\right)$. Taking differences (for sounds *A* and *B*) we find

$$\Delta\beta = 10\log\left(\frac{P_A}{I_o 4\pi r^2}\right) - 10\log\left(\frac{P_B}{I_o 4\pi r^2}\right) = 10\log\left(\frac{P_A}{P_B}\right)$$

using well-known properties of logarithms. Thus, we see that $\Delta\beta$ is independent of *r* and can be evaluated anywhere.

(a) At $r = 1000$ m it is easily seen (in the graph) that $\Delta\beta = 5.0$ dB. This is the same $\Delta\beta$ we expect to find, then, at $r = 10$ m.

(b) We can also solve the above relation (once we know $\Delta\beta = 5.0$) for the ratio of powers; we find $P_A/P_B \approx 3.2$.

30. (a) The intensity is

$$I = \frac{P}{4\pi r^2} = \frac{30.0\,\text{W}}{(4\pi)(200\,\text{m})^2} = 5.97\times10^{-5}\ \text{W/m}^2.$$

(b) Let A (= 0.750 cm^2) be the cross-sectional area of the microphone. Then the power intercepted by the microphone is

$$P' = IA = 0 = (6.0\times10^{-5}\ \text{W/m}^2)(0.750\,\text{cm}^2)(10^{-4}\ \text{m}^2/\text{cm}^2) = 4.48\times10^{-9}\ \text{W}.$$

31. (a) As discussed on page 408, the average potential energy transport rate is the same as that of the kinetic energy. This implies that the (average) rate for the total energy is

$$\left(\frac{dE}{dt}\right)_{\text{avg}} = 2\left(\frac{dK}{dt}\right)_{\text{avg}} = 2\,(\tfrac{1}{4}\,\rho A\, v\, \omega^2\, s_m{}^2)$$

using Eq. 17-44. In this equation, we substitute (with SI units understood) $\rho = 1.21$, $A = \pi r^2 = \pi(0.02)^2$, $v = 343$, $\omega = 3000$, $s_m = 12 \times 10^{-9}$, and obtain the answer 3.4×10^{-10} W.

(b) The second string is in a separate tube, so there is no question about the waves superposing. The total rate of energy, then, is just the addition of the two: $2(3.4 \times 10^{-10}$ W$) = 6.8 \times 10^{-10}$ W.

(c) Now we *do* have superposition, with $\phi = 0$, so the resultant amplitude is twice that of the individual wave which leads to the energy transport rate being four times that of part (a). We obtain $4(3.4 \times 10^{-10}$ W$) = 1.4 \times 10^{-9}$ W.

(d) In this case $\phi = 0.4\pi$, which means (using Eq. 17-39) $s_m{}' = 2\, s_m \cos(\phi/2) = 1.618 s_m$. This means the energy transport rate is $(1.618)^2 = 2.618$ times that of part (a). We obtain $2.618(3.4 \times 10^{-10}$ W$) = 8.8 \times 10^{-10}$ W.

(e) The situation is as shown in Fig. 17-14(b). The answer is zero.

32. (a) Using Eq. 17–39 with v = 343 m/s and n = 1, we find $f = nv/2L$ = 86 Hz for the fundamental frequency in a nasal passage of length L = 2.0 m (subject to various assumptions about the nature of the passage as a "bent tube open at both ends").

(b) The sound would be perceptible as *sound* (as opposed to just a general vibration) of very low frequency.

(c) Smaller L implies larger f by the formula cited above. Thus, the female's sound is of higher pitch (frequency).

33. (a) We note that 1.2 = 6/5. This suggests that both even and odd harmonics are present, which means the pipe is open at both ends (see Eq. 17-39).

(b) Here we observe 1.4 = 7/5. This suggests that only odd harmonics are present, which means the pipe is open at only one end (see Eq. 17-41).

34. The distance between nodes referred to in the problem means that $\lambda/2 = 3.8$ cm, or $\lambda = 0.076$ m. Therefore, the frequency is

$$f = v/\lambda = 1500/0.076 \approx 20 \times 10^3 \text{ Hz}.$$

35. (a) From Eq. 17–53, we have

$$f = \frac{nv}{2L} = \frac{(1)(250\,\text{m/s})}{2(0.150\,\text{m})} = 833\,\text{Hz}.$$

(b) The frequency of the wave on the string is the same as the frequency of the sound wave it produces during its vibration. Consequently, the wavelength in air is

$$\lambda = \frac{v_{\text{sound}}}{f} = \frac{348\,\text{m/s}}{833\,\text{Hz}} = 0.418\,\text{m}.$$

36. At the beginning of the exercises and problems section in the textbook, we are told to assume v_{sound} = 343 m/s unless told otherwise. The second harmonic of pipe *A* is found from Eq. 17–39 with n = 2 and $L = L_A$, and the third harmonic of pipe *B* is found from Eq. 17–41 with n = 3 and $L = L_B$. Since these frequencies are equal, we have

$$\frac{2v_{\text{sound}}}{2L_A} = \frac{3v_{\text{sound}}}{4L_B} \Rightarrow L_B = \frac{3}{4}L_A.$$

(a) Since the fundamental frequency for pipe *A* is 300 Hz, we immediately know that the second harmonic has f = 2(300) = 600 Hz. Using this, Eq. 17–39 gives

$$L_A = (2)(343)/2(600) = 0.572 \text{ m}.$$

(b) The length of pipe *B* is $L_B = \frac{3}{4}L_A = 0.429\,\text{m}$.

37. (a) When the string (fixed at both ends) is vibrating at its lowest resonant frequency, exactly one-half of a wavelength fits between the ends. Thus, $\lambda = 2L$. We obtain

$$v = f\lambda = 2Lf = 2(0.220 \text{ m})(920 \text{ Hz}) = 405 \text{ m/s}.$$

(b) The wave speed is given by $v = \sqrt{\tau/\mu}$, where τ is the tension in the string and μ is the linear mass density of the string. If M is the mass of the (uniform) string, then $\mu = M/L$. Thus

$$\tau = \mu v^2 = (M/L)v^2 = [(800 \times 10^{-6} \text{ kg})/(0.220 \text{ m})]\,(405 \text{ m/s})^2 = 596 \text{ N}.$$

(c) The wavelength is $\lambda = 2L = 2(0.220 \text{ m}) = 0.440$ m.

(d) The frequency of the sound wave in air is the same as the frequency of oscillation of the string. The wavelength is different because the wave speed is different. If v_a is the speed of sound in air the wavelength in air is $\lambda_a = v_a/f = (343 \text{ m/s})/(920 \text{ Hz}) = 0.373$ m.

38. The frequency is f = 686 Hz and the speed of sound is v_{sound} = 343 m/s. If L is the length of the air-column, then using Eq. 17–41, the water height is (in unit of meters)

$$h = 1.00 - L = 1.00 - \frac{nv}{4f} = 1.00 - \frac{n(343)}{4(686)} = (1.00 - 0.125n) \text{ m}$$

where n = 1, 3, 5,… with only one end closed.

(a) There are 4 values of n (n = 1,3,5,7) which satisfies $h > 0$.

(b) The smallest water height for resonance to occur corresponds to n = 7 with $h = 0.125$ m.

(c) The second smallest water height corresponds to n = 5 with h = 0.375 m.

39. (a) Since the pipe is open at both ends there are displacement antinodes at both ends and an integer number of half-wavelengths fit into the length of the pipe. If L is the pipe length and λ is the wavelength then $\lambda = 2L/n$, where n is an integer. If v is the speed of sound then the resonant frequencies are given by $f = v/\lambda = nv/2L$. Now $L = 0.457$ m, so

$$f = n(344 \text{ m/s})/2(0.457 \text{ m}) = 376.4n \text{ Hz}.$$

To find the resonant frequencies that lie between 1000 Hz and 2000 Hz, first set $f = 1000$ Hz and solve for n, then set $f = 2000$ Hz and again solve for n. The results are 2.66 and 5.32, which imply that $n = 3$, 4, and 5 are the appropriate values of n. Thus, there are 3 frequencies.

(b) The lowest frequency at which resonance occurs is ($n = 3$) $f = 3(376.4 \text{ Hz}) = 1129$ Hz.

(c) The second lowest frequency at which resonance occurs is ($n = 4$)

$$f = 4(376.4 \text{ Hz}) = 1506 \text{ Hz}.$$

40. (a) Since the difference between consecutive harmonics is equal to the fundamental frequency (see section 17-6) then $f_1 = (390 - 325)$ Hz = 65 Hz. The next harmonic after 195 Hz is therefore (195 + 65) Hz = 260 Hz.

(b) Since $f_n = nf_1$ then $n = 260/65 = 4$.

(c) Only *odd* harmonics are present in tube B so the difference between consecutive harmonics is equal to *twice* the fundamental frequency in this case (consider taking differences of Eq. 17-41 for various values of n). Therefore,

$$f_1 = \frac{1}{2}(1320 - 1080) \text{ Hz} = 120 \text{ Hz}.$$

The next harmonic after 600 Hz is consequently [600 + 2(120)] Hz = 840 Hz.

(d) Since $f_n = nf_1$ (for n odd) then $n = 840/120 = 7$.

41. The top of the water is a displacement node and the top of the well is a displacement anti-node. At the lowest resonant frequency exactly one-fourth of a wavelength fits into the depth of the well. If d is the depth and λ is the wavelength then $\lambda = 4d$. The frequency is $f = v/\lambda = v/4d$, where v is the speed of sound. The speed of sound is given by $v = \sqrt{B/\rho}$, where B is the bulk modulus and ρ is the density of air in the well. Thus $f = (1/4d)\sqrt{B/\rho}$ and

$$d = \frac{1}{4f}\sqrt{\frac{B}{\rho}} = \frac{1}{4(7.00\,\text{Hz})}\sqrt{\frac{1.33\times10^5\,\text{Pa}}{1.10\,\text{kg/m}^3}} = 12.4\,\text{m}.$$

42. (a) Using Eq. 17–39 with $n = 1$ (for the fundamental mode of vibration) and 343 m/s for the speed of sound, we obtain

$$f = \frac{(1)v_{\text{sound}}}{4L_{\text{tube}}} = \frac{343\,\text{m/s}}{4(1.20\,\text{m})} = 71.5\,\text{Hz}.$$

(b) For the wire (using Eq. 17–53) we have

$$f' = \frac{nv_{\text{wire}}}{2L_{\text{wire}}} = \frac{1}{2L_{\text{wire}}}\sqrt{\frac{\tau}{\mu}}$$

where $\mu = m_{\text{wire}}/L_{\text{wire}}$. Recognizing that $f = f'$ (both the wire and the air in the tube vibrate at the same frequency), we solve this for the tension τ:

$$\tau = (2L_{\text{wire}}\,f)^2\left(\frac{m_{\text{wire}}}{L_{\text{wire}}}\right) = 4f^2 m_{\text{wire}} L_{\text{wire}} = 4(71.5\,\text{Hz})^2(9.60\times10^{-3}\,\text{kg})(0.330\,\text{m}) = 64.8\,\text{N}.$$

43. The string is fixed at both ends so the resonant wavelengths are given by $\lambda = 2L/n$, where L is the length of the string and n is an integer. The resonant frequencies are given by $f = v/\lambda = nv/2L$, where v is the wave speed on the string. Now $v = \sqrt{\tau/\mu}$, where τ is the tension in the string and μ is the linear mass density of the string. Thus $f = (n/2L)\sqrt{\tau/\mu}$. Suppose the lower frequency is associated with $n = n_1$ and the higher frequency is associated with $n = n_1 + 1$. There are no resonant frequencies between so you know that the integers associated with the given frequencies differ by 1. Thus $f_1 = (n_1/2L)\sqrt{\tau/\mu}$ and

$$f_2 = \frac{n_1+1}{2L}\sqrt{\frac{\tau}{\mu}} = \frac{n_1}{2L}\sqrt{\frac{\tau}{\mu}} + \frac{1}{2L}\sqrt{\frac{\tau}{\mu}} = f_1 + \frac{1}{2L}\sqrt{\frac{\tau}{\mu}}.$$

This means $f_2 - f_1 = (1/2L)\sqrt{\tau/\mu}$ and

$$\tau = 4L^2\mu(f_2 - f_1)^2 = 4(0.300\,\text{m})^2(0.650\times10^{-3}\,\text{kg/m})(1320\,\text{Hz} - 880\,\text{Hz})^2 = 45.3\,\text{N}.$$

44. We observe that "third lowest … frequency" corresponds to harmonic number $n = 3$ for a pipe open at both ends. Also, "second lowest … frequency" corresponds to harmonic number $n = 3$ for a pipe closed at one end.

(a) Since $\lambda = 2L/n$ for pipe A, where $L = 1.2$ m, then $\lambda = 0.80$ m for this mode. The change from node to anti-node requires a distance of $\lambda/4$ so that every increment of 0.20 m along the x axis involves a switch between node and anti-node. Since the opening is a displacement anti-node, then the locations for displacement nodes are at $x = 0.20$ m, $x = 0.60$ m, and $x = 1.0$ m. So there are 3 nodes.

(b) The smallest value of x where a node is present is $x = 0.20$m.

(c) The second smallest value of x where a node is present is $x = 0.60$m.

(d) The waves in both pipes have the same wave speed (sound in air) and frequency, so the standing waves in both pipes have the same wavelength (0.80 m). Therefore, using Eq. 17–38 for pipe B, we find $L = 3\lambda/4 = 0.60$ m.

(e) Using $v = 343$ m/s, we find $f_3 = v/\lambda = 429$ Hz. Now, we find the fundamental resonant frequency by dividing by the harmonic number, $f_1 = f_3/3 = 143$ Hz.

45. Since the beat frequency equals the difference between the frequencies of the two tuning forks, the frequency of the first fork is either 381 Hz or 387 Hz. When mass is added to this fork its frequency decreases (recall, for example, that the frequency of a mass-spring oscillator is proportional to $1/\sqrt{m}$). Since the beat frequency also decreases the frequency of the first fork must be greater than the frequency of the second. It must be 387 Hz.

46. Let the period be T. Then the beat frequency is $1/T - 440\,\text{Hz} = 4.00\,\text{beats/s}.$ Therefore, $T = 2.25 \times 10^{-3}$ s. The string that is “too tightly stretched” has the higher tension and thus the higher (fundamental) frequency.

47. Each wire is vibrating in its fundamental mode so the wavelength is twice the length of the wire ($\lambda = 2L$) and the frequency is $f = v/\lambda = (1/2L)\sqrt{\tau/\mu}$, where $v\left(=\sqrt{\tau/\mu}\right)$ is the wave speed for the wire, τ is the tension in the wire, and μ is the linear mass density of the wire. Suppose the tension in one wire is τ and the oscillation frequency of that wire is f_1. The tension in the other wire is $\tau + \Delta\tau$ and its frequency is f_2. You want to calculate $\Delta\tau/\tau$ for f_1 = 600 Hz and f_2 = 606 Hz. Now, $f_1 = (1/2L)\sqrt{\tau/\mu}$ and $f_2 = (1/2L)\sqrt{(\tau + \Delta\tau/\mu}$, so

$$f_2/f_1 = \sqrt{(\tau + \Delta\tau)/\tau} = \sqrt{1 + (\Delta\tau/\tau)}.$$

This leads to $\Delta\tau/\tau = (f_2/f_1)^2 - 1 = [(606\,\text{Hz})/(600\,\text{Hz})]^2 - 1 = 0.020.$

48. (a) The number of different ways of picking up a pair of tuning forks out of a set of five is 5!/(2!3!) = 10. For each of the pairs selected, there will be one beat frequency. If these frequencies are all different from each other, we get the maximum possible number of 10.

(b) First, we note that the minimum number occurs when the frequencies of these forks, labeled 1 through 5, increase in equal increments: $f_n = f_1 + n\Delta f$, where n = 2, 3, 4, 5. Now, there are only 4 different beat frequencies: $f_{\text{beat}} = n\Delta f$, where n = 1, 2, 3, 4.

49. We use $v_S = r\omega$ (with r = 0.600 m and ω = 15.0 rad/s) for the linear speed during circular motion, and Eq. 17–47 for the Doppler effect (where f = 540 Hz, and v = 343 m/s for the speed of sound).

(a) The lowest frequency is

$$f' = f\left(\frac{v+0}{v+v_S}\right) = 526 \text{ Hz}.$$

(b) The highest frequency is

$$f' = f\left(\frac{v+0}{v-v_S}\right) = 555 \text{ Hz}.$$

50. The Doppler effect formula, Eq. 17–47, and its accompanying rule for choosing ± signs, are discussed in §17-10. Using that notation, we have v = 343 m/s,

$$v_D = v_S = 160000/3600 = 44.4 \text{ m/s},$$

and f = 500 Hz. Thus,

$$f' = (500 \text{ Hz})\left(\frac{343 - 44.4}{343 - 44.4}\right) = 500\,\text{Hz} \;\Rightarrow\; \Delta f = 0.$$

51. The Doppler effect formula, Eq. 17–47, and its accompanying rule for choosing ± signs, are discussed in §17-10. Using that notation, we have v = 343 m/s, v_D = 2.44 m/s, f' = 1590 Hz and f = 1600 Hz. Thus,

$$f' = f\left(\frac{v + v_D}{v + v_S}\right) \Rightarrow v_S = \frac{f}{f'}\,(v + v_D) - v = 4.61\,\text{m/s}.$$

52. We are combining two effects: the reception of a moving object (the truck of speed u = 45.0 m/s) of waves emitted by a stationary object (the motion detector), and the subsequent emission of those waves by the moving object (the truck) which are picked up by the stationary detector. This could be figured in two steps, but is more compactly computed in one step as shown here:

$$f_{\text{final}} = f_{\text{initial}}\left(\frac{v+u}{v-u}\right) = (0.150\,\text{MHz})\left(\frac{343\,\text{m/s} + 45\,\text{m/s}}{343\,\text{m/s} - 45\,\text{m/s}}\right) = 0.195\,\text{MHz}.$$

53. In this case, the intruder is moving *away* from the source with a speed u satisfying $u/v \ll 1$. The Doppler shift (with $u = -0.950$ m/s) leads to

$$f_{\text{beat}} = \left| f_r - f_s \right| \approx \frac{2|u|}{v} f_s = \frac{2(0.95\,\text{m/s})(28.0\text{ kHz})}{343\,\text{m/s}}) = 155\,\text{Hz}\,.$$

54. We denote the speed of the French submarine by u_1 and that of the U.S. sub by u_2.

(a) The frequency as detected by the U.S. sub is

$$f_1' = f_1 \left(\frac{v+u_2}{v-u_1}\right) = (1000\,\text{Hz}) \left(\frac{5470 + 70}{5470 - 50}\right) = 1.02 \times 10^3\ \text{Hz}.$$

(b) If the French sub were stationary, the frequency of the reflected wave would be $f_r = f_1(v+u_2)/(v - u_2)$. Since the French sub is moving towards the reflected signal with speed u_1, then

$$f_r' = f_r\left(\frac{v+u_1}{v}\right) = f_1\frac{(v+u_1)(v+u_2)}{v(v-u_2)} = \frac{(1000\,\text{Hz})(5470+50)(5470+70)}{(5470)(5470-70)}$$
$$= 1.04\times 10^3\ \text{Hz}.$$

55. We use Eq. 17–47 with f = 1200 Hz and v = 329 m/s.

(a) In this case, v_D = 65.8 m/s and v_S = 29.9 m/s, and we choose signs so that f' is larger than f:

$$f' = f\left(\frac{329+65.8}{329-29.9}\right) = 1.58\times10^3\ \text{Hz}.$$

(b) The wavelength is $\lambda = v/f'$ = 0.208 m.

(c) The wave (of frequency f') "emitted" by the moving reflector (now treated as a "source," so v_S = 65.8 m/s) is returned to the detector (now treated as a detector, so v_D = 29.9 m/s) and registered as a new frequency f'':

$$f'' = f'\left(\frac{329+29.9}{329-65.8}\right) = 2.16\times10^3\ \text{Hz}.$$

(d) This has wavelength v/f'' = 0.152 m.

56. When the detector is stationary (with respect to the air) then Eq. 17-47 gives

$$f' = f\frac{1}{1 - v_s/v}$$

where v_s is the speed of the source (assumed to be approaching the detector in the way we've written it, above). The difference between the approach and the recession is

$$f' - f'' = f\left(\frac{1}{1 - v_s/v} - \frac{1}{1 + v_s/v}\right) = f\left(\frac{2\, v_s/v}{1 - (v_s/v)^2}\right)$$

which, after setting $(f' - f'')/f = 1/2$, leads to an equation which can be solved for the ratio v_s/v. The result is $\sqrt{5} - 2 = 0.236$. Thus, $v_s/v = 0.236$.

57. As a result of the Doppler effect, the frequency of the reflected sound as heard by the bat is

$$f_r = f'\left(\frac{v+u_{\text{bat}}}{v-u_{\text{bat}}}\right) = (3.9\times10^4 \text{ Hz})\left(\frac{v+v/40}{v-v/40}\right) = 4.1\times10^4 \text{ Hz}.$$

58. The "third harmonic" refers to a resonant frequency $f_3 = 3\ f_1$, where f_1 is the fundamental lowest resonant frequency. When the source is stationary, with respect to the air, then Eq. 17-47 gives

$$f' = f\left(1 - \frac{v_d}{v}\right)$$

where v_d is the speed of the detector (assumed to be moving away from the source, in the way we've written it, above). The problem, then, wants us to find v_d such that $f' = f_1$ when the emitted frequency is $f = f_3$. That is, we require $1 - v_d/v = 1/3$. Clearly, the solution to this is $v_d/v = 2/3$ (independent of length and whether one or both ends are open [the latter point being due to the fact that the odd harmonics occur in both systems]). Thus,

(a) For tube 1, $v_d = 2v/3$.

(b) For tube 2, $v_d = 2v/3$.

(c) For tube 3, $v_d = 2v/3$.

(d) For tube 4, $v_d = 2v/3$.

59. (a) The expression for the Doppler shifted frequency is

$$f' = f\,\frac{v \pm v_D}{v \mp v_S},$$

where f is the unshifted frequency, v is the speed of sound, v_D is the speed of the detector (the uncle), and v_S is the speed of the source (the locomotive). All speeds are relative to the air. The uncle is at rest with respect to the air, so $v_D = 0$. The speed of the source is $v_S = 10$ m/s. Since the locomotive is moving away from the uncle the frequency decreases and we use the plus sign in the denominator. Thus

$$f' = f\,\frac{v}{v + v_S} = (500.0\,\text{Hz})\left(\frac{343\,\text{m/s}}{343\,\text{m/s} + 10.00\,\text{m/s}}\right) = 485.8\,\text{Hz}.$$

(b) The girl is now the detector. Relative to the air she is moving with speed $v_D = 10.00$ m/s toward the source. This tends to increase the frequency and we use the plus sign in the numerator. The source is moving at $v_S = 10.00$ m/s away from the girl. This tends to decrease the frequency and we use the plus sign in the denominator. Thus $(v + v_D) = (v + v_S)$ and $f' = f = 500.0$ Hz.

(c) Relative to the air the locomotive is moving at $v_S = 20.00$ m/s away from the uncle. Use the plus sign in the denominator. Relative to the air the uncle is moving at $v_D = 10.00$ m/s toward the locomotive. Use the plus sign in the numerator. Thus

$$f' = f\,\frac{v + v_D}{v + v_S} = (500.0\,\text{Hz})\left(\frac{343\,\text{m/s} + 10.00\,\text{m/s}}{343\,\text{m/s} + 20.00\,\text{m/s}}\right) = 486.2\,\text{Hz}.$$

(d) Relative to the air the locomotive is moving at $v_S = 20.00$ m/s away from the girl and the girl is moving at $v_D = 20.00$ m/s toward the locomotive. Use the plus signs in both the numerator and the denominator. Thus $(v + v_D) = (v + v_S)$ and $f' = f = 500.0$ Hz.

60. The Doppler shift formula, Eq. 17–47, is valid only when both u_S and u_D are measured with respect to a stationary medium (i.e., no wind). To modify this formula in the presence of a wind, we switch to a new reference frame in which there is no wind.

(a) When the wind is blowing from the source to the observer with a speed w, we have $u'_S = u'_D = w$ in the new reference frame that moves together with the wind. Since the observer is now approaching the source while the source is backing off from the observer, we have, in the new reference frame,

$$f' = f\left(\frac{v+u'_D}{v+u'_S}\right) = f\left(\frac{v+w}{v+w}\right) = 2.0\times10^3 \text{ Hz}.$$

In other words, there is no Doppler shift.

(b) In this case, all we need to do is to reverse the signs in front of both u'_D and u'_S. The result is that there is still no Doppler shift:

$$f' = f\left(\frac{v-u'_D}{v-u'_S}\right) = f\left(\frac{v-w}{v-w}\right) = 2.0\times10^3 \text{ Hz}.$$

In general, there will always be no Doppler shift as long as there is no relative motion between the observer and the source, regardless of whether a wind is present or not.

61. We use Eq. 17–47 with f = 500 Hz and v = 343 m/s. We choose signs to produce $f' > f$.

(a) The frequency heard in still air is

$$f' = (500\text{ Hz})\left(\frac{343+30.5}{343-30.5}\right) = 598\text{ Hz}.$$

(b) In a frame of reference where the air seems still, the velocity of the detector is 30.5 – 30.5 = 0, and that of the source is 2(30.5). Therefore,

$$f' = 500\left(\frac{343+0}{343-2(30.5)}\right) = 608\text{ Hz}.$$

(c) We again pick a frame of reference where the air seems still. Now, the velocity of the source is 30.5 – 30.5 = 0, and that of the detector is 2(30.5). Consequently,

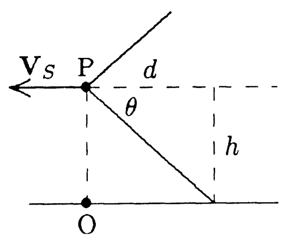
$$f' = (500\text{ Hz})\left(\frac{343+2(30.5)}{343-0)}\right) = 589\text{ Hz}.$$

62. We note that 1350 km/h is v_S = 375 m/s. Then, with $\theta = 60º$, Eq. 17-57 gives v = 3.3×10^2 m/s.

63. (a) The half angle θ of the Mach cone is given by $\sin\theta = v/v_S$, where v is the speed of sound and v_S is the speed of the plane. Since $v_S = 1.5v$, $\sin\theta = v/1.5v = 1/1.5$. This means $\theta = 42°$.

(b) Let h be the altitude of the plane and suppose the Mach cone intersects Earth's surface a distance d behind the plane. The situation is shown on the diagram below, with P indicating the plane and O indicating the observer. The cone angle is related to h and d by $\tan\theta = h/d$, so $d = h/\tan\theta$. The shock wave reaches O in the time the plane takes to fly the distance d:

$$t = d/v = h/v\tan\theta = (5000\text{ m})/1.5(331\text{ m/s})\tan 42° = 11\text{ s}.$$



64. The altitude H and the horizontal distance x for the legs of a right triangle, so we have

$$H = x\tan\theta = v_p t\tan\theta = 1.25vt\sin\theta$$

where v is the speed of sound, v_p is the speed of the plane and

$$\theta = \sin^{-1}\left(\frac{v}{v_p}\right) = \sin^{-1}\left(\frac{v}{1.25v}\right) = 53.1°.$$

Thus the altitude is

$$H = x\tan\theta = (1.25)(330\,\text{m/s})(60\,\text{s})(\tan 53.1°) = 3.30\times10^4\ \text{m}.$$

65. When the source is stationary (with respect to the air) then Eq. 17-47 gives

$$f' = f\left(1 - \frac{v_d}{v}\right)$$

where v_d is the speed of the detector (assumed to be moving away from the source, in the way we've written it, above). The difference between the approach and the recession is

$$f'' - f' = f\left[\left(1 + \frac{v_d}{v}\right) - \left(1 - \frac{v_d}{v}\right)\right] = f\left(2\frac{v_d}{v}\right)$$

which, after setting $(f'' - f')/f = 1/2$, leads to an equation which can be solved for the ratio v_d/v. The result is 1/4. Thus, $v_d/v = 0.250$.

66. (a) The separation distance between points *A* and *B* is one-quarter of a wavelength; therefore, $\lambda = 4(0.15 \text{ m}) = 0.60 \text{ m}$. The frequency, then, is

$$f = v/\lambda = 343/0.60 = 572 \text{ Hz}.$$

(b) The separation distance between points *C* and *D* is one-half of a wavelength; therefore, $\lambda = 2(0.15 \text{ m}) = 0.30 \text{ m}$. The frequency, then, is

$$f = v/\lambda = 343/0.30 = 1144 \text{ Hz (or 1.14 kHz)}.$$

67. Since they oscillate out of phase, then their waves will cancel (producing a node) at a point exactly midway between them (the midpoint of the system, where we choose $x = 0$). We note that Figure 17-14, and the $n = 3$ case of Figure 17-15(a) have this property (of a node at the midpoint). The distance Δx between nodes is $\lambda/2$, where $\lambda = v/f$ and $f = 300$ Hz and $v = 343$ m/s. Thus, $\Delta x = v/2f = 0.572$ m.

Therefore, nodes are found at the following positions:

$$x = n\Delta x = n(0.572\,\text{m}),\ \ n = 0, \pm 1, \pm 2, \ldots$$

(a) The shortest distance from the midpoint where nodes are found is $\Delta x = 0$.

(b) The second shortest distance from the midpoint where nodes are found is $\Delta x = 0.572$ m.

(c) The third shortest distance from the midpoint where nodes are found is $2\Delta x = 1.14$ m.

68. (a) Adapting Eq. 17-39 to the notation of this chapter, we have

$$s_m' = 2\, s_m \cos(\phi/2) = 2(12 \text{ nm}) \cos(\pi/6) = 20.78 \text{ nm}.$$

Thus, the amplitude of the resultant wave is roughly 21 nm.

(b) The wavelength (λ = 35 cm) does not change as a result of the superposition.

(c) Recalling Eq. 17-47 (and the accompanying discussion) from the previous chapter, we conclude that the standing wave amplitude is 2(12 nm) = 24 nm when they are traveling in opposite directions.

(d) Again, the wavelength (λ = 35 cm) does not change as a result of the superposition.

69. We note that waves 1 and 3 differ in phase by π radians (so they cancel upon superposition). Waves 2 and 4 also differ in phase by π radians (and also cancel upon superposition). Consequently, there is no resultant wave.

70. Let r stand for the ratio of the source speed to the speed of sound. Then, Eq. 17-55 (plus the fact that frequency is inversely proportional to wavelength) leads to

$$2\left(\frac{1}{1+r}\right) = \frac{1}{1-r} \, .$$

Solving, we find $r = 1/3$. Thus, $v_s/v = 0.33$.

71. Pipe A (which can only support odd harmonics – see Eq. 17-41) has length L_A. Pipe B (which supports both odd and even harmonics [any value of n] – see Eq. 17-39) has length $L_B = 4L_A$. Taking ratios of these equations leads to the condition:

$$\left(\frac{n}{2}\right)_B = \left(n_{\text{odd}}\right)_A \quad .$$

Solving for n_B we have $n_B = 2n_{\text{odd}}$.

(a) Thus, the smallest value of n_B at which a harmonic frequency of B matches that of A is $n_B = 2(1)=2$.

(b) The second smallest value of n_B at which a harmonic frequency of B matches that of A is $n_B = 2(3)=6$.

(c) The third smallest value of n_B at which a harmonic frequency of B matches that of A is $n_B = 2(5)=10$.

72. (a) Incorporating a term ($\lambda/2$) to account for the phase shift upon reflection, then the path difference for the waves (when they come back together) is

$$\sqrt{L^2 + (2d)^2} - L + \lambda/2 = \Delta(\text{path}) .$$

Setting this equal to the condition needed to destructive interference ($\lambda/2$, $3\lambda/2$, $5\lambda/2$ …) leads to d = 0, 2.10 m, … Since the problem explicitly excludes the d = 0 possibility, then our answer is d = 2.10 m.

(b) Setting this equal to the condition needed to constructive interference (λ, 2λ, 3λ …) leads to d = 1.47 m, … Our answer is d = 1.47 m.

73. Any phase changes associated with the reflections themselves are rendered inconsequential by the fact that there are an even number of reflections. The additional path length traveled by wave A consists of the vertical legs in the zig-zag path: $2L$. To be (minimally) out of phase means, therefore, that $2L = \lambda/2$ (corresponding to a half-cycle, or 180°, phase difference). Thus, $L = \lambda/4$, or $L/\lambda = 1/4 = 0.25$.

74. (a) To be out of phase (and thus result in destructive interference if they superpose) means their path difference must be $\lambda/2$ (or $3\lambda/2$ or $5\lambda/2$ or …). Here we see their path difference is L, so we must have (in the least possibility) $L = \lambda/2$, or $q = L/\lambda = 0.5$.

(b) As noted above, the next possibility is $L = 3\lambda/2$, or $q = L/\lambda = 1.5$.

75. (a) The time it takes for sound to travel in air is $t_a = L/v$, while it takes $t_m = L/v_m$ for the sound to travel in the metal. Thus

$$t = t_a - t_m = \frac{L}{v} - \frac{L}{v_m} = \frac{L(v_m - v)}{v_m v}.$$

(b) Using the values indicated (see Table 17-1), we obtain

$$L = \frac{t}{1/v - 1/v_m} = \frac{1.00\,\text{s}}{1/(343\,\text{m/s}) \; - \; 1/(5941\,\text{m/s})} = 364\,\text{m}.$$

76. (a) We observe that “third lowest … frequency” corresponds to harmonic number n = 5 for such a system. Using Eq. 17–41, we have

$$f = \frac{nv}{4L} \Rightarrow 750 = \frac{5v}{4(0.60)}$$

so that $v = 3.6\times10^2$ m/s.

(b) As noted, $n = 5$; therefore, $f_1 = 750/5 = 150$ Hz.

77. The siren is between you and the cliff, moving away from you and towards the cliff. Both "detectors" (you and the cliff) are stationary, so $v_D = 0$ in Eq. 17–47 (and see the discussion in the textbook immediately after that equation regarding the selection of ± signs). The source is the siren with $v_S = 10$ m/s. The problem asks us to use $v = 330$ m/s for the speed of sound.

(a) With $f = 1000$ Hz, the frequency f_y you hear becomes

$$f_y = f\left(\frac{v+0}{v+v_S}\right) = 970.6 \approx 9.7\times10^2 \text{ Hz.}$$

(b) The frequency heard by an observer at the cliff (and thus the frequency of the sound reflected by the cliff, ultimately reaching your ears at some distance from the cliff) is

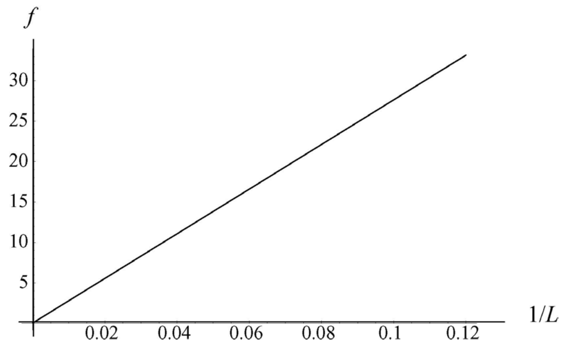
$$f_c = f\left(\frac{v+0}{v-v_S}\right) = 1031.3 \approx 1.0\times10^3 \text{ Hz.}$$

(c) The beat frequency is $f_c - f_y = 60$ beats/s (which, due to specific features of the human ear, is too large to be perceptible).

78. Since they are approaching each other, the sound produced (of emitted frequency f) by the flatcar-trumpet received by an observer on the ground will be of higher pitch f'. In these terms, we are told $f' - f = 4.0$ Hz, and consequently that $f'/f = 444/440 = 1.0091$. With v_S designating the speed of the flatcar and $v = 343$ m/s being the speed of sound, the Doppler equation leads to

$$\frac{f'}{f} = \frac{v+0}{v-v_S} \Rightarrow v_S = (343 \text{ m/s})\frac{1.0091-1}{1.0091} = 3.1 \text{ m/s}.$$

79. The points and the least-squares fit is shown in the graph that follows.



The graph has frequency in Hertz along the vertical axis and $1/L$ in inverse meters along the horizontal axis. The function found by the least squares fit procedure is $f = 276(1/L) + 0.037$. We shall assume that this fits either the model of an open organ pipe (mathematically similar to a string fixed at both ends) or that of a pipe closed at one end.

(a) In a tube with two open ends, $f = v/2L$. If the least-squares slope of 276 fits the first model, then a value of $v = 2(276 \text{ m/s}) = 553 \text{ m/s} \approx 5.5\times10^2 \text{ m/s}$ is implied.

(b) In a tube with only one open end, $f = v/4L$, and we find $v = 4(276 \text{ m/s}) = 1106 \text{ m/s} \approx 1.1\times10^3 \text{ m/s}$ which is more "in the ballpark" of the 1400 m/s value cited in the problem.

(c) This suggests that the acoustic resonance involved in this situation is more closely related to the $n = 1$ case of Figure 17-15(b) than to Figure 17-14.

80. The source being isotropic means $A_{\text{sphere}} = 4\pi r^2$ is used in the intensity definition $I = P/A$, which further implies

$$\frac{I_2}{I_1} = \frac{P/4\pi r_2^2}{P/4\pi r_1^2} = \left(\frac{r_1}{r_2}\right)^2 .$$

(a) With $I_1 = 9.60 \times 10^{-4}$ W/m^2, $r_1 = 6.10$ m, and $r_2 = 30.0$ m, we find

$$I_2 = (9.60 \times 10^{-4}\ \text{W/m}^2)(6.10/30.0)^2 = 3.97 \times 10^{-5}\ \text{W/m}^2.$$

(b) Using Eq. 17–27 with $I_1 = 9.60 \times 10^{-4}$ W/m^2, $\omega = 2\pi(2000\ \text{Hz})$, $v = 343$ m/s and $\rho = 1.21$ kg/m^3, we obtain

$$s_m = \sqrt{\frac{2I}{\rho v \omega^2}} = 1.71 \times 10^{-7}\ \text{m}.$$

(c) Eq. 17-15 gives the pressure amplitude:

$$\Delta p_m = \rho v \omega s_m = 0.893\ \text{Pa}.$$

81. When $\phi = 0$ it is clear that the superposition wave has amplitude $2\Delta p_m$. For the other cases, it is useful to write

$$\Delta p_1 + \Delta p_2 = \Delta p_m \left(\sin(\omega t) + \sin(\omega t - \phi)\right) = \left(2\Delta p_m \cos\frac{\phi}{2}\right)\sin\left(\omega t - \frac{\phi}{2}\right).$$

The factor in front of the sine function gives the amplitude Δp_r. Thus, $\Delta p_r / \Delta p_m = 2\cos(\phi/2)$.

(a) When $\phi = 0$, $\Delta p_r / \Delta p_m = 2\cos(0) = 2.00$.

(b) When $\phi = \pi/2$, $\Delta p_r / \Delta p_m = 2\cos(\pi/4) = \sqrt{2} = 1.41$.

(c) When $\phi = \pi/3$, $\Delta p_r / \Delta p_m = 2\cos(\pi/6) = \sqrt{3} = 1.73$.

(d) When $\phi = \pi/4$, $\Delta p_r / \Delta p_m = 2\cos(\pi/8) = 1.85$.

82. We use $v = \sqrt{B/\rho}$ to find the bulk modulus B:

$$B = v^2\rho = \left(5.4\times10^3 \text{ m/s}\right)^2 \left(2.7\times10^3 \text{ kg/m}^3\right) = 7.9\times10^{10} \text{ Pa}.$$

83. (a) With r = 10 m in Eq. 17–28, we have

$$I = \frac{P}{4\pi r^2} \quad \Rightarrow \quad P = 10\,\text{W}.$$

(b) Using that value of P in Eq. 17–28 with a new value for r, we obtain

$$I = \frac{P}{4\pi(5.0)^2} = 0.032\,\frac{\text{W}}{\text{m}^2}.$$

Alternatively, a ratio $I'/I = (r/r')^2$ could have been used.

(c) Using Eq. 17–29 with $I = 0.0080\ \text{W/m}^2$, we have

$$\beta = 10\log\frac{I}{I_0} = 99\,\text{dB}$$

where $I_0 = 1.0 \times 10^{-12}\ \text{W/m}^2$.

84. (a) Since the source is moving toward the wall, the frequency of the sound as received at the wall is

$$f' = f\left(\frac{v}{v - v_S}\right) = (440\,\text{Hz})\left(\frac{343\,\text{m/s}}{343\,\text{m/s} - 20.0\,\text{m/s}}\right) = 467\,\text{Hz}.$$

(b) Since the person is moving with a speed u toward the reflected sound with frequency f', the frequency registered at the source is

$$f_r = f'\left(\frac{v + u}{v}\right) = (467\,\text{Hz})\left(\frac{343\,\text{m/s} + 20.0\,\text{m/s}}{343\,\text{m/s}}\right) = 494\,\text{Hz}.$$

85. Let the frequencies of sound heard by the person from the left and right forks be f_l and f_r, respectively.

(a) If the speeds of both forks are u, then $f_{l,r} = fv/(v \pm u)$ and

$$f_{\text{beat}} = |f_r - f_l| = fv\left(\frac{1}{v-u} - \frac{1}{v+u}\right) = \frac{2fuv}{v^2 - u^2} = \frac{2(440\,\text{Hz})(3.00\,\text{m/s})(343\,\text{m/s})}{(343\,\text{m/s})^2 - (3.00\,\text{m/s})^2}$$

$$= 7.70\,\text{Hz}.$$

(b) If the speed of the listener is u, then $f_{l,r} = f(v \pm u)/v$ and

$$f_{\text{beat}} = |f_l - f_r| = 2f\left(\frac{u}{v}\right) = 2(440\,\text{Hz})\left(\frac{3.00\,\text{m/s}}{343\,\text{m/s}}\right) = 7.70\,\text{Hz}.$$

86. (a) The period is the reciprocal of the frequency: $T = 1/f = 1/(90 \text{ Hz}) = 1.1 \times 10^{-2}$ s.

(b) Using $v = 343$ m/s, we find $\lambda = v/f = 3.8$ m.

87. We use $\beta = 10\log(I/I_o)$ with $I_o = 1 \times 10^{-12}$ W/m^2 and Eq. 17–27 with $\omega = 2\pi f = 2\pi(260\text{ Hz})$, $v = 343$ m/s and $\rho = 1.21$ kg/m^3.

$$I = I_o\left(10^{8.5}\right) = \frac{1}{2}\rho v\left(2\pi f\right)^2 s_m^2 \quad \Rightarrow \quad s_m = 7.6\times10^{-7}\text{ m} = 0.76\ \mu\text{m}.$$

88. We use $\beta = 10 \log (I/I_o)$ with $I_o = 1 \times 10^{-12}$ W/m^2 and $I = P/4\pi r^2$ (an assumption we are asked to make in the problem). We estimate $r \approx 0.3$ m (distance from knuckle to ear) and find

$$P \approx 4\pi(0.3\,\text{m})^2\left(1\times10^{-12}\ \text{W/m}^2\right)10^{6.2} = 2\times10^{-6}\ \text{W} = 2\ \mu\text{W}.$$

89. Using Eq. 17-47 with great care (regarding its ± sign conventions), we have

$$f' = (440\ \text{Hz})\left(\frac{340\ \text{m/s}\ - 80.0\ \text{m/s}}{340\ \text{m/s} - 54.0\ \text{m/s}}\right) = 400\ \text{Hz}\,.$$

90. (a) It is clear from the last sentence (before part (a)) that the distance between the sources must be 5.0 λ.

(b) Point P_1 is equidistant from the sources so the waves are fully constructive when they superpose there.

(c) We add $2(\lambda/2)\sin(30^\circ)$ to the aforementioned 5.0 λ and obtain 5.5 λ.

(d) The "0.5" part of that "5.5 λ" means the superposition is fully destructive there.

91. The rule: if you divide the time (in seconds) by 3, then you get (approximately) the straight-line distance d. We note that the speed of sound we are to use is given at the beginning of the problem section in the textbook, and that the speed of light is very much larger than the speed of sound. The proof of our rule is as follows:

$$t = t_{\text{sound}} - t_{\text{light}} \approx t_{\text{sound}} = \frac{d}{v_{\text{sound}}} = \frac{d}{343\,\text{m/s}} = \frac{d}{0.343\,\text{km/s}}.$$

Cross-multiplying yields (approximately) (0.3 km/s)t = d which (since 1/3 ≈ 0.3) demonstrates why the rule works fairly well.

92. The wave is written as $s(x,t) = s_m \cos(kx \pm \omega t)$.

(a) The amplitude s_m is equal to the maximum displacement: $s_m = 0.30 \text{ cm}$.

(b) Since λ = 24 cm, the angular wave number is $k = 2\pi / \lambda = 0.26 \text{ cm}^{-1}$.

(c) The angular frequency is $\omega = 2\pi f = 2\pi(25 \text{ Hz}) = 1.6\times10^2 \text{ rad/s}$.

(d) The speed of the wave is $v = \lambda f$ = (24 cm)(25 Hz) = 6.0×10^2 cm/s.

(e) Since the direction of propagation is $-x$, the sign is plus, i.e., $s(x,t) = s_m \cos(kx + \omega t)$.

93. (a) The intensity is given by $I = \frac{1}{2}\rho v\omega^2 s_m^2$, where ρ is the density of the medium, v is the speed of sound, ω is the angular frequency, and s_m is the displacement amplitude. The displacement and pressure amplitudes are related by $\Delta p_m = \rho v\omega s_m$, so $s_m = \Delta p_m/\rho v\omega$ and $I = (\Delta p_m)^2/2\rho v$. For waves of the same frequency the ratio of the intensity for propagation in water to the intensity for propagation in air is

$$\frac{I_w}{I_a} = \left(\frac{\Delta p_{mw}}{\Delta p_{ma}}\right)^2 \frac{\rho_a v_a}{\rho_w v_w},$$

where the subscript a denotes air and the subscript w denotes water. Since $I_a = I_w$,

$$\frac{\Delta p_{mw}}{\Delta p_{ma}} = \sqrt{\frac{\rho_w v_w}{\rho_a v_a}} = \sqrt{\frac{(0.998\times10^3\ \text{kg/m}^3)(1482\ \text{m/s})}{(1.21\ \text{kg/m}^3)(343\ \text{m/s})}} = 59.7.$$

The speeds of sound are given in Table 17-1 and the densities are given in Table 15-1.

(b) Now, $\Delta p_{mw} = \Delta p_{ma}$, so

$$\frac{I_w}{I_a} = \frac{\rho_a v_a}{\rho_w v_w} = \frac{(1.21\ \text{kg/m}^3)(343\ \text{m/s})}{(0.998\times10^3\ \text{kg/m}^3)(1482\ \text{m/s})} = 2.81\times10^{-4}.$$

94. (a) Let P be the power output of the source. This is the rate at which energy crosses the surface of any sphere centered at the source and is therefore equal to the product of the intensity I at the sphere surface and the area of the sphere. For a sphere of radius r, $P = 4\pi r^2 I$ and $I = P/4\pi r^2$. The intensity is proportional to the square of the displacement amplitude s_m. If we write $I = Cs_m^2$, where C is a constant of proportionality, then $Cs_m^2 = P/4\pi r^2$. Thus

$$s_m = \sqrt{P/4\pi r^2 C} = \left(\sqrt{P/4\pi C}\right)(1/r).$$

The displacement amplitude is proportional to the reciprocal of the distance from the source. We take the wave to be sinusoidal. It travels radially outward from the source, with points on a sphere of radius r in phase. If ω is the angular frequency and k is the angular wave number then the time dependence is $\sin(kr - \omega t)$. Letting $b = \sqrt{P/4\pi C}$, the displacement wave is then given by

$$s(r,t) = \sqrt{\frac{P}{4\pi C}}\frac{1}{r}\sin(kr - \omega t) = \frac{b}{r}\sin(kr - \omega t).$$

(b) Since s and r both have dimensions of length and the trigonometric function is dimensionless, the dimensions of b must be length squared.

95. (a) When the right side of the instrument is pulled out a distance d the path length for sound waves increases by $2d$. Since the interference pattern changes from a minimum to the next maximum, this distance must be half a wavelength of the sound. So $2d = \lambda/2$, where λ is the wavelength. Thus $\lambda = 4d$ and, if v is the speed of sound, the frequency is

$$f = v/\lambda = v/4d = (343 \text{ m/s})/4(0.0165 \text{ m}) = 5.2 \times 10^3 \text{ Hz}.$$

(b) The displacement amplitude is proportional to the square root of the intensity (see Eq. 17–27). Write $\sqrt{I} = Cs_m$, where I is the intensity, s_m is the displacement amplitude, and C is a constant of proportionality. At the minimum, interference is destructive and the displacement amplitude is the difference in the amplitudes of the individual waves: $s_m = s_{SAD} - s_{SBD}$, where the subscripts indicate the paths of the waves. At the maximum, the waves interfere constructively and the displacement amplitude is the sum of the amplitudes of the individual waves: $s_m = s_{SAD} + s_{SBD}$. Solve

$$\sqrt{100} = C(s_{SAD} - s_{SBD}) \quad \text{and} \quad \sqrt{900} = C(s_{SAD} - s_{SBD})$$

for s_{SAD} and s_{SBD}. Add the equations to obtain

$$s_{SAD} = (\sqrt{100} + \sqrt{900} / 2C = 20 / C,$$

then subtract them to obtain

$$s_{SBD} = (\sqrt{900} - \sqrt{100}) / 2C = 10 / C.$$

The ratio of the amplitudes is $s_{SAD}/s_{SBD} = 2$.

(c) Any energy losses, such as might be caused by frictional forces of the walls on the air in the tubes, result in a decrease in the displacement amplitude. Those losses are greater on path B since it is longer than path A.

96. We use $\Delta\beta_{12} = \beta_1 - \beta_2 = (10 \text{ dB}) \log(I_1/I_2)$.

(a) Since $\Delta\beta_{12} = (10 \text{ dB}) \log(I_1/I_2) = 37$ dB, we get

$$I_1/I_2 = 10^{37 \text{ dB}/10 \text{ dB}} = 10^{3.7} = 5.0 \times 10^3.$$

(b) Since $\Delta p_m \propto s_m \propto \sqrt{I}$, we have

$$\Delta p_{m1} / \Delta p_{m2} = \sqrt{I_1 / I_2} = \sqrt{5.0 \times 10^3} = 71.$$

(c) The displacement amplitude ratio is $s_{m1} / s_{m2} = \sqrt{I_1 / I_2} = 71$.

97. The angle is $\sin^{-1}(v/v_s) = \sin^{-1}(343/685) = 30°$.

98. The difference between the sound waves that travel along R_1 and thus that bounce and travel along R_2 is

$$\Delta d = \sqrt{25.0^2 + 12.5^2} - \sqrt{20.0^2 + 12.5^2} + \tfrac{1}{2}\lambda$$

where the last term is included for the reflection effect (mentioned in the problem). To produce constructive interference at D then we require $\Delta d = m\lambda$ where m is an integer. Since λ relates to frequency by the relation $\lambda = v/f$ (with v = 343 m/s) then we have an equation for a set of values (depending on m) for the frequency. We find

$$f = 39.3 \text{ Hz} \quad \text{for} \quad m = 1$$
$$f = 118 \text{ Hz} \quad \text{for} \quad m = 2$$
$$f = 196 \text{ Hz} \quad \text{for} \quad m = 3$$
$$f = 275 \text{ Hz} \quad \text{for} \quad m = 4$$

and so on.

(a) The lowest frequency is f = 39.3 Hz.

(b) The second lowest frequency is f = 118 Hz.

99. (a) With f = 686 Hz and v = 343 m/s, then the "separation between adjacent wavefronts" is $\lambda = v/f$ = 0.50 m.

(b) This is one of the effects which are part of the Doppler phenomena. Here, the wavelength shift (relative to its "true" value in part (a)) equals the source speed v_s (with appropriate ± sign) relative to the speed of sound v:

$$\frac{\Delta\lambda}{\lambda} = \pm\frac{v_s}{v}.$$

In front of the source, the shift in wavelength is –(0.50 m)(110 m/s)/(343 m/s) = –0.16 m, and the wavefront separation is 0.50 – 0.16 = 0.34 m.

(c) Behind the source, the shift in wavelength is +(0.50 m)(110 m/s)/(343 m/s) = +0.16 m, and the wavefront separation is0.50 + 0.16 = 0.66 m.

100. (a) The problem is asking at how many angles will there be "loud" resultant waves, and at how many will there be "quiet" ones? We consider the resultant wave (at large distance from the origin) along the $+x$ axis; we note that the path-length difference (for the waves traveling from their respective sources) divided by wavelength gives the (dimensionless) value n = 3.2, implying a sort of intermediate condition between constructive interference (which would follow if, say, n = 3) and destructive interference (such as the n = 3.5 situation found in the solution to the previous problem) between the waves. To distinguish this resultant along the $+x$ axis from the similar one along the $-x$ axis, we label one with n = +3.2 and the other n = –3.2. This labeling facilitates the complete enumeration of the loud directions in the upper-half plane: n = –3, –2, –1, 0, +1, +2, +3. Counting also the "other" –3, –2, –1, 0, +1, +2, +3 values for the *lower*-half plane, then we conclude there are a total of 7 + 7 = 14 "loud" directions.

(b) The labeling also helps us enumerate the quiet directions. In the upper-half plane we find: n = –2.5, –1.5, –0.5, +0.5, +1.5, +2.5. This is duplicated in the lower half plane, so the total number of quiet directions is 6 + 6 = 12.

101. The source being isotropic means $A_{sphere} = 4\pi r^2$ is used in the intensity definition $I = P/A$. Since intensity is proportional to the square of the amplitude (see Eq. 17–27), this further implies

$$\frac{I_2}{I_1} = \left(\frac{s_{m2}}{s_{m1}}\right)^2 = \frac{P/4\pi r_2^2}{P/4\pi r_1^2} = \left(\frac{r_1}{r_2}\right)^2$$

or $s_{m2}/s_{m1} = r_1/r_2$.

(a) $I = P/4\pi r^2 = (10\text{ W})/4\pi(3.0\text{ m})^2 = 0.088\text{ W/m}^2$.

(b) Using the notation A instead of s_m for the amplitude, we find

$$\frac{A_4}{A_3} = \frac{3.0\,\text{m}}{4.0\,\text{m}} = 0.75\,.$$

102. (a) Using m = 7.3 × 10^7 kg, the initial gravitational potential energy is $U = mgy = 3.9\times10^{11}$ J, where h = 550 m. Assuming this converts primarily into kinetic energy during the fall, then K = 3.9 × 10^{11} J just before impact with the ground. Using instead the mass estimate m = 1.7 × 10^8 kg, we arrive at K = 9.2 × 10^{11} J.

(b) The process of converting this kinetic energy into other forms of energy (during the impact with the ground) is assumed to take Δt = 0.50 s (and in the average sense, we take the "power" P to be wave-energy/Δt). With 20% of the energy going into creating a seismic wave, the intensity of the body wave is estimated to be

$$I = \frac{P}{A_{\text{hemisphere}}} = \frac{(0.20)K/\Delta t}{\frac{1}{2}(4\pi r^2)} = 0.63\,\text{W/m}^2$$

using r = 200 × 10^3 m and the smaller value for K from part (a). Using instead the larger estimate for K, we obtain I = 1.5 W/m^2.

(c) The surface area of a cylinder of "height" d is $2\pi rd$, so the intensity of the surface wave is

$$I = \frac{P}{A_{\text{cylinder}}} = \frac{(0.20)K/\Delta t}{(2\pi rd)} = 25\times10^3\ \text{W/m}^2$$

using d = 5.0 m, r = 200 × 10^3 m and the smaller value for K from part (a). Using instead the larger estimate for K, we obtain I = 58 kW/m^2.

(d) Although several factors are involved in determining which seismic waves are most likely to be detected, we observe that on the basis of the above findings we should expect the more intense waves (the surface waves) to be more readily detected.

103. The round-trip time is $t = 2L/v$ where we estimate from the chart that the time between clicks is 3 ms. Thus, with $v = 1372$ m/s, we find $L = \frac{1}{2}vt = 2.1\ \text{m}$.

104. (a) The problem asks for the source frequency f. We use Eq. 17–47 with great care (regarding its ± sign conventions).

$$f' = f\left(\frac{340-16}{340-40}\right)$$

Therefore, with f' = 950 Hz, we obtain f = 880 Hz.

(b) We now have

$$f' = f\left(\frac{340+16}{340+40}\right)$$

so that with f = 880 Hz, we find f' = 824 Hz.

105. We use $I \propto r^{-2}$ appropriate for an isotropic source. We have

$$\frac{I_{r=d}}{I_{r=D-d}} = \frac{(D-d)^2}{D^2} = \frac{1}{2},$$

where d = 50.0 m. We solve for

$$D: D = \sqrt{2}d/\left(\sqrt{2}-1\right) = \sqrt{2}\,(50.0\,\text{m})/\left(\sqrt{2}-1\right) = 171\,\text{m}.$$

106. (a) In regions where the speed is constant, it is equal to distance divided by time. Thus, we conclude that the time difference is

$$\Delta t = \left(\frac{L-d}{V} + \frac{d}{V-\Delta V}\right) - \frac{L}{V}$$

where the first term is the travel time through bone and rock and the last term is the expected travel time purely through rock. Solving for *d* and simplifying, we obtain

$$d = \Delta t\,\frac{V\left(V-\Delta V\right)}{\Delta V} \approx \Delta t\,\frac{V^2}{\Delta V}.$$

(b) If we estimate $d \approx 10$ cm (as the lower limit of a range that goes up to a diameter of 20 cm), then the above expression (with the numerical values given in the problem) leads to $\Delta t = 0.8\ \mu$s (as the lower limit of a range that goes up to a time difference of $1.6\ \mu$s).

107. (a) The blood is moving towards the right (towards the detector), because the Doppler shift in frequency is an *increase*: $\Delta f > 0$.

(b) The reception of the ultrasound by the blood and the subsequent remitting of the signal by the blood back toward the detector is a two step process which may be compactly written as

$$f + \Delta f = f\left(\frac{v + v_x}{v - v_x}\right) \qquad \text{where } v_x = v_{\text{blood}} \cos\theta.$$

If we write the ratio of frequencies as $R = (f + \Delta f)/f$, then the solution of the above equation for the speed of the blood is

$$v_{\text{blood}} = \frac{(R-1)v}{(R+1)\cos\theta} = 0.90\,\text{m/s}$$

where $v = 1540$ m/s, $\theta = 20°$, and $R = 1 + 5495/5 \times 10^6$.

(c) We interpret the question as asking how Δf (still taken to be positive, since the detector is in the "forward" direction) changes as the detection angle θ changes. Since larger θ means smaller horizontal component of velocity v_x then we expect Δf to decrease towards zero as θ is increased towards 90°.

108. (a) We expect the center of the star to be a displacement node. The star has spherical symmetry and the waves are spherical. If matter at the center moved it would move equally in all directions and this is not possible.

(b) We assume the oscillation is at the lowest resonance frequency. Then, exactly one-fourth of a wavelength fits the star radius. If λ is the wavelength and R is the star radius then $\lambda = 4R$. The frequency is $f = v/\lambda = v/4R$, where v is the speed of sound in the star. The period is $T = 1/f = 4R/v$.

(c) The speed of sound is $v = \sqrt{B/\rho}$, where B is the bulk modulus and ρ is the density of stellar material. The radius is $R = 9.0 \times 10^{-3} R_s$, where R_s is the radius of the Sun (6.96×10^8 m). Thus

$$T = 4R\sqrt{\frac{\rho}{B}} = 4(9.0\times10^{-3})(6.96\times10^{8}\text{ m})\sqrt{\frac{1.0\times10^{10}\text{ kg/m}^3}{1.33\times10^{22}\text{ Pa}}} = 22\text{ s}.$$

109. The source being a "point source" means $A_{\text{sphere}} = 4\pi r^2$ is used in the intensity definition $I = P/A$, which further implies

$$\frac{I_2}{I_1} = \frac{P/4\pi r_2^2}{P/4\pi r_1^2} = \left(\frac{r_1}{r_2}\right)^2 .$$

From the discussion in §17-5, we know that the intensity ratio between "barely audible" and the "painful threshold" is $10^{-12} = I_2/I_1$. Thus, with $r_2 = 10000$ m, we find

$$r_1 = r_2\sqrt{10^{-12}} = 0.01\,\text{m} = 1\text{ cm.}$$

110. We find the difference in the two applications of the Doppler formula:

$$f_2 - f_1 = 37 = f\left(\frac{340 + 25}{340 - 15} - \frac{340}{340 - 15}\right) = f\left(\frac{25}{340 - 15}\right)$$

which leads to $f = 4.8\times10^2$ Hz .

111. (a) We proceed by dividing the (velocity) equation involving the new (fundamental) frequency f' by the equation when the frequency f is 440 Hz to obtain

$$\frac{f'\lambda}{f\lambda} = \sqrt{\frac{\tau'/\mu}{\tau/\mu}} \quad \Rightarrow \quad \frac{f'}{f} = \sqrt{\frac{\tau'}{\tau}}$$

where we are making an assumption that the mass-per-unit-length of the string does not change significantly. Thus, with $\tau' = 1.2\tau$, we have $f'/440 = \sqrt{1.2}$. Therefore, $f' = 482\text{ Hz}$.

(b) In this case, neither tension nor mass-per-unit-length change, so the wave speed v is unchanged. Hence, using Eq. 17–38 with $n = 1$,

$$f'\lambda' = f\lambda \;\Rightarrow\; f'(2L') = f(2L)$$

Since $L' = \frac{2}{3}L$, we obtain $f' = \frac{3}{2}(440) = 660\text{ Hz}$.