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

(c) Equation 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.

25. 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:

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

30. (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

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

35. (a) The intensity is

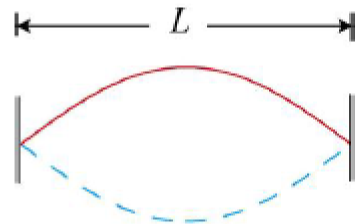
$$I = \frac{P}{4\pi r^2} = \frac{30.0\,\text{W}}{(4\pi)(200\,\text{m})^2} = 5.97\times10^{-5}\ \text{W/m}^2.$$

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

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

39. **THINK** Violin strings are fixed at both ends. A string clamped at both ends can be made to oscillate in standing wave patterns.

EXPRESS When the string is fixed at both ends and set to vibrate at its fundamental, lowest resonant frequency, exactly one-half of a wavelength fits between the ends (see figure to the right). The wave speed is given by $v = \lambda f = \sqrt{\tau / \mu}$, where τ is the tension in the string and μ is the linear mass density of the string.



$L=\lambda/2$

ANALYZE (a) With $\lambda = 2L$, we find the wave speed to be

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

(b) If M is the mass of the (uniform) string, then $\mu = M/L$. Thus, the string tension is

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

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

(d) If v_a is the speed of sound in air, then the wavelength in air is

$$\lambda_a = v_a/f = (343\text{ m/s})/(920\text{ Hz}) = 0.373\text{ m}.$$

LEARN The frequency of the sound wave in air is the same as the frequency of oscillation of the string. However, the wavelengths of the wave on the string and the sound waves emitted by the string are different because their wave speeds are not the same.

40. 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 Hz) = 600 Hz. Using this, Eq. 17-39 gives

$$L_A = (2)(343 \text{ m/s})/2(600 \text{ s}^{-1}) = 0.572 \text{ m}.$$

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

41. (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

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

47. 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

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

49. **THINK** Violin strings are fixed at both ends. A string clamped at both ends can be made to oscillate in standing wave patterns.

EXPRESS 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 $f_n = v/\lambda = nv/2L$, 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 $f_n=(n/2L)\sqrt{\tau/\mu}$.

ANALYZE Suppose the lower frequency is associated with n_1 and the higher frequency is associated with $n_2 = n_1 + 1$. There are no resonant frequencies between so you know that the integers associated with the given frequencies differ by 1. Thus, $f_{n_1}=(n_1/2L)\sqrt{\tau/\mu}$ and

$$f_{n_2}=\frac{n_1+1}{2L}\sqrt{\frac{\tau}{\mu}}=\frac{n_1}{2L}\sqrt{\frac{\tau}{\mu}}+\frac{1}{2L}\sqrt{\frac{\tau}{\mu}}=f_{n_1}+\frac{1}{2L}\sqrt{\frac{\tau}{\mu}}.$$

This means $f_{n_2}-f_{n_1}=(1/2L)\sqrt{\tau/\mu}$ and

$$\begin{aligned}\tau &= 4L^2\mu(f_{n_2}-f_{n_1})^2=4(0.300\,\text{m})^2(0.650\times10^{-3}\,\text{kg/m})(1320\,\text{Hz}-880\,\text{Hz})^2\\ &=45.3\,\text{N}.\end{aligned}$$

LEARN Since the difference between any successive pair of the harmonic frequencies is equal to the fundamental frequency: $\Delta f = f_{n+1}-f_n=\dfrac{v}{2L}=f_1$, we find

$$f_1=1320\,\text{Hz}-880\,\text{Hz}=440\,\text{Hz}.$$

Since 880 Hz = 2(440 Hz) and 1320 Hz = 3(440 Hz), the two frequencies correspond to $n_1=2$ and $n_2=3$, respectively.

52. 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.

53. **THINK** Beat arises when two waves detected have slightly different frequencies: $f_{\text{beat}} = f_2 - f_1$.

EXPRESS 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 $v = \sqrt{\tau/\mu}$ 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

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

ANALYZE The fractional increase in tension is

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

LEARN Beat frequency $f_{\text{beat}} = f_2 - f_1$ is zero when $\Delta\tau = 0$. The beat phenomenon is used by musicians to tune musical instruments. The instrument tuned is sounded against a standard frequency until beat disappears.

55. 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

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

56. The Doppler effect formula, Eq. 17-47, and its accompanying rule for choosing ± signs, are discussed in Section 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,

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

59. 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

$$f_1' = f_1\left(\frac{v+u_2}{v-u_1}\right) = (1.000\times10^3\ \text{Hz})\left(\frac{5470\ \text{km/h}\ +70.00\ \text{km/h}}{5470\ \text{km/h}\ -\ 50.00\ \text{km/h}}\right) = 1.022\ \times\ 10^3\ \text{Hz}.$$

(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 toward the reflected signal with speed u_1, then

$$f_r' = f_r\left(\frac{v+u_1}{v}\right) = f_1\frac{(v+u_1)(v+u_2)}{v(v-u_2)} = \frac{(1.000\times10^3\ \text{Hz})(5470+50.00)(5470+70.00)}{(5470)(5470-70.00)}$$

$$= 1.045\times10^3\ \text{Hz}.$$

63. 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

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

65. 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,

$$f' = f\left(\frac{v + u'_D}{v + u'_S}\right) = f\left(\frac{v + w}{v + w}\right) = 2.0 \times 10^3\ \text{Hz}.$$

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:

$$f' = f\left(\frac{v - u'_D}{v - u'_S}\right) = f\left(\frac{v - w}{v - w}\right) = 2.0 \times 10^3\ \text{Hz}.$$

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.