E19-1 (a) $v = f\lambda = (25\text{ Hz})(0.24\,\text{m}) = 6.0\,\text{m/s}$.

(b) $k = (2\pi\text{ rad})/(0.24\,\text{m}) = 26\text{ rad/m}$; $\omega = (2\pi\text{ rad})(25\text{ Hz}) = 160\text{ rad/s}$. The wave equation is

$$s = (3.0\times10^{-3}\text{m})\sin[(26\text{ rad/m})x + (160\text{ rad/s})t]$$

E19-2 (a) $[\Delta P]_\text{m} = 1.48\,\text{Pa}$.

(b) $f = (334\pi\text{ rad/s})/(2\pi\text{ rad}) = 167\text{ Hz}$.

(c) $\lambda = (2\pi\text{ rad})/(1.07\pi\text{ rad/m}) = 1.87\,\text{m}$.

(d) $v = (167\text{ Hz})(1.87\,\text{m}) = 312\,\text{m/s}$.

E19-3 (a) The wavelength is given by $\lambda = v/f = (343\,\text{m/s})/(4.50\times10^6\text{Hz} = 7.62\times10^{-5}\text{m}$.

(b) The wavelength is given by $\lambda = v/f = (1500\,\text{m/s})/(4.50\times10^6\text{Hz} = 3.33\times10^{-4}\text{m}$.

E19-4 Note: There is a typo; the mean free path should have been measured in "μm" instead of "pm".

$\lambda_\text{min} = 1.0\times10^{-6}\text{m}$; $f_\text{max} = (343\,\text{m/s})/(1.0\times10^{-6}\text{m}) = 3.4\times10^8\text{Hz}$.

E19-5 (a) $\lambda = (240\,\text{m/s})/(4.2\times10^9\text{Hz}) = 5.7\times10^{-8}\text{m}$.

E19-6 (a) The speed of sound is

$$v = (331\,\text{m/s})(6.21\times10^{-4}\text{ mi/m}) = 0.206\text{ mi/s}.$$

In five seconds the sound travels $(0.206\text{ mi/s})(5.0\,\text{s}) = 1.03$ mi, which is 3% too large.

(b) Count seconds and divide by 3.

E19-7 Marching at 120 paces per minute means that you move a foot every half a second. The soldiers in the back are moving the wrong foot, which means they are moving the correct foot half a second later than they should. If the speed of sound is 343 m/s, then the column of soldiers must be $(343\,\text{m/s})(0.5\,\text{s}) = 172$ m long.

E19-8 It takes $(300\,\text{m})/(343\,\text{m/s}) = 0.87\,\text{s}$ for the concert goer to hear the music after it has passed the microphone. It takes $(5.0\times10^6\text{m})/(3.0\times10^8\text{m/s}) = 0.017\,\text{s}$ for the radio listener to hear the music after it has passed the microphone. The radio listener hears the music first, 0.85 s before the concert goer.

E19-9 $x/v_\text{P} = t_\text{P}$ and $x/v_\text{S} = t_\text{S}$; subtracting and rearranging,

$$x = \Delta t/[1/v_\text{S} - 1/v_\text{P}] = (180\,\text{s})/[1/(4.5\text{ km/s}) - 1/(8.2\text{ km/s})] = 1800\text{ km}.$$

E19-10 Use Eq. 19-8, $s_\text{m} = [\Delta p]_\text{m}/kB$, and Eq. 19-14, $v = \sqrt{B/\rho_0}$. Then

$$[\Delta p]_\text{m} = kBs_\text{m} = kv^2\rho_0 s_\text{m} = 2\pi f v\rho_0 s_\text{m}.$$

Insert into Eq. 19-18, and

$$I = 2\pi^2\rho v f^2 {s_\text{m}}^2.$$

E19-11 If the source emits equally in all directions the intensity at a distance r is given by the average power divided by the surface area of a sphere of radius r centered on the source.

The power output of the source can then be found from

$$P = IA = I(4\pi r^2) = (197\times10^{-6}\text{W/m}^2)4\pi(42.5\,\text{m})^2 = 4.47\,\text{W}.$$

E19-12 Use the results of Exercise 19-10.

$$s_{\rm m} = \sqrt{\frac{(1.13\times10^{-6}{\rm W/m^2})}{2\pi^2(1.21\,{\rm kg/m^3})(343\,{\rm m/s})(313\ {\rm Hz})^2}} = 3.75\times10^{-8}{\rm m}.$$

E19-13 $U = IAt = (1.60\times10^{-2}{\rm W/m^2})(4.70\times10^{-4}{\rm m^2})(3600\,{\rm s}) = 2.71\times10^{-2}{\rm W}.$

E19-14 Invert Eq. 19-21:

$$I_1/I_2 = 10^{(1.00{\rm dB})/10} = 1.26.$$

E19-15 (a) Relative sound level is given by Eq. 19-21,

$$SL_1 - SL_2 = 10\log\frac{I_1}{I_2} \text{ or } \frac{I_1}{I_2} = 10^{(SL_1-SL_2)/10},$$

so if $\Delta SL = 30$ then $I_1/I_2 = 10^{30/10} = 1000$.

(b) Intensity is proportional to pressure amplitude squared according to Eq. 19-19; so

$$\Delta p_{\rm m,1}/\Delta p_{\rm m,2} = \sqrt{I_1/I_2} = \sqrt{1000} = 32.$$

E19-16 We know where her ears hurt, so we know the intensity at that point. The power output is then

$$P = 4\pi(1.3\,{\rm m})^2(1.0\,{\rm W/m^2}) = 21\,{\rm W}.$$

This is less than the advertised power.

E19-17 Use the results of Exercise 18-18, $I = uv$. The intensity is

$$I = (5200\,{\rm W})/4\pi(4820\,{\rm m})^2 = 1.78\times10^{-5}{\rm W/m^2},$$

so the energy density is

$$u = I/v = (1.78\times10^{-5}{\rm W/m^2})/(343\,{\rm m/s}) = 5.19\times10^{-8}{\rm J/m^3}.$$

E19-18 $I_2 = 2I_1$, since $I \propto 1/r^2$ then $r_1^2 = 2r_2^2$. Then

$$\begin{aligned} D &= \sqrt{2}(D - 51.4\,{\rm m}), \\ D(\sqrt{2}-1) &= \sqrt{2}(51.4\,{\rm m}), \\ D &= 176\,{\rm m}. \end{aligned}$$

E19-19 The sound level is given by Eq. 19-20,

$$SL = 10\log\frac{I}{I_0}$$

where I_0 is the threshold intensity of 10^{-12} W/m^2. Intensity is given by Eq. 19-19,

$$I = \frac{(\Delta p_{\rm m})^2}{2\rho v}$$

If we assume the maximum possible pressure amplitude is equal to one atmosphere, then

$$I = \frac{(\Delta p_{\rm m})^2}{2\rho v} = \frac{(1.01\times10^5{\rm Pa})^2}{2(1.21\,{\rm kg/m^3})(343\,{\rm m/s})} = 1.22\times10^7{\rm W/m^2}.$$

The sound level would then be

$$SL = 10 \log \frac{I}{I_0} = 10 \log \frac{1.22\times 10^7 \mathrm{W/m^2}}{(10^{-12}\ \mathrm{W/m^2})} = 191\ \mathrm{dB}$$

E19-20 Let one person speak with an intensity I_1. N people would have an intensity NI_1. The ratio is N, so by inverting Eq. 19-21,

$$N = 10^{(15\mathrm{dB})/10} = 31.6,$$

so 32 people would be required.

E19-21 Let one leaf rustle with an intensity I_1. N leaves would have an intensity NI_1. The ratio is N, so by Eq. 19-21,

$$SL_N = (8.4\ \mathrm{dB}) + 10 \log(2.71\times 10^5) = 63\ \mathrm{dB}.$$

E19-22 Ignoring the finite time means that we can assume the sound waves travels vertically, which considerably simplifies the algebra.

The intensity ratio can be found by inverting Eq. 19-21,

$$I_1/I_2 = 10^{(30\mathrm{dB})/10} = 1000.$$

But intensity is proportional to the inverse distance squared, so $I_1/I_2 = (r_2/r_1)^2$, or

$$r_2 = (115\,\mathrm{m})\sqrt{(1000)} = 3640\,\mathrm{m}.$$

E19-23 A minimum will be heard at the detector if the path length difference between the straight path and the path through the curved tube is half of a wavelength. Both paths involve a straight section from the source to the start of the curved tube, and then from the end of the curved tube to the detector. Since it is the path difference that matters, we'll only focus on the part of the path between the start of the curved tube and the end of the curved tube. The length of the straight path is one diameter, or $2r$. The length of the curved tube is half a circumference, or πr. The difference is $(\pi - 2)r$. This difference is equal to half a wavelength, so

$$\begin{aligned} (\pi - 2)r &= \lambda/2, \\ r &= \frac{\lambda}{2\pi - 4} = \frac{(42.0\ \mathrm{cm})}{2\pi - 4} = 18.4\ \mathrm{cm}. \end{aligned}$$

E19-24 The path length difference here is

$$\sqrt{(3.75\,\mathrm{m})^2 + (2.12\,\mathrm{m})^2} - (3.75\,\mathrm{m}) = 0.5578\,\mathrm{m}.$$

(a) A minimum will occur if this is equal to a half integer number of wavelengths, or $(n-1/2)\lambda = 0.5578\,\mathrm{m}$. This will occur when

$$f = (n - 1/2)\frac{(343\,\mathrm{m/s})}{(0.5578\,\mathrm{m})} = (n - 1/2)(615\ \mathrm{Hz}).$$

(b) A maximum will occur if this is equal to an integer number of wavelengths, or $n\lambda = 0.5578\,\mathrm{m}$. This will occur when

$$f = n\frac{(343\,\mathrm{m/s})}{(0.5578\,\mathrm{m})} = n(615\ \mathrm{Hz}).$$

E19-25 The path length difference here is

$$\sqrt{(24.4\,\text{m} + 6.10\,\text{m})^2 + (15.2\,\text{m})^2} - \sqrt{(24.4\,\text{m})^2 + (15.2\,\text{m})^2} = 5.33\,\text{m}.$$

A maximum will occur if this is equal to an integer number of wavelengths, or $n\lambda = 5.33\,\text{m}$. This will occur when

$$f = n(343\,\text{m/s})/(5.33\,\text{m}) = n(64.4 \text{ Hz})$$

The two lowest frequencies are then 64.4 Hz and 129 Hz.

E19-26 The wavelength is $\lambda = (343\,\text{m/s})/(300 \text{ Hz}) = 1.143\,\text{m}$. This means that the sound maxima will be half of this, or 0.572 m apart. Directly in the center the path length difference is zero, but since the waves are out of phase, this will be a minimum. The maxima should be located on either side of this, a distance $(0.572\,\text{m})/2 = 0.286\,\text{m}$ from the center. There will then be maxima located each 0.572 m farther along.

E19-27 (a) $f_1 = v/2L$ and $f_2 = v/2(L - \Delta L)$. Then

$$\frac{1}{r} = \frac{f_1}{f_2} = \frac{L - \Delta L}{L} = 1 - \frac{\Delta L}{L},$$

or $\Delta L = L(1 - 1/r)$.

(b) The answers are $\Delta L = (0.80\,\text{m})(1 - 5/6) = 0.133\,\text{m}$; $\Delta L = (0.80\,\text{m})(1 - 4/5) = 0.160\,\text{m}$; $\Delta L = (0.80\,\text{m})(1 - 3/4) = 0.200\,\text{m}$; and $\Delta L = (0.80\,\text{m})(1 - 2/3) = 0.267\,\text{m}$.

E19-28 The wavelength is twice the distance between the nodes in this case, so $\lambda = 7.68$ cm. The frequency is

$$f = (1520\,\text{m/s})/(7.68\times 10^{-2}\text{m}) = 1.98\times 10^4\text{Hz}.$$

E19-29 The well is a tube open at one end and closed at the other; Eq. 19-28 describes the allowed frequencies of the resonant modes. The lowest frequency is when $n = 1$, so $f_1 = v/4L$. We know f_1; to find the depth of the well, L, we need to know the speed of sound.

We should use the information provided, instead of looking up the speed of sound, because maybe the well is filled with some kind of strange gas.

Then, from Eq. 19-14,

$$v = \sqrt{\frac{B}{\rho}} = \sqrt{\frac{(1.41 \times 10^5 \text{ Pa})}{(1.21\,\text{kg/m}^3)}} = 341\,\text{m/s}.$$

The depth of the well is then

$$L = v/(4f_1) = (341\,\text{m/s})/[4(7.20 \text{ Hz})] = 11.8\,\text{m}.$$

E19-30 (a) The resonant frequencies of the pipe are given by $f_n = nv/2L$, or

$$f_n = n(343\,\text{m/s})/2(0.457\,\text{m}) = n(375 \text{ Hz}).$$

The lowest frequency in the specified range is $f_3 = 1130$ Hz; the other allowed frequencies in the specified range are $f_4 = 1500$ Hz, and $f_5 = 1880$ Hz.

E19-31 The maximum reflected frequencies will be the ones that undergo constructive interference, which means the path length difference will be an integer multiple of a wavelength. A wavefront will strike a terrace wall and part will reflect, the other part will travel on to the next terrace, and then reflect. Since part of the wave had to travel to the next terrace and back, the path length difference will be $2 \times 0.914\,\text{m} = 1.83\,\text{m}$.

If the speed of sound is $v = 343\,\text{m/s}$, the lowest frequency wave which undergoes constructive interference will be

$$f = \frac{v}{\lambda} = \frac{(343\,\text{m/s})}{(1.83\,\text{m})} = 187 \text{ Hz}$$

Any integer multiple of this frequency will also undergo constructive interference, and will also be heard. The ear and brain, however, will most likely interpret the complex mix of frequencies as a single tone of frequency 187 Hz.

E19-32 Assume there is no frequency between these two that is amplified. Then one of these frequencies is $f_n = nv/2L$, and the other is $f_{n+1} = (n+1)v/2L$. Subtracting the larger from the smaller, $\Delta f = v/2L$, or

$$L = v/2\Delta f = (343\,\text{m/s})/2(138 \text{ Hz} - 135 \text{ Hz}) = 57.2\,\text{m}.$$

E19-33 (a) $v = 2Lf = 2(0.22\,\text{m})(920 \text{ Hz}) = 405\,\text{m/s}$.
(b) $F = v^2\mu = (405\,\text{m/s})^2(820\times10^{-6}\text{kg})/(0.220\,\text{m}) = 611\,\text{N}$.

E19-34 $f \propto v$, and $v \propto \sqrt{F}$, so $f \propto \sqrt{F}$. Doubling f requires F increase by a factor of 4.

E19-35 The speed of a wave on the string is the same, regardless of where you put your finger, so $f\lambda$ is a constant. The string will vibrate (mostly) in the lowest harmonic, so that $\lambda = 2L$, where L is the length of the part of the string that is allowed to vibrate. Then

$$\begin{aligned} f_2\lambda_2 &= f_1\lambda_1, \\ 2f_2L_2 &= 2f_1L_1, \\ L_2 &= L_1\frac{f_1}{f_2} = (30 \text{ cm})\frac{(440 \text{ Hz})}{(528 \text{ Hz})} = 25 \text{ cm}. \end{aligned}$$

So you need to place your finger 5 cm from the end.

E19-36 The open organ pipe has a length

$$L_\text{o} = v/2f_1 = (343\,\text{m/s})/2(291 \text{ Hz}) = 0.589\,\text{m}.$$

The second harmonic of the open pipe has frequency $2f_1$; this is the first overtone of the closed pipe, so the closed pipe has a length

$$L_\text{c} = (3)v/4(2f_1) = (3)(343\,\text{m/s})/4(2)(291 \text{ Hz}) = 0.442\,\text{m}.$$

E19-37 The unknown frequency is either 3 Hz higher or lower than the standard fork. A small piece of wax placed on the fork of this unknown frequency tuning fork will result in a lower frequency because $f \propto \sqrt{k/m}$. If the beat frequency decreases then the two tuning forks are getting *closer* in frequency, so the frequency of the first tuning fork must be above the frequency of the standard fork. Hence, 387 Hz.

E19-38 If the string is too taut then the frequency is too high, or $f = (440 + 4)$Hz. Then $T = 1/f = 1/(444\text{ Hz}) = 2.25\times10^{-3}$s.

E19-39 One of the tuning forks need to have a frequency 1 Hz different from another. Assume then one is at 501 Hz. The next fork can be played against the first or the second, so it could have a frequency of 503 Hz to pick up the 2 and 3 Hz beats. The next one needs to pick up the 5, 7, and 8 Hz beats, and 508 Hz will do the trick. There are other choices.

E19-40 $f = v/\lambda = (5.5\,\text{m/s})/(2.3\,\text{m}) = 2.39$ Hz. Then

$$f' = f(v + v_O)/v = (2.39\text{ Hz})(5.5\,\text{m/s} + 3.3\,\text{m/s})/(5.5\,\text{m/s}) = 3.8\text{ Hz}.$$

E19-41 We'll use Eq. 19-44, since both the observer and the source are in motion. Then

$$f' = f\frac{v \pm v_O}{v \mp v_S} = (15.8\text{ kHz})\frac{(343\,\text{m/s}) + (246\,\text{m/s})}{(343\,\text{m/s}) + (193\,\text{m/s})} = 17.4\text{ kHz}r$$

E19-42 Solve Eq. 19-44 for v_S;

$$v_S = (v + v_O)f/f' - v = (343\,\text{m/s} + 2.63\,\text{m/s})(1602\text{ Hz})/(1590\text{ Hz}) - (343\,\text{m/s}) = 5.24\,\text{m/s}.$$

E19-43 $v_S = (14.7\text{ Rad/s})(0.712\,\text{m}) = 10.5\,\text{m/s}$.

(a) The low frequency heard is

$$f' = (538\text{ Hz})(343\,\text{m/s})/(343\,\text{m/s} + 10.5\,\text{m/s}) = 522\text{ Hz}.$$

(a) The high frequency heard is

$$f' = (538\text{ Hz})(343\,\text{m/s})/(343\,\text{m/s} - 10.5\,\text{m/s}) = 555\text{ Hz}.$$

E19-44 Solve Eq. 19-44 for v_S;

$$v_S = v - vf/f' = (343\,\text{m/s}) - (343\,\text{m/s})(440\text{ Hz})/(444\text{ Hz}) = 3.1\,\text{m/s}.$$

E19-45

E19-46 The approaching car "hears"

$$f' = f\frac{v + v_O}{v - v_S} = (148\text{ Hz})\frac{(343\,\text{m/s}) + (44.7\,\text{m/s})}{(343\,\text{m/s}) - (0)} = 167\text{ Hz}$$

This sound is reflected back at the same frequency, so the police car "hears"

$$f' = f\frac{v + v_O}{v - v_S} = (167\text{ Hz})\frac{(343\,\text{m/s}) + (0)}{(343\,\text{m/s}) - (44.7\,\text{m/s})} = 192\text{ Hz}$$

E19-47 The departing intruder "hears"

$$f' = f\frac{v - v_O}{v + v_S} = (28.3\text{ kHz})\frac{(343\,\text{m/s}) - (0.95\,\text{m/s})}{(343\,\text{m/s}) - (0)} = 28.22\text{ kHz}$$

This sound is reflected back at the same frequency, so the alarm "hears"

$$f' = f\frac{v - v_O}{v + v_S} = (28.22\text{ kHz})\frac{(343\,\text{m/s}) + (0)}{(343\,\text{m/s}) + (0.95\,\text{m/s})} = 28.14\text{ kHz}$$

The beat frequency is 28.3 kHz − 28.14 kHz = 160 Hz.

E19-48 (a) $f' = (1000\text{ Hz})(330\,\text{m/s})(330\,\text{m/s} + 10.0\,\text{m/s}) = 971$ Hz.
(b) $f' = (1000\text{ Hz})(330\,\text{m/s})(330\,\text{m/s} - 10.0\,\text{m/s}) = 1030$ Hz.
(c) 1030 Hz − 971 Hz = 59 Hz.

E19-49 (a) The frequency "heard" by the wall is

$$f' = f\frac{v + v_O}{v - v_S} = (438\text{ Hz})\frac{(343\,\text{m/s}) + (0)}{(343\,\text{m/s}) - (19.3\,\text{m/s})} = 464\text{ Hz}$$

(b) The wall then reflects a frequency of 464 Hz back to the trumpet player. Sticking with Eq. 19-44, the source is now at rest while the observer moving,

$$f' = f\frac{v + v_O}{v - v_S} = (464\text{ Hz})\frac{(343\,\text{m/s}) + (19.3\,\text{m/s})}{(343\,\text{m/s}) - (0)} = 490\text{ Hz}$$

E19-50 The body part "hears"

$$f' = f\frac{v + v_b}{v}.$$

This sound is reflected back to the detector which then "hears"

$$f'' = f'\frac{v}{v - v_b} = f\frac{v + v_b}{v - v_b}.$$

Rearranging,

$$v_b/v = \frac{f'' - f}{f'' + f} \approx \frac{1}{2}\frac{\Delta f}{f},$$

so $v \approx 2(1\times10^{-3}\text{m/s})/(1.3\times10^{-6}) \approx 1500\,\text{m/s}$.

E19-51 The wall "hears"

$$f' = f\frac{v + v_O}{v - v_S} = (39.2\text{ kHz})\frac{(343\,\text{m/s}) + (0)}{(343\,\text{m/s}) - (8.58\,\text{m/s})} = 40.21\text{ kHz}$$

This sound is reflected back at the same frequency, so the bat "hears"

$$f' = f\frac{v + v_O}{v - v_S} = (40.21\text{ kHz})\frac{(343\,\text{m/s}) + (8.58\,\text{m/s})}{(343\,\text{m/s}) - (0)} = 41.2\text{ kHz}.$$

P19-1 (a) $t_{\text{air}} = L/v_{\text{air}}$ and $t_{\text{m}} = L/v$, so the difference is

$$\Delta t = L(1/v_{\text{air}} - 1/v)$$

(b) Rearrange the above result, and

$$L = (0.120\,\text{s})/[1/(343\,\text{m/s}) - 1/(6420\,\text{m/s})] = 43.5\,\text{m}.$$

P19-2 The stone falls for a time t_1 where $y = gt_1^2/2$ is the depth of the well. Note y is positive in this equation. The sound travels back in a time t_2 where $v = y/t_2$ is the speed of sound in the well. $t_1 + t_2 = 3.00\,\text{s}$, so

$$2y = g(3.00\,\text{s} - t_2)^2 = g[(9.00\,\text{s}^2) - (6.00\,\text{s})y/v + y^2/v^2],$$

or, using $g = 9.81\,\text{m/s}^2$ and $v = 343\,\text{m/s}$,

$$y^2 - (2.555\times10^5\,\text{m})y + (1.039\times10^7\,\text{m}^2) = 0,$$

which has a positive solution $y = 40.7\,\text{m}$.

P19-3 (a) The intensity at 28.5 m is found from the $1/r^2$ dependence;

$$I_2 = I_1(r_1/r_2)^2 = (962\,\mu\text{W/m}^2)(6.11\,\text{m}/28.5\,\text{m})^2 = 44.2\,\mu\text{W/m}^2.$$

(c) We'll do this part first. The pressure amplitude is found from Eq. 19-19,

$$\Delta p_\text{m} = \sqrt{2\rho v I} = \sqrt{2(1.21\,\text{kg/m}^3)(343\,\text{m/s})(962\times10^{-6}\text{W/m}^2)} = 0.894\,\text{Pa}.$$

(b) The displacement amplitude is found from Eq. 19-8,

$$s_\text{m} = \Delta p_\text{m}/(kB),$$

where $k = 2\pi f/v$ is the wave number. From Eq. 19-14 w know that $B = \rho v^2$, so

$$s_\text{m} = \frac{\Delta p_\text{m}}{2\pi f \rho v} = \frac{(0.894\,\text{Pa})}{2\pi(2090\text{ Hz})(1.21\,\text{kg/m}^3)(343\,\text{m/s})} = 1.64\times10^{-7}\text{m}.$$

P19-4 (a) If the intensities are equal, then $\Delta p_\text{m} \propto \sqrt{\rho v}$, so

$$\frac{[\Delta p_\text{m}]_\text{water}}{[\Delta p_\text{m}]_\text{air}} = \sqrt{\frac{(998\,\text{kg/m}^3)(1482\,\text{m/s})}{(1.2\,\text{kg/m}^3)(343\,\text{m/s})}} = 59.9.$$

(b) If the pressure amplitudes are equal, then $I \propto\propto 1/\rho v$, so

$$\frac{I_\text{water}}{I_\text{air}} = \frac{(1.2\,\text{kg/m}^3)(343\,\text{m/s})}{(998\,\text{kg/m}^3)(1482\,\text{m/s})} = 2.78\times10^{-4}.$$

P19-5 The energy is dissipated on a cylindrical surface which grows in area as r, so the intensity is proportional to $1/r$. The amplitude is proportional to the square root of the intensity, so $s_\text{m} \propto 1/\sqrt{r}$.

P19-6 (a) The first position corresponds to maximum destructive interference, so the waves are half a wavelength out of phase; the second position corresponds to maximum constructive interference, so the waves are in phase. Shifting the tube has in effect added half a wavelength to the path through B. But each segment is added, so

$$\lambda = (2)(2)(1.65\text{ cm}) = 6.60\text{ cm},$$

and $f = (343\,\text{m/s})/(6.60\text{ cm}) = 5200$ Hz.

(b) $I_\text{min} \propto (s_1 - s_2)^2$, $I_\text{max} \propto (s_1 + s_2)^2$, then dividing one expression by the other and rearranging we find

$$\frac{s_1}{s_2} = \frac{\sqrt{I_\text{max}} + \sqrt{I_\text{min}}}{\sqrt{I_\text{max}} - \sqrt{I_\text{min}}} = \frac{\sqrt{90} + \sqrt{10}}{\sqrt{90} - \sqrt{10}} = 2$$

P19-7 (a) $I = P/4\pi r^2 = (31.6\,\text{W})/4\pi(194\,\text{m})^2 = 6.68\times10^{-5}\text{W/m}^2$.

(b) $P = IA = (6.68\times10^{-5}\text{W/m}^2)(75.2\times10^{-6}\text{m}^2) = 5.02\times10^{-9}\text{W}$.

(c) $U = Pt = (5.02\times10^{-9}\text{W})(25.0\text{ min})(60.0\text{ s/min}) = 7.53\,\mu\text{J}$.

P19-8 Note that the reverberation time is logarithmically related to the intensity, but linearly related to the sound level. As such, the reverberation time is the amount of time for the sound level to decrease by

$$\Delta SL = 10\log(10^{-6}) = 60\text{ dB}.$$

Then

$$t = (87\text{ dB})(2.6\,s)/(60\text{ dB}) = 3.8\,\text{s}$$

P19-9 What the device is doing is taking all of the energy which strikes a large surface area and concentrating it into a small surface area. It doesn't succeed; only 12% of the energy is concentrated. We can think, however, in terms of power: 12% of the average power which strikes the parabolic reflector is transmitted into the tube.

If the sound intensity on the reflector is I_1, then the average power is $P_1 = I_1 A_1 = I_1 \pi r_1^2$, where r_1 is the radius of the reflector. The average power in the tube will be $P_2 = 0.12 P_1$, so the intensity in the tube will be

$$I_2 = \frac{P_2}{A_2} = \frac{0.12 I_1 \pi r_1^2}{\pi r_2^2} = 0.12 I_1 \frac{r_1^2}{r_2^2}$$

Since the lowest audible sound has an intensity of $I_0 = 10^{-12}\ \mathrm{W/m^2}$, we can set $I_2 = I_0$ as the condition for "hearing" the whisperer through the apparatus. The minimum sound intensity at the parabolic reflector is

$$I_1 = \frac{I_0}{0.12} \frac{r_2^2}{r_1^2}.$$

Now for the whisperers. Intensity falls off as $1/d^2$, where d is the distance from the source. We are told that when $d = 1.0$ m the sound level is 20 dB; this sound level has an intensity of

$$I = I_0 10^{20/10} = 100 I_0$$

Then at a distance d from the source the intensity must be

$$I_1 = 100 I_0 \frac{(1\,\mathrm{m})^2}{d^2}.$$

This would be the intensity "picked-up" by the parabolic reflector. Combining this with the condition for being able to hear the whisperers through the apparatus, we have

$$\frac{I_0}{0.12} \frac{r_2^2}{r_1^2} = 100 I_0 \frac{(1\,\mathrm{m})^2}{d^2}$$

or, upon some rearranging,

$$d = (\sqrt{12}\,\mathrm{m}) \frac{r_1}{r_2} = (\sqrt{12}\,\mathrm{m}) \frac{(0.50\,\mathrm{m})}{(0.005\,\mathrm{m})} = 346\,\mathrm{m}.$$

P19-10 (a) A displacement node; at the center the particles have nowhere to go.

(b) This systems acts like a pipe which is closed at one end.

(c) $v\sqrt{B/\rho}$, so

$$T = 4(0.009)(6.96\times 10^8\mathrm{m})\sqrt{(1.0\times 10^{10}\mathrm{kg/m^3})/(1.33\times 10^{22}\mathrm{Pa})} = 22\,\mathrm{s}.$$

P19-11 The cork filing collect at pressure antinodes when standing waves are present, and the antinodes are each half a wavelength apart. Then $v = f\lambda = f(2d)$.

P19-12 (a) $f = v/4L = (343\,\mathrm{m/s})/4(1.18\,\mathrm{m}) = 72.7$ Hz.

(b) $F = \mu v^2 = \mu f^2 \lambda^2$, or

$$F = (9.57\times 10^{-3}\mathrm{kg}/0.332\,\mathrm{m})(72.7\ \mathrm{Hz})^2[2(0.332\,\mathrm{m})]^2 = 67.1\,N.$$

P19-13 In this problem the string is observed to resonate at 880 Hz and then again at 1320 Hz, so the two corresponding values of n must differ by 1. We can then write two equations

$$(880\text{ Hz}) = \frac{nv}{2L} \text{ and } (1320\text{ Hz}) = \frac{(n+1)v}{2L}$$

and solve these for v. It is somewhat easier to first solve for n. Rearranging both equations, we get

$$\frac{(880\text{ Hz})}{n} = \frac{v}{2L} \text{ and } \frac{(1320\text{ Hz})}{n+1} = \frac{v}{2L}.$$

Combining these two equations we get

$$\begin{aligned} \frac{(880\text{ Hz})}{n} &= \frac{(1320\text{ Hz})}{n+1}, \\ (n+1)(880\text{ Hz}) &= n(1320\text{ Hz}), \\ n &= \frac{(880\text{ Hz})}{(1320\text{ Hz}) - (880\text{ Hz})} = 2. \end{aligned}$$

Now that we know n we can find v,

$$v = 2(0.300\,\text{m})\frac{(880\text{ Hz})}{2} = 264\,\text{m/s}$$

And, finally, we are in a position to find the tension, since

$$F = \mu v^2 = (0.652\times10^{-3}\text{kg/m})(264\,\text{m/s})^2 = 45.4\,\text{N}.$$

P19-14 (a) There are five choices for the first fork, and four for the second. That gives 20 pairs. But order doesn't matter, so we need divide that by two to get a maximum of 10 possible beat frequencies.

(b) If the forks are ordered to have equal differences (say, 400 Hz, 410 Hz, 420 Hz, 430 Hz, and 440 Hz) then there will actually be only 4 beat frequencies.

P19-15 $v = (2.25\times10^8\text{m/s})/\sin(58.0°) = 2.65\times10^8\text{m/s}$.

P19-16 (a) $f_1 = (442\text{ Hz})(343\,\text{m/s})/(343\,\text{m/s} - 31.3\,\text{m/s}) = 486\text{ Hz}$, while

$$f_2 = (442\text{ Hz})(343\,\text{m/s})/(343\,\text{m/s} + 31.3\,\text{m/s}) = 405\text{ Hz},$$

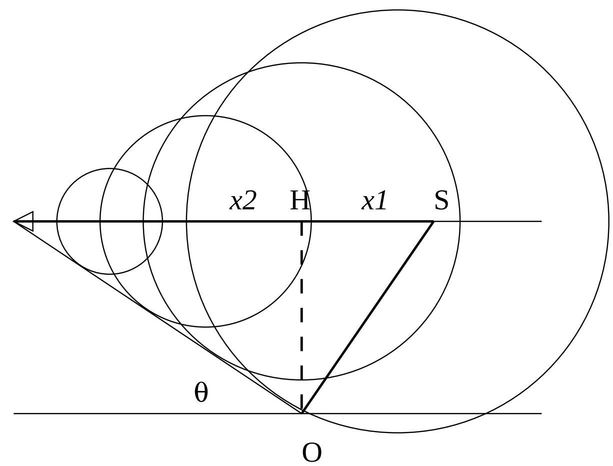
so $\Delta f = 81$ Hz.

(b) $f_1 = (442\text{ Hz})(343\,\text{m/s} - 31.3\,\text{m/s})/(343\,\text{m/s}) = 402\text{ Hz}$, while

$$f_2 = (442\text{ Hz})(343\,\text{m/s} + 31.3\,\text{m/s})/(343\,\text{m/s}) = 482\text{ Hz},$$

so $\Delta f = 80$ Hz.

P19-17 The sonic boom that you hear is not from the sound given off by the plane when it is overhead, it is from the sound given off *before* the plane was overhead. So this problem isn't as simple as distance equals velocity × time. It is *very* useful to sketch a picture.



We can find the angle θ from the figure, we'll get Eq. 19-45, so

$$\sin\theta = \frac{v}{v_s} = \frac{(330\,\mathrm{m/s})}{(396\,\mathrm{m/s})} = 0.833 \text{ or } \theta = 56.4^\circ$$

Note that v_s is the speed of the source, not the speed of sound!

Unfortunately $t = 12\,\mathrm{s}$ is *not* the time between when the sonic boom leaves the plane and when it arrives at the observer. It is the time between when the plane is overhead and when the sonic boom arrives at the observer. That's why there are so many marks and variables on the figure. x_1 is the distance from where the sonic boom which is heard by the observer is emitted to the point directly overhead; x_2 is the distance from the point which is directly overhead to the point where the plane is when the sonic boom is heard by the observer. We do have $x_2 = v_s(12.0\,\mathrm{s})$. This length forms one side of a right triangle HSO, the opposite side of this triangle is the side HO, which is the height of the plane above the ground, so

$$h = x_2 \tan\theta = (343\,\mathrm{m/s})(12.0\,\mathrm{s})\tan(56.4^\circ) = 7150\,\mathrm{m}.$$

P19-18 (a) The target "hears"

$$f' = f_s \frac{v+V}{v}.$$

This sound is reflected back to the detector which then "hears"

$$f_r = f' \frac{v}{v-V} = f_s \frac{v+V}{v-V}.$$

(b) Rearranging,

$$V/v = \frac{f_r - f_s}{f_r + f_s} \approx \frac{1}{2}\frac{f_r - f_s}{f_s},$$

where we have assumed that the source frequency and the reflected frequency are almost identical, so that when added $f_r + f_s \approx 2f_s$.

P19-19 (a) We apply Eq. 19-44

$$f' = f\frac{v+v_O}{v-v_S} = (1030\text{ Hz})\frac{(5470\text{ km/h}) + (94.6\text{ km/h})}{(5470\text{ km/h}) - (20.2\text{ km/h})} = 1050\text{ Hz}$$

(b) The reflected signal has a frequency equal to that of the signal received by the second sub originally. Applying Eq. 19-44 again,

$$f' = f\frac{v + v_O}{v - v_S} = (1050\text{ Hz})\frac{(5470\text{ km/h}) + (20.2\text{ km/h})}{(5470\text{ km/h}) - (94.6\text{ km/h})} = 1070\text{ Hz}$$

P19-20 In this case $v_S = 75.2\text{ km/h} - 30.5\text{ km/h} = 12.4\,\text{m/s}$. Then

$$f' = (989\text{ Hz})(1482\,\text{m/s})(1482\,\text{m/s} - 12.4\,\text{m/s}) = 997\text{ Hz}.$$

P19-21 There is no relative motion between the source and observer, so there is no frequency shift regardless of the wind direction.

P19-22 (a) $v_S = 34.2\,\text{m/s}$ and $v_O = 34.2\,\text{m/s}$, so

$$f' = (525\text{ Hz})(343\,\text{m/s} + 34.2\,\text{m/s})/(343\,\text{m/s} - 34.2\,\text{m/s}) = 641\text{ Hz}.$$

(b) $v_S = 34.2\,\text{m/s} + 15.3\,\text{m/s} = 49.5\,\text{m/s}$ and $v_O = 34.2\,\text{m/s} - 15.3\,\text{m/s} = 18.9\,\text{m/s}$, so

$$f' = (525\text{ Hz})(343\,\text{m/s} + 18.9\,\text{m/s})/(343\,\text{m/s} - 49.5\,\text{m/s}) = 647\text{ Hz}.$$

(c) $v_S = 34.2\,\text{m/s} - 15.3\,\text{m/s} = 18.9\,\text{m/s}$ and $v_O = 34.2\,\text{m/s} + 15.3\,\text{m/s} = 49.5\,\text{m/s}$, so

$$f' = (525\text{ Hz})(343\,\text{m/s} + 49.5\,\text{m/s})/(343\,\text{m/s} - 18.9\,\text{m/s}) = 636\text{ Hz}.$$