17-13. From graph: $\Delta p_m = 8 \times 10^{-3}$ Pa; $T = 2 \times 10^{-3}$ s. Data from problem: $\rho = 1.21\,\mathrm{kg/m^3}$ (later $1.35\,\mathrm{kg/m^3}$), $v = 343\,\mathrm{m/s}$ (later $320\,\mathrm{m/s}$)

(a) Eq. 17-15 reports: $s_m = \Delta p_m / v\rho\omega$ and as usual $\omega = 2\pi/T$ so:

$$s_m = \frac{\Delta p_m}{v\rho\omega} = \frac{\Delta p_m T}{v\rho 2\pi} = \frac{8 \times 10^{-3} \cdot 2 \times 10^{-3}}{343 \cdot 1.21 \cdot 2\pi} \; \frac{\mathrm{N/m^2 \cdot s}}{\mathrm{m/s \cdot kg/m^3}} = 6.14 \times 10^{-9}\ \mathrm{m}$$

(b)

$$k = \frac{\omega}{v} = \frac{2\pi}{Tv} = \frac{2\pi}{2 \times 10^{-3}\,\mathrm{s} \cdot 343\,\mathrm{m/s}} = 9.16\,\mathrm{m^{-1}}$$

(c)

$$\omega = \frac{2\pi}{T} = \frac{2\pi}{2 \times 10^{-3}\,\mathrm{s}} = 3140\,\mathrm{s^{-1}}$$

(d)

$$s_m = \frac{\Delta p_m T}{v\rho 2\pi} = \frac{8 \times 10^{-3} \cdot 2 \times 10^{-3}}{320 \cdot 1.35 \cdot 2\pi} \; \frac{\mathrm{N/m^2 \cdot s}}{\mathrm{m/s \cdot kg/m^3}} = 5.89 \times 10^{-9}\ \mathrm{m}$$

(e)

$$k = \frac{2\pi}{Tv} = \frac{2\pi}{2 \times 10^{-3}\,\mathrm{s} \cdot 320\,\mathrm{m/s}} = 9.82\,\mathrm{m^{-1}}$$

(f) unchanged

17-17. 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.

(a) 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

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

(b) 3

(c) 5

(d) 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

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

Since $20,000/686 = 29.2$, n must be in the range from 1 to 29 for the frequency to be audible and $f = 686,\ 1372,\ \ldots,\ 19890\,\mathrm{Hz}$.

(e) 2

(f) 3

17-36. At the beginning of the exercises and problems section in the textbook, we are told to assume $v_{\text{sound}} = 343$ 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

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

(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 $L_A = (2)(343)/2(600) = 0.572$ m.

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

17-47. 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 $(= \sqrt{\tau/\mu})$ 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 $f_1 = 600\,\text{Hz}$ and $f_2 = 606\,\text{Hz}$. 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

$$\Delta\tau/\tau = (f_2/f_1)^2 - 1 = [(606\,\text{Hz})/(600\,\text{Hz})]^2 - 1 = 0.0201 .$$

17-69. Since the amplitudes are all the same: $\sum_{k=1}^{4} a_k e^{i\delta_k} = a_1 \sum_{k=1}^{4} e^{i\delta_k}$, however the sum of the phase shifts is exactly zero: $e^{0i} + e^{.7\pi i} + e^{\pi i} + e^{1.7\pi i} = 1 + e^{\pi i} + e^{.7\pi i}\left(1 + e^{\pi i}\right) = 0$. As usual we have used:

$$\begin{aligned}
h(t) &= a_1\cos(\omega t + \delta_1) + a_2\cos(\omega t + \delta_2) + \cdots + a_N\cos(\omega t + \delta_N) \\
&= \sum_{k=1}^{N} a_k \cos(\omega t + \delta_k) \\
&= \text{Re}\left[\left(a_1 e^{i\delta_1} + a_2 e^{i\delta_1} + \cdots + a_N e^{i\delta_N}\right)\ e^{i\omega t}\right] \\
&= \text{Re}\left[\left(\sum_{k=1}^{N} a_k e^{i\delta_k}\right)\ e^{i\omega t}\right]
\end{aligned}$$

17-27. (a) From Eq. 17-29 we have:

$$\begin{aligned}
10\log\left(\frac{I}{I_0}\right) &= \beta \\
\log\left(\frac{I}{I_0}\right) &= \beta/10 \\
\left(\frac{I}{I_0}\right) &= 10^{\beta/10} \\
I &= I_0\ 10^{\beta/10} \\
&= 10^{-12}\ 10^{70/10} = 10^{-5}\ \text{W/m}^2
\end{aligned}$$

(b) Note that intensity ratios are related to dB differences:

$$\begin{aligned}
10\log\left(\frac{I_1}{I_0}\right) &= \beta_1 \\
10\log\left(\frac{I_2}{I_0}\right) &= \beta_2
\end{aligned}$$

since subtracting these two equations shows:

$$10\left[\log\left(\frac{I_1}{I_0}\right) - \log\left(\frac{I_2}{I_0}\right)\right] = 10\left[\log\left(\frac{I_1}{I_2}\right)\right] = \beta_1 - \beta_2$$

so

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

Here final/initial is requested:

$$\left(\frac{I_f}{I_i}\right) = 10^{(\beta_f-\beta_i)/10} = 10^{(50-70)/10} = 10^{-2}$$

(c) Using Eq. 17-27 we can realted intensities to displacement amplitudes:

$$s_m = \sqrt{\frac{2I}{\rho v\omega^2}} = \sqrt{\frac{2\cdot 10^{-5}}{1.21\cdot 343\cdot(2\pi\ 500)^2}} = 69.9\times 10^{-9}\ \mathrm{m}$$

Unit check:

$$\sqrt{\frac{(\mathrm{N}\cdot\mathrm{m/s})\cdot\mathrm{m}^{-2}}{\mathrm{kg/m}^3\cdot\mathrm{m/s}\cdot\mathrm{s}^{-2}}} = \sqrt{\mathrm{m}^2} = \mathrm{m}$$

(d) Note that $I \propto s_m^2$ so:

$$10\log\left(\frac{I}{I_0}\right) = 20\log\left(\frac{s_m}{s_{m0}}\right) = \beta$$

As above, consider dB differences to find s_m ratios:

$$20\left[\log\left(\frac{s_{m1}}{s_{m2}}\right)\right] = \beta_1-\beta_2$$

We are asked to find ratio: final/initial:

$$\left(\frac{s_{mf}}{s_{mi}}\right) = 10^{(\beta_f-\beta_i)/20} = 10^{-1}$$

17-50. The Doppler effect formula, Eq. 17-47, and its accompanying rule for choosing $\pm$ signs, are discussed in §17-9. Using that notation, we have $v = 343$ m/s, $v_D = v_S = 160000/3600 = 44.4$ m/s, and $f = 500$ Hz. Thus,

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

17-61. 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

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

(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,

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

(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,

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

17-63. (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 $\theta = 41.8°$.

(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: $t = d/v = h/v\tan\theta = (5000\,\mathrm{m})/1.5(331\,\mathrm{m/s})\tan 41.8° = 11.3\,\mathrm{s}$.