Chapter 14
Sound

Answers to Even Numbered Conceptual Questions

2. The resonant frequency depends on the length of the pipe. Thus, changing the length of the pipe will cause different frequencies to be emphasized in the resulting sound.

8. The speed of light is so high that the arrival of the flash is practically simultaneous with the lightning discharge. Thus, the delay between the flash and the arrival of the sound of thunder is the time sound takes to travel the distance separating the lightning from you. By counting the seconds between the flash and thunder and knowing the approximate speed of sound in air, you have a rough measure of the distance to the lightning bolt.

12. No. Adding two sounds of equal loudness will produce an intensity double that associated with either individual sound. However, the decibel scale is a logarithmic function of intensity, so doubling the intensity only increases the decibel level by $10\log 2$. Thus, the decibel level with both sounds present will be 53 dB.

14. A beam of radio waves of known frequency is sent toward a speeding car, which reflects the beam back to a detector in the police car. The amount the returning frequency has been shifted depends on the velocity of the oncoming car.

20. A vibrating string is not able to set very much air into motion when vibrated alone. Thus it will not be very loud. If it is placed on the instrument, however, the string's vibration sets the sounding board of the guitar into vibration. A vibrating piece of wood is able to move a lot of air, and the note is louder.

Problem Solutions

14.1 Since $v_{light} >> v_{sound}$, we ignore the time required for the lightning flash to reach the observer in comparison to the transit time for the sound. Then,

$$d \approx (343\text{ m/s})(16.2\text{ s}) = 5.56\times10^{3}\text{ m} = \boxed{5.56\text{ km}}$$

14.9 The decibel level $\beta = 10\log(I/I_0)$, where $I_0 = 1.00\times10^{-12}\text{ W/m}^2$.

(a) If $\beta = 100$, then $\log(I/I_0) = 10$ giving $I = 10^{10} I_0 = \boxed{1.00\times10^{-2}\text{ W/m}^2}$

(b) If all three toadfish sound at the same time, the total intensity of the sound produced is $I' = 3I = 3.00\times10^{-2}\text{ W/m}^2$, and the decibel level is

$$\beta' = 10\log\left(\frac{3.00\times10^{-2}\text{ W/m}^2}{1.00\times10^{-12}\text{ W/m}^2}\right)$$

$$= 10\log\left[(3.00)(10^{10})\right] = 10\left[\log(3.00)+10\right] = \boxed{105}$$

14.10 The sound power incident on the eardrum is $\mathcal{P} = IA$ where I is the intensity of the sound and $A = 5.0\times10^{-5}\text{ m}^2$ is the area of the eardrum.

(a) At the threshold of hearing, $I = 1.0\times10^{-12}\text{ W/m}^2$, and

$$\mathcal{P} = (1.0\times10^{-12}\text{ W/m}^2)(5.0\times10^{-5}\text{ m}^2) = \boxed{5.0\times10^{-17}\text{ W}}$$

(b) At the threshold of pain, $I = 1.0\text{ W/m}^2$, and

$$\mathcal{P} = (1.0\text{ W/m}^2)(5.0\times10^{-5}\text{ m}^2) = \boxed{5.0\times10^{-5}\text{ W}}$$

14.17 (a) The intensity of sound at 10 km from the horn (where $\beta = 50$ dB) is

$$I = I_0 10^{\beta/10} = \left(1.0 \times 10^{-12} \text{ W/m}^2\right) 10^{5.0} = 1.0 \times 10^{-7} \text{ W/m}^2$$

Thus, from $I = \tilde{A}/4\pi r^2$, the power emitted by the source is

$$\tilde{A} = 4\pi r^2 I = 4\pi\left(10 \times 10^3 \text{ m}\right)^2\left(1.0 \times 10^{-7} \text{ W/m}^2\right) = \boxed{1.3 \times 10^2 \text{ W}}$$

(b) At $r = 50$ m, the intensity of the sound will be

$$I = \frac{\tilde{A}}{4\pi r^2} = \frac{1.3 \times 10^2 \text{ W}}{4\pi(50 \text{ m})^2} = 4.0 \times 10^{-3} \text{ W/m}^2$$

and the sound level is

$$\beta = 10 \log\left(\frac{I}{I_0}\right) = 10 \log\left(\frac{4.0 \times 10^{-3} \text{ W/m}^2}{1.0 \times 10^{-12} \text{ W/m}^2}\right) = 10 \log\left(4.0 \times 10^9\right) = \boxed{96 \text{ dB}}$$

14.21 When a stationary observer $(v_O = 0)$ hears a moving source, the observed frequency is $f_O = f_S\left(\frac{v + v_O}{v - v_S}\right) = f_S\left(\frac{v}{v - v_S}\right)$.

(a) When the train is approaching, $v_S = +40.0$ m/s and

$$\left(f_O\right)_{approach} = (320 \text{ Hz})\left(\frac{345 \text{ m/s}}{345 \text{ m/s} - 40.0 \text{ m/s}}\right) = 362 \text{ Hz}$$

After the train passes and is receding, $v_S = -40.0$ m/s and

$$\left(f_O\right)_{recede} = (320 \text{ Hz})\left[\frac{345 \text{ m/s}}{345 \text{ m/s} - (-40.0 \text{ m/s})}\right] = 287 \text{ Hz}.$$

Thus, the frequency shift that occurs as the train passes is

$\Delta f_O = \left(f_O\right)_{recede} - \left(f_O\right)_{approach} = -75.2$ Hz, or it is a $\boxed{75.2 \text{ Hz drop}}$

(b) As the train approaches, the observed wavelength is

$$\lambda = \frac{v}{(f_O)_{approach}} = \frac{345 \text{ m/s}}{362 \text{ Hz}} = \boxed{0.953 \text{ m}}$$

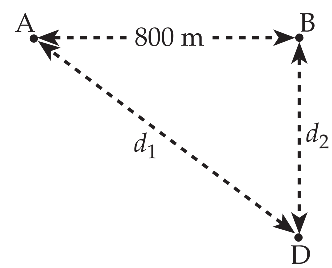
14.23 Both source and observer are in motion, so $f_O = f_S\left(\frac{v+v_O}{v-v_S}\right)$. Since each train moves *toward* the other, $v_O > 0$ and $v_S > 0$. The speed of the source (train 2) is

$$v_S = 90.0 \frac{\text{km}}{\text{h}}\left(\frac{1000 \text{ m}}{1 \text{ km}}\right)\left(\frac{1 \text{ h}}{3600 \text{ s}}\right) = 25.0 \text{ m/s}$$

and that of the observer (train 1) is $v_O = 130 \text{ km/h} = 36.1 \text{ m/s}$. Thus, the observed frequency is

$$f_O = (500 \text{ Hz})\left(\frac{345 \text{ m/s} + 36.1 \text{ m/s}}{345 \text{ m/s} - 25.0 \text{ m/s}}\right) = \boxed{595 \text{ Hz}}$$

14.31 At point D, the distance of the ship from point A is



$$d_1 = \sqrt{d_2^2 + (800 \text{ m})^2} = \sqrt{(600 \text{ m})^2 + (800 \text{ m})^2} = 1000 \text{ m}$$

Since destructive interference occurs for the first time when the ship reaches D, it is necessary that $d_1 - d_2 = \lambda/2$, or

$$\lambda = 2(d_1 - d_2) = 2(1000 \text{ m} - 600 \text{ m}) = \boxed{800 \text{ m}}$$

14.35 In the third harmonic, the string forms a standing wave of three loops, each of length $\frac{\lambda}{2} = \frac{8.00 \text{ m}}{3} = 2.67 \text{ m}$. The wavelength of the wave is then $\lambda = 5.33 \text{ m}$.

(a) The nodes in this string fixed at each end will occur at distances of

$\boxed{0, 2.67 \text{ m}, 5.33 \text{ m}, \text{and } 8.00 \text{ m}}$ from the end. Antinodes occur halfway between each pair of adjacent nodes, or at $\boxed{1.33 \text{ m}, 4.00 \text{ m}, \text{and } 6.67 \text{ m}}$ from the end.

(b) The linear density is $\mu = \frac{m}{L} = \frac{40.0 \times 10^{-3}\ \text{kg}}{8.00\ \text{m}} = 5.00 \times 10^{-3}\ \text{kg/m}$

and the wave speed is $v = \sqrt{\frac{F}{\mu}} = \sqrt{\frac{49.0\ \text{N}}{5.00 \times 10^{-3}\ \text{kg/m}}} = 99.0\ \text{m/s}$

Thus, the frequency is $f = \frac{v}{\lambda} = \frac{99.0\ \text{m/s}}{5.33\ \text{m}} = \boxed{18.6\ \text{Hz}}$

14.37 The facing speakers produce a standing wave in the space between them, with the spacing between nodes being

$$d_{\text{NN}} = \frac{\lambda}{2} = \frac{1}{2}\left(\frac{v}{f}\right) = \frac{343\ \text{m/s}}{2(800\ \text{Hz})} = 0.214\ \text{m}$$

If the speakers vibrate in phase, the point halfway between them is an

antinode of pressure, at $\frac{1.25\ \text{m}}{2} = 0.625\ \text{m}$ from either speaker.

Then there is a node at $0.625\ \text{m} - \frac{0.214\ \text{m}}{2} = \boxed{0.518\ \text{m}}$,

a node at $0.518\ \text{m} - 0.214\ \text{m} = \boxed{0.303\ \text{m}}$,

a node at $0.303\ \text{m} - 0.214\ \text{m} = \boxed{0.0891\ \text{m}}$,

a node at $0.518\ \text{m} + 0.214\ \text{m} = \boxed{0.732\ \text{m}}$,

a node at $0.732\ \text{m} + 0.214\ \text{m} = \boxed{0.947\ \text{m}}$, and

a node at $0.947\ \text{m} + 0.214\ \text{m} = \boxed{1.16\ \text{m}}$ from one speaker.

14.41 The speed of transverse waves in the string is

$$v = \sqrt{\frac{F}{\mu}} = \sqrt{\frac{50.000\ \text{N}}{1.0000 \times 10^{-2}\ \text{kg/m}}} = 70.711\ \text{m/s}$$

The fundamental wavelength is $\lambda_1 = 2L = 1.2000\ \text{m}$ and its frequency is

$$f_1 = \frac{v}{\lambda_1} = \frac{70.711\ \text{m/s}}{1.2000\ \text{m}} = 58.926\ \text{Hz}$$

The harmonic frequencies are then

$f_n = nf_1 = n(58.926\ \text{Hz})$, with n being an integer

The largest one under $20\,000\ \text{Hz}$ is $f_{339} = 19\,976\ \text{Hz} = \boxed{19.976\ \text{kHz}}$

14.42 The distance between adjacent nodes is one-quarter of the circumference.

$$d_{\text{NN}} = d_{\text{AA}} = \frac{\lambda}{2} = \frac{20.0\ \text{cm}}{4} = 5.00\ \text{cm}$$

so $\lambda = 10.0\ \text{cm} = 0.100\ \text{m}$,

and $f = \dfrac{v}{\lambda} = \dfrac{900\ \text{m/s}}{0.100\ \text{m}} = 9.00 \times 10^3\ \text{Hz} = \boxed{9.00\ \text{kHz}}$

The singer must match this frequency quite precisely for some interval of time to feed enough energy into the glass to crack it.

14.45 Hearing would be best at the fundamental resonance, so $\lambda = 4L = 4(2.8\ \text{cm})$

and $f = \dfrac{v}{\lambda} = \dfrac{340\ \text{m/s}}{4(2.8\ \text{cm})}\left(\dfrac{100\ \text{cm}}{1\ \text{m}}\right) = 3.0 \times 10^3\ \text{Hz} = \boxed{3.0\ \text{kHz}}$

14.46 For a closed box, the resonant frequencies will have nodes at both sides, so the permitted wavelengths will be $L = \frac{n\lambda}{2} = \frac{nv}{2f}$, $(n = 1, 2, 3, \ldots)$.

Thus, $f_n = \frac{nv}{2L}$. With $L = 0.860\text{ m}$ and $L' = 2.10\text{ m}$, the resonant frequencies are:

$$f_n = \boxed{n(206\text{ Hz})} \text{ for } L = 0.860\text{ m} \text{ for each } n \text{ from 1 to 9}$$

and $$f_n = \boxed{n(84.5\text{ Hz})} \text{ for } L' = 2.10\text{ m} \text{ for each } n \text{ from 2 to 23}$$

14.49 Since the lengths, and hence the wavelengths of the first harmonics, of the strings are identical, the ratio of their fundamental frequencies is

$$\frac{f_1'}{f_1} = \frac{v'/\lambda_1}{v/\lambda_1} = \frac{v'}{v}, \text{ or } f_1' = f_1\left(\frac{v'}{v}\right)$$

Thus, the beat frequency heard when the two strings are sounded simultaneously is

$$f_{beat} = f_1 - f_1' = f_1(1 - v'/v)$$

From $v = \sqrt{F/\mu}$, the speeds of transverse waves in the two strings are

$$v = \sqrt{\frac{200\text{ N}}{\mu}} \text{ and } v' = \sqrt{\frac{196\text{ N}}{\mu}}, \text{ so } \frac{v'}{v} = \sqrt{\frac{196\text{ N}}{200\text{ N}}} = \sqrt{0.980}$$

Therefore, $f_{beat} = (523\text{ Hz})\left(1 - \sqrt{0.980}\right) = \boxed{5.26\text{ Hz}}$