14

Sound

ANSWERS TO MULTIPLE CHOICE QUESTIONS

1. All sound waves travel at the same speed in air of a given temperature. Thus, $v = \lambda f = \lambda_2 f_2$, giving

$$f_2 = \left(\frac{\lambda}{\lambda_2}\right) f = \left(\frac{\lambda}{\lambda/2}\right) f = 2f$$

and the correct choice is (b).

2. The Celsius temperature on this day was $T_C = \frac{5}{9}\left(T_F - 32\right) = \frac{5}{9}\left(134 - 32\right) = 56.7°\text{C}$. The speed of sound in the air was

$$v = \left(331\ \text{m/s}\right)\sqrt{1 + \frac{T_C}{273}} = \left(331\ \text{m/s}\right)\sqrt{1 + \frac{56.7}{273}} = 364\ \text{m/s}$$

and the correct answer is (c).

3. The speed of sound in a fluid is given in Equation 14.1 as $v = \sqrt{B/\rho}$, where B is the bulk modulus of the fluid and ρ is its density. The speed of sound in ethyl alcohol is found to be

$$v = \sqrt{\frac{B}{\rho}} = \sqrt{\frac{1.0 \times 10^9\ \text{Pa}}{0.806 \times 10^3\ \text{kg/m}^3}} = 1.1 \times 10^3\ \text{m/s}$$

and (a) is the correct choice.

4. Note that the value given for the speed of sound in aluminum in Table 14.1 is for “bulk media” only and does not apply to the thin, solid rod at issue here. Thus, we turn to Equation 14.3, and use data from Tables 9.1 and 9.2 to obtain

$$v_{\text{Al}} = \sqrt{\frac{Y_{\text{Al}}}{\rho_{\text{Al}}}} = \sqrt{\frac{7.0\times 10^{10}\ \text{Pa}}{2.7\times 10^{3}\ \text{kg/m}^{3}}} = 5.1\times 10^{3}\ \text{m/s}$$

This shows choice (e) to be the correct answer.

8. When a sound wave travels from air into water, several properties will change. The wave speed will increase as the wave crosses the boundary into the water, the spacing between crests (the wavelength) will increase since crests move away from the boundary faster than they move up to the boundary, and the sound intensity in the water will be less than it was in air because some sound is reflected by the water surface. However, the frequency (number of crests passing each second) will be unchanged, since a crest moves away from the boundary every time a crest arrives at the boundary. Among the listed choices, the only correct statement is choice (d).

PROBLEM SOLUTIONS

14.1 (a) We ignore the time required for the lightning flash to arrive. Then, the distance to the lightning stroke is

$$d \approx v_{\text{sound}} \cdot \Delta t = (343\ \text{m/s})(16.2\ \text{s}) = 5.56\times 10^{3}\ \text{m} = \boxed{5.56\ \text{km}}$$

(b) $\boxed{\text{No.}}$ Since $v_{\text{light}} >> v_{\text{sound}}$, the time required for the flash of light to reach the observer is negligible in comparison to the time required for the sound to arrive, and knowledge of the actual value of the speed of light is not needed.

14.3 The Celsius temperature is $T_C = \frac{5}{9}(T_F - 32) = \frac{5}{9}(114 - 32) = 45.6°\text{C}$ and the speed of sound in the air is

$$v = (331\ \text{m/s})\sqrt{1 + \frac{T_C}{273}} = (331\ \text{m/s})\sqrt{1 + \frac{45.6}{273}} = \boxed{358\ \text{m/s}}$$

14.5 Since the sound had to travel the distance between the hikers and the mountain twice, the time required for a one-way trip was 1.50 s. The distance the sound traveled to the mountain was

$$d = (343\ \text{m/s})(1.50\ \text{s}) = \boxed{515\ \text{m}}$$

14.10 (a) The decibel level, β, of a sound is given $\beta = 10\log(I/I_0)$, where I is the intensity of the sound, and $I_0 = 1.0 \times 10^{-12}\ \text{W/m}^2$ is the reference intensity. Therefore, if $\beta = 150$ dB, the intensity is

$$I = I_0 \times 10^{\beta/10} = (1.0 \times 10^{-12}\ \text{W/m}^2) \times 10^{15} = \boxed{1.0 \times 10^3\ \text{W/m}^2}$$

(b) The threshold of pain is $I = 1\ \text{W/m}^2$ and the answer to part (a) is 1 000 times greater than this, explaining why some airport employees must wear hearing protection equipment.

14.24 The general expression for the observed frequency of a sound when the source and/or the observer are in motion is

$$f_O = f_S\left(\frac{v + v_O}{v - v_S}\right)$$

Here, v is the velocity of sound in air, v_O is the velocity of the observer, v_S is the velocity of the source, and f_S is the frequency that would be detected if both the source and observer were stationary.

(a) If $f_s = 5.00\ \text{kHz}$ and the observer is stationary $(v_o = 0)$, the frequency detected when the source moves toward the observer at half the speed of sound $(v_s = +v/2)$ is

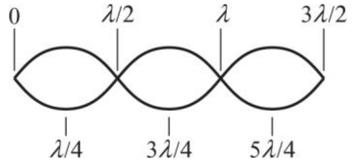
$$f_o = (5.00\ \text{kHz})\left(\frac{v+0}{v-v/2}\right) = (5.00\ \text{kHz})(2) = \boxed{10.0\ \text{kHz}}$$

(b) When $f_s = 5.00\ \text{kHz}$ and the source moves away from a stationary observer at half the speed of sound $(v_s = -v/2)$, the observed frequency is

$$f_o = (5.00\ \text{kHz})\left(\frac{v+0}{v+v/2}\right) = (5.00\ \text{kHz})\left(\frac{2}{3}\right) = \boxed{3.33\ \text{kHz}}$$

14.39 In the third harmonic, the string of length L forms a standing wave of three loops, each of length $\lambda/2 = L/3$. The wavelength of the wave is then

$$\lambda = \frac{2L}{3} = \frac{16.0\ \text{m}}{3} \approx 5.33\ \text{m}$$



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

$\boxed{0,\ \lambda/2 = 2.67\ \text{m},\ \lambda = 5.33\ \text{m, and }\ 3\lambda/2 = 8.00\ \text{m}}$ from the end.

Antinodes occur halfway between each pair of adjacent nodes, or at distances of

$\boxed{\lambda/4 = 1.33\ \text{m},\ 3\lambda/4 = 4.00\ \text{m, and }\ 5\lambda/4 = 6.67\ \text{m}}$ 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 $f = \dfrac{v}{\lambda} = \dfrac{99.0\ \text{m/s}}{5.33\ \text{m}} = \boxed{18.6\ \text{Hz}}$

14.40 In the fundamental mode, the distance from the finger of the cellist to the far end of the string is one-half of the wavelength for the transverse waves in the string. Thus, when the string resonates at 449 Hz,

$$\lambda = 2(68.0\ \text{cm} - 20.0\ \text{cm}) = 96.0\ \text{cm}$$

The speed of transverse waves in the string is therefore

$$v = \lambda f = (0.960\ \text{m})(449\ \text{Hz}) = 431\ \text{m/s}$$

For a resonance frequency of 440 Hz, the wavelength would be

$$\lambda' = \frac{v}{f'} = \frac{431\ \text{m/s}}{440\ \text{Hz}} = 0.980\ \text{m} = 98.0\ \text{cm}$$

To produce this tone, the cellist should position her finger at a distance of

$$x = L - \frac{\lambda}{2} = 68.0\text{ cm} - \frac{98.0\text{ cm}}{2} = 19.0\text{ cm}$$

from the nut. Thus, she should $\boxed{\text{move her finger 1.00 cm toward the nut.}}$

$$f_1' = \frac{v'}{\lambda_1'} = \frac{(331\text{ m/s})\sqrt{1 + 52.2/273}}{2(0.500\text{ m})[1 + (19 \times 10^{-6}\ ^\circ\text{C}^{-1})(20.0^\circ\text{C})]} = \boxed{3.6 \times 10^{2}\text{ Hz}}$$