Chapter 15 Traveling Waves

Problems: 2, 8, 11, 12, 25, 48, 54, 57, 72, 74, 87 Bonus: 17, 73

2 A pulse on a horizontal taut string travels to the right. If the rope's mass per unit length decreases to the right, what happens to the speed of the pulse as it travels to the right? (*a*) It slows down. (*b*) It speeds up. (*c*) Its speed is constant. (*d*) You cannot tell from the information given.

Determine the Concept The speed v of a pulse on the string varies with the tension F_T in the string and its mass per unit length μ according to $v = \sqrt{F_T/\mu}$. Because the rope's mass per unit length decreases to the right, the speed of the pulse increases. $\boxed{(b)}$ is correct.

8 Sound travels at 343 m/s in air and 1500 m/s in water. A sound of 256 Hz is made under water, but you hear the sound while walking along the side of the pool. In the air, the frequency is (*a*) the same, but the wavelength of the sound is shorter, (*b*) higher, but the wavelength of the sound stays the same, (*c*) lower, but the wavelength of the sound is longer, (*d*) lower, and the wavelength of the sound is shorter, (*e*) the same, and the wavelength of the sound stays the same.

Determine the Concept In any medium, the wavelength, frequency, and speed of a sound wave are related through $\lambda = v/f$. Because the frequency of a wave is determined by its source and is independent of the nature of the medium, if v is greater in water than in air, λ will be greater in water than in air. $\boxed{(a)}$ is correct.

11 At a given location, two harmonic sound waves have the same amplitude, but the frequency of sound A is twice the frequency of sound B. How do their average energy densities compare? (*a*) The average energy density of A is twice the average energy density of B. (*b*) The average energy density of A is four times the average energy density of B. (*c*) The average energy density of A is 16 times the average energy density of B. (*d*) You cannot compare the average energy densities from the data given.

Determine the Concept The average energy density of a sound wave is given by $\eta_{av} = \frac{1}{2}\rho\omega^2 s_0^2$ where ρ is the average density of the medium, s_0 is the displacement amplitude of the molecules making up the medium, and ω is the angular frequency of the sound waves.

Express the average energy density of sound A:

$$\eta_{av,A} = \frac{1}{2}\rho_A\omega_A^2 s_{0,A}^2$$

The average energy density of sound B is given by:

$$\eta_{\text{av, B}} = \tfrac{1}{2}\rho_B\omega_B^2 s_{0,B}^2$$

Dividing the first of these equation by the second yields:

$$\frac{\eta_{\text{av, A}}}{\eta_{\text{av, B}}} = \frac{\tfrac{1}{2}\rho_A\omega_A^2 s_{0,A}^2}{\tfrac{1}{2}\rho_B\omega_B^2 s_{0,B}^2}$$

Because the sound waves are identical except for their frequencies:

$$\frac{\eta_{\text{av, A}}}{\eta_{\text{av, B}}} = \frac{\omega_A^2}{\omega_B^2} = \left(\frac{2\pi f_A}{2\pi f_B}\right)^2 = \left(\frac{f_A}{f_B}\right)^2$$

Because $f_A = 2f_B$:

$$\frac{\eta_{\text{av, A}}}{\eta_{\text{av, B}}} = \left(\frac{2f_B}{f_B}\right)^2 = 4 \Rightarrow \eta_{\text{av, A}} = 4\eta_{\text{av, B}}$$

$\boxed{(b)}$ is correct.

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Because the sound waves are identical except for their displacement amplitudes:

$$\frac{\eta_{\text{av, A}}}{\eta_{\text{av, B}}} = \frac{s_{0,A}^2}{s_{0,B}^2} = \left(\frac{s_{0,A}}{s_{0,B}}\right)^2$$

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$\boxed{(b)}$ is correct.

17 One end of a very light (but strong) thread is attached to an end of a thicker and denser cord. The other end of the thread is fastened to a sturdy post and you pull the other end of the cord so the thread and cord are taut. A pulse is sent down the thicker, denser cord. True or false:

(*a*) The pulse that is reflected back from the thread-cord attachment point is inverted compared to the initial incoming pulse.

(*b*) The pulse that continues past the thread-cord attachment point is not inverted compared to the initial incoming pulse.
(*c*) The pulse that continues past the thread-cord attachment point has an amplitude that is smaller than the pulse that is reflected.

(*a*) False. Because the reflection medium (cord) in which the pulse travels initially has a greater linear density than the transmission medium (thread), there is no phase shift in the reflected pulse.
(*b*) True. Because the thread-cord attachment point of the media is more like a loose end than a fixed end, the pulse transmitted into the light thread is in phase with the incoming pulse in the thicker, denser cord.
(*c*) True. Because the string is attached to a thicker, denser cord, the reflected pulse behaves almost as though it was reflected from a fixed end and is, therefore, inverted. The pulse in the light thread is in phase with the incoming pulse in the thicker, denser cord. Because energy is conserved and there is some energy transmitted and some reflected, the transmitted wave cannot have an amplitude as large as the amplitude of the pulse in the thicker, denser cord.

25 The explosion of a depth charge beneath the surface of the water is recorded by a helicopter hovering above its surface, as shown in Figure 15-31. Along which path, A, B, or C, will the sound wave take the least time to reach the helicopter? Explain why you chose the path you did.

Determine the Concept Path C. Because the wave speed is highest in the water, and more of path C is underwater than A or B, the sound wave will spend the least time on path C.

48 (*a*) Middle C on the musical scale has a frequency of 262 Hz. What is the wavelength of this note in air? (*b*) The frequency of the C an octave above middle C is twice that of middle C. What is the wavelength of this note in air?

Picture the Problem The frequency, wavelength, and speed of the sound waves are related by $v = f\lambda$.

(*a*) The wavelength of middle C is given by:

$$\lambda = \frac{v}{f} = \frac{340\,\text{m/s}}{262\,\text{s}^{-1}} = \boxed{1.30\,\text{m}}$$

(*b*) Evaluate λ for a frequency twice that of middle C:

$$\lambda = \frac{v}{f} = \frac{340\,\text{m/s}}{2\left(262\,\text{s}^{-1}\right)} = \boxed{0.649\,\text{m}}$$

54 A spherical sinusoidal source radiates sound uniformly in all directions. At a distance of 10.0 m, the sound intensity level is $1.00 \times 10^{-4}\ \text{W/m}^2$. (*a*) At what distance from the source is the intensity $1.00 \times 10^{-6}\ \text{W/m}^2$? (*b*) What power is radiated by this source?

Picture the Problem The intensity of the sound from the spherical sinusoidal source varies inversely with the square of the distance from the source. The power radiated by the source is the product of the intensity of the radiation and the surface area over which it is distributed.

(*a*) Relate the intensity at 10.0 m to the distance from the source:

$$I = \frac{P_{av}}{4\pi r^2}$$

or

$$1.00\times10^{-4}\ \text{W/m}^2 = \frac{P_{av}}{4\pi(10.0\ \text{m})^2}$$

Letting r' represent the distance at which the intensity is 10^{-6} W/m^2, express the intensity as above:

$$1.00\times10^{-6}\ \text{W/m}^2 = \frac{P_{av}}{4\pi r'^2}$$

Divide the first of these equations by the second to obtain:

$$\frac{1.00\times10^{-4}\ \text{W/m}^2}{1.00\times10^{-6}\ \text{W/m}^2} = \frac{\dfrac{P_{av}}{4\pi(10.0\ \text{m})^2}}{\dfrac{P_{av}}{4\pi r'^2}}$$

Solving for r' yields:

$$r' = \sqrt{(1.00\times10^2)(10.0\ \text{m})^2} = \boxed{100\ \text{m}}$$

(*b*) Solve $I = \dfrac{P_{av}}{4\pi r^2}$ for P_{av}:

$$P_{av} = 4\pi r^2 I$$

Substitute numerical values and evaluate P_{av}:

$$P_{av} = 4\pi(10.0\ \text{m})^2(1.00\times10^{-4}\ \text{W/m}^2) = \boxed{126\ \text{mW}}$$

57 What is the intensity level in decibels of a sound wave of intensity (*a*) 1.00×10^{-10} W/m^2 and (*b*) 1.00×10^{-2} W/m^2?

Picture the Problem The intensity level β of a sound wave, measured in decibels, is given by $\beta = (10\ \text{dB})\log(I/I_0)$ where $I_0 = 10^{-12}$ W/m^2 is defined to be the threshold of hearing.

(*a*) Using its definition, calculate the intensity level of a sound wave whose intensity is 1.00×10^{-10} W/m^2:

$$\beta = (10\ \text{dB})\log\left(\frac{1.00\times10^{-10}\ \text{W/m}^2}{10^{-12}\ \text{W/m}^2}\right) = 10\log10^2 = \boxed{20.0\ \text{dB}}$$

(*b*) Proceed as in (*a*) with $I = 1.00\times10^{-2}$ W/m^2:

$$\beta = (10\ \text{dB})\log\left(\frac{1.00\times10^{-2}\ \text{W/m}^2}{10^{-12}\ \text{W/m}^2}\right) = 10\log10^{10} = \boxed{100\ \text{dB}}$$

72 A sound source is moving at 80 m/s toward a stationary listener that is standing in still air. (*a*) Find the wavelength of the sound in the region between the source and the listener. (*b*) Find the frequency heard by the listener.

Picture the Problem We can use Equation 15-38 ($\lambda = \frac{v \pm u_s}{f_s}$) to find the wavelength of the sound between the source and the listener and Equation15-41*a* ($f_r = \frac{v \pm u_r}{v \pm u_s} f_s$) to find the frequency heard by the listener.

(*a*) Apply Equation 15-38 to find λ:

$$\lambda = \frac{v \pm u_s}{f_s} = \frac{v - u_s}{f_s} = \frac{343\,\text{m/s} - 80\,\text{m/s}}{200\,\text{s}^{-1}} = \boxed{1.32\,\text{m}}$$

(*b*) Apply Equation 15-41<u>*a*</u> to obtain f_r:

$$f_r = \frac{v \pm u_r}{v \pm u_s} f_s = \frac{v \pm 0}{v - u_s} f_s = \frac{343\,\text{m/s}}{343\,\text{m/s} - 80\,\text{m/s}} \left(200\,\text{s}^{-1}\right) = \boxed{261\,\text{Hz}}$$

73 Consider the situation described in Problem 72 from the reference frame of the source. In this frame, the listener and the air are moving toward the source at 80 m/s and the source is at rest. (*a*) At what speed, relative to the source, is the sound traveling in the region between the source and the listener? (*b*) Find the wavelength of the sound in the region between the source and the listener. (*c*) Find the frequency heard by the listener.

Picture the Problem (*a*) In the reference frame of the source, the speed of sound from the source to the listener is reduced by the speed of the air. (*b*) We can find the wavelength of the sound in the region between the source and the listener from $v = f\lambda$. (*c*) Because the sound waves in the region between the source and the listener will be compressed by the motion of the listener, the frequency of the sound heard by the listener will be higher than the frequency emitted by the source and can be calculated using $f_r = \frac{v \pm u_r}{v \pm u_s} f_s$ (Equation 15-41*a*).

(*a*) The speed of sound in the reference frame of the source is:

$$v' = v - u_{\text{wind}} = 343\,\text{m/s} - 80\,\text{m/s} = \boxed{263\,\text{m/s}}$$

(*b*) Noting that the frequency is unchanged, express the wavelength of the sound:

$$\lambda = \frac{v'}{f} = \frac{263\,\text{m/s}}{200\,\text{s}^{-1}} = \boxed{1.32\,\text{m}}$$

(*c*) Apply Equation 15-41*a* to obtain:

$$f_r = \frac{v' \pm u_r}{v' \pm u_s} f_s = \left(\frac{v' + u_r}{v' \pm 0}\right) f_s$$

$$= \left(\frac{263\,\text{m/s} + 80\,\text{m/s}}{263\,\text{m/s}}\right)\left(200\,\text{s}^{-1}\right)$$

$$= \boxed{261\,\text{Hz}}$$

74 A sound source is moving away from the stationary listener at 80 m/s. (*a*) Find the wavelength of the sound waves in the region between the source and the listener. (*b*) Find the frequency heard by the listener.

Picture the Problem We can use $\lambda = (v \pm u_s)/f_s$ (Equation 15-38) to find the wavelength of the sound in the region between the source and the listener and $f_r = \frac{v \pm u_r}{v \pm u_s} f_s$ (Equation 15-41*a*) to find the frequency heard by the listener. Because the sound waves in the region between the source and the listener will be spread out by the motion of the listener, the frequency of the sound heard by the listener will be lower than the frequency emitted by the source.

(*a*) Because the source is moving away from the listener, use the positive sign in the numerator of Equation 15-38 to find the wavelength of the sound between the source and the listener:

$$\lambda = \frac{v \pm u_s}{f_s} = \frac{v + u_s}{f_s}$$

$$= \frac{343\,\text{m/s} + 80\,\text{m/s}}{200\,\text{s}^{-1}}$$

$$= \boxed{2.12\,\text{m}}$$

(*b*) Because the listener is at rest and the source is receding, $u_r = 0$ and the denominator of Equation 15-41*a* is the sum of the two speeds:

$$f_r = \frac{v \pm u_r}{v \pm u_s} f_s = \frac{v \pm 0}{v + u_s} f_s$$

$$= \frac{343\,\text{m/s}}{343\,\text{m/s} + 80\,\text{m/s}}\left(200\,\text{s}^{-1}\right)$$

$$= \boxed{162\,\text{Hz}}$$

87 The driver of a car traveling at 100 km/h toward a vertical wall briefly sounds the horn. Exactly 1.00 s later she hears the echo and notes that its frequency is 840 Hz. How far from the wall was the car when the driver sounded the horn and what is the frequency of the horn?

Picture the Problem Let $t = 0$ when the driver sounds her horn and let the distance to the wall at that instant be d. The received and transmitted frequencies are related through $f_r = \frac{v \pm u_r}{v \pm u_s} f_s$ (Equation 15-41*a*). Solving this equation for f_s

will allow us to determine the frequency of the car horn. We can use the total distance the sound travels (car-to-wall plus wall-back to-car … now closer to the wall) to determine the distance to the wall when the horn was briefly sounded.

Use Equation 15-41*a* to relate the frequency heard by the driver to her speed and to the frequency of her horn:

$$f_r = \frac{v \pm u_r}{v \pm u_s} f_s = \frac{1 \pm \frac{u_r}{v}}{1 \pm \frac{u_s}{v}} f_s = \frac{1 + \frac{u_r}{v}}{1 - \frac{u_s}{v}} f_s$$

Solving for f_s yields:

$$f_s = \frac{1 - \frac{u_s}{v}}{1 + \frac{u_r}{v}} f_r$$

Substitute numerical values and evaluate f_s:

$$f_s = \frac{1 - \frac{100\frac{\text{km}}{\text{h}} \times \frac{1\,\text{h}}{3600\,\text{s}}}{343\,\text{m/s}}}{1 + \frac{100\frac{\text{km}}{\text{h}} \times \frac{1\,\text{h}}{3600\,\text{s}}}{343\,\text{m/s}}}(840\,\text{Hz}) = \frac{1 - \frac{27.78\,\text{m/s}}{343\,\text{m/s}}}{1 + \frac{27.78\,\text{m/s}}{343\,\text{m/s}}}(840\,\text{Hz}) = \boxed{714\,\text{Hz}}$$

Relate the distance *d* to the wall at $t = 0$ to the distance she travels in time $\Delta t = 1$ s, her speed u_s, and the speed of sound *v*:

$$d + (d - u_s \Delta t) = v\Delta t \Rightarrow d = \tfrac{1}{2}(u_s + v)\Delta t$$

Substitute numerical values and evaluate *d*:

$$d = \tfrac{1}{2}(27.78\,\text{m/s} + 343\,\text{m/s})(1.00\,\text{s}) = \boxed{185\,\text{m}}$$