of the wave increase, decrease, or remain the same? Give a reason for your choice.

7. One end of each of two identical strings is attached to a wall. Each string is being pulled tight by someone at the other end. A transverse pulse is sent traveling along one of the strings. A bit later an identical pulse is sent traveling along the other string. What, if anything, can be done to make the second pulse catch up with and pass the first pulse? Account for your answer.

8. In Section 4.10 the concept of a "massless" rope is discussed. Would it take any time for a transverse wave to travel the length of a massless rope? Justify your answer.

9. In a traveling sound wave, are there any particles that are *always* at rest as the wave passes by? Justify your answer.

10. Do you expect an echo to return to you more quickly or less quickly on a hot day as compared to a cold day, other things being equal? Account for your answer.

11. A loudspeaker produces a sound wave. Does the wavelength of the sound increase, decrease, or remain the same, when the wave travels from air into water? Justify your answer. *(Hint: The frequency does not change as the sound enters the water.)*

12. JELL-O starts out as a liquid and then sets to a gel. What would you expect to happen to the speed of sound in this material as the JELL-O sets? Does it increase, decrease, or remain the same? Give your reasoning.

13. Some animals rely on an acute sense of hearing for survival, and the visible part of the ear on such animals is often relatively large. Explain how this anatomical feature helps to increase the sensitivity of the animal's hearing for low-intensity sounds.

14. A source is emitting sound uniformly in all directions. There are no reflections anywhere. A *flat* surface faces the source. Is the sound intensity the same at all points on the surface? Give your reasoning.

15. If two people talk simultaneously and each creates an intensity level of 65 dB at a certain point, does the total intensity level at this point equal 130 dB? Account for your answer.

16. Two cars, one behind the other, are traveling in the same direction at the same speed. Does either driver hear the other's horn at a frequency that is different from that heard when both cars are at rest? Justify your answer.

17. A source of sound produces the same frequency underwater as it does in air. This source has the same velocity in air as it does underwater. The observer of the sound is stationary, both in air and underwater. Is the Doppler effect greater in air or underwater when the source (a) approaches and (b) moves away from the observer? Explain.

18. A music fan at a swimming pool is listening to a radio on a diving platform. The radio is playing a constant frequency tone when this fellow, clutching his radio, jumps. Describe the Doppler effect heard by (a) a person left behind on the platform and (b) a person down below floating on a rubber raft. In each case, specify (1) whether the observed frequency is greater or smaller than the frequency produced by the radio, (2) whether the observed frequency is constant, and (3) how the observed frequency changes during the fall, if it does change. Give your reasoning.

19. When a car is at rest, its horn emits a frequency of 600 Hz. A person standing in the middle of the street hears the horn with a frequency of 580 Hz. Should the person jump out of the way? Account for your answer.

20. The text discusses how the Doppler effect arises when (1) the observer is stationary and the source moves and (2) the observer moves and the source is stationary. A car is speeding toward a large wall and sounds the horn. Is the Doppler effect present in the echo that the driver hears? If it is present, from which of the above situations does it arise, (1) or (2) or both? Explain.

PROBLEMS

ssm Solution is in the Student Solutions Manual. www Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell
This icon represents a biomedical application.

Section 16.1 The Nature of Waves, Section 16.2 Periodic Waves

1. ssm A person standing in the ocean notices that after a wave crest passes by, ten more crests pass in a time of 120 s. What is the frequency of the wave?

2. The magnetic tape of a cassette deck moves with a speed of 0.048 m/s ($1\frac{7}{8}$ inches per second). The recording head records a 15-kHz tone on the tape. What is the wavelength λ of the magnetized regions?

3. ssm In Figure 16.2 the hand moves the end of the Slinky up and down through two complete cycles in one second. The wave moves along the Slinky at a speed of 0.50 m/s. Find the distance between two adjacent crests on the wave.

4. Consider the freight train in Figure 16.7. Suppose 15 boxcars pass by in a time of 12.0 s and each has a length of 14.0 m. (a) What is the frequency at which each boxcar passes? (b) What is the speed of the train?

5. A longitudinal wave with a frequency of 3.0 Hz takes 1.7 s to travel the length of a 2.5-m Slinky (see Figure 16.3). Determine the wavelength of the wave.

6. Tsunamis are fast-moving waves often generated by underwater earthquakes. In the deep ocean their amplitude is barely noticeable, but upon reaching shore, they can rise up to the astonishing height of a six-story building. One tsunami, generated off the Aleutian islands in Alaska, had a wavelength of 750 km and traveled a distance of 3700 km in 5.3 h. (a) What was the speed

(in m/s) of the wave? For reference, the speed of a 747 jetliner is about 250 m/s. Find the wave's (b) frequency and (c) period.

7. ssm Suppose the amplitude and frequency of the transverse wave in Figure 16.2*c* are, respectively, 1.3 cm and 5.0 Hz. Find the *total vertical distance* (in cm) through which the colored dot moves in 3.0 s.

8. A person fishing from a pier observes that four wave crests pass by in 7.0 s and estimates the distance between two successive crests as 4.0 m. The timing starts with the first crest and ends with the fourth. What is the speed of the wave?

***9.** The speed of a transverse wave on a string is 450 m/s, while the wavelength is 0.18 m. The amplitude of the wave is 2.0 mm. How much time is required for a particle of the string to move through a total distance of 1.0 km?

***10.** In Figure 16.3*c* the colored "dot" exhibits simple harmonic motion as the longitudinal wave passes. The wave has an amplitude of 5.4×10^{-3} m and a frequency of 4.0 Hz. Find the maximum acceleration of the dot.

****11.** A water-skier is moving at a speed of 12.0 m/s. When she skis in the same direction as a traveling wave, she springs upward every 0.600 s because of the wave crests. When she skis in the direction opposite to that in which the wave moves, she springs upward every 0.500 s in response to the crests. The speed of the skier is greater than the speed of the wave. Determine (a) the speed and (b) the wavelength of the wave.

Section 16.3 The Speed of a Wave on a String

12. A 0.75-m string is stretched so the tension is 2.3 N. A transverse wave with a frequency of 150 Hz and a wavelength of 0.40 m travels on the string. What is the mass of the string?

***13. ssm** The linear density of the A string on a violin is 7.8×10^{-4} kg/m. A wave on the string has a frequency of 440 Hz and a wavelength of 65 cm. What is the tension in the string?

14. A vibrator moves one end of a rope up and down to generate a wave. The tension in the rope is 58 N. The frequency is then doubled. To what value must the tension be adjusted, so the new wave has the same wavelength as the old one?

15. ssm www The middle C string on a piano is under a tension of 944 N. The period and wavelength of a wave on this string are 3.82 ms and 1.26 m, respectively. Find the linear density of the string.

16. Two wires are parallel, and one is directly above the other. Each has a length of 50.0 m and a mass per unit length of 0.020 kg/m. However, the tension in wire A is 6.00×10^2 N, while the tension in wire B is 3.00×10^2 N. Transverse wave pulses are generated simultaneously, one at the left end of wire A and one at the right end of wire B. The pulses travel toward each other. How much time does it take until the pulses pass each other?

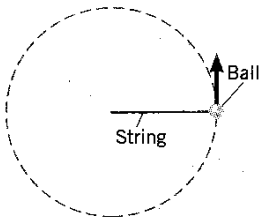
***17.** To measure the acceleration due to gravity on a distant planet, an astronaut hangs a 0.085-kg ball from the end of a wire. The wire has a length of 1.5 m and a linear density of 3.1×10^{-4} kg/m. Using electronic equipment, the astronaut measures the time for a transverse pulse to travel the length of the wire and obtains a value of 0.083 s. The mass of the wire is negligible compared to the mass of the ball. Determine the acceleration due to gravity.

***18.** Review Conceptual Example 3 before starting this problem. The amplitude of a transverse wave on a string is 4.5 cm. The ratio of the maximum particle speed to the speed of the wave is 3.1. What is the wavelength (in cm) of the wave?

***19. ssm** Two blocks are connected by a wire that has a mass per unit length of 8.50×10^{-4} kg/m. One block has a mass of 19.0 kg, while the other has a mass of 42.0 kg. These blocks are being pulled across a horizontal frictionless floor by a horizontal force **P** that is applied to the less massive block. A transverse wave travels on the wire between the blocks with a speed of 352 m/s (relative to the wire). The mass of the wire is negligible compared to the mass of the blocks. Find the magnitude of **P**.

****20.** A copper wire, whose cross-sectional area is 1.1×10^{-6} m^2, has a linear density of 7.0×10^{-3} kg/m and is strung between two walls. At the ambient temperature, a transverse wave travels with a speed of 46 m/s on this wire. The coefficient of linear expansion for copper is $17 \times 10^{-6}\,(\text{C}^\circ)^{-1}$, and Young's modulus for copper is 1.1×10^{11} N/m^2. What will be the speed of the wave when the temperature is lowered by 14 C°? Ignore any change in the linear density caused by the change in temperature.

****21.** The drawing shows a 15.0-kg ball being whirled in a circular path on the end of a string. The motion occurs on a frictionless, horizontal table. The angular speed of the ball is $\omega = 12.0$ rad/s. The string has a mass of 0.0230 kg. How much time does it take for a wave on the string to travel from the center of the circle to the ball?



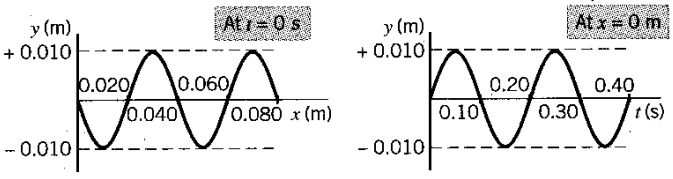
Section 16.4 The Mathematical Description of a Wave

(Note: The phase angles $(2\pi ft - 2\pi x/\lambda)$ and $(2\pi ft + 2\pi x/\lambda)$ are measured in radians, not degrees.)

22. A wave is moving in the $+x$ direction. Assuming that the wave has the following properties, write the equation of the wave (similar to Equation 16.3 or 16.4): speed = 7.1 m/s, amplitude = 0.15 m, wavelength = 0.28 m.

***23. ssm** A wave has the following properties: amplitude = 0.37 m, period = 0.77 s, wave speed = 12 m/s. The wave is traveling in the $-x$ direction. What is the mathematical expression (similar to Equation 16.3 or 16.4) for the wave?

24. The drawing shows two graphs that represent a transverse wave on a string. The wave is moving in the $+x$ direction. Using the information contained in these graphs, write the mathematical expression (similar to Equation 16.3 or 16.4) for the wave.



25. The displacement (in meters) of a wave is $y = 0.26 \sin(\pi t - 3.7\pi x)$, where t is in seconds and x is in meters. (a) Is the wave traveling in the $+x$ or $-x$ direction? (b) What is the displacement y when $t = 38$ s and $x = 13$ m?

***26.** The tension in a string is 15 N, and its linear density is 0.85 kg/m. A wave on the string travels toward the $-x$ direction; it has an amplitude of 3.6 cm and a frequency of 12 Hz. What are the (a) speed and (b) wavelength of the wave? (c) Write down a mathematical expression (like Equation 16.3 or 16.4) for the wave, substituting numbers for the variables A, f, and λ.

***27. ssm** A transverse wave is traveling on a string. The displacement y of a particle from its equilibrium position is given by $y = (0.021 \text{ m}) \sin(25t - 2.0x)$. Note that the phase angle $25t - 2.0x$ is in radians, t is in seconds, and x is in meters. The linear density of the string is 1.6×10^{-2} kg/m. What is the tension in the string?

****28.** A transverse wave on a string has an amplitude of 0.20 m and a frequency of 175 Hz. Consider the particle of the string at $x = 0$ m. It begins with a displacement of $y = 0$ m when $t = 0$ s, according to Equation 16.3 or 16.4. How much time passes between the first two instants when this particle has a displacement of $y = 0.10$ m?

Section 16.5 The Nature of Sound, Section 16.6 The Speed of Sound

29. ssm The speed of a sound in a container of hydrogen at 201 K is 1220 m/s. What would be the speed of sound if the temperature were raised to 405 K? Assume that hydrogen behaves like an ideal gas.

30. A sonar unit on a submarine sends out a pulse of sound into seawater. The pulse returns 1.30 s later. What is the distance to the object that reflects the pulse back to the submarine?

31. The right-most key on a piano produces a sound wave that has a frequency of 4185.6 Hz. Assuming that the speed of sound in air is 343 m/s, find the corresponding wavelength.

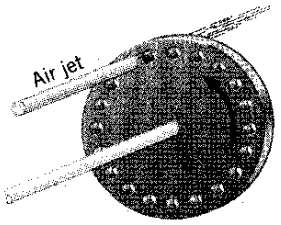
32. Have you ever listened for an approaching train by kneeling next to a railroad track and putting your "ear to the rail?" Young's modulus for steel is $Y = 2.0 \times 10^{11}$ N/m^2, and the density of steel is $\rho = 7860$ kg/m^3. On a day when the temperature is 20 °C, how many times greater is the speed of sound in the rail than in the air?

***33. ssm** Argon (molecular mass = 39.9 u) is a monatomic gas. Assuming that it behaves like an ideal gas at 298 K ($\gamma = 1.67$), find (a) the rms speed of argon atoms and (b) the speed of sound in argon.

34. A sound wave is incident on a pool of fresh water. The sound enters the water perpendicularly and travels a distance of 0.45 m before striking a 0.15-m-thick copper block lying on the bottom. The sound passes through the block, reflects from the bottom surface of the block, and returns to the top of the water along the same path. How much time elapses between when the sound enters and leaves the water?

***35.** An explosion occurs at the end of a pier. The sound reaches the other end of the pier by traveling through three media: air, fresh water, and a slender handrail of solid steel. The speeds of sound in air, water, and the handrail are 343, 1482, and 5040 m/s, respectively. The sound travels a distance of 125 m in each medium. (a) Through which medium does the sound arrive first, second, and third? (b) After the first sound arrives, how much later do the second and third sounds arrive?

36. As the drawing illustrates, a siren can be made by blowing a jet of air through 20 equally spaced holes in a rotating disk. The time it takes for successive holes to move past the air jet is the period of the sound. The siren is to produce a 2200-Hz tone. What must be the angular speed ω (in rad/s) of the disk?



37. At what temperature is the speed of sound in helium (atomic mass = 4.003 u) the same as the speed of sound in oxygen at 0 °C? Consider helium to be an ideal gas ($\gamma = 1.67$).

***38.** Review the rule of thumb in Conceptual Example 5. Suppose the speed of light were 961 m/s, instead of 3.0×10^8 m/s, but the speed of sound remained at 343 m/s. The new rule of thumb is stated as follows:

> After you see a flash of lightning, count off the seconds until the thunder is heard. Divide the number of seconds by the number X. The result gives the approximate distance (in miles) to the thunderstorm.

What is the number X?

***39. ssm** A long slender bar is made from an unknown material. The length of the bar is 0.83 m, its cross-sectional area is 1.3×10^{-4} m^2, and its mass is 2.1 kg. A sound wave travels from one end of the bar to the other end in 1.9×10^{-4} s. From which one of the materials listed in Table 10.1 is the bar most likely to be made?

***40.** When an earthquake occurs, two types of sound waves are generated and travel through the earth. The primary, or P, wave has a speed of about 8.0 km/s and the secondary, or S, wave has a speed of about 4.5 km/s. A seismograph, located some distance away, records the arrival of the P wave and then, 78 s later, records the arrival of the S wave. Assuming that the waves travel in a straight line, how far is the seismograph from the earthquake?

***41. ssm** A hunter is standing on flat ground between two vertical cliffs that are directly opposite one another. He is closer to one cliff than the other. He fires a gun and, after a while, hears three echoes. The second echo arrives 1.6 s after the first, and the third echo arrives 1.1 s after the second. Assuming that the speed of sound is 343 m/s and that there are no reflections of sound from the ground, find the distance between the cliffs.

***42.** At a height of ten meters above the surface of a lake, a sound pulse is generated. The echo from the bottom of the lake returns to the point of origin 0.140 s later. The air and water temperatures are 20 °C. How deep is the lake?

*43. A monatomic ideal gas ($\gamma = 1.67$) is contained within a box whose volume and pressure are 2.5 m^3 and 3.5×10^5 Pa, respectively. The total mass of the gas is 2.3 kg. Find the speed of sound in the gas.

*44. Both krypton (Kr) and neon (Ne) can be approximated as monatomic ideal gases. The atomic mass of krypton is 83.8 u, while that of neon is 20.2 u. A loudspeaker produces a sound whose wavelength in krypton is 1.25 m. If the loudspeaker were used to produce sound of the same frequency in neon at the same temperature, what would be the wavelength?

**45. In a mixture of argon (atomic mass = 39.9 u) and neon (atomic mass = 20.2 u), the speed of sound is 363 m/s at 3.00×10^2 K. Assume that both monatomic gases behave as ideal gases. Find the percentage of the atoms that are argon and the percentage that are neon.

**46. The sonar unit on a boat is designed to measure the depth of fresh water ($\rho = 1.00 \times 10^3$ kg/m^3, $B_{ad} = 2.20 \times 10^9$ Pa). When the boat moves into salt water ($\rho = 1025$ kg/m^3, $B_{ad} = 2.37 \times 10^9$ Pa), the sonar unit is no longer calibrated properly. In salt water, the sonar unit indicates the water depth to be 10.0 m. What is the actual depth of the water?

47. **ssm www As a prank, someone drops a water-filled balloon out of a window. The balloon is released from rest at a height of 10.0 m above the ears of a man who is the target. Because of a guilty conscience, however, the prankster shouts a warning after the balloon is released. The warning will do no good, however, if shouted after the balloon reaches a certain point, even if the man could react infinitely quickly. Assuming that the air temperature is 20 °C and ignoring the effect of air resistance on the balloon, determine how far above the man's ears this point is.

Section 16.7 Sound Intensity

48. A typical adult ear has a surface area of 2.1×10^{-3} m^2. The sound intensity during a normal conversation is about 3.2×10^{-6} W/m^2 at the listener's ear. Assume the sound strikes the surface of the ear perpendicularly. How much power is intercepted by the ear?

49. **ssm www** At a distance of 3.8 m from a siren, the sound intensity is 3.6×10^{-2} W/m^2. Assuming that the siren radiates sound uniformly in all directions, find the total power radiated.

50. The average sound intensity inside a busy restaurant is 3.2×10^{-5} W/m^2. How much energy goes into each ear (area = 2.1×10^{-3} m^2) during a one-hour meal?

51. A rocket in a fireworks display explodes high in the air. The sound spreads out uniformly in all directions. The intensity of the sound is 2.0×10^{-6} W/m^2 at a distance of 120 m from the explosion. Find the distance from the source at which the intensity is 0.80×10^{-6} W/m^2.

52. Suppose in Conceptual Example 8 (see Figure 16.25) that the person is producing 1.1 mW of sound power. Some of the sound is reflected from the floor and ceiling. The intensity of this reflected sound at a distance of 3.0 m from the source is 4.4×10^{-6} W/m^2. What is the total sound intensity due to both the direct and reflected sounds, at this point?

53. **ssm** A loudspeaker has a circular opening with a radius of 0.0950 m. The electrical power needed to operate the speaker is 25.0 W. The average sound intensity at the opening is 17.5 W/m^2. What percentage of the electrical power is converted by the speaker into sound power?

*54. Deep ultrasonic heating is used to promote healing of torn tendons. It is produced by applying ultrasonic sound to the body. The sound transducer (generator) is circular with a radius of 1.8 cm, and it produces a sound intensity of 5.9×10^3 W/m^2. How much time is required for the transducer to emit 4800 J of sound energy?

*55. A dish of lasagna is being heated in a microwave oven. The effective area of the lasagna that is exposed to the microwaves is 1.6×10^{-2} m^2. The mass of the lasagna is 0.25 kg, and its specific heat capacity is 3400 J/(kg · C°). The temperature rises by 80.0 C° in 7.0 minutes. What is the intensity of the microwaves in the oven?

*56. When a helicopter is hovering 1450 m directly overhead, an observer on the ground measures a sound intensity I. Assume that sound is radiated uniformly from the helicopter and that ground reflections are negligible. How far must the helicopter fly in a straight line parallel to the ground before the observer measures a sound intensity of $\frac{1}{4}I$?

57. **ssm A rocket, starting from rest, travels straight up with an acceleration of 58.0 m/s^2. When the rocket is at a height of 562 m, it produces sound that eventually reaches a ground-based monitoring station directly below. The sound is emitted uniformly in all directions. The monitoring station measures a sound intensity I. Later, the station measures an intensity $\frac{1}{3}I$. Assuming that the speed of sound is 343 m/s, find the time that has elapsed between the two measurements.

Section 16.8 Decibels

58. The volume control on a stereo amplifier is adjusted so the sound intensity level increases from 23 to 61 dB. What is the ratio of the final sound intensity to the original sound intensity?

59. The bellow of a territorial bull hippopotamus has been measured at 115 dB above the threshold of hearing. What is the sound intensity?

60. A recording engineer works in a soundproofed room that is 44.0 dB quieter than the outside. If the sound intensity in the room is 1.20×10^{-10} W/m^2, what is the intensity outside?

61. **ssm** When a person wears a hearing aid, the sound intensity level increases by 30.0 dB. By what factor does the sound intensity increase?

62. The equation $\beta = (10 \text{ dB}) \log (I/I_0)$, which defines the decibel, is sometimes written in terms of power P (in watts) rather than intensity I (in watts/meter^2). The form $\beta = (10 \text{ dB}) \log (P/P_0)$ can be used to compare two power levels in terms of decibels. Suppose that stereo amplifier A is rated at $P =$ 250 watts per channel, while amplifier B has a rating of $P_0 = 45$

watts per channel. (a) Expressed in decibels, how much more powerful is A compared to B? (b) Will A sound more than twice as loud as B? Justify your answer.

63. ssm A listener doubles his distance from a source that emits sound uniformly in all directions. By how many decibels does the sound intensity level change?

64. For information, read problem 62 before working this problem. Stereo manufacturers express the power output of a stereo amplifier using the decibel, abbreviated as dBW, where the "W" indicates that a reference power level of $P_0 = 1.00$ W has been used. If an amplifier has a power rated at 17.5 dBW, how many watts of power can this amplifier deliver?

*__65.__ Sound is coming through an open window whose dimensions are 1.1 m × 0.75 m. The sound intensity level is 95 dB above the threshold of hearing. How much sound *energy* comes through the window in one hour?

*__66.__ When a single person shouts at a football game, the sound intensity level at the center of the field is 60.0 dB. When all the people shout together, the intensity level increases to 109 dB. Assuming that each person generates the same sound intensity at the center of the field, how many people are at the game?

*__67.__ A portable radio is sitting at the edge of a balcony 5.1 m above the ground. The unit is emitting sound uniformly in all directions. By accident, it falls from rest off the balcony and continues to play on the way down. A gardener is working in a flower bed directly below the falling unit. From the instant the unit begins to fall, how much time is required for the sound intensity level heard by the gardener to increase by 10.0 dB?

**__68.__ A source emits sound uniformly in all directions. A radial line is drawn from this source. On this line, determine the positions of two points, 1.00 m apart, such that the intensity level at one point is 2.00 dB greater than that at the other.

__69.__ **ssm Suppose that when a certain sound intensity level (in dB) triples, the sound intensity (in W/m^2) also triples. Determine this sound intensity level.

Section 16.9 The Doppler Effect

70. A source is generating circular waves on the surface of a lake. The waves have a wavelength of 13.4 m and travel outward at a speed of 6.70 m/s. You are in a boat whose speed is 4.20 m/s and heading directly toward the source of the waves. What do you observe for the frequency of the waves?

71. The security alarm on a parked car goes off and produces a frequency of 960 Hz. The speed of sound is 343 m/s. As you drive toward this parked car, pass it, and drive away, you observe the frequency to change by 95 Hz. At what speed are you driving?

72. Suppose you are stopped for a traffic light, and an ambulance approaches you from behind with a speed of 18 m/s. The siren on the ambulance produces sound with a frequency of 955 Hz. The speed of sound in air is 343 m/s. What is the wavelength of the sound reaching your ears?

73. ssm From a vantage point very close to the track at a stock car race, you hear the sound emitted by a moving car. You detect a frequency that is 0.86 times smaller than that emitted by the car when it is stationary. The speed of sound is 343 m/s. What is the speed of the car?

*__74.__ A loudspeaker in a parked car is producing sound whose frequency is 20 510 Hz. The sound cannot be heard because the frequency is too high. When the car is moving, however, a person standing on the street hears the sound. (a) Is the car moving toward or away from the person? Why? (b) If the speed of sound is 343 m/s, what is the minimum speed of the car if the person is a student with normal hearing?

*__75.__ **ssm** An aircraft carrier has a speed of 13.0 m/s relative to the water. A jet is catapulted from the deck and has a speed of 67.0 m/s relative to the water. The engines produce a 1550-Hz whine, and the speed of sound is 343 m/s. What is the frequency of the sound heard by the crew on the ship?

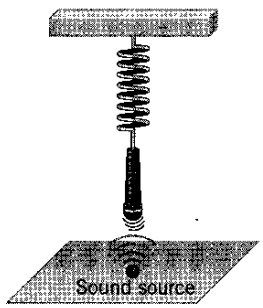
*__76.__ A microphone is moving in air toward a stationary source of sound (speed of sound = 343 m/s). The detected frequency is 83.0 Hz greater than the emitted frequency. When the microphone moves at the same speed toward the same stationary source in a liquid, the detected frequency is only 23.0 Hz greater than the emitted frequency. What is the speed of sound in the liquid?

2*__77.__ A bungee jumper jumps from rest and screams with a frequency of 589 Hz. The air temperature is 20 °C. What is the frequency heard by the people on the ground below when she has fallen a distance of 11.0 m? Assume that the bungee cord has not yet taken effect, so she is in free-fall.

*__78.__ Two submarines are underwater and approaching each other head-on. Sub A has a speed of 12 m/s and sub B has a speed of 8 m/s. Sub A sends out a 1550-Hz sonar wave that travels at a speed of 1522 m/s. (a) What is the frequency detected by sub B? (b) Part of the sonar wave is reflected from B and returns to A. What frequency does A detect for this reflected wave?

2*__79.__ **ssm** A motorcycle starts from rest and accelerates along a straight line at 2.81 m/s^2. The speed of sound is 343 m/s. A siren at the starting point remains stationary. How far has the motorcycle gone when the driver hears the frequency of the siren at 90.0% of the value it has when the motorcycle is stationary?

**__80.__ A microphone is attached to a spring that is suspended from the ceiling, as the drawing indicates. Directly below on the floor is a stationary 440-Hz source of sound. The microphone vibrates up and down in simple harmonic motion with a period of 2.0 s. The difference between the maximum and minimum sound frequencies detected by the microphone is 2.1 Hz. Ignoring any reflections of sound in the room and using 343 m/s for the speed of sound, determine the amplitude of the simple harmonic motion.



ADDITIONAL PROBLEMS

81. An amplified guitar has a sound intensity level that is 14 dB greater than the same unamplified sound. What is the ratio of the amplified intensity to the unamplified intensity?

82. To navigate, a porpoise emits a sound wave that has a wavelength of 2.5 cm. The speed at which sound travels in seawater is 1470 m/s. Find the period of the wave.

83. ssm At 20 °C the densities of fresh water and ethanol are, respectively, 998 and 789 kg/m^3. Find the ratio of the adiabatic bulk modulus of fresh water to the adiabatic bulk modulus of ethanol at 20 °C.

84. A transverse wave is traveling with a speed of 300 m/s on a horizontal string. If the tension in the string is increased by a factor of four, what is the speed of the wave?

85. At a football game, a stationary spectator is watching the halftime show. A trumpet player in the band is playing a 784-Hz tone while marching directly toward the spectator at a speed of 0.83 m/s. On a day when the speed of sound is 343 m/s, what frequency does the spectator hear?

86. A person lying on an air mattress in the ocean rises and falls through one complete cycle every five seconds. The crests of the wave causing the motion are 20.0 m apart. Determine (a) the frequency and (b) the speed of the wave.

87. ssm Humans can detect a difference in sound intensity levels as small as 1.0 dB. What is the ratio of the sound intensities?

88. Suppose that sound is emitted uniformly in all directions by a public address system. The intensity at a location 22 m away from the sound source is 3.0×10^{-4} W/m^2. What is the intensity at a spot that is 78 m away?

89. The distance between a loudspeaker and the left ear of a listener is 2.70 m. (a) Calculate the time required for sound to travel this distance if the air temperature is 20 °C. (b) Assuming that the sound frequency is 523 Hz, how many wavelengths of sound are contained in this distance?

90. A wave has a displacement (in meters) of $y = (0.45) \sin (8.0\pi t + \pi x)$, where t and x are expressed in seconds and meters, respectively. (a) Find the amplitude, the frequency, the wavelength, and the speed of the wave. (b) Is this wave traveling in the $+x$ or $-x$ direction?

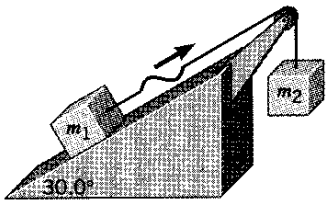
91. ssm A speeder looks in his rearview mirror. He notices that a police car has pulled behind him and is matching his speed of 38 m/s. The siren on the police car has a frequency of 860 Hz when the police car and the listener are stationary. The speed of sound is 343 m/s. What frequency does the speeder hear when the siren is turned on in the moving police car?

92. The wavelength of a sound wave in air is 2.74 m at 20 °C. What is the wavelength of this sound wave in fresh water at 20 °C? *(Hint: The frequency of the sound is the same in both media.)*

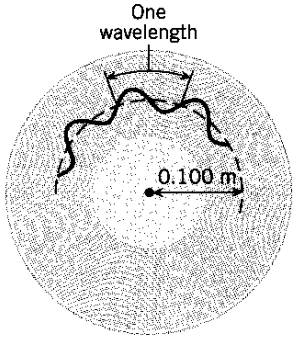
93. A rocket engine emits 2.0×10^5 J of sound energy every second. The sound is emitted uniformly in all directions. What is the sound intensity level, measured relative to the threshold of hearing, at a distance of 85 m away from the engine?

***94.** Two identical rifles are shot at the same time, and the sound intensity level is 80.0 dB. What would be the sound intensity level if only one rifle were shot? *(Hint: The answer is not 40.0 dB.)*

***95. ssm www** The drawing shows a frictionless incline and pulley. The two blocks are connected by a wire (mass per unit length = 0.0250 kg/m) and remain stationary. A transverse wave on the wire has a speed of 75.0 m/s. Neglecting the weight of the wire relative to the tension in the wire, find the masses m_1 and m_2 of the blocks.



***96.** A 3.49 rad/s ($33\frac{1}{3}$ rpm) record has a 5.00-kHz tone cut in the groove. If the groove is located 0.100 m from the center of the record (see drawing), what is the "wavelength" in the groove?



Problem 96

***97.** A steel cable of cross-sectional area 2.83×10^{-3} m^2 is kept under a tension of 1.00×10^4 N. The density of steel is 7860 kg/m^3 (this is *not* the linear density). At what speed does a transverse wave move along the cable?

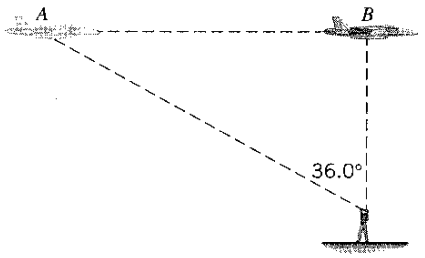
***98.** Review Conceptual Example 3 before starting this problem. A horizontal wire is under a tension of 315 N and has a mass per unit length of 6.50×10^{-3} kg/m. A transverse wave with an amplitude of 2.50 mm and a frequency of 585 Hz is traveling on this wire. As the wave passes, a particle of the wire moves up and down in simple harmonic motion. Obtain (a) the speed of the wave and (b) the maximum speed with which the particle moves up and down.

***99. ssm** Review Conceptual Example 8 as background for this problem. A loudspeaker is generating sound in a room. At a certain point, the sound waves coming directly from the speaker (without reflecting from the walls) create an intensity level of 75.0 dB. The waves reflected from the walls create, by themselves, an intensity level of 72.0 dB at the same point. What is the total intensity level? *(Hint: The answer is not 147.0 dB.)*

***100.** The sound intensity level of a person speaking normally is about 65 dB above the threshold of hearing. What is the minimum number of people speaking simultaneously, each with this intensity level, that is necessary to produce a sound intensity level at least 78 dB above the threshold of hearing?

****101.** A jet is flying horizontally, as the drawing shows. When the plane is directly overhead at B, a person on the ground hears the

sound coming from A in the drawing. The average temperature of the air is 20 °C. If the speed of the plane at A is 164 m/s, what is its speed at B, assuming that it has a constant acceleration?



**102. Civil engineers use a transit theodolite when surveying. A modern version of this device determines distance by measuring the time required for an ultrasonic pulse to reach a target, reflect from it, and return. Effectively, such a theodolite is calibrated properly when it is programmed with the speed of sound appropriate for the ambient air temperature. (a) Suppose the round-trip time for the pulse is 0.580 s on a day when the air temperature is 293 K, the temperature for which the instrument is calibrated. How far is the target from the theodolite? (b) Assume that air behaves as an ideal gas. If the air temperature were 298 K, rather than the calibration temperature of 293 K, what percentage error would there be in the distance measured by the theodolite?

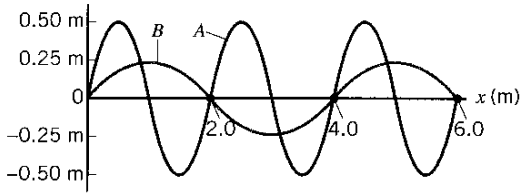
CONCEPTS & CALCULATIONS

GROUP LEARNING PROBLEMS

Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on the concepts with which the problems deal. Recognizing the concepts is the essential initial step in any problem-solving technique.

103. Concept Questions The drawing shows a snapshot of two waves traveling to the right at the same speed. (a) Rank the waves according to their wavelengths, largest first. (b) Which wave, if either, has the higher frequency? (c) If a particle were attached to each wave, like that in Figure 16.10, which particle would have the greater maximum speed as it moves up and down? Justify your answers.

Problem (a) From the data in the drawing, determine the wavelength of each wave. (b) If the speed of the waves is 12 m/s, calculate the frequency of each one. (c) What is the maximum speed for a particle attached to each wave? Check that your answers are consistent with those for the Concept Questions.



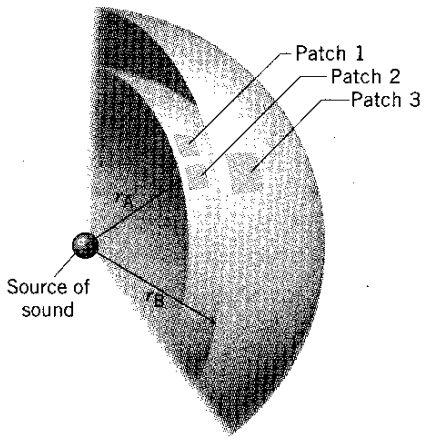
104. Concept Questions Example 4 in the text discusses an ultrasonic ruler that displays the distance between the ruler and an object, such as a wall. The ruler sends out a pulse of ultrasonic sound and measures the time it takes for the pulse to reflect from the object and return. The ruler uses this time, along with a preset value for the speed of sound in air, to determine the distance. Suppose you use this ruler underwater, rather than in air. (a) Is the speed of sound in water greater than, less than, or equal to the speed of sound in air? (b) Is the reading on the ruler greater than, less than, or equal to the actual distance? Provide reasons for your answers.

Problem The actual distance from the ultrasonic ruler to an object is 25.0 m. The adiabatic bulk modulus and density of seawater are $B = 2.31 \times 10^9$ Pa and $\rho = 1025$ kg/m^3, respectively. Assume that the ruler uses a preset value of 343 m/s for the speed of sound in air, and determine the distance reading on its display. Verify that your answer is consistent with your answer to the Concept Questions.

105. Concept Question Suppose you are part of a team that is trying to break the "sound barrier" with a jet-powered car, which means that it must travel faster than the speed of sound in air. Would you attempt this feat early in the morning when the temperature is cool, later in the afternoon when the temperature is warmer, or does it even matter what the temperature is?

Problem In the morning, the air temperature is 0 °C and the speed of sound is 331 m/s. What must be the speed of your car if it is to break the sound barrier when the temperature has risen to 43 °C in the afternoon? Assume that air behaves like an ideal gas.

106. Concept Questions A source of sound is located at the center of two concentric spheres, parts of which are shown in the drawing. The source emits sound uniformly in all directions. On the spheres are drawn three small patches that may, or may not, have equal areas. However, the same sound power passes through each patch. (a) Rank the sound intensity at each patch, greatest first. (b) Rank the area of each patch, largest first. Provide reasons for your answers.



Problem The source produces 2.3 W of sound power, and the radii of the concentric spheres are $r_A = 0.60$ m and $r_B = 0.80$ m.