device focuses ultrasonic waves at a frequency of 3 GHz through a droplet of water onto the object. The speed of the waves in the water, which couples the microscope to the specimen, is 1.5 km/s. Compute the wavelength of the radiation and compare it to the wavelength of green light in air ≈500 nm.

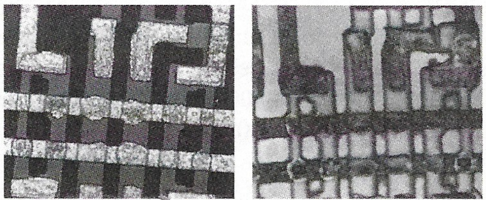

Figure P1

2. [I] A long metal rod is struck by a vibrating hammer in such a way that a compression wave with a wavelength of 4.3 m travels down its length at a speed of 3.5 km/s. What was the frequency of the vibration?

3. [I] An A note of 440 Hz is played on a violin submerged in a swimming pool at the wedding of two scuba divers. Given that the speed of compression waves in pure water is 1498 m/s, what is the wavelength of that tone?

4. [I] A wave on a string travels a 10-m length in 2.0 s. A harmonic disturbance of wavelength 0.50 m is then generated on the string. What is its frequency?

5. [I] Show that, for a periodic wave, $\omega = (2\pi/\lambda)v$.

SOLUTION: $\omega = 2\pi f$, but here we have v and λ instead of f. That suggests using $v = \lambda f$ to replace f. Since $f = v/\lambda$, $\omega = (2\pi/\lambda)v$.

6. [I] Imagine a sinusoidal pressure wave for which the distance between successive maxima is 2.25 m. If exactly 10 such peaks pass a microphone each 1.00 s, what is the speed of the wave?

7. [I] A harmonic wave has a profile described by the expression $y = (1.2 \text{ cm}) \sin [2\pi x/(10.0 \text{ cm})]$. What are the values of the amplitude and wavelength of the wave? If the speed of the wave is 2.00 m/s, what is its frequency? [*Hint: Term by term compare this expression with Eq. (11.2), and remember that* $v = f\lambda$.]

8. [I] The speed of a sinusoidal wave is 4.00 m/s, and its profile is specified by the expression $y = (10 \text{ cm}) \sin [2\pi x/(0.0314 \text{ cm})]$. Determine its period.

9. [I] A harmonic wave has a profile given by $z = (2.5 \text{ cm}) \cos (0.0796 \text{ m}^{-1})y$. What are its amplitude, axis of travel, and wavelength?

10. [II] THIS PROBLEM EXPLORES THE GENERAL CHARACTERISTICS OF A PERIODIC WAVE. Figure P10 shows a wave traveling at 5.0 m/s on a beaded string. Any given bead vibrates up and down 3.0 times in each 6.0 s interval. (a) What is the amplitude of the wave? (b) What is the relationship between the frequency of the vertical oscillation of any given bead and the frequency of the wave itself? (c) What is the frequency of the wave? (d) Determine the wavelength of the wave.

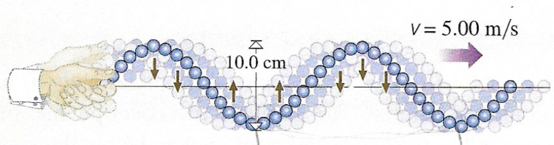

Figure P10

11. [II] THIS PROBLEM EXPLORES THE GENERAL CHARACTERISTICS OF A PERIODIC WAVE. Figure P11 shows a wave produced on a taut string by a 50-Hz generator. (a) What is the amplitude of the wave? (b) What is the frequency of the wave? (c) What is the wavelength? (d) Determine the speed of the wave. (e) What is the wave's period?

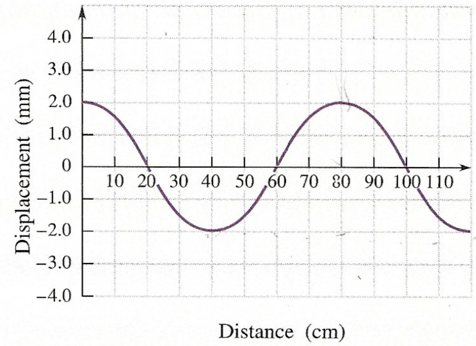

Figure P11

12. [II] Write an expression for the profile of a sinusoidal wave traveling in the x-direction at a speed of 10.0 m/s if it has a frequency of 20.0 Hz and an amplitude in the y-direction of 0.010 m.

13. [II] Imagine a sinusoidal wave traveling to the right on a stretched string. Suppose that the distance between successive positive peaks is 50.0 cm. There is a dot of red paint on the rope and at a given instant the displacement of that dot is zero, and it is moving downward. At that moment the displacement of the rope 12.5 cm to the right of the dot is +4.0 cm. What is the displacement, at that instant, of a point 60.0 cm to the right of the dot?

14. [II] A transverse harmonic wave on a beaded string has an amplitude of 2.5 cm and a wavelength of 160 cm. If at $t = 0$ a life-sized photo shows that the height of the wave at $x = 0$ is zero and at $x = 40$ cm it is +2.5 cm, then what is the string's displacement at $x = 10$ cm?

15. [II] A member of the Vespertilionidea family of bats typically emits a sequence of chirps, wavetrains lasting about 3.0 ms and having a carrier frequency that varies from 100 kHz to about 30 kHz. Generally, there is a time between individual chirps of 70 ms. Assuming the air speed of one of these wavetrains is 330 m/s, how far away can an object be and still be detected without being masked by the next outgoing chirp?

16. [II] A radar beam transmitted with a carrier frequency of 9.8 GHz is composed of a stream of nearly harmonic wavetrains each lasting 1.0 μs. Determine the number of wavelengths of the carrier that are in each pulse and show that this number is independent of v, provided the speed of the pulse equals the speed of the carrier wave.

17. [II] Figure P17 represents a rather idealized square water wave. Show that doubling its amplitude would increase its energy by a factor of four, thus again making the point that the energy of a wave is proportional to its amplitude squared.

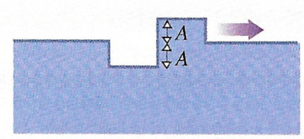

Figure P17

18. [II] The function

$$y = (2.0 \text{ m}) \sin \frac{2\pi}{\lambda}(x - vt)$$

describes the displacement of a harmonic wave traveling in the positive x-direction at a speed v. If the frequency of the wave is 2.0 Hz, what is the value of y at $x = 0$ when $t = 4.0$ s?

19. [II] Show mathematically that shifting the phase of a sinusoidal wave profile by $\frac{1}{2}\pi$ rad turns it into a cosine profile. Begin with

$$y = A \sin\left(\frac{2\pi}{\lambda}x \mp \tfrac{1}{2}\pi\right)$$

20. [III] Determine the profile of the wavefunction

$$y = A \sin 2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)$$

at $t = 0$. Find the values of y at $x = 0, \lambda/8, \lambda/4, 3\lambda/8, \lambda/2, 5\lambda/8, 3\lambda/4, 7\lambda/8$, and λ. Make a plot of the profile. Now do the same thing for the wavefunction

$$y' = A \sin 2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)$$

where T is its period and compare your results.

SECTION 11.2: TRANSVERSE WAVES: STRINGS

21. [I] During a lab experiment a long bronze wire is held taut by fixing one end, passing the other over a pulley, and attaching a known hanging mass to it. The wire is then tapped, creating a transverse wave whose speed is measured. If the hanging mass is now quadrupled, what, if anything, will happen to the speed of subsequent transverse waves?

22. [I] During a lab experiment a long silver wire is held taut by fixing one end, passing the other over a pulley, and attaching a known hanging mass to it. The wire is then tapped, creating a transverse wave whose speed is measured. If a new wire of the same length and quadruple the mass is now used, and all else is unchanged, what, if anything, will happen to the speed of subsequent transverse waves?

23. [I] The A string of a violin has a linear mass-density (i.e., a mass per unit length) of 0.59×10^{-3} kg/m and is stretched to a tension of 10 N. What is the speed of the transverse waves it can sustain? Incidentally, the four violin strings, when mounted and properly tuned, produce a net tension on the instrument of about 220 N (50 lb). [*Hint: Eq. (11.3) provides a relationship between speed, tension, and mass per unit length for a stretched string.*]

24. [I] A wire having a mass of 60.0 g is 6.00-m long. If transverse waves travel along it at 200 m/s, what is the tension in the wire?

25. [I] The end of a 100-cm-long wire is plucked, and a transverse wave travels along it at 180 m/s. If the tension in the wire is measured to be 480 N, what is its mass?

26. [I] A heavy rope is tied to a tree 30 m away, and it is then pulled taut with a force of 360 N. The rope is struck near its end with a stick, thus setting up a transverse wavepulse. If the rope has a linear mass-density of 0.06 kg/m, how long will it take for the pulse to make the round trip from end to tree to end?

27. [I] If the speed of a wavepulse set up on the longest string of a grand piano is 129 m/s and if the mass per unit length of the string is 64.9×10^{-3} kg/m, what is the tension? Typically, the net tension on the frame of a concert grand due to all the strings is around 2.7×10^5 N or 30 tons (60 000 lb).

28. [I] Figure P28 depicts two identical symmetrical transverse wavepulses, each traveling at a speed of 5.0 m/s heading toward one another. Draw the resultant disturbance 2.0 s later and again 2.0 s after that.

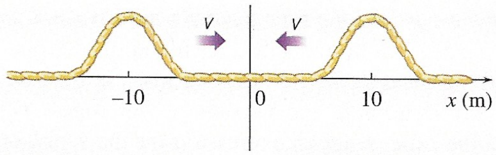

Figure P28

29. [I] Figure P29 depicts two identical symmetrical transverse wavepulses, each traveling at a speed of 5.0 m/s heading toward one another. Draw the resultant disturbance 2.0 s later and again 2.0 s after that.

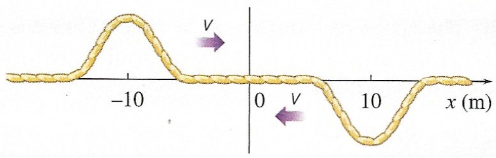

Figure P29

30. [II] Write an expression for the profile of a transverse harmonic wave of amplitude 10 cm and wavelength 1.2 m traveling along a rope in the positive z-direction and oscillating in the yz-plane. The height of the wave is zero at $t = 0$ and $z = 0$.

31. [II] The profile of a transverse harmonic wave on a long taut nylon thread is described in SI units by the function

$$y = 0.040 \sin 2\pi x$$

Given that the wave travels at a speed of 2.0 m/s, determine the maximum *transverse* acceleration of any point on the thread.

32. [II] The profile of a transverse harmonic wave on a long beaded string is described in SI units by the function

$$y = 0.020 \sin (6.28x)$$

Given that the wave has a speed of 5.0 m/s, determine the maximum *transverse* speed of any bead on the string.

33. [II] A string has a mass per unit length of 2.50 g/m and is put under a tension of 25.0 N as it is stretched taut along the z-axis. The free end is attached to a tuning fork that vibrates at 50.0 Hz, setting up a transverse wave on the string having an amplitude of 5.00 mm. Determine the speed, angular frequency, period, and wavelength of the disturbance.

34. [II] Using Problem 33, write an expression for the profile of the wave given that, at $t = 0$, the end of the rope ($x = 0$) is at $y = +5.00$ mm. The wave travels in the z-direction.

35. [II] THIS PROBLEM EXPLORES THE BEHAVIOR OF AN OSCILLATING STRING. One end of a long horizontal string is passed over a frictionless pulley, and a 3.0-N weight is hung from it. The other end is tied to a hook in the wall. A 150-Hz oscillator sets up a transverse harmonic traveling wave on the string that has a peak-to-positive-peak distance of 45.0 cm. (a) What is the frequency and wave-

length of the wave on the string? (b) Determine the speed of the wave. (c) What is the tension in the string? (d) Write an expression for the speed in terms of the tension. (e) If the oscillating horizontal portion of the string is 2.0 m long, what is its mass?

36. [II] THIS PROBLEM EXPLORES THE BEHAVIOR OF A TRANSVERSE WAVE ON A TAUT ROPE. A long rope having a mass per unit length of 0.025 kg/m is stretched horizontally. Each end of the rope passes over a light frictionless pulley. A 10.0-kg mass is then hung from each end. (a) Determine the tension in the rope. (b) If someone plucks the rope, write an expression for the speed of the resulting wave in terms of the tension. (c) Compute the speed of the wave. (d) If a point on the rope is displaced transversely in SHM at 3.00 Hz, what will be the resulting wavelength?

37. [II] A heavy nylon guitar string with a linear mass-density of 7.5 g/m is stretched to a tension of 80 N. What is the speed of the transverse wave that can be generated on the string? What tension will be required to double the speed?

38. [II] The speed of a transverse wave on a wire is 90 m/s when the tension in the wire is 120 N. What will be the speed if the tension is reduced to 80 N?

39. [II] A homemade telegraph system sends transverse pulses along a stretched string. It operates between two neighboring houses using 12 m of a string having a total weight of 0.20 N. What should be the tension in the string if the signals are to travel at least as fast as they would were the users simply to yell? Take the speed of sound in air to be 333 m/s.

40. [III] A transverse harmonic wave on a long beaded string is described in SI units by the function

$$y = 0.02 \sin (6.28x - 15t)$$

If we have a detector at $x = 0$, what will be the speed of the bead at that location at a time $t = 1.2$ s?

41. [III] A uniform rope of length L and mass m hangs freely straight down from a hook in the ceiling. Taking the bottommost point as $y = 0$, write an expression for the mass of a segment of arbitrary length Δy. What is the tension in the rope at a height Δy? Derive an expression for the speed of a transverse wave set up by wiggling the lower end. What is the maximum speed? Determine an expression for the speed of the wave if a mass M is hung on the bottom of the rope.

42. [III] The very end of a 14.5-m-long wire having a mass of 0.12 kg is clamped in a vise. The other end is tugged on, putting a tension of 50 N in the wire. That end is then driven transversely by a tuning fork oscillating at 440 Hz, and the wire vibrates with a maximum displacement of 0.15 mm. (a) Find the wavelength and period of the resulting disturbance. (b) Determine the maximum transverse speed of any point on the wire.

43. [III] Given the equation

$$y = A \sin 2\pi\left(\frac{t}{0.01} - \frac{x}{40}\right)$$

describing the displacement of a string of beads in SI units, write an expression for the motion of a bead at $x = 5.0$ m as a function of time. What is the value of y at $t = 0$ and $t = 0.01$ s? When is $y = 0$? Graph your results.

SECTION 11.3: COMPRESSION WAVES

44. [I] According to folklore, one can best listen for trains, out in the countryside, by putting an ear to the rails. Steel track has a density of 7.8×10^3 kg/m^3 and a Young's Modulus of 200 GPa. What is the speed of compression waves in the track (the speed of sound in air is $\approx$330 m/s)?

45. [I] The speed of a compression wave (e.g., sound) in a metal rod is measured to be 4319 m/s. Given that the rod has a density of 19.3×10^3 kg/m^3, determine its Young's Modulus.

46. [I] Show that the $\sqrt{B/\rho}$ has the units of speed.

47. [I] An underwater explosion occurs in a fresh water lake. What is the speed of the resulting compression wave if the Bulk Modulus of water is 2.0 GPa? [*Hint: When treating liquids the wave speed is determined by the Bulk Modulus and the density.*]

48. [I] At 20 °C mercury has a density of 13.55×10^3 kg/m^3. The measured speed of sound (at 1 atm) in mercury is 1451 m/s. Determine its Bulk Modulus.

49. [I] What is the speed of a compression wave in ethyl alcohol?

50. [I] Considering Problem 48, what is the wavelength of a 1000-Hz compression wave in mercury? Compare that to its wavelength in air where $v = 331.4$ m/s.

51. [II] A particular kind of glass has a Shear Modulus of 25 GPa, a Young's Modulus of 62 GPa, and a density 2.5×10^3 kg/m^3. A 100-m-long rod of this material is struck at one end with a hammer. How long will it take for the compression wave to run down the rod, hit the end, and be reflected so that it returns to where it started?

52. [II] Use the method of dimensional analysis to "derive" an expression for the speed of a compression wave in a solid rod. We guess that the answer depends on Young's Modulus and the density and write

$$v = KY^a\rho^b$$

where a and b are to be determined and K is a dimensionless constant (like 2π). Finish out the calculation by balancing the units.

53. [II] Laboratory measurements show that a quantity of a certain liquid decreases in volume by 9.52×10^{-3} percent when it is exposed to a pressure increase of 200 kPa. If the liquid has a density of 1.025×10^3 kg/m^3, what is the speed at which compression waves like sound traverse it?

54. [II] Imagine a uniform wire of density ρ, cross-sectional area A, and modulus Y. What must the tension on the wire be (in terms of A and Y) such that both transverse and longitudinal waves on the wire have the same speed? Incidentally, the tension will have to be unrealistically high—as a rule, longitudinal waves travel much faster than transverse ones.

SECTION 11.4: ACOUSTICS: SOUND WAVES

55. [I] In music, the standard A_4 note has a frequency of 440 Hz. What are its period and wavelength at room temperature?

56. [I] A person standing at one side of a playing field on a cold winter night emits a brief yell. The short acoustical wavetrain returns 1.00 s later as an echo having "bounced off" a distant dormitory. Approximately how far away was the building?

57. [I] A string vibrating at 1000 Hz produces a sound wave that travels at 344 m/s. How many wavelengths will correspond to 1 m?

58. [I] A low-frequency loudspeaker is called a woofer. At what frequency will a tone have a wavelength equal to the diameter of a 15-in. woofer? Take the speed of sound to be 344 m/s.

59. [I] A groove on a monophonic phonograph record wiggles laterally such that its amplitude and frequency more or less correspond to the sound that is recorded. If at a given moment the needle is moving through the groove at 0.50 m/s, what would be the wiggle-wavelength for a 1.5-kHz tone?

60. [I] The speed of sound in ether (25 °C, 1 atm) is 976 m/s. What is the wavelength in ether produced by a tuning fork oscillating at 1000 Hz?

61. [I] The contact time between the hammers and strings of a piano is one of the determining factors of the tone of the instrument; if it's too long, the higher overtones will be damped out. Though contact time varies across the keyboard, an average is about half of a period. To two significant figures, what is the contact time for middle-C at 261.6 Hz?

62. [II] Suppose that a tuning fork in air, where the speed of sound is 343 m/s, produces a tone having a wavelength of 0.779 5 m. The fork is immersed in acetone and then tapped. How long a wave will be created in the liquid given that acetone (20 °C, 1 atm) supports sound waves that travel at 1203 m/s?

63. [II] A bar of aluminum alloy 10-m long with a cross-sectional area of 1.0 cm^2 has a mass of 2.7 kg and a Young's Modulus of 7.0×10^{10} N/m^2. If the end is tapped at a rate of 100 Hz, how long will it take for the sound wave to reach the other end of the bar? What will be its wavelength?

64. [II] Galileo determined experimentally that the fundamental frequency of a string fixed at both ends was inversely proportional to both its diameter and to the square root of its density. Prove that this description is true theoretically.

65. [II] The speed of sound (20 °C, 1 atm) in pure water is 1482.3 m/s as compared to 1522.2 m/s in seawater. What is the ratio of the wavelengths of a 1000-Hz tone in fresh water to that in seawater?

SECTION 11.5: WAVEFRONTS & INTENSITY

SECTION 11.6: THE SPEED OF SOUND IN AIR

66. [I] A detector placed perpendicular to a streaming sound wave has an active area of 10.0 cm^2 and records energy incident at a rate of 25.0 μJ/s. What is the intensity of the wave?

67. [I] Envision a sound wave incident perpendicularly on a detector that records an incident acoustic intensity of 50.0×10^{-4} W/m^2. If the sensing aperture of the detector is 4.0 cm in radius, what is the amount of power entering it?

68. [I] The intensity of the acoustic wave from an underground explosion measured 5.0 km away is 1.6×10^4 W/m^2. What intensity will be recorded at a site 50 km away? Assume no losses.

69. [I] The speaker in a sound system has a diameter of 38 cm. If it pumps out sound uniformly over its entire surface with an intensity of 10.0 mW/m^2, how much power is radiated?

70. [I] Air is pumped into a chamber that is then sealed, and the speed of sound through the gas is measured. The temperature of the gas is subsequently increased, and a gauge shows that the inside pressure doubled. Compare the speed of sound before and after the temperature rise.

71. [I] A measured quantity of air is put into a chamber that is fitted with a movable piston so that the pressure is kept constant. The temperature of the gas is subsequently increased and its volume doubles. Compare the speed of sound before and after the temperature rise. This is similar to what happens in the atmosphere when it's heated by the Sun.

72. [I] At what temperature will the speed of sound in air at standard pressure equal 320 m/s?

73. [I] If a tuning fork puts out a tone at 440 Hz, what is its wavelength in air at 25 °C?

74. [I] By what percentage does the speed of sound change when the air temperature rises from 0 °C to 30 °C?

75. [II] A point source of sound waves emits a disturbance with a power of 50 W into a surrounding homogeneous medium. Determine the intensity of the radiation at a distance of 10 m from the source. How much energy arrives on a little detector with an area of 1.0 cm^2 held perpendicular to the flow each second? Assume no losses.

76. [II] As a sound wave travels along it causes an oscillatory displacement of the air molecules that has an amplitude s_0. If a detector of area A is placed perpendicular to the propagation direction it can be shown that the average incident power is given by

$$P_{av} = \frac{1}{2}\omega^2 s_0{}^2 \rho A v$$

Check that this has the correct units. Write an expression for the intensity of the sound wave.

77. [II] An ideal gas (p. 438) is described by the expression $PV = nRT$ where n is the number of kilomoles present in the sample, T is the temperature, and R is a constant equal to 8.314×10^3 J/kmol·K. Most gases, air included, behave as if they were ideal gases. If M is the mass per kilomole, assuming Eq. (11.7) applies, prove that

$$v = \sqrt{\gamma RT/M}$$

Note that when n is expressed in kilomoles, R must be in terms of kilomoles, as well.

78. [II] Both gaseous hydrogen and oxygen consist of diatomic molecules. What is the ratio of the speed of sound in hydrogen to the speed in oxygen at the same temperature and pressure? [*Hint: Use the results of the previous problem.*]

79. [III] If the displacement of the oscillating air molecules in a sound wave is written in terms of a cosine function of amplitude A, then (with a bit of calculus and some effort) the corresponding gauge pressure can be expressed as

$$P = \frac{2\pi}{\lambda} BA \sin\left(\frac{2\pi}{\lambda}x - \omega t\right)$$

(a) Show that both sides of this expression have the same units. (b) What can you say about the displacement as compared to the pressure? (c) Show that the maximum value of the change in pressure (P_0) from the no-wave ambient value, the so-called *pressure amplitude*, is given by

$$P_0 = \frac{2\pi}{\lambda}\rho v^2 A$$

(d) Discuss, in general terms, why it is reasonable to have B and A in the equation for P.

80. [III] The pressure amplitude associated with the loudest sounds tolerable by human beings is roughly 30 Pa. Such pressure waves vary ± 30 Pa with respect to atmospheric pressure (10^5 Pa). Determine (using the results of Problem 79) the maximum displacement of the air molecules in such a disturbance having a frequency of 1000 Hz at human body temperature. Take the density of the air to be 1.22 kg/m^3.

SECTION 11.8: SOUND-LEVEL

81. [I] A faint sound with an intensity of 10^{-9} W/m^2 is measured by a sound-level meter—what will the reading be in dB?

82. [I] One of the most important acoustical characteristics of a room is its *reverberation time*, the time it takes for a sound to decrease 60 dB. What does that mean as far as the sound's intensity is concerned? For a concert hall, the reverberation time is typically 1 to 3 s.

83. [I] A radio playing quietly produces a sound intensity of about 10^{-8} W/m^2. What is the corresponding sound-level?

84. [I] Someone playing a CD at 60 dB wants to make the music twice as loud. At what sound-level should it be played?

85. [I] Two (otherwise identical) audio systems at a demonstration are blasting away, with one putting out 10 times the acoustic power of the other. What is the difference in their sound-levels?

86. [I] Two people having a normal conversation are 1.0 m from a sound-level meter. Approximately what will the meter read?

87. [I] Two audio systems each produce 50 W of acoustic power at the location of a microphone. What is the difference in their sound-levels in dB at that point?

88. [I] Does a 0-dB sound-level mean there is no sound? Explain.

89. [I] The intensity of a sound is tripled. By how many decibels does it increase?

90. [I] THIS PROBLEM TREATS THE RELATIONSHIP BETWEEN INTENSITY AND SOUND-LEVEL. We want to compute the sound-level given that the intensity of a sound wave is $6.0\ \mu\text{W/m}^2$. (a) Write an expression for the sound-level in terms of I. (b) What is the usual reference intensity? (c) Compute the sound-level in dB.

91. [I] THIS PROBLEM TREATS THE RELATIONSHIP BETWEEN INTENSITY AND SOUND-LEVEL. A vacuum cleaner generates a sound-level of 52 dB, and we need to find the corresponding intensity. (a) Write an expression for the sound-level in terms of I. (b) What is the usual reference intensity? (c) Plug in all the numbers you know and then raise 10 to the power of each side of the equation. (d) Using the fact that $10^{\log_{10} x} = x$, compute the intensity.

92. [I] On occasion, it turns out that we know the sound-level of a sound and wish to find out the associated intensity. Show that

$$I = 10^{\beta/10} I_0$$

93. [I] The noise of traffic registers 77 dB on a meter. To what intensity does that correspond?

94. [I] A cannon produces a 90-dB sound-level at a certain distance from a detector. What will the device read when two such cannons at that same distance are fired?

95. [II] What is the sound-level 10 m away from a point source radiating 1.2 W of acoustic power?

SOLUTION: To find the sound-level we need the intensity. We have the power at the point source and so at a distance R away $I = P/4\pi R^2 = (1.2 \text{ W})/4\pi(10 \text{ m})^2 = 9.55 \times 10^{-4} \text{ W/m}^2$.

$$\beta = 10 \log_{10} \frac{I}{I_0} = 10 \log_{10} \frac{9.55 \times 10^{-4} \text{ W/m}^2}{1.0 \times 10^{-12} \text{ W/m}^2} = 90 \text{ dB}$$

96. [II] THIS PROBLEM TREATS THE RELATIONSHIP BETWEEN ACOUSTIC POWER AND SOUND-LEVEL. A point source emits sound uniformly in all directions, at a power that we would like to determine. An observer standing 5.0 m from the source measures a sound-level of 40 dB. (a) Write an expression for the sound-level. (b) What is the usual reference intensity? (c) Determine the intensity 5.0 m from the source. (d) What is the power radiated at the source?

97. [II] THIS PROBLEM DEALS WITH THE RELATIONSHIP BETWEEN INTENSITY AND SOUND-LEVEL. A large engine has a decibel noise level of 120 dB above the threshold of hearing, and we want to find the intensity of the sound. (a) What physical quantity does 120 dB correspond to? (b) Write an expression for the sound-level in terms of intensity. (c) Determine the intensity of the sound. (d) If two such machines were operating right next to each other, what would be the intensity of the noise nearby? (e) What would be the sound-level?

98. [II] Two sounds have intensities of 10^{-2} W/m^2 and 10^{-10} W/m^2. What will be the difference in their sound-levels as read by a sound-level meter?

99. [II] A small but noisy printer produces an acoustic intensity of $56 \times 10^{-5} \text{ W/m}^2$ at a point 5.0 m away. Approximately what value will a dB-meter read at that location and, again, at 20.0 m from the printer?

100. [II] With Problem 99 in mind, what will be the *change* in sound-level measured for any point source at 5.0 m and then at a 20.0-m distance?

101. [II] A small source emits nearly spherical waves with an acoustic power of 60 W. How far away must a sound-level meter be if it is to read 60 dB?

102. [II] The sound-level of a large engine is measured to be 130 dB at a distance of 10.0 m. Approximately what intensity will exist at a point 100 m away?

103. [II] The sound-level 2.0 m from a pneumatic chipper is 120 dB. Assuming it radiates uniformly in all directions, how far from it must you be in order for the level to drop 40 dB down to something more comfortable?

104. [II] How much acoustic power impinges on a 10-cm^2 detector when the intensity-level is 70 dB?

105. [II] Given that the standard reference pressure for sound is $P_0 = 2 \times 10^{-5}$ Pa, write an expression for the sound-level in terms of the pressure of the disturbance P. [*Hint: p. 392.*]

106. [II] Someone turns on a radio at 65.0 dB while vacuuming the floor at 80.0 dB. What will be the total sound-level in the room?

107. [III] If one audio system sounds six times louder than another, what is the difference in their sound-levels?

SECTION 11.9: SOUND WAVES: BEATS

SECTION 11.10: STANDING WAVES

108. [I] Two sound waves of angular frequencies 900.0 rad/s and 896.0 rad/s overlap. What is the resulting beat frequency?

109. [I] The sound from a tuning fork of 1000 Hz is beat against the unknown emission from a vibrating wire. If beats are heard at a frequency of 4 Hz, what can be said about the frequency of the wire?

110. [I] With Problem 101 in mind, what can you say if a small piece of tape is fixed to the tuning fork and the beat frequency now increases?

111. [I] On tapping two tuning forks, an observer hears a succession of intensity maxima arriving at a rate of one every 0.99 s. What is the difference in frequency between the two forks?

112. [I] THIS PROBLEM EXPLORES THE PHENOMENON OF BEATS. Two tuning forks are struck and they produce sounds of frequency 440 Hz and 444 Hz that subsequently overlap. (a) Describe what an observer will hear? (b) Determine the frequency of the resulting wave? (c) Compute the number of beats per second?

113. [I] Two waves of wavelength λ, traveling in opposite directions give rise to the standing-wave pattern shown in Fig. P113. Determine λ.

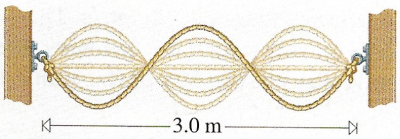

Figure P113

114. [I] THIS PROBLEM TREATS THE PHENOMENON OF STANDING WAVES. A 1.20-m long guitar string is held under tension and made to vibrate, with a central antinode, at middle C (262 Hz). (a) What is the frequency of that oscillation? (b) Draw a picture of the vibrating string. (c) Determine the wavelength of the fundamental oscillation of the string. (d) What is the frequency of the resulting sound? (e) What is the wavelength of the resulting sound wave, given that the speed of sound is 341 m/s?

115. [I] A standing-wave pattern consists of a series of nodes and antinodes. If the distance between successive antinodes is N meters, what are the wavelengths of the two waves that produce this pattern?

116. [I] A thin wire is stretched between two posts 50 cm apart. It is then bowed and thereby set into oscillation. What are the wavelengths of the fundamental and the first overtone of the system?

117. [I] A taut string is fixed at both ends, which are 0.50 m apart. It is then set into resonance at its sixth harmonic. Determine the wavelength of the oscillation and draw the standing-wave pattern.

118. [I] A string stretched between fixed posts is 250-cm long and oscillates in its fundamental mode at 100 Hz. Determine the speed of a transverse wave on the string.

119. [I] A piece of steel piano wire is held fixed at both ends under a tension of 100 N. The free length of wire is 1.00 m, and it has a mass of 2.5 g. What is its fundamental frequency?

120. [I] A narrow tube 1.00 m long is closed rigidly at one end and with a piston at the other. Given that the speed of sound is 335 m/s, what is the frequency of the tube's fundamental oscillatory mode?

121. [I] Show theoretically that for a string fixed at both ends, its standing-wave frequencies are given by

$$f_N = \tfrac{1}{2}N\sqrt{\frac{F_T}{Lm}}$$

where L is its length and m its mass.

122. [I] A trumpet is a bent tube roughly 140-cm long and closed at one end by the player's mouth. Determine the fundamental (which will be quite difficult to blow) and the first three overtones. Take the temperature to be 20°C.

123. [II] THIS PROBLEM DEALS WITH THE CONCEPT OF BEATS. A taut wire vibrates making a constant tone. When a 260-Hz tuning fork is struck, 6.0 beats/s result and when a 270-Hz tuning fork is struck, 4.0 beats/s result. (a) What possible frequencies of the wire would produce 6.0 beats/s? (b) What possible frequencies of the wire would produce 4.0 beats/s? (c) Determine the frequency at which the wire vibrates.

124. [II] THIS PROBLEM WILL HELP US UNDERSTAND STANDING WAVES. The generator in Fig. P124 sends a wave down the string that reflects back off the wall, which is 4.0 m away. These two oppositely directed waves, each traveling at 2.0 m/s, create the pattern shown. (a) How many nodes, and how many antinodes are there? (b) Looking at the diagram, what is the wavelength of the wave produced by the generator? (c) Determine the frequency of the generator.

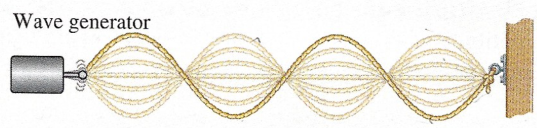

Figure P124

125. [II] A B-string from a guitar is held fixed at both ends under tension with a vibrating length of 33 cm. It oscillates at its fundamental frequency of 246 Hz. What are the wavelengths of the transverse wave on the string and the sound wave in the air at room temperature? Take the speed of sound in the air to be 344 m/s.

SOLUTION: The wavelength on the string is twice the node-to-node distance of the fundamental: $\lambda = 2(33\text{ cm}) = 66\text{ cm}$. For the sound wave in air $\lambda = v/f = (344\text{ m/s})/(246\text{ Hz}) = 1.40\text{ m}$

126. [II] Imagine a hypothetical piano with all strings made of the same material and all under the same tension. The piano extends from 27.5 Hz to 4186 Hz, which is over seven octaves—that is, seven doublings of frequency. If the highest note corresponds to a string 15-cm long, how long will the lowest string have to be? What can you conclude about this approach to piano design?

127. [II] Two identical piano strings are both tuned to 440 Hz. The tension in one is then increased by 1.00%, and both strings, which are kept at the same length, are activated so that they sound their fundamental frequencies. What will be the resulting beat frequency?

128. [II] A narrow glass tube 0.50-m long and sealed at its bottom end is held vertically just below a loudspeaker that is connected to an audio generator and amplifier. A tone with a gradually increasing frequency is fed into the tube, and a loud resonance is first observed at 170 Hz. What is the speed of sound in the room?

129. [II] An organ pipe that ordinarily sounds at 600 Hz at 0 °C is connected to a source of helium at that temperature. At what frequency will it now operate?

130. [II] A quartz tube open at both ends has a fundamental resonant frequency of 200 Hz at 0 °C. Neglecting any changes in length, by how much will the fundamental change when the tube is sounded in a chamber at 40 °C?

131. [II] A wire stretched between two posts and under a tension of 200 N oscillates at a fundamental frequency of 420 Hz. At what tension would it oscillate instead at 430 Hz?

132. [II] Referring to Kundt's tube (Fig. Q19), if v_a and v_r are the speeds of sound in the air and rod, respectively, and if L is the length of the rod and l the node-to-node distance, show that

$$v_r = \frac{v_a L}{l}$$

In other words, knowing the speed of sound in air, we can determine it in the material of the rod.

133. [II] A copper bar 1.00-m long is clamped at its middle and set vibrating. Given that $v = \sqrt{Y/\rho}$ and the bar has a density of $8.9 \times 10^3\ \text{kg/m}^3$ and a Young's Modulus of $11 \times 10^{10}\ \text{N/m}^2$, what will its frequency be?

134. [II] A C-flute with all its holes covered plays a middle C (262 Hz) as its fundamental. Assuming room temperature (20°C) and overlooking end corrections, how long should the flute be from embouchure hole to end?

135. [III] Consider the expressions for two waves of the same amplitude with slightly different frequencies traveling in the same direction:

$$y_1 = A \sin(\omega_1 t) \qquad \text{and} \qquad y_2 = A \sin(\omega_2 t)$$

where we simplify things a little by just looking at them at the point $x = 0$. Now, supposing the two waves were to overlap, derive the following equation for the combined waveform:

$$y = 2A \cos\left[\tfrac{1}{2}(\omega_1 - \omega_2)t\right] \sin\left[\tfrac{1}{2}(\omega_1 + \omega_2)t\right]$$

and interpret each term in reference to Fig. 11.37.

136. [III] Consider a long, narrow rod of length L clamped at both ends. If the rod is rubbed with a rosined cloth, a compression wave will travel its length. Show that the expression for the resulting standing-wave modes is

$$f_N = \frac{N}{2L}\sqrt{\frac{Y}{\rho}}$$

where $N = 1, 2, 3, \ldots$. A novice playing with a violin is likely to move the bow lengthwise along a string. Explain why this movement will generally produce a shrill squeaking sound.

SECTION 11.11: THE DOPPLER EFFECT

137. [I] THIS PROBLEM EXAMINES THE RELATIONSHIP BETWEEN THE MOTION OF A SOUND SOURCE AND ITS PERCEIVED WAVELENGTH. A 310-Hz siren is on the roof of a car traveling at 31.0 m/s toward an observer who is at rest. If the speed of sound is 341 m/s, (a) what is the wavelength measured by the observer when the car is at rest? (b) What is the wavelength the observer measures when the car approaches? (c) What is the wavelength the observer measures when the car recedes from it?

138. [I] A hawk flying horizontally screeches at a central frequency of 900 Hz. A person standing still on the ground sees the bird flying away at 10.0 m/s. At what frequency does she hear the screech? Take the speed of sound to be 341 m/s.

139. [I] A police car, its siren blaring at 1000 Hz, is traveling at 20.00 m/s while chasing a garbage truck moving at 15.00 m/s a block in front of it. What apparent frequency will the garbage collectors hear? The speed of sound is 330.0 m/s.

140. [I] A train whistle is blown by an engineer who hears it sound at 650 Hz. If the train is heading toward a station at 20 m/s, what will the whistle sound like to a waiting commuter? Take the speed of sound to be 340 m/s.

141. [I] A car with its horn blaring at 500 Hz passed a woman standing on the street at 25 m/s. What frequency did she hear as the car receded into the distance? The speed of sound that day was 344 m/s.

142. [I] An ultrasonic wave at 80 000 Hz is emitted into a vein where the speed of sound is about 1.5 km/s. The wave reflects off the red blood cells moving toward the stationary receiver. If the frequency of the returning signal is 80 020 Hz, what is the speed of the blood flow?

143. [I] A man running toward the stage in a theater hears an A_4 note from a stationary tuning fork to have a frequency of 441 Hz instead of its more normal 440 Hz. About how fast is he going?

144. [II] A point source of sound on top of a police car emits a signal at 1000 Hz. If the car is traveling in a straight line at 30 m/s, what will be the wavelength perceived by people standing on the road both directly in front of and behind the car? Take the speed of sound to be 335 m/s. What is the wavelength as measured in the car?

145. [II] A bat flying straight toward a wall at 11 m/s emits a pulse at 60 kHz. What is the frequency of the reflected ultrasonic echo wave reaching a stationary observer standing under the bat. Take the speed of sound to be 341 m/s.

146. [II] THIS PROBLEM TREATS THE DOPPLER EFFECT WHEN SOUND IS REFLECTED BACK TO A MOVING SOURCE. A 310-Hz siren is on the roof of a police car traveling at 31.0 m/s directly toward a large wall. The speed of sound is 341 m/s. (a) As far as an observer at the wall is concerned, what is the positive direction? (b) What is the frequency (f_W) measured by that observer standing in front of the wall? Consider the sound reflected off the wall, and take the wall as a source at rest. (c) What is the positive direction now? (d) Determine the frequency of the reflected sound as measured by the approaching cop?

147. [II] An observer with a stationary source of sound sends out a signal directly toward an approaching target. Write an expression for the frequency of the beats heard by the observer.

148. [II] A sound wave at 1000 Hz is sent out from a stationary source toward a target approaching at 20.0 m/s. What will be the frequency of the returning signal? Take the speed of sound to be 340 m/s.