Waves and Sound

Advanced Placement Physics B
Mr. DiBucci

Name____ per.___ date _______
Wave Motion DiBucci

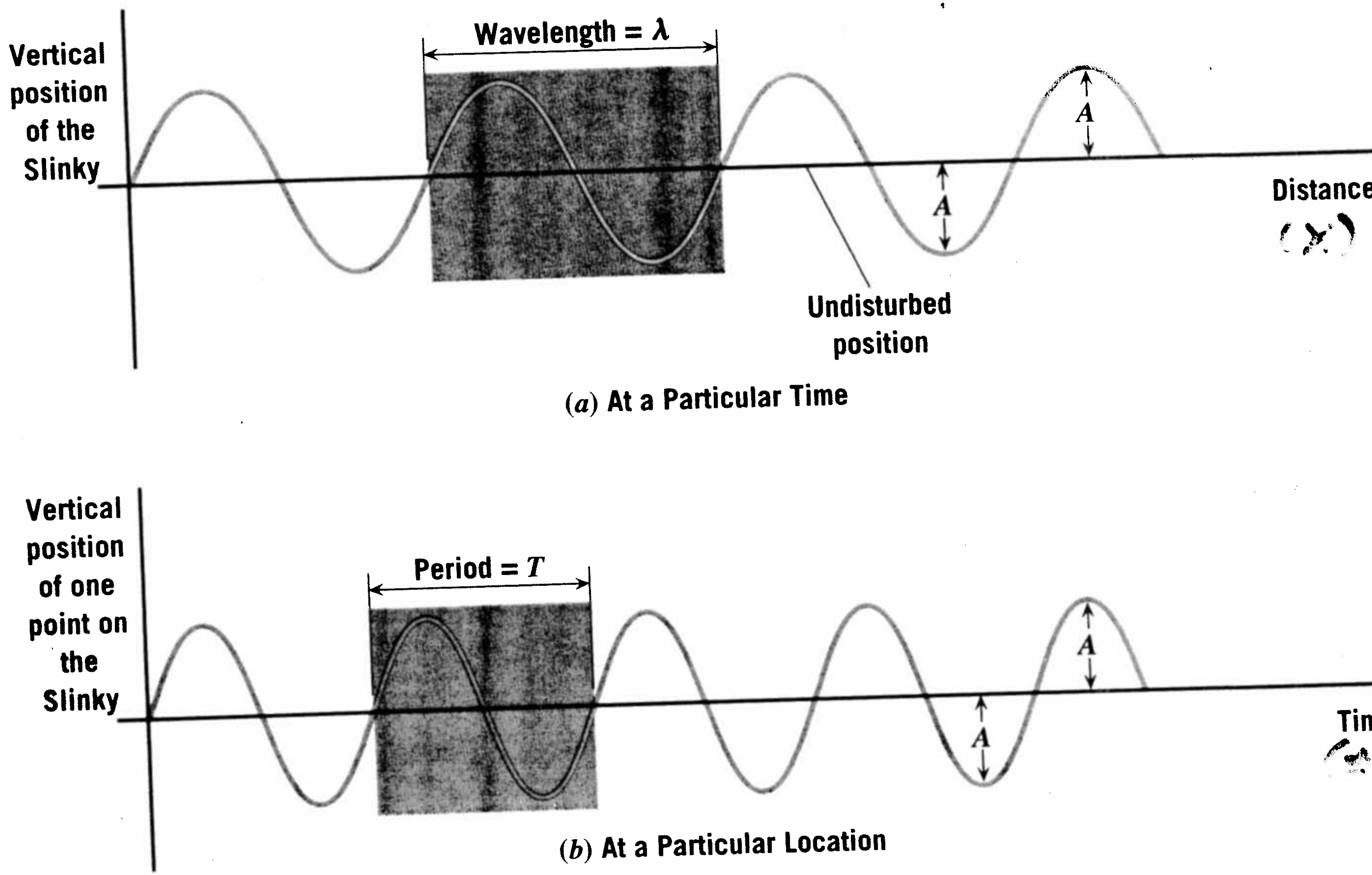
A wave has an amplitude of 5.0m , wavelength of 5.5m and travels to the right with a speed of 150 m/s.

a. Calculate the frequency (f) and angular frequency (w), and wave number (k) of this wave

b. Write an equation describing the wave.

C. Sketch the following graphs in the space below:

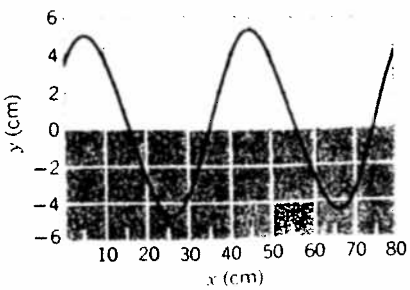
- y (vertical displacement) vs. x graph (label the wavelength)
- y vs. time graph.(label the period)



(*a*) At a Particular Time

(*b*) At a Particular Location

FIGURE 16-6



A simple harmonic transverse wave is propagating along a string toward the left (or $-x$) direction. Figure 23 shows a plot of the displacement as a function of position at time $t = 0$. The string tension is 3.6 N and its linear density is 25 g/m. Calculate (*a*) the amplitude, (*b*) the wavelength, (*c*) the wave speed, (*d*) the period. (e) WRITE THE WAVE FUNCTION FOR THIS WAVE.

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. 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.

3. 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?

4. A light wave travels through air at a speed of 3.0×10^8 m/s. Red light has a wavelength of about 6.6×10^{-7} m. What is the frequency of red light?

5. **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.

6. 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.

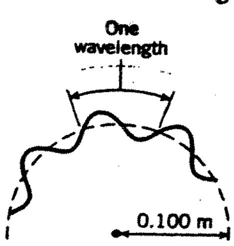
7. A wave has a frequency of 45 Hz and a speed of 22 m/s. Determine, if possible, (a) its period, (b) its wavelength, and (c) its amplitude. If it is not possible to determine any of these quantities, then so state.

8. 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.

9. **ssm** Suppose the amplitude and frequency of the transverse wave in Figure 16.2c 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.

*10. 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?

*11. 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?



*12. 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.

1) 0.083 Hz
2) 1.7×10^{-5} s
3) 1.25 Hz, 17.5 m/s
4) 4.5×10^{14} Hz
5) 0.25 m
6) 0.49 m
7) 0.022 s, 0.49 m AMP. CAN Not BE Determined
8) 0.200 Hz, 4.00 m/s
9) 78 cm
10) 50 s
11) 6.98×10^{-5} m
12) 1.1 m/s, 6.55 m

Section 16.3 The Speed of a Wave on a 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 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?

15. 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?

16. A wire is stretched between two posts. Another wire is stretched between two posts that are twice as far apart. The wires have the same mass. If the same tension exists in both wires, find the ratio of the speed of a transverse wave on the shorter wire to that on the longer wire.

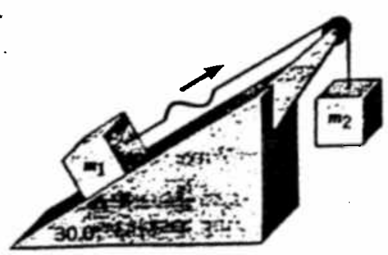
17. **ssm www** The middle C string on a piano is under a tension of 944 N. The period and wavelength of a wave on this string are 3.82×10^{-3} s and 1.26 m, respectively. Find the linear density of the string.

18. 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?

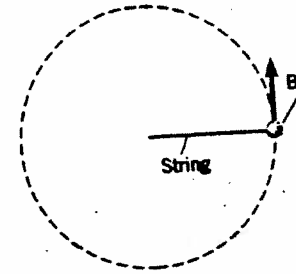
*19. To measure the acceleration due to gravity on a distant planet, an astronaut hangs a 0.085-kg ball from the end of a wire. The wire has a length of 1.5 m and a linear density of 3.1×10^{-4} kg/m. Using electronic equipment, the astronaut measures the time for a transverse pulse to travel the length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

*20. 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.

21. **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.



2. 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?

23. 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 17×10^{-6} (C°)$^{-1}$, 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.

13) 64N
14) 600 m/s
15) 4.8×10^{-4} kg
16) .707
17) 8.68×10^{-3} kg/m
18) 0.17 s
19) 1.2 m/s²
20) 2.2×10^{2} m/s
9.19 m/s
21) 28.7 kg, 14.3 kg
22) 3.26×10^{-3} s
23) 79 m/s

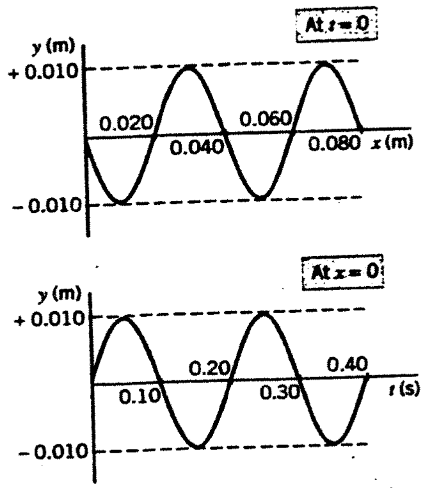
Section 16.4 The Mathematical Description of a Wave

(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.)***

24. 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?

25. 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?

[redacted] 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.



27. 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?

***28.** Refer to the graphs that accompany problem 26. From the data in these graphs, determine the speed of the wave.

***29. 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?

****30.** 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 $x = 0$. It begins with a displacement of $y = 0$ when $t = 0$, 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?

24) .45m, 4Hz, 2m, 8 m/s, -x dir

25) $y = .37\sin(2.6\pi t + .22\pi x)$

26) $y = .01\sin(10\pi t - 50\pi x)$

27) +x, -0.080m

28) 0.20 m/s

29) 2.5N

30) 1.9×10^{-3} s

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

31. A rhinoceros is calling to her mate using infrasonic sound with a frequency of 5.0 Hz. Her mate is 480 m away. The speed of sound is 343 m/s. How many cycles of the sound wave are between the two animals?

32. 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.)*

Section 16.7 Sound Intensity

• 51. 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?

*52. 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?

• 53. **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.

• 54. 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?

• 55. A source of sound radiates power uniformly in all directions. Two spheres are centered on this source. Sphere A has a radius of 0.80 m, while sphere B has a radius of 1.1 m. Consider the sound power that passes through a 0.17-m^2 patch of surface on sphere A. What is the area of the surface on sphere B through which this same power passes?

56. Suppose in Conceptual Example 9 (see Figure 16.25) that the person is producing 0.50 watt 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 2.1×10^{-3} W/m^2. What is the total sound intensity due to both the direct and reflected sounds, at this point?

57. **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?

*58. 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 $\frac{1}{4}I$?

*59. 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?

*60. Two sources each emit sound power uniformly in all directions. There are no reflections. Both sources are located on the x axis, one at the origin and the other at $x = +123$ m. The source at the origin emits four times more power than the other source. Where on the x axis is the intensity of each source equal? Note that there are two answers.

31) 7
32) 11.8 m
51) 6.7x10^{-9} w
52) 2.4x10^{-4} J
53) 6.5 W
54) 2.4x10^{-5} W/m^2
55) 0.32 m^2
56) 6.5x10^{-3} W/m^2
57) 1.98%
58) 2510 m
59) 1.0x10^4 W/m^2
60) 82.0 m, 246 m

Section 16.8 Decibels

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

•63. 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?

•64. One of the important specifications of a cassette tape deck is its signal-to-noise rating. This specification indicates how much of the sound intensity created when playing a tape is due to the musical tones (the signal) and how much is due to the hissing sound produced by the moving tape (the noise). Suppose the sound intensity due to the musical tones is 3.0×10^{-5} W/m², while that due to the tape hiss is 4.8×10^{-11} W/m². What is the signal-to-noise rating, which is the number of *decibels* by which the signal exceeds the noise?

65. **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?

•66. The sound intensity level of a jet engine is 138 dB, while at a rock concert it is 115 dB. Find the ratio of the sound intensity of the jet engine to the sound intensity at the rock concert.

67. The equation $\beta = 10 \log (I/I_0)$, which defines the decibel, is sometimes written in terms of power P (in watts) rather than intensity I (in watts/meter²). The form $\beta = 10 \log (P/P_0)$ 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.

68. For information, read problem 67 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?

69. **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?

*70. 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.)***

*71. 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 be-

62) 0.316 W/m²
63) 25
64) 58dB
65) 1000
66) 2×10²
67) 7.4dB, No
68) 56.2 W
69) -6.0dB
70) 77dB
71) .845

Section 16.10 The Doppler Effect

75. At a football game, a stationary spectator is watching the alftime show. A trumpet player in the band is playing a 784-Hz one 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?

76. A hawk is flying directly away from a bird watcher at a speed of 11.0 m/s. The hawk produces a shrill cry whose frequency is 865 Hz. The speed of sound is 343 m/s. What is the frequency that the bird watcher hears?

77. **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?

78. 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?

79. A train is blowing its whistle while traveling at a speed of 33.0 m/s. The speed of sound is 343 m/s. Observer A is directly in front of the train, while observer B is directly behind it. Find the ratio of the whistle frequency heard by A to that heard by B.

***80.** A bicyclist and a car have the same speed and are moving toward each other. The car emits a sound of frequency 508 Hz, and the bicyclist hears the frequency as 542 Hz. The temperature of the air is 20 °C. How fast is each going?

81. **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?

***82.** 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?

***83.** Two trucks travel at the same speed. They are far apart on adjacent lanes and approach each other essentially head-on. One driver hears the horn of the other truck at a frequency that is 1.20 times the frequency he hears when the trucks are stationary. The speed of sound is 343 m/s. At what speed is each truck moving?

***84.** 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.

***85.** **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?

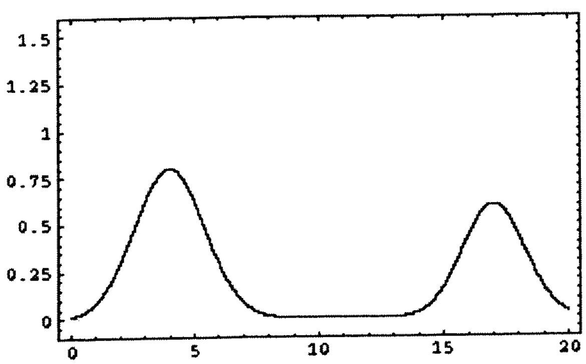
A microphone is attached to a spring that is suspended from ceiling, as the drawing indicates. Directly below on the floor is ationary 440-Hz source of sound. The microphone vibrates up l down in simple harmonic motion with a period of 2.0 s. The erence between the maximum and minimum sound frequen- ; detected by the microphone is 2.1 Hz. Ignoring any reflec- ıs of sound in the room and using 343 m/s for the speed of nd, determine the amplitude of the simple harmonic motion.

75) 786 Hz
76) 838 Hz
77) 56 m/s
78) 0.340 m
79) 1.21
80) 11 m/s
81) 1350 Hz
82) 1240 m/s
83) 31 m/s
84) 615 Hz
85) 209 m
86) 0.26 m

Superposition of Waves

The principle of superposition may be applied to waves whenever two (or more) waves travelling through the same medium at the same time. The waves pass through each other without being disturbed. The net displacement of the medium at any point in space or time, is simply the sum of the individual wave dispacements. This is true of waves which are finite in length (wave pulses) or which are continuous sine waves.

Two guassian waves travelling in opposite directions



The movie at left shows two gaussian wave pulses are travelling on a string, one is moving to the right, the other is moving to the left. They pass through each other without being disturbed, and the net displacement is the sum of the two individual displacements. It should also be mentioned that this string is nondispersive (all frequencies travel at the same speed) since the gaussian wave pulses do not change their shape as they propagate. If the medium was dispersive, then the waves would change their shape.

Two sine waves travelling in the same direction: Constructive and Destructive Interference

Two waves (with the same amplitude, frequency, and wavelength) are travelling in the same direction on a string. Using the principle of superposition, the resulting string displacement may be written as:

$$\begin{aligned} y(x,t) &= y_m \sin(kx - \omega t) + y_m \sin(kx - \omega t + \phi) \\ &= 2y_m \cos\left(\frac{\phi}{2}\right) \sin\left(kx - \omega t + \frac{\phi}{2}\right) \end{aligned}$$

which is a travelling wave whose amplitude depends on the phase (phi). When the two waves are **in-phase** (phi=0), they interfere **constructively** and the result has twice the amplitude of the individual waves. When the two waves have **opposite-phase** (phi=180), they interfere **destructively** and cancel each other out.

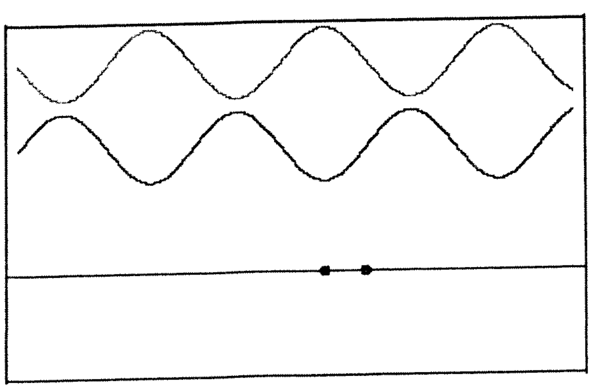
The animation at left shows two sinusoidal waves travelling in the same direction. The phase difference between the two waves varies increases with time so that the effects of both constructive and destructive interference may be seen. First of all, notice that the sum wave (in blue) is a travelling wave which moves from left to right. When the two gray waves are in phase the result is large amplitude. When the two gray waves become out of phase the sum wave is zero.

Two sine waves travelling in opposite directions create a standing wave

A **travelling wave** moves from one place to another, whereas a **standing wave** appears to stand still, vibrating in place. Two waves (with the same amplitude, frequency, and wavelength) are travelling in opposite directions on a string. Using the principle of superposition, the resulting string displacement may be written as:

$$\begin{aligned} y(x,t) &= y_m \sin(kx - \omega t) + y_m \sin(kx + \omega t) \\ &= 2y_m \sin kx \cos \omega t \end{aligned}$$

This wave is no longer a travelling wave because the position and time dependence have been separated. The displacement of the string as a function of position has an amplitude of $2y_m \sin kx$. This amplitude does not travel along the string, but stands still and oscillates up and down according to cos *wt*. Characteristic of standing waves are locations with maximum displacement (**antinodes**) and locations with zero displacement (**nodes**).



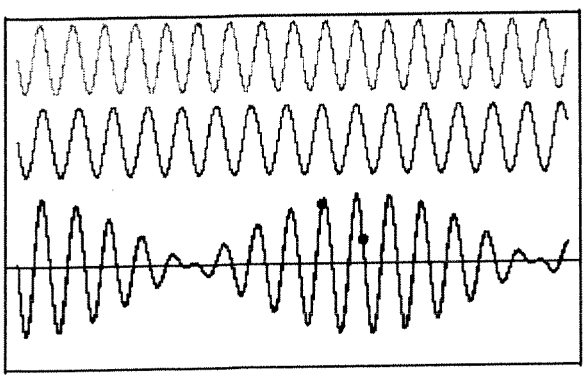
The movie at left shows how a standing wave may be created from two travelling waves. If two sinusoidal waves having the same frequency (wavelength) and the same amplitude are travelling in opposite directions in the same medium then, using superposition, the net displacement of the medium is the sum of the two waves. As the movie shows, when the two waves are 180° out-of-phase with each other they cancel, and when they are in-phase with each other they add together. As the two waves pass through each other, the net result alternates between zero and some maximum amplitude. However, this pattern simply oscillates; it does not travel to the right or the left. I have placed two dots on the string, one at an antinode and one at a node. Which is which?

Two sine waves with different frequencies: Beats

Two waves of equal amplitude are travelling in the same direction. The two waves have different frequencies and wavelengths, but they both travel with the same wave speed. Using the principle of superposition, the resulting particle displacement may be written as:

$$y(x,t) = y_m \sin(k_1 x - \omega_1 t) + y_m \sin(k_2 x - \omega_2 t)$$
$$= 2y_m \cos\left[\frac{(k_1 - k_2)}{2}x - \frac{(\omega_1 - \omega_2)}{2}t\right] \sin\left[\frac{(k_1 + k_2)}{2}x - \frac{(\omega_1 + \omega_2)}{2}t\right]$$

This resulting particle motion is the product of **two** travelling waves. One part is a sine wave which oscillates with the average frequency $f = ½(f_1 + f_2)$. This is the frequency which is perceived by a listener. The other part is a cosine wave which oscillates with the difference frequency $f = ½(f_1 - f_2)$. This term controls the amplitude "envelope" of the wave and causes the perception of "beats". The beat frequency is actually twice the difference frequency, $f_{\text{beat}} = (f_1 - f_2)$.



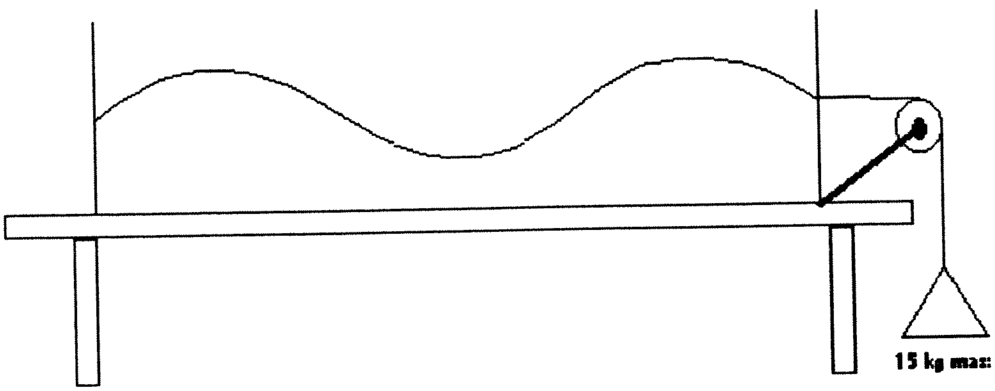
In the movie at left two waves with slightly different frequencies are travelling to the right. The resulting wave travels in the same direction and with the same speed as the two component waves. The "beat" wave oscillates with the average frequency, and its amplitude envelope varies according to the difference frequency.

Back to the Vibrations and Waves: Demos and Animations Page

Name________________________________ Date_________

Quiz 3
General Physics 2, Summer 1996

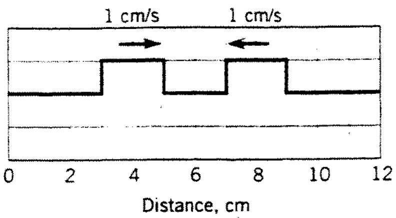
Consider a transverse standing wave on a string that is connected between to posts.(see the diagram) A 15 kg mass is connected to one end of the rope and hangs over the side of the table. The rope has a linear density of 0.05 kg/m and has a length of 0.75 meters.



Determine the frequency of the standing wave on the string.

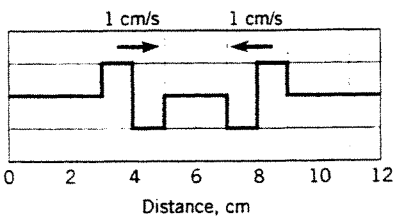
Section 17.1 The Principle of Linear Superposition, Section 17.2 Constructive and Destructive Interference of Sound Waves

1. ssm The drawing shows a string on which two rectangular pulses are traveling at a constant speed of 1 cm/s at time $t = 0$. Using the principle of linear superposition, draw the shape of the string at t = 1 s, 2 s, 3 s, and 4 s.



2. Repeat problem 1, assuming that the pulse on the right is pointing downward, rather than upward.

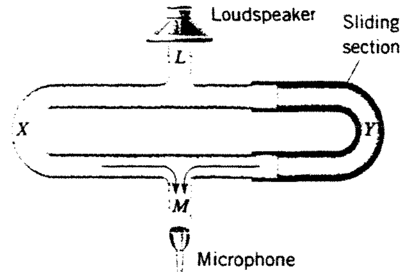
3. Repeat problem 1, assuming that the pulses have the shape (half up and half down) shown in the drawing.



4. In Figure 17.9, the two speakers are vibrating in phase and are separated by 3.20 m. Both are reproducing identical 214-Hz tones. The speed of sound is 343 m/s. Suppose point C is 6.00 m directly in front of speaker B, instead of the 2.40 m shown in the drawing. Does constructive or destructive interference occur at point C? Why?

5. ssm Two loudspeakers are vibrating in phase. They are set up as in Figure 17.9, and point C is located as shown there. The speed of sound is 343 m/s. The speakers play the same tone. What is the smallest frequency that will produce destructive interference at point C?

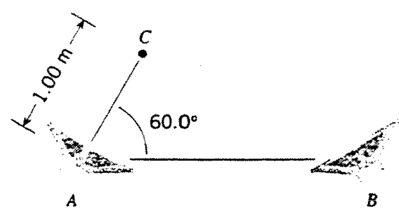
6. The sound produced by the loudspeaker in the drawing has a frequency of 12 000 Hz and arrives at the microphone via two different paths. The sound travels through the left tube *LXM*, which has a fixed length. Simultaneously, the sound travels through the right tube *LYM*, the length of which can be changed by moving the sliding section. At M, the sound waves coming from the two paths interfere. As the length of the path *LYM* is changed, the sound loudness detected by the microphone changes. When the sliding section is pulled out by 0.020 m, the loudness changes from a maximum to a minimum. Find the speed at which sound travels through the gas in the tube.



***7.** Two loudspeakers on a concert stage are vibrating in phase. A listener is 51.4 m from the left speaker and 30.0 m from the right one. The listener can respond to all frequencies from 20 to 20 000 Hz, and the speed of sound is 343 m/s. What are the two lowest frequencies that can be heard loudly due to constructive interference?

***8.** Review Conceptual Example 2 in preparation for this problem. Assume that the two loudspeakers in Figure 17.9 are vibrating *out of phase* instead of in phase. The speed of sound is 343 m/s. What is the smallest frequency that will produce destructive interference at point C?

***9. ssm www** The drawing shows a loudspeaker A and point C, where a listener is positioned. A second loudspeaker B is located somewhere to the right of A. Both speakers vibrate in phase and are playing a 68.6-Hz tone. The speed of sound is 343 m/s. What is the closest to speaker A that speaker B can be located, so that the listener hears no sound?



****10.** Speakers A and B are vibrating in phase. They are directly facing each other, are 7.80 m apart, and are each playing a 73.0-Hz tone. The speed of sound is 343 m/s. On the line *between* the speakers there are three points where constructive interference occurs. What are the distances of these three points from speaker A?

1) 2) 3) } See Solutions Manual
4)
5) 107 Hz
6) 960 m/s
7) 48.1 Hz
8) 214 Hz
9) 3.89 m
10) 1.55 From A
6.25 from A

Section 17.5 Transverse Standing Waves

25. **ssm** The A string on a string bass is tuned to vibrate at a fundamental frequency of 55.0 Hz. If the tension in the string were increased by a factor of four, what would be the new fundamental frequency?

26. If the string in Figure 17.21 is vibrating at a frequency of 4.0 Hz and the distance between two successive nodes is 0.30 m, what is the speed of the waves on the string?

27. The G string on a guitar has a fundamental frequency of 196 Hz and a length of 0.62 m. This string is pressed against the proper fret to produce the note C, whose fundamental frequency is 262 Hz. What is the distance L between the fret and the end of the string at the bridge of the guitar (see Figure 17.23*b*)?

28. The lowest note on a piano has a fundamental frequency of 27.5 Hz and is produced by a wire that has a length of 1.18 m. The speed of sound in air is 343 m/s. Determine the ratio of the wavelength of the sound wave to the wavelength of the waves that travel on the wire.

29. **ssm** On a cello, the string with the largest linear density (1.56×10^{-2} kg/m) is the C string. This string produces a fundamental frequency of 65.4 Hz and has a length of 0.800 m between the two fixed ends. Find the tension in the string.

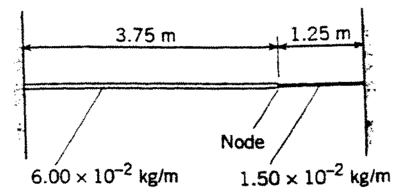
30. A string of length 2.50 m is fixed at both ends. When the string vibrates at a frequency of 85.0 Hz, a standing wave with five loops is formed. (a) What is the wavelength of the waves that travel on the string? (b) What is the speed of the waves? (c) What would be the fundamental frequency of this string?

31. Electric guitars often come equipped with a "whammy bar," which is a lever that allows the performer to adjust the tension in the strings. In this way, the performer can "dive bomb." To dive bomb means to produce a tone that begins with a high frequency and ends with a low frequency and to go through all the frequencies in between. Suppose that a performer dive bombs the frequency in half. By what factor has the whammy bar reduced the tension in the strings?

32. Sometimes, when a wind blows across a long wire, a low-frequency "moaning" sound is produced. This sound arises because a standing wave is set up on the wire, like a standing wave on a guitar string. Assume that a wire (linear density = 0.0140 kg/m) sustains a tension of 323 N, because the wire is stretched between two poles that are 19.0 m apart. The lowest frequency that a human ear can detect is about 20.0 Hz. What is the lowest harmonic number n that could be responsible for the "moaning" sound?

***33.** **ssm** The E-string on an electric bass guitar has a length of 0.628 m and, when producing the note E, vibrates at a fundamental frequency of 41.2 Hz. Players sometimes add to their instruments a device called a "D-tuner." This device allows the E-string to be used to produce the note D, which has a fundamental frequency of 36.7 Hz. The D-tuner works by extending the length of the string, keeping all other factors the same. By how much does a D-tuner extend the length of the E-string?

***34.** Two strings have different lengths and linear densities, as the drawing shows. They are joined together and stretched so that the tension in each string is 190.0 N. The free ends of the joined string are fixed in place. Find the lowest frequency that permits standing waves in both strings with a node at the junction. The standing wave pattern in each string may have a different number of loops.



25) 110.0 Hz
26) 2.4 m/s
27) .46 m
28) 5.3
29) 171 N
30) 1 m, 85 m/s, 17 Hz
31) Factor of 4
32) 5
33) 0.077 m
34) 45 Hz

Section 17.6 Longitudinal Standing Waves, Section 17.7 Complex Sound Waves

38. A cylindrical tube sustains standing waves at the following frequencies: 500, 700, and 900 Hz. There are no standing waves at frequencies of 600 and 800 Hz. (a) What is the fundamental frequency? (b) Is the tube open at both ends or at only one end?

39. A piccolo and a flute can be approximated as cylindrical tubes with both ends open. The lowest fundamental frequency produced by one kind of piccolo is 587.3 Hz, while that produced by a flute is 261.6 Hz. What is the ratio of the length of the piccolo to that of the flute?

40. The range of human hearing is roughly from twenty hertz to twenty kilohertz. Based on these limits and a value of 343 m/s for the speed of sound, what are the lengths of the longest and shortest pipes (open at both ends and producing sound at their fundamental frequencies) that you expect to find in a pipe organ?

41. **ssm** A tube of air is open at only one end and has a length of 1.5 m. This tube sustains a standing wave at its third harmonic. What is the distance between one node and the adjacent antinode?

42. One method for measuring the speed of sound uses standing waves. A cylindrical tube is open at both ends, and one end is placed against a loudspeaker. A movable plunger is inserted into the other end. The distance between the loudspeaker and the plunger is L. When the loudspeaker generates a 485-Hz tone, the smallest value of L for which a standing wave is formed is 0.264 m. What is the speed of sound in the gas in the tube? (*Hint: The plunger closes one end of the tube.*)

43. The fundamental frequencies of two air columns are the same. Column A is open at both ends, while column B is open at only one end. The length of column A is 0.60 m. What is the length of column B?

44. Refer to Conceptual Example 7 as background for this problem. Suppose that someone's lungs are first filled with pure helium at 36 °C and then air at 20 °C. Assume that both helium and air are ideal gases. The nth harmonic frequency of the person's voice is f_n^{helium} and f_n^{air}. Find the ratio $f_n^{\text{helium}}/f_n^{\text{air}}$.

45. **ssm** Both neon (Ne) and helium (He) are monatomic gases and can be assumed to be ideal gases. The fundamental frequency of a tube of neon is 268 Hz. What is the fundamental frequency of the tube if the tube is filled with helium, all other factors remaining the same?

***46.** A tube, open at both ends, contains an unknown ideal gas for which $\gamma = 1.40$. At 293 K, the shortest tube in which a standing wave can be set up with a 294-Hz tuning fork has a length of 0.248 m. Find the mass of a gas molecule.

***47.** A cylindrical pipe is *closed at both ends.* Derive an expression for the frequencies of the allowed standing waves, similar in form to Equations 17.4 and 17.5, in terms of the speed of sound v, the length of the pipe L, and the harmonic number n. State which integer values of n are allowed.

***48.** A person hums into the top of a well and finds that standing waves are established at frequencies of 42, 70.0, and 98 Hz. The frequency of 42 Hz is not necessarily the fundamental frequency. The speed of sound is 343 m/s. How deep is the well?

***49.** **ssm www** A vertical tube is closed at one end and open to air at the other end. The air pressure is 1.01×10^5 Pa. The tube has a length of 0.75 m. Mercury (mass density = 13 600 kg/m^3) is poured into it to shorten the effective length for standing waves. What is the absolute pressure at the bottom of the mercury column, when the fundamental frequency of the shortened, air-filled tube is equal to the third harmonic of the original tube?

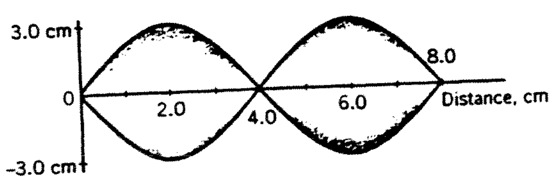
****50.** A tube, open at only one end, is cut into two shorter (nonequal) lengths. The piece open at both ends has a fundamental frequency of 425 Hz, while the piece open only at one end has a fundamental frequency of 675 Hz. What is the fundamental frequency of the original tube?

49) 1.68×10^5 Pa
50) 162 Hz

58) 8 cm
1.5 Hz
28.3 cm/s

38) 100 Hz, open at one end
39) 0.445
40) 8.6 m, 8.6×10^{-3} m
41) 0.5 m
42) 512 m/s
43) 0.30 m
44) 2.99
45) 602 Hz
46) 2.66×10^{-25} kg
47) $f = \frac{nv}{2L}$ $n = 1, 2, 3 \ldots$
48) 6.1 m

***58.** The graph shows a transverse standing wave on a string. (a) What is the wavelength of each wave that combines to form the standing wave? (b) If the velocity of one of the component waves is +12.0 cm/s, what is the velocity of the other? (c) What is the frequency of each component wave? (d) Suppose that a "dot" is attached to the string at x = 2.0 cm. Determine the maximum speed (in cm/s) of this dot as it vibrates up and down.



Hearing and the Human Ear

Physics in Practice

How good are human ears as detectors of sound? We can hear sounds ranging from the faint buzz of a mosquito's wings to the roar of a jet engine. In each case, air is set in vibration. Eventually the vibrations of the air reach your ear and act on your eardrum, letting you hear the sound. The human ear is an exceptional detector because it works over such a wide range of intensities and frequencies.

Your ears are not equally sensitive to all frequencies. In Fig. B15.3 we plot the intensity of the softest sound heard at different frequencies. The lowest region of the curve corresponds to the range of frequencies where the ear is most sensitive, which is in the range of 3–4 kHz. This is the frequency range of the upper notes on a piano.

We can see just how sensitive the ear is by using the relationship between vibrational amplitude and intensity given in Eq. (15.3). To find the amplitude of a sound that can just be heard by a person with good hearing, we use the value for the minimum detectable intensity, 10^{-12} W/m^2, and a frequency of 4000 Hz corresponding to the most sensitive frequency region. On using these values, along with representative values for the other parameters, we find a vibrational amplitude of about 3×10^{-12} m. This truly is a small displacement; it is approximately 1/100 of the diameter of the oxygen molecules that make up the air. Your eardrum is unquestionably very sensitive to respond to such small fluctuations.

On the other hand, a sound loud enough to cause pain, say 120 dB or louder, has an amplitude of about 3×10^{-6} m. Though this value is quite a bit larger than the amplitude of the softest sound, it is still quite small. If a sheet of paper were of this thickness, a stack of 400 sheets would be about as thick as a dime.

Figure B15.4 shows a schematic diagram of the human ear. The auditory canal of the outer ear acts in an interesting way as an amplifier for certain frequencies. Consider the canal to be a pipe closed at one end by the eardrum. In Section 15.10 we discuss the resonant frequencies of such pipes. The average length of the auditory canal is about 2.5 cm, with a resonant frequency of 3400 Hz. Figure B15.3 shows an increase in sensitivity in the region of this resonance. It is interesting to note that this is also the frequency range of a baby's cry. This is, however, somewhat higher than the range of adult human speech, which lies primarily in the 500-2000 Hz region. Passive hearing aids that do not require batteries have been designed to effectively shift the resonance region downward toward the range of adult speech.

Beginning in the mid-teens, a gradual decrease in the sensitivity of hearing begins — both in frequency range and in threshold of hearing. A young child may be able to hear sounds with frequencies as high as 40 kHz. By the teens this upper limit has dropped to about 20 kHz, and from then on a relatively steady decrease of about 160 Hz per year is observed. For people 50 years old, an upper limit of 10-15 kHz is typical.

Temporary loss of hearing often follows exposure to a single, short, loud noise. For the most part the ear recovers from such short duration overloads. More damaging are extended and repeated loud noises. People who work in loud environments are known to suffer permanent and irreversible hearing loss. For this reason they often wear special headgear or earplugs to reduce the sound's intensity level at their ears. Musicians who play loud music for long periods also frequently wear hearing protectors.

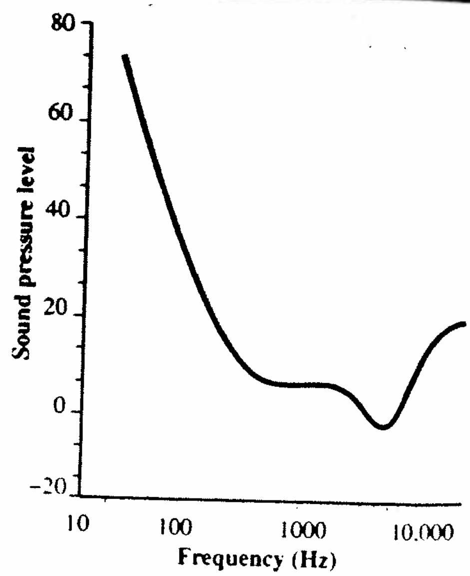


Figure B15.3 Frequency response of the human ear.

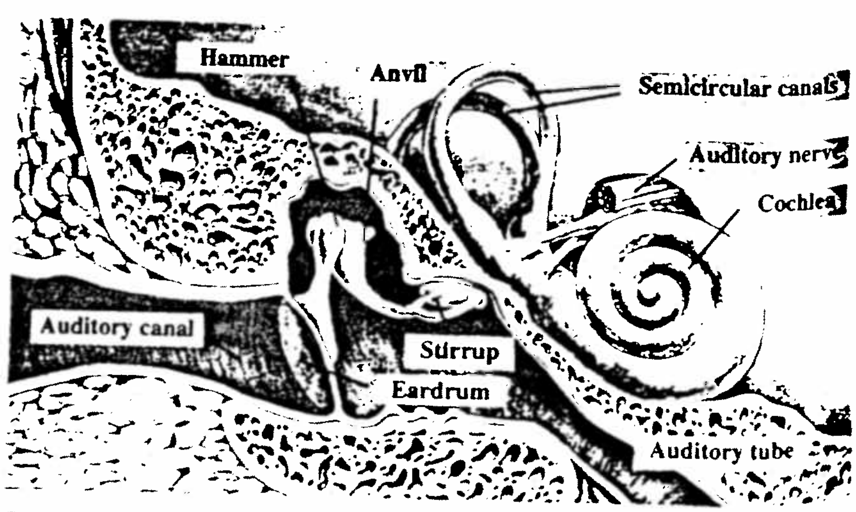


Figure B15.4 Schematic diagram of the human ear.

Practice Test Waves and sound #2

MULTIPLE CHOICE

1. An object in simple harmonic motion obeys the following position versus time equation: y = ~~(0.50 m) sin (ã/2 t)~~. What is the period of vibration?

$y = (.5m)\cos[(\pi/2)t]$

a) 1.0 s
b) 2.0 s
c) 3.0 s
d) 4.0 s

2. An object in simple harmonic motion obeys the following position versus time equation: y = ~~(0.50 m) sin (ã/2 t)~~. What is the maximum speed of the object?

$y = (.5m)\cos[(\pi/4)t]$

a) 0.13 m/s
b) 0.26 m/s
c) 0.39 m/s
d) 0.52 m/s

3. A mass is attached to a vertical spring and bobs up and down between points A and B. Where is the mass located when its kinetic energy is a minimum?

a) At either A or B
b) Midway between A and B
c) One-fourth of the way between A and B
d) None of the above

4. A string of linear density 6.0 g/m is under a tension of 180 N. What is the velocity of propagation of transverse waves along the string?

a) 2.9X104 m/s
b) 1.7X102 m/s
c) 13 m/s
d) 5.8X10-3 m/s

5. What is the velocity of propagation if a wave has a frequency of 12 Hz and a wavelength of 3.0 m?

a) 0.25 m/s
b) 4.0 m/s
c) 36 m/s
d) None of the above

6. Find the first three harmonics of a string of linear mass density 2.00 g/m and length 0.600 m when it is subjected to tension of 50.0 N.

a) 132 Hz, 264 Hz, 396 Hz
b) 66 Hz, 132 Hz, 198 Hz
c) 264 Hz, 528 Hz, 792 Hz
d) None of the above

7. A stretched string is observed to have three equal segments in a standing wave driven at a frequency of 480 Hz. What driving frequency will set up a standing wave with four equal segments?

a) 480 Hz
b) 640 Hz
c) 360 Hz
d) 160 Hz

8. A string of linear density 1.5 g/m is under a tension of 20 N. What should its length be if its fundamental resonance frequency is 220 Hz?

a) 0.26 m
b) 0.96 m
c) 1.1 m
d) 1.2 m

9. A string, fixed at both ends, vibrates at a frequency of 12 Hz with a standing transverse wave pattern containing 3 loops. What frequency is needed if the standing wave pattern is to contain 4 loops?

a) 48 Hz
b) 36 Hz
c) 16 Hz
d) 12 Hz

10. The number of crests of a wave passing a point per unit time is called the wave's

a) speed.
b) frequency.
c) wavelength.
d) amplitude.

11. The distance between successive crests on a wave is called the wave's

a) speed.
b) frequency.
c) wavelength.
d) amplitude.

12. In a wave, the maximum displacement of points of the wave from equilibrium is called the wave's

a) speed.
b) frequency.
c) wavelength.
d) amplitude.

13. For a wave, the frequency times the wavelength is the wave's

a) speed.
b) amplitude.
c) intensity.
d) power.

14. What is the frequency of a wave which has a period of 3.00 ms?

a) 33.3 Hz
b) 333 Hz
c) 3.33 kHz
d) 33.3 kHz

15. What is the period of a wave with a frequency of 1500 Hz?

a) 0.67 ~~ms~~ μs
b) 0.67 ms
c) 0.67 s
d) 6.7 s

16. What is the velocity of a wave that has a wavelength of 4.0 m and a frequency of 50 Hz?

a) 0.005 m/s
b) 0.08 m/s
c) 12.5 m/s
d) 200 m/s

17. If a guitar string has a fundamental frequency of 500 Hz, which one of the following frequency can set the string into resonant vibration?

a) 250 Hz
b) 750 Hz
c) 1500 Hz
d) 1750 Hz

18. Resonance in a system, such as a string fixed at both ends, occurs when

a) it is oscillating in simpler harmonic motion.
b) its frequency is the same as the frequency of an external source.
c) its frequency is greater than the frequency of an external source.
d) its frequency is smaller than the frequency of an external source.

19. The speed of an ultrasonic sound of frequency 45 kHz in air is 342 m/s. What is the air

temperature?

a) 16øC
b) 17øC
c) 18øC
d) 19øC

20. What is the ratio of the speed of sound in air at 0øC to the speed at 100øC?

a) 0.75
b) 0.85
c) 0.95
d) 1.1

21. In general, sound is conducted fastest through

a) gases.
b) liquids.
c) solids.
d) a vacuum.

22. Which of the following is a false statement?

a) Sound waves are longitudinal pressure waves.
b) Sound can travel through a vacuum.
c) Light travels very much faster than sound.
d) The transverse waves on a vibrating string are different from sound waves.
e) "Pitch" (in music) and frequency have approximately the same meaning.

23. What is the intensity of a 70-dB sound?

a) 10-4 W/m2
b) 10-5 W/m2
c) 10-6 W/m2
d) 10-7 W/m2

24. The intensity of a point source at a distance d from the source is I. What is the intensity at a distance 2d from the source?

a) 4I
b) 2I
c) I/2
d) I/4

25. For spherically diverging waves, intensity is proportional to

a) R2
b) R
c) 1/R
d) 1/R2

26. What is the ratio of the intensities of two sounds with intensity levels of 70 dB and 40 dB?

a) 10:1
b) 100:1
c) 1000:1
d) 10,000:1

27. The intensity at a distance of 6.0 m from a source that is radiating equally in all directions is 6.0X10-10 W/m2. What is the power emitted by the source?

a) 2.1X10-8 W
b) 2.7X10-7 W
c) 2.1X10-6 W
d) 2.7X10-5 W

28. A barking dog delivers about 1 mW of power, which is assumed to be uniformly distributed in all directions. What is the intensity level at a distance 5.00 m from the dog?

a) 61 dB
b) 63 dB

c) 65 dB
d) 68 dB

29. The intensity level is 65 dB at a distance 5.00 m from a barking dog. What would be the intensity level if two identical dogs very close to each other are barking?

a) 65 dB
b) 68 dB
c) 130 dB
d) 136 dB

30. You double your distance from a sound source that is radiating equally in all directions. What happens to the intensity level of the sound? It drops by

a) 2 dB.
b) 3 dB.
c) 6 dB.
d) 8 dB.

31. Which of the following increases as a sound becomes louder?

a) Frequency
b) Wavelength
c) Amplitude
d) Period
e) Velocity

32. The fundamental frequency in a closed pipe is 330 Hz. What is the frequency of the third harmonic?

a) 110 Hz
b) 220 Hz
c) 660 Hz
d) 990 Hz

33. An organ pipe open at both ends has a length of 0.80 m. If the velocity of sound in air is 340 m/s, what is the frequencies of the second harmonic?

a) 213 Hz
b) 425 Hz
c) 638 Hz
d) 850 Hz

34. An organ pipe open at both ends has a length of 0.80 m. If the velocity of sound in air is 340 m/s, what is the frequencies of the third harmonic?

a) 213 Hz
b) 425 Hz
c) 638 Hz
d) 850 Hz

35. What is the length of the shortest closed pipe that will have a fundamental frequency of 60 Hz on a day when the velocity of sound is 340 m/s?

a) 1.24 m
b) 1.42 m
c) 2.14 m
d) 4.12 m

36. Which of the following is most closely identified with loudness of a musical note?

a) Frequency
b) Velocity
c) Phase
d) Amplitude

37. A 3.00-m long pipe is in a room where the temperature is 20øC. What is the fundamental frequency if the pipe is closed at one end?

a) 57 Hz
b) 114 Hz
c) 29 Hz
d) none of the above

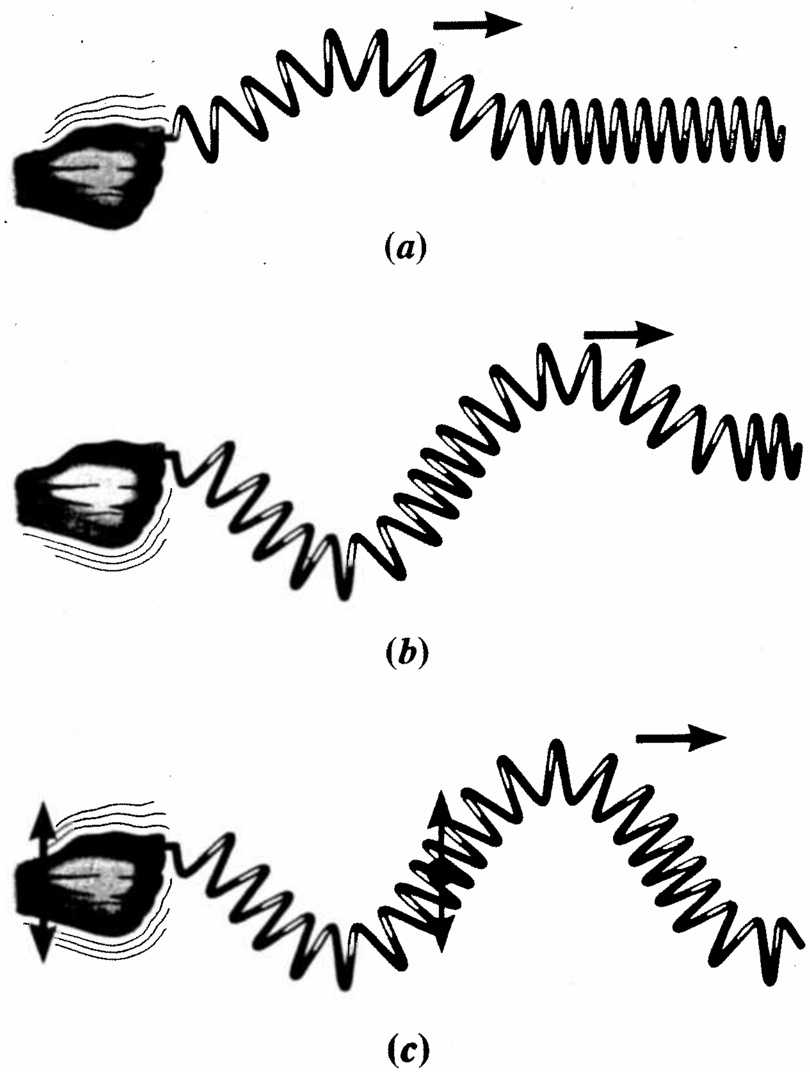


FIGURE 16-2

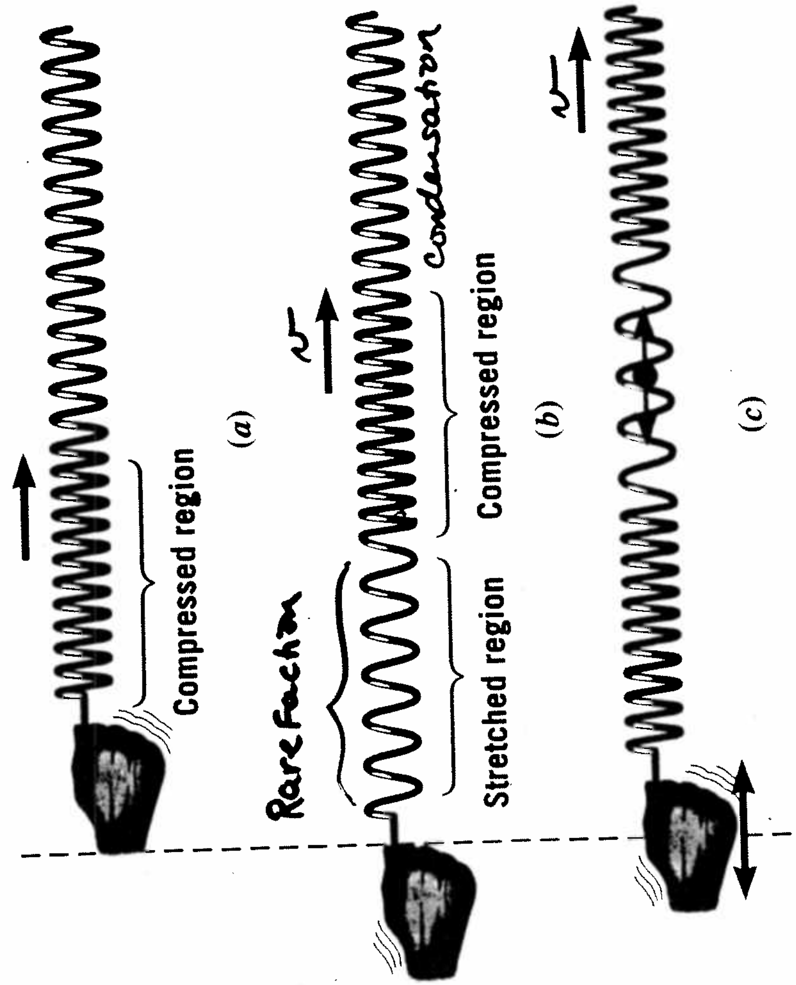


FIGURE 16-3

FIGURE 16-6 137

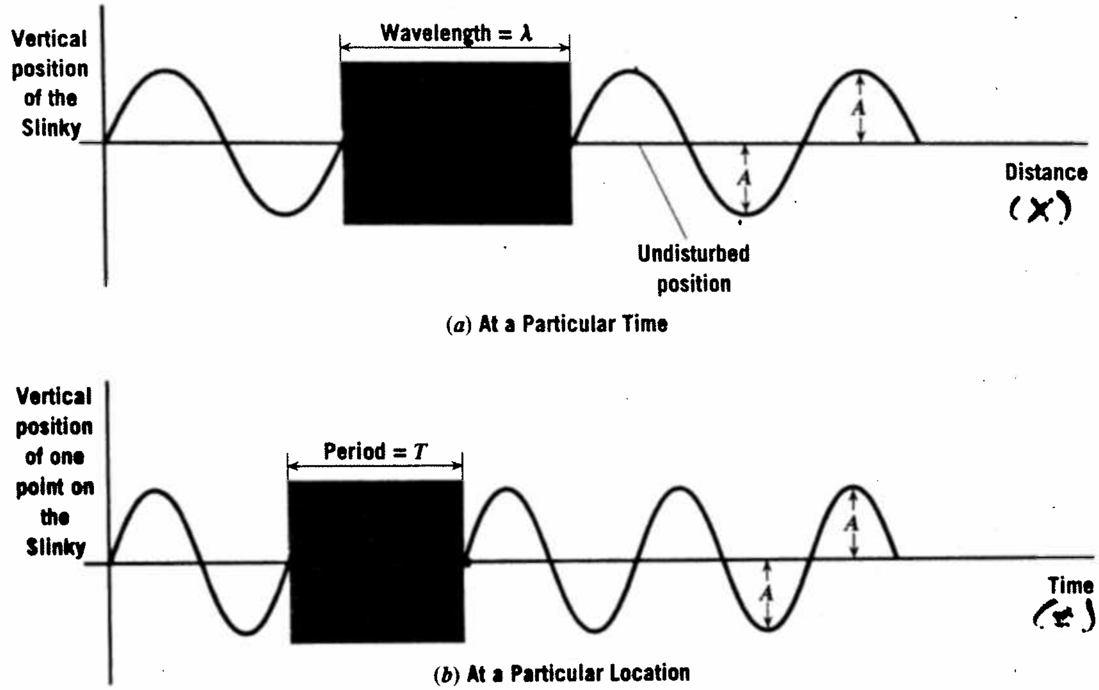
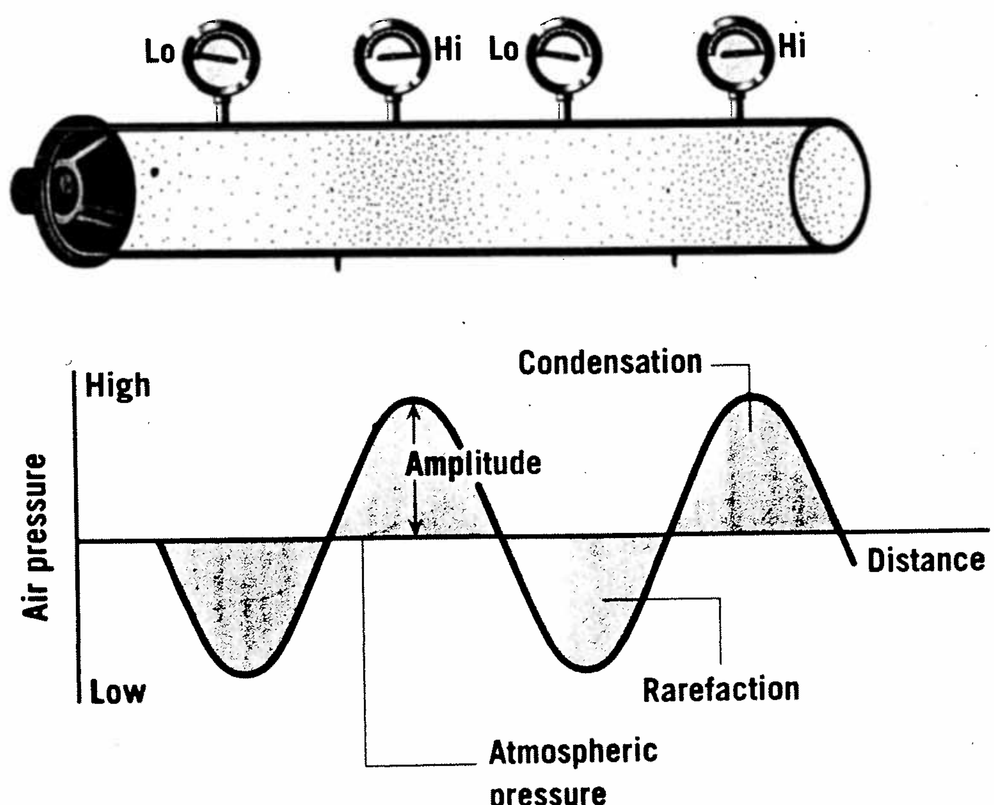


FIGURE 16-18 141



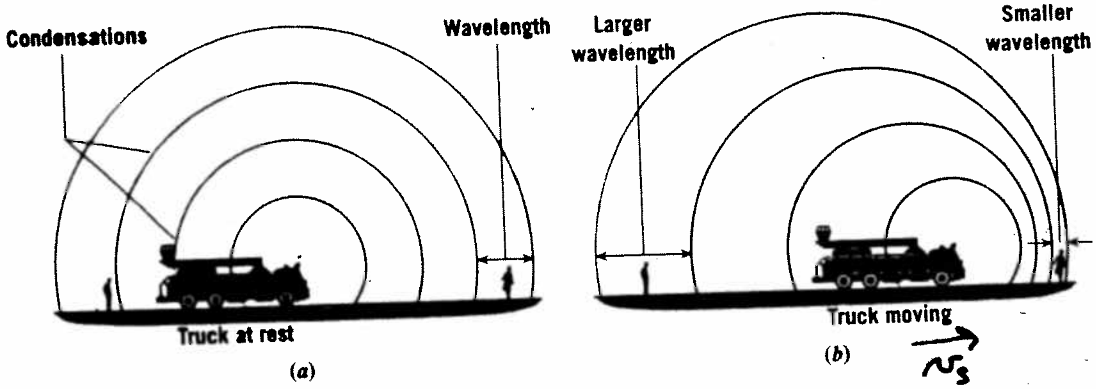


FIGURE 18-32 144

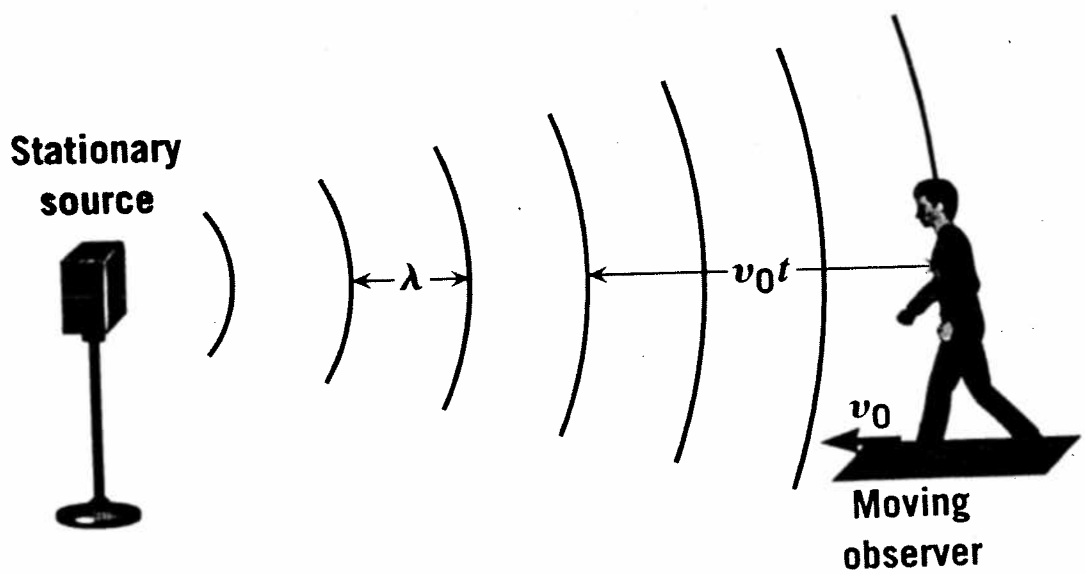


FIGURE 18-34 145

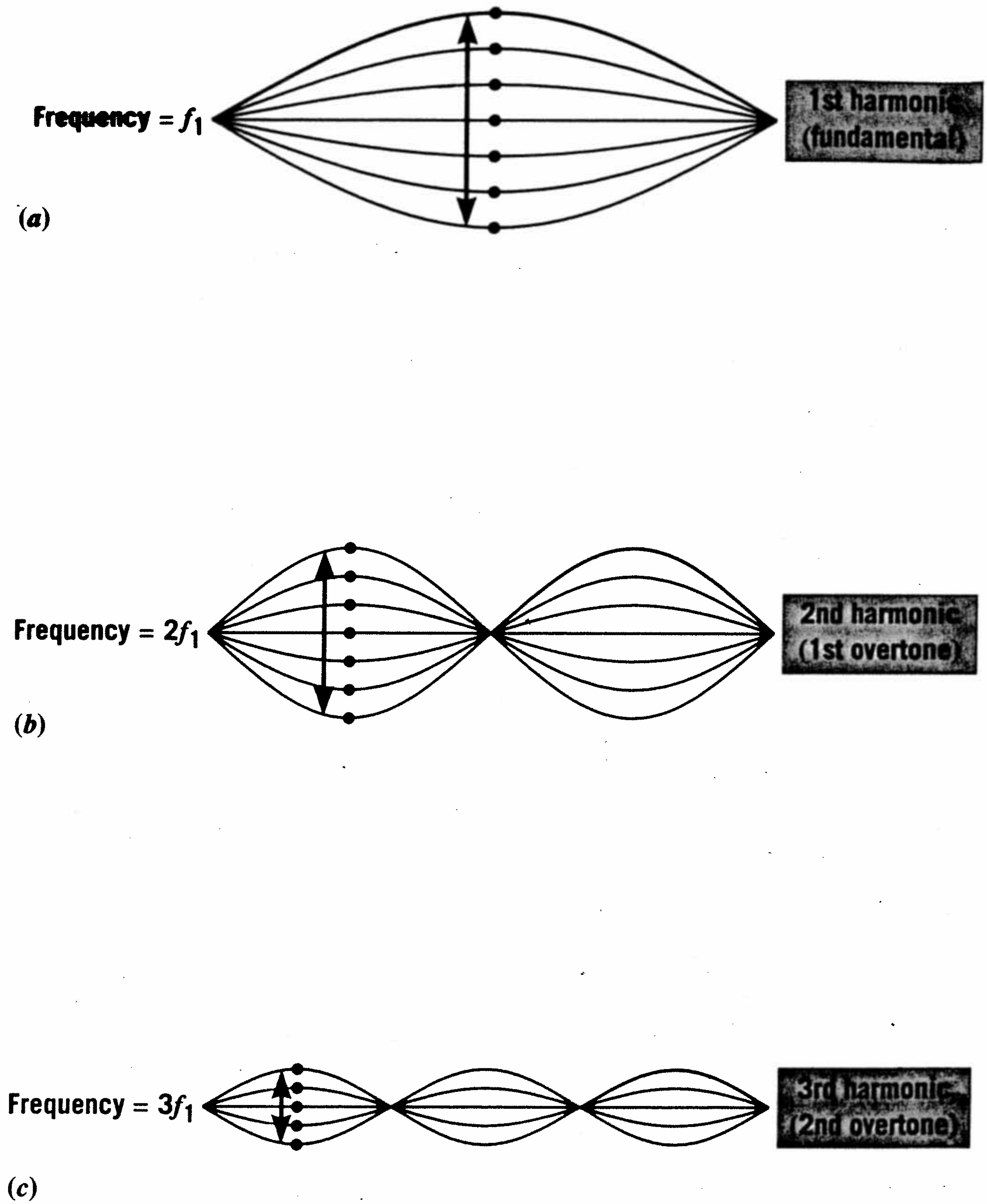

Frequency = f_1
1st harmonic (fundamental)
(a)
Frequency = $2f_1$
2nd harmonic (1st overtone)
(b)
Frequency = $3f_1$
3rd harmonic (2nd overtone)
(c)

FIGURE 17-21

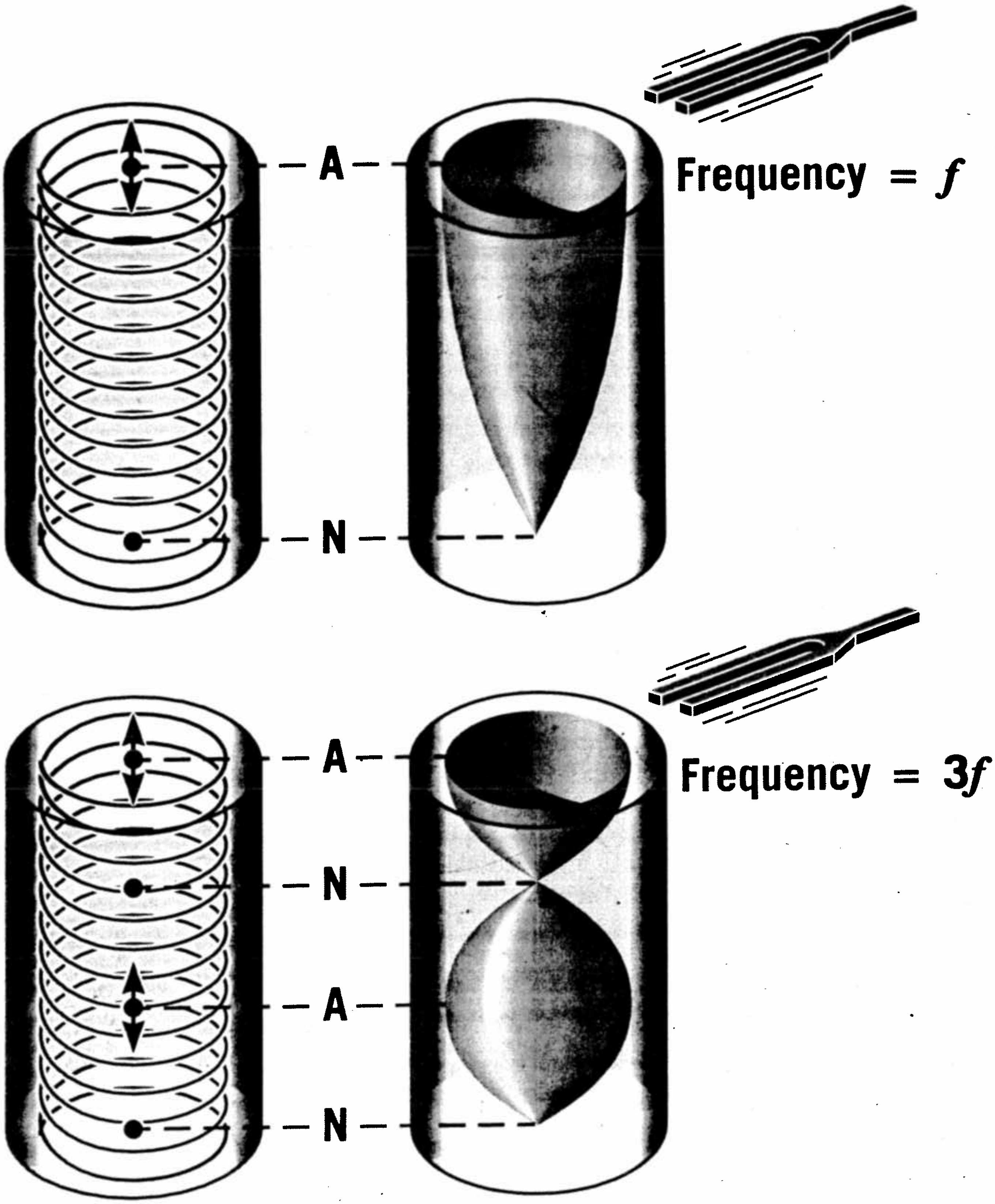


FIGURE 17-28