(5th ed)

KEY TERMS

amplitude: The maximum distance from the equilibrium position that occurs in periodic motion.

antinode: One of the positions in a standing wave or interference pattern where there is maximal movement; that is, the amplitude is a maximum.

crest: The peak of a wave disturbance.

cycle: One complete repetition of a periodic motion. It may start anyplace in the motion.

diffraction: The spreading of waves passing through an opening or around a barrier.

displacement: In wave (or oscillatory) motion, the distance of the disturbance (or object) from its equilibrium position.

equilibrium position: A position where the net force is zero.

frequency: The number of times a periodic motion repeats in a unit of time. It is equal to the inverse of the period.

fundamental frequency: The lowest resonant frequency for an oscillating system.

harmonic: A frequency that is a whole-number multiple of the fundamental frequency.

in phase: Two or more waves with the same wavelength and frequency that have their crests lined up.

interference: The superposition of waves.

longitudinal wave: A wave in which the vibrations of the medium are parallel to the direction the wave is moving.

node: One of the positions in a standing wave or interference pattern where there is no movement; that is, the amplitude is zero.

oscillation: A vibration about an equilibrium position or shape.

period: The shortest length of time it takes a periodic motion to repeat. It is equal to the inverse of the frequency.

periodic wave: A wave in which all the pulses have the same size and shape. The wave pattern repeats itself over a distance of one wavelength and over a time of one period.

resonance: A large increase in the amplitude of a vibration when a force is applied at a natural frequency of the medium or object.

spring constant: The amount of force required to stretch a spring by one unit of length. Measured in newtons per meter.

standing wave: The interference pattern produced by two waves of equal amplitude and frequency traveling in opposite directions. The pattern is characterized by alternating nodal and antinodal regions.

superposition: The combining of two or more waves at a location in space.

transverse wave: A wave in which the vibrations of the medium are perpendicular to the direction the wave is moving.

trough: A valley of a wave disturbance.

vibration: An oscillation about an equilibrium position or shape.

wave: The movement of energy from one place to another without any accompanying matter.

wavelength: The shortest repetition length for a periodic wave. For example, it is the distance from crest to crest or trough to trough.

CONCEPTUAL QUESTIONS

1. If the net force on a mass oscillating at the end of a vertical spring is zero at the equilibrium point, why doesn't the mass stop there?
2. If the restoring force on a pendulum is zero when it is vertical, why doesn't it quit swinging at this point?
3. A mass is oscillating up and down on a vertical spring. When the mass is above the equilibrium point and moving down, what direction is the net force on the mass? When the mass is above the equilibrium point and moving up, what direction is the net force on the mass?
4. A mass is oscillating up and down on a vertical spring. When the mass is below the equilibrium point and moving down, what direction is its acceleration? Is the mass speeding up or slowing down?
5. A mass is oscillating up and down on a vertical spring. If the mass is increased, will the period of oscillation increase, decrease, or stay the same? Will the frequency increase, decrease, or stay the same?
6. You have a grandfather clock (with a pendulum) that keeps perfect time on Earth. If you were to transport this clock to the Moon, would its period of oscillation increase, decrease, or stay the same? Would its frequency increase, decrease, or stay the same? Explain.
7. You hang a 1-kilogram block from a spring and find that the spring stretches 15 centimeters. What mass of block would you need to stretch the spring by 45 centimeters?
8. Which spring would you expect to have the greater spring constant, the one in the suspension of your Chevy or the one in the mechanism of your watch? Why?
9. Assume that you pull the mass on the spring 1 centimeter from the equilibrium position, let go, and measure the period of the oscillation. Would you expect the period to be

larger, the same, or smaller if you pulled the mass 2 centimeters from the equilibrium position? Why?

10. The amplitudes of real pendula decrease because of frictional forces. How does the period of a real pendulum change as it dies down?

11. What is the period of the hand on a clock that measures the seconds? What is its frequency?

12. What is the period of the hand on a clock that measures the minutes? What is its frequency?

13. Suppose your grandfather clock runs too fast. If the mass on the pendulum can be moved up or down, which way would you move it to adjust the clock? Explain your reasoning.

***14.** How does the natural frequency of a swing change when you move from sitting down to standing up?

George Semple

15. You find that the exhaust system on your 1979 Chrysler Cordoba tends to rattle loudly when the tachometer, which measures the engine's frequency, reads 2000 rpm. It is relatively quiet at frequencies above or below this. Use the concept of resonance to explain this.

16. Why do soldiers "break step" before crossing a suspension bridge?

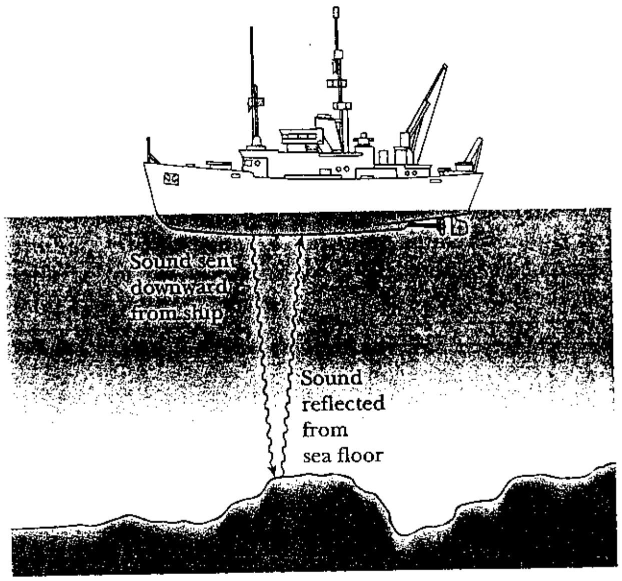
17. You hold one end of a spring in your hand and hang a block from the other end. After lifting the block up slightly and releasing it, you find that it oscillates up and down at a frequency of 2 hertz. At which of the following frequencies could you jiggle your hand up and down and produce resonance: 5 hertz, 4 hertz, 1.5 hertz, 1 hertz, or 0.5 hertz?

18. You stand to the side of the low point of a child's swing and always push the child in the same direction. Which of the following multiples of the fundamental frequency will not produce resonance: $\frac{1}{3}$, $\frac{1}{2}$, 1, or 2?

19. When you yell at your friend, are the air molecules that strike his ear the same ones that were in your lungs? Explain.

20. What is being transported along a clothesline when a wave moves from one end to the other?

21. Sonar devices use underwater sound to explore the ocean floor. Would you expect sonar to be a longitudinal or a transverse wave? Explain.



22. You fasten one end of a long spring to the base of a wall and stretch it out along the floor, holding the other end in your hand. Describe how you would generate a transverse pulse on the spring. Describe how you would generate a longitudinal pulse on the spring.

23. Is it possible for a shout to overtake a whisper? Explain.

24. You stretch a long spring between a doorknob and your hand. You generate a small transverse pulse on the spring traveling toward the doorknob. How could you generate a second pulse that would overtake the first pulse?

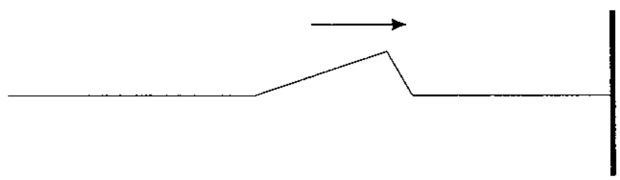
25. Which of the following properties affect the speed of waves along a rope: amplitude of the pulse, shape of the pulse, tension in the rope, and/or the mass per unit length of the rope? Why?

26. You stretch a long spring between a doorknob and your hand. You jerk your hand up and down to send a pulse down the spring. If you want to generate a slower-traveling pulse, which of the following would you do? Move your hand up and down the same distance as before but do it more slowly; move your hand up and down a smaller distance at the same speed as before; or move slightly closer to the doorknob to decrease the tension in the spring.

27. You fasten one end of a long spring to the base of a wall and stretch it out along the floor, holding the other end in your hand. You send a pulse of amplitude 5 centimeters down the right side of the spring, and a moment later you send a second identical pulse on the same side. The first pulse reflects from the fixed boundary and returns along the spring toward you. When the reflected pulse meets the second pulse, will the resulting amplitude be less than, equal to, or greater than 5 centimeters? Explain your reasoning.

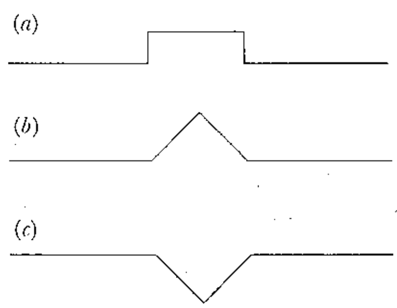
28. Imagine that the string in Figure 15-14 is tied to the pole with a loose loop such that the end is free to move up and down. A pulse of amplitude 10 centimeters is sent down the top of the string, and a moment later a second identical pulse is sent, also on the top. The first pulse reflects from the free boundary and returns along the string. When the reflected pulse meets the second pulse, will the resulting amplitude be less than, equal to, or greater than 10 centimeters? Explain your reasoning.

29. The pulse in the figure is traveling on a string to the right toward a fixed end. Draw the shape of the pulse after it reflects from the boundary.



30. A pulse in the shape of a crest is sent from left to right along a stretched rope. A trough travels in the opposite direction so that the pulses meet in the middle of the rope. Would you expect to observe a crest or a trough arrive at the right-hand end of the rope? Explain.

31. If shapes a and b in the figure correspond to idealized wave pulses on a rope, what shape is produced when they completely overlap?



32. Repeat Question 31 for shapes a and c.

33. Which of the following properties are meaningful for periodic waves but not for single pulses: frequency, wavelength, speed, amplitude?

34. In the following list of properties of periodic waves, which one is independent of the others: frequency, wavelength, speed, amplitude?

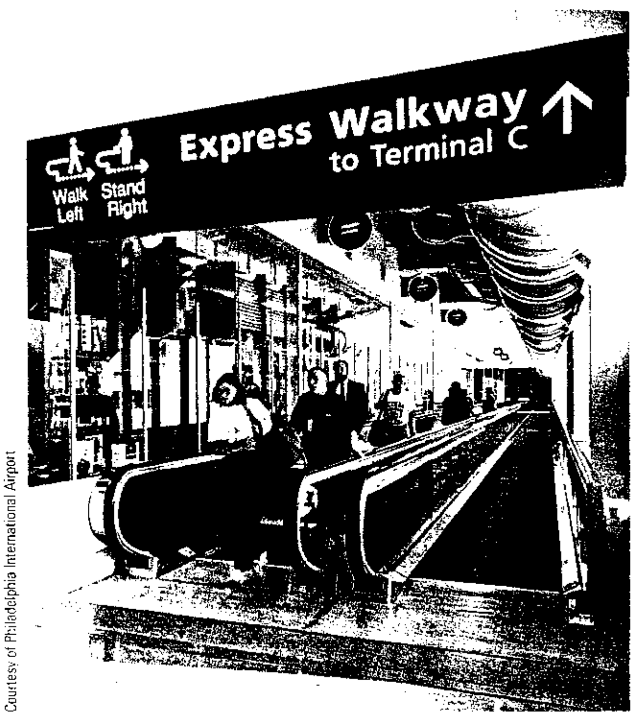
35. Two waves have the same speed but one has twice the frequency of the other. Which one has the longer wavelength? Explain.

36. If the frequency of a periodic wave is cut in half while the speed remains the same, what happens to the wavelength?

37. If the speed of a periodic wave doubles while the period remains the same, what happens to the wavelength?

38. What happens to the wavelength of a periodic wave if both the speed of the wave and the frequency are cut in half?

39. Travelers are spaced 10 feet apart on a moving sidewalk in an airport. They are all walking at exactly 3 mph relative to the sidewalk. When the moving sidewalk ends, they continue to walk at 3 mph. An observer standing still next to the moving sidewalk notes that the travelers are passing at a frequency of 1 hertz. A second observer stands just beyond the end of the moving sidewalk and notes the frequency at which the travelers pass. Would this frequency be greater than, equal to, or less than 1 hertz? Is the spacing between the travelers after leaving the moving sidewalk greater than, equal to, or less than 10 feet? Explain.



Courtesy of Philadelphia International Airport

40. A waterproof electric buzzer has a membrane that vibrates at a constant frequency of 440 hertz. The buzzer is placed in a bucket of water. Knowing that the speed of sound is much greater in water than in air, will the frequency of the sound heard in the air be greater than, equal to, or less than 440 hertz? Will the wavelength of the sound in air be greater than, equal to, or less than what it was in the water? Explain (*Hint:* Review Question 39 and think of the travelers as the wave crests.)

41. Draw a diagram to represent the standing-wave pattern for the third harmonic of a rope fixed at both ends.

42. How many antinodes are there when a rope fixed at both ends vibrates in its third harmonic?

43. Draw a diagram to represent the standing-wave pattern for the fourth harmonic of a rope fixed at both ends.

44. How many nodes are there when a rope fixed at both ends vibrates in its fourth harmonic?

45. How much higher is the frequency of the fifth harmonic on a rope than the fundamental frequency?

46. How much higher is the frequency of the sixth harmonic on a rope than that of the second?

47. Standing waves can be established on a rope that is fixed on one end but free to slide up and down a pole on the other. The fixed end remains a node, while the free end must be an antinode. Draw diagrams to represent the standing-wave patterns for the two lowest frequencies.

48. How does the fundamental wavelength of standing waves on a string with one end fixed and the other free compare to the fundamental wavelength if the same string is held with both ends fixed?

49. How does the wavelength of the fourth harmonic on a rope with both ends fixed compare with the length of the rope?

50. How does the wavelength of the fourth harmonic on a rope with both ends fixed compare with that of the second harmonic?

51. A longitudinal standing wave can be established in a long aluminum rod by stroking it with rosin on your fingers. If the rod is held tightly at its midpoint, what is the wavelength of the fundamental standing wave? Assume that there are antinodes at each end of the rod and a node where the rod is held.

52. What is the wavelength of the fundamental standing wave for the rod in Question 51 if it is held midway between the center and one end? Will the resulting pitch be higher or lower than when the rod was held at its midpoint? Explain.

53. Two point sources produce waves of the same wavelength and are in phase. At a point midway between the sources, would you expect to find a node or an antinode? Explain.

54. Two point sources produce waves of the same wavelength and are completely out of phase (that is, one produces a crest at the same time as the other produces a trough). At a point midway between the sources, would you expect to find a node or an antinode? Why?

***55.** What happens to the spacing of the antinodal lines in an interference pattern when the two sources are moved farther apart? Explain.

***56.** As you increase the frequency of the sources, what happens to the spacing of the nodal lines in an interference pattern produced by two sources? Explain.

57. An interference pattern is produced in a ripple tank. As the two sources are brought closer together, does the separation of the locations of maximum amplitude along the far edge of the tank decrease, increase, or remain the same? Why?

Courtesy of Central Scientific Company

58. As the frequency of the two sources forming an interference pattern in a ripple tank increases, does the separation of the locations of minimum amplitude along the far edge of the tank increase, decrease, or remain the same? Why?

EXERCISES

1. If a mass on a spring takes 6 s to complete two cycles, what is its period?

2. If a mass on a spring has a frequency of 4 Hz, what is its period?

3. A Foucault pendulum with a length of 9 m has a period of 6 s. What is its frequency?

4. A mass on a spring bobs up and down over a distance of 30 cm from the top to the bottom of its path twice each second. What are its period and amplitude?

5. A spring hanging from the ceiling has an unstretched length of 80 cm. A mass is then suspended at rest from the spring, causing its length to increase to 89 cm. The mass is pulled down an additional 3 cm and released. What is the amplitude of the resulting oscillation?

6. A mass oscillates up and down on a vertical spring with an amplitude of 4 cm and a period of 2 s. What total distance does the mass travel in 10 seconds?

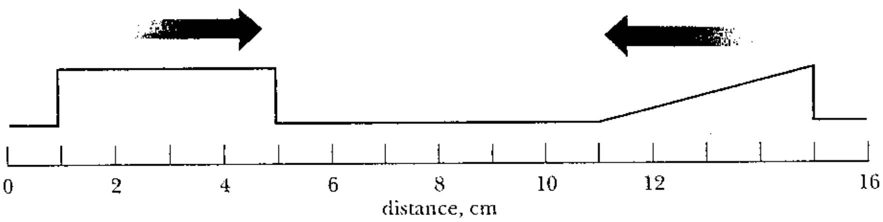
7. What is the period of a 0.4-kg mass suspended from a spring with a spring constant of 40 N/m?

8. A boy with a mass of 50 kg is hanging from a spring with a spring constant of 200 N/m. With what frequency does the boy bounce up and down?

9. By what factor would you have to increase the spring constant to double the frequency for a mass on a spring?

10. By what factor would you have to increase the mass to triple the period for a mass on a spring?

11. A pendulum has a length of 5 m. What is its period?



12. A girl with a mass of 40 kg is swinging from a rope with a length of 2.5 m. What is the frequency of her swinging?

*13. The highly idealized wave pulses shown in the figure at a time equal to zero have the same amplitudes and travel at 1 cm/s. Draw the shape of the rope at 2, 4, 5, and 8 s.

*14. Work Exercise 13 but change the rectangular pulse from a crest to a trough.

15. A train, consisting of identical 10-m boxcars, passes you such that 25 boxcars pass you each minute. Find the speed of the train.

16. You observe that 25 crests of a water wave pass you each minute. If the wavelength is 10 m, what is the speed of the wave?

17. A periodic wave on a string has a wavelength of 25 cm and a frequency of 3 Hz. What is the speed of the wave?

18. If the breakers at a beach are separated by 5 m and hit shore with a frequency of 0.3 Hz, at what speed are they traveling?

19. What is the distance between adjacent crests of ocean waves that have a frequency of 0.2 Hz if the waves have a speed of 3 m/s?

20. Sound waves in iron have a speed of about 5100 m/s. If the waves have a frequency of 400 Hz, what is their wavelength?

21. For sound waves, which travel at 343 m/s in air at room temperature, what frequency corresponds to a wavelength of 1 m?

22. What is the period of waves on a rope if their wavelength is 0.8 m and their speed is 2 m/s?

*23. A rope is tied between two posts separated by 3 m. What possible wavelengths will produce standing waves on the rope?

*24. A 3-m-long rope is tied to a very thin string so that one end is essentially free. What possible wavelengths will produce standing waves on this rope?

*25. What is the fundamental frequency on a 6-m rope that is tied at both ends if the speed of the waves is 18 m/s?

*26. Tweety Bird hops up and down at a frequency of 0.5 Hz on a power line at the midpoint between the poles, which are separated by 20 m. Assuming Tweety is exciting the fundamental standing wave, find the speed of transverse waves on the power line. (*Hint:* What is the wavelength for this standing wave?)

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