End-of-Chapter Exercises

Exercises 1 – 12 are primarily conceptual questions designed to see whether you understand the main concepts of the chapter. For Exercises 1 – 4, the corresponding figure shows the profile of a string at $t = 0$ and at $t = 1.0$ s, as two pulses approach one another.

1. Two pulses travel toward one another, as shown in Figure 21.27. Sketch the profile of the string at (a) $t = 4.0$ s, (b) $t = 5.0$ s, and (c) $t = 6.0$ s.

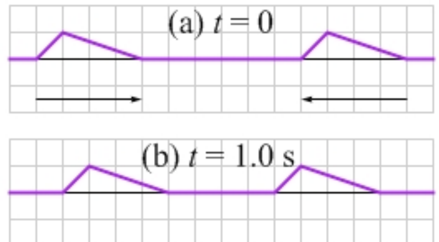


Figure 21.27: Two pulses approach each other along a string, for Exercise 1.

2. Two pulses travel toward one another, as shown in Figure 21.28. Sketch the profile of the string at (a) $t = 4.0$ s, (b) $t = 5.0$ s, and (c) $t = 6.0$ s.

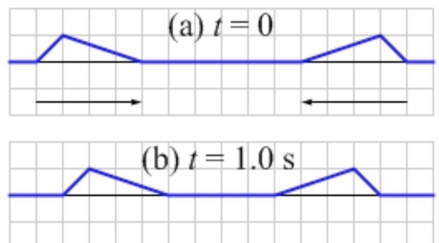


Figure 21.28: Two pulses approach each other along a string, for Exercise 2.

3. Two pulses travel toward one another, as shown in Figure 21.29. Sketch the profile of the string at (a) $t = 4.0$ s, (b) $t = 5.0$ s, and (c) $t = 6.0$ s.

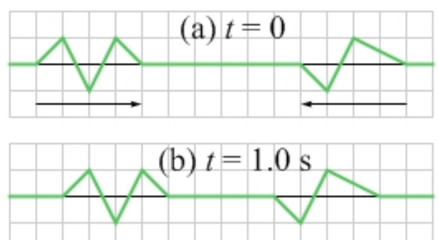


Figure 21.29: Two pulses approach each other along a string, for Exercise 3.

4. Two pulses travel toward one another, as shown in Figure 21.30. Sketch the profile of the string at (a) $t = 4.0$ s, (b) $t = 5.0$ s, and (c) $t = 6.0$ s.

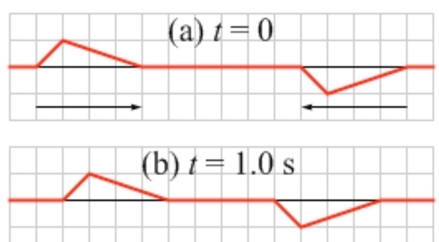


Figure 21.30: Two pulses approach each other along a string, for Exercise 4.

5. Two identical speakers, which are separated by a distance of 7.2 m, are pointed at one another. The speakers, which are in phase with one another, broadcast identical, single-frequency sound waves. There is one point on the line joining the speakers which always experiences constructive interference no matter what the frequency of the identical waves emitted by the speakers is. Where is this point? Explain why the interference is always constructive there.

6. Return to the situation discussed in Exercise 5. If the speed of sound is 340 m/s and the frequency of the waves emitted by each speaker is 170 Hz, find the location of all points along the line between the speakers at which the interference is (a) completely constructive, and (b) completely destructive.

7. Two pulses are traveling along a string, as shown in Figure 21.31. A particular point on the string is marked with a black dot. Plot the displacement of that point as a function of time, over the time interval $t = 0$ to $t = 8.0$ s.

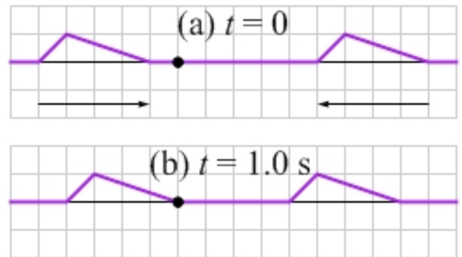


Figure 21.31: Two pulses travel along a string. A particular point on the string is marked with a black dot. For Exercise 7.

8. Two pulses are traveling along a string, as shown in Figure 21.32. A particular point on the string is marked with a black dot. Plot the displacement of that point as a function of time, over the time interval $t = 0$ to $t = 8.0$ s.

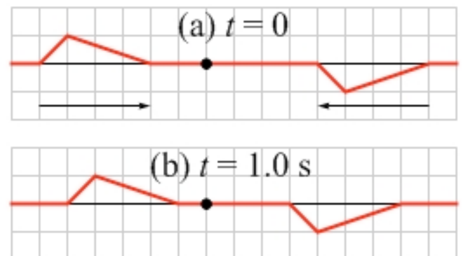


Figure 21.32: Two pulses travel along a string. A particular point on the string is marked with a black dot. For Exercise 8.

9. You have four tuning forks, with frequencies of 440 Hz, 445 Hz, 448 Hz, and 452 Hz. By using two tuning forks at a time, how many different beat frequencies can you produce, and what are the numerical values of these frequencies?

10. When you strike two tuning forks and listen to them both at the same time, you hear beats with a beat frequency of 6 Hz. If one tuning fork has a frequency of 512 Hz, what is the frequency of the other?

11. The profile of a string that supports a particular standing wave is shown at $t = 0$ in Figure 21.33. The string is fixed at both ends. At $t = 0$, the standing wave is at its maximum displacement from equilibrium. The standing wave is created by two identical traveling waves on the string, one moving to the right and the other to the left. (a) What is the amplitude of each of these traveling waves? (b) Sketch the profile of the string one-quarter of a period after $t = 0$. (c) Sketch the right-going and left-going waves one-quarter of a period after $t = 0$. Hint: the superposition of these two waves should give the profile in part (b).

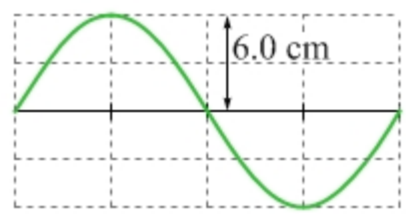


Figure 21.33: The profile of a string, at $t = 0$, that is fixed at both ends. The wave on the string is a standing wave, and the situation shown in the diagram shows the standing wave at its maximum displacement from equilibrium. For Exercise 11.

12. As you are walking along the street, a car blaring loud music passes you. As the car drives away from you, you recognize the music but you realize that it sounds funny. What is the problem?

Exercises 13 – 17 involve applying the equation of motion for a transverse wave.

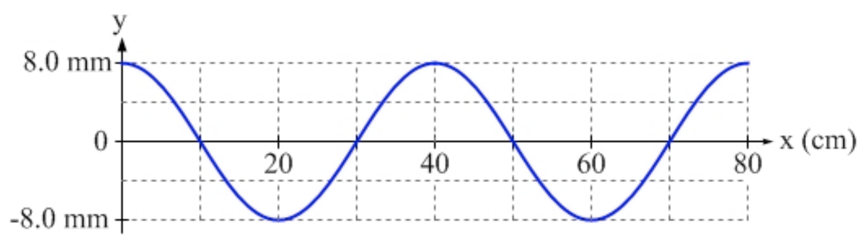
13. The equation of motion for a particular transverse wave is $y = (7.0 \text{ mm})\sin\left[(4\pi \text{ rad/s})t + (\pi \text{ m}^{-1})x\right]$. Determine the wave's (a) amplitude, (b) angular frequency, (c) frequency, (d) wavelength, and (e) velocity.

14. For a particular transverse wave that travels along a string that lies on the x-axis, the equation of motion is $y = (6.0\text{ cm})\cos\left[(50\text{ rad/s})t - (0.25\text{ m}^{-1})x\right]$. Determine (a) the wave's amplitude, wavelength, and frequency, (b) the speed of the wave, (c) the tension in the string, if the string has a mass per unit length of 0.040 kg/m, (d) the direction of propagation of the wave, (e) the maximum transverse speed of a point on the string, (f) the displacement of a point at x = 1.0 m when t = 2.0 s.

15. The equation of motion for a particular wave traveling along a string along the x-axis is $y = A\cos\left[\omega t + (4.0\text{ m}^{-1})x\right]$. The tension in the string is 34 N, and the string has a mass per unit length of 0.050 kg/m. The maximum transverse speed of a point on the string is 25 cm/s. Determine (a) the angular frequency, ω, and (b) the amplitude, A, of the wave.

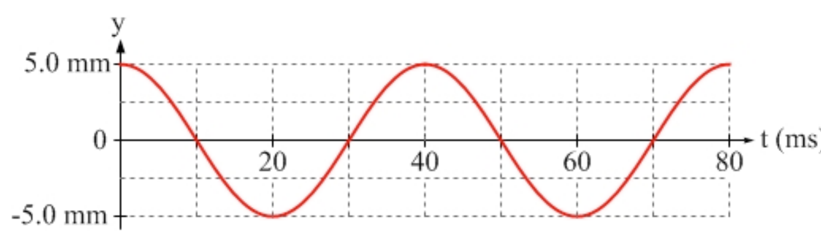
16. At a time of t = 0, the profile of part of a string is shown in Figure 21.34. The wave on the string is traveling in the $+x$ direction (to the right) at a speed of 20 cm/s. Write out the equation of motion for the wave.

Figure 21.34: The profile of part of a string at t = 0. The wave on the string is traveling to the right at 20 cm/s. For Exercise 16.



17. A graph of the motion of one point on a string (specifically, the point at x = 0), as a function of time is shown in Figure 21.35. The wave is traveling in the negative x-direction on a string that has a tension of 32 N, and with a mass per unit length of 60 grams per meter. Determine (a) the frequency of the wave, (b) the speed of the wave, (c) the wavelength, and (d) the expression for the wave's equation of motion.

Figure 21.35: A graph of the motion of one point on a string, at x = 0. The wave on the string is traveling in the negative x-direction. For Exercise 17.



Exercises 18 – 22 involve sound, sound intensity, and the decibel scale.

18. You are listening to the radio when one of your favorite songs comes on, so you turn up the volume. If you managed to increase the sound intensity by 15 dB, by what factor did the intensity of the sound, in W/m^2, increase?

19. You are working in a room in which the sound intensity is 75 dB. What is the corresponding intensity, in W/m^2?

20. When you apply the brakes on your car, they happen to squeak, emitting a 70 dB sound as observed by you sitting in the driver's seat of the car. When you sound the car's horn, however, you observe an 80 dB sound. As you are driving, a dog runs into the road in

front of your car, so you apply the brakes and sound the horn simultaneously. (Fortunately, the dog escapes unharmed.) Do you observe a 150 dB sound while you are stopping, with the brakes squeaking and the horn sounding together? Explain your answer, being as quantitative as possible.

21. When you stand 2.0 m away from a speaker that is emitting sound uniformly in all directions, the sound intensity you observe is 90 dB. What is the sound intensity at a distance of (a) 1.0 m from the speaker, and (b) 4.0 m from the speaker?

22. You are observing fishermen illegally catching fish by using a small explosive device to stun the fish. The explosion takes place near the surface of the water, so the sound of the explosion travels through both the air and the water. You record the sound of the explosion using two separate microphones, one in the air above the water and one below the water surface. (a) Which microphone picks up the sound first? (b) If the time delay between the sounds reaching the two microphones is 0.50 seconds, about how far are you from the fishermen?

Exercises 23 – 27 involve the Doppler effect. Assume the speed of sound is 340 m/s.

23. In a common classroom demonstration, a buzzer is turned on inside a soft football. The buzzer emits a tone of 256 Hz. (a) If the football is thrown directly at you at a speed of 12.0 m/s, what frequency do you hear? (b) Fortunately, you duck in time to have the ball pass over your head. What frequency do you observe as the ball moves away from you?

24. In another common classroom demonstration of the Doppler effect, the instructor whirls a buzzer, on the end of a string or electric cable, in a horizontal circle around their head. If the buzzer has a frequency of 500 Hz, the circle has a radius of 1.0 m, and the period of the buzzer's motion is 0.50 s, what are the maximum and minimum frequencies observed by the students in the classroom as they sit in their seats listening to the buzzer?

25. As you are riding your bicycle at 10.0 m/s north along a road, an ambulance traveling south approaches you. You observe the ambulance's siren to have a frequency of 352 Hz. However, the siren's frequency is actually 325 Hz, when the ambulance is at rest. (a) How fast is the ambulance traveling? (b) After the ambulance has passed you, what frequency do you observe for the siren?

26. Your car horn happens to have the unusual property of emitting a pure tone at a frequency of 440 Hz. You drive at 20 m/s toward a high wall, and sound the horn briefly. After a short time, you hear the echo of the sound, after it was reflected by the wall. What is the frequency of the echo?

27. A particular bat emits ultrasonic waves with a frequency of 68.0 kHz. The bat is flying at 12.00 m/s toward a moth, which is traveling at 3.00 m/s toward from the bat. The speed of sound is 340.00 m/s. (a) Assuming the moth could detect the waves, what frequency waves would it observe? (b) What frequency are the waves that reflect off the moth and are detected by the bat?

Exercises 28 – 32 involve standing waves.

28. A particular guitar string has a length of 75 cm, and a mass per unit length of 80 grams/meter. You hear a pure tone of 1320 Hz when a particular standing wave, represented by the sequence of images shown in Figure 21.24, is excited on the string. (a) What is the wavelength of this standing wave? (b) What is the speed of waves on this string? (c) What is the tension in the string? (d) What is the fundamental frequency of this string?

29. An Aeolian harp (named after Aeolus, the Greek god of the wind) consists of several strings fixed to a frame or a sounding box. The device is simply placed outside, and the strings are played randomly by the wind. You decide to make such a harp out of strings that all have a mass per unit length of 80 grams per meter, and that all have a tension of 50 N. (a) If you want one of the strings to have a fundamental frequency of 330 Hz, how long should you make it? (b) If you want another of the strings to have a fundamental frequency of 660 Hz (double that of the first string, and therefore exactly one octave higher up the scale), how long should it be?

30. The profile of a particular standing wave on a string is shown in Figure 21.36, showing the string at its maximum displacement from equilibrium at $t = 0$. The string has a length of 1.0 m, extending from $x = 0$ to $x = +1.0$ m. Over one period of oscillation for the standing wave, plot a graph of displacement as a function of time for the point at (a) $x = 0.25$ m, (b) $x = 0.50$ m, (c) $x = 0.65$ m.

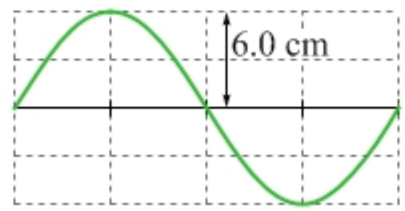


Figure 21.36: The profile of a particular standing wave on a string at $t = 0$, when the string is in one of its maximum displacement states, for Exercise 30.

31. As shown in Figure 21. 37, the height of an air column in a particular pipe is adjusted by changing the water level in the pipe. In a traditional experiment, a tuning fork is placed over the pipe, and the height of the air column is adjusted, by moving a reservoir of water up and down, until the pipe makes a loud sound, which is when the pipe's fundamental frequency matches the frequency of the tuning fork. If the speed of sound is 340 m/s, and an air column of 22.4 cm produces the loudest sound, what is the frequency of the tuning fork?

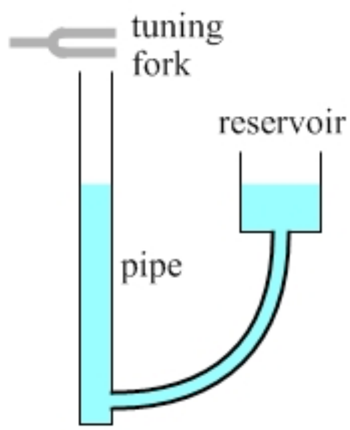


Figure 21.37: The height of the air column in this pipe can be adjusted by changing the water level in the pipe. When a tuning fork, which is emitting sound, is placed over the pipe, the pipe will emit a loud sound when the frequency of the tuning fork matches the fundamental frequency of the pipe. For Exercise 31.

32. A bloogle is a corrugated plastic tube, which is open at both ends, that emits a tone when you whirl it around your head. Generally, if you whirl it faster, the tube will emit a higher-frequency harmonic. You measure the various frequencies of a particular bloogle to be 420 Hz, 560 Hz, 700 Hz, and 840 Hz. (a) What is the fundamental frequency of this bloogle? (b) Estimate the length of the bloogle.

Exercises 33 – 38 involve applications of sound and waves.

33. Some cameras have automatic focusing systems that rely on ultrasonic emitters and detectors. You are trying to take a picture of your friends, who are 4.5 m from your camera. To focus correctly, the camera sends out a short ultrasonic pulse that reflects off your friends. If the speed of sound is 340 m/s, how much time passes between the emission of the pulse and the detection of the pulse by the camera?

34. One useful application of sound waves is a pair of noise canceling headphones. Such headphones have a microphone that picks up ambient noise (such as the noise of the engines inside a jet airplane). The wave representing the sound is then inverted and played through the speakers of the headphones into your ears. Explain, using principles of physics addressed in this chapter, how this works so that you hear a low-amplitude sound in the headphones.

35. One medical application of sound waves is in the use of ultrasound to see inside the womb to create an image of a fetus, as in the photograph shown in Figure 21.38. Do some research about this particular application of sound waves, and write two or three paragraphs describing how it works, and how it exploits the principles of physics discussed in this chapter.

Figure 21.38: An image of a fetus in the womb, at 24 weeks, obtained by ultrasonic imaging. Photo credit: Maciej Korzekwa, via iStockPhoto.com.

36. The frequencies of neighboring notes on a musical scale differ by a factor of $2^{1/12}$. A particular guitar string is tuned to sound an A note, of 440 Hz. The next highest note is $A^{\#}$ (A sharp). (a) What is the frequency of this particular note? (b) By changing the effective length of the string, by pressing the string down onto one of the frets on the guitar, you can get the string to sound $A^{\#}$ instead of A. If the string has a length L when it sounds A, what is the effective length of the string when it is sounding $A^{\#}$? (c) Explain why the spacing between frets on the guitar decreases as the effective length decreases.

37. You want to make a simple set of wind chimes out of metal pipes that are open at both ends. You would like to create a set of three pipes that sound a C-major chord, playing the notes C (264 Hz), E (330 Hz), and G (396 Hz). (a) What is the ratio of the lengths of the three pipes you should use to make your wind chimes? (b) Which pipe is the shortest, and what is its length? Assume the speed of sound is 340 m/s.

38. The human ear can be modeled, to a first approximation, as a pipe that is open at one end only. If the length of the ear canal is 25 mm in a typical person, and the speed of sound in air is 340 m/s, what is the ear's resonance frequency? (This is the frequency of the fundamental frequency of the pipe and, in theory, should correspond to the frequency of sound that a typical person is most sensitive to.)

General problems and conceptual questions

39. A track designed for running 100-meter races is 8 m wide. If the starter fires her starting pistol from one side of the track, near the runners, the runner next to her has an advantage over the runner in the lane on the other side of the track. (a) Approximately how much time passes between when the closest runner hears the sound of the starting gun and when the farthest runner hears the sound of the gun? (b) If the runners run at an average speed of 10 m/s, what distance does this time difference translate to? Note that in serious competitions, the starting gun is electronically connected to speakers attached to the starting blocks for each runner, so that the start is fair.

40. A single-frequency wave, with a wavelength of 25 cm, is traveling in the positive x-direction along a string, causing each particle in the string to oscillate in simple harmonic motion with a period of 0.20 s. If the maximum transverse speed of each particle is 20 cm/s, and the particle at $x = 0$ is at its maximum positive displacement from equilibrium at $t = 0$, determine: (a) the speed of the wave, (b) the amplitude of the wave, and (c) the equation of motion for the wave.

41. Figure 21.39 (a) shows a snapshot of a traveling wave at $t = 0$, while Figure 21.39 (b) is a graph of the displacement versus time for the point at $x = 0$. (a) Is the wave traveling in the positive or negative x-direction? Explain. (b) Write out the equation of motion for the wave. (c) Does the equation of motion change if the graph in Figure 21.39 (b) applies to the point at $x = 20$ cm, instead? If so, what is the equation of motion in that case?

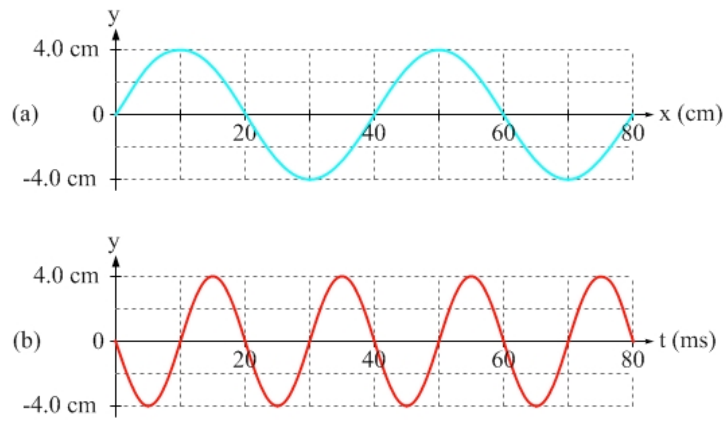


Figure 21.39: (a) A photograph of a wave on a string at $t = 0$. (b) A graph of the displacement versus time for the point at $x = 0$. For Exercises 41 and 42.

42. Figure 21.39 shows two representations of a traveling wave on a string. Figure 21.39 (a) shows a snapshot of a traveling wave at $t = 0$, while Figure 21.39 (b) is a graph of the displacement versus time for the point at $x = 0$. In each part below, state which representation you can use to find the answer, as well as giving the numerical value of the answer. (a) What is the wavelength? (b) What is the period? (c) What is the amplitude? (d) What is the speed of the wave?

43. Two trains are traveling along parallel tracks. Each train has a whistle that emits a tone of 333 Hz when the train is at rest. One train is traveling east at 5.00 m/s. The engineer in that train hears a beat frequency of 4.00 Hz when both train whistles are sounding. What is the velocity of the second train? Assume the speed of sound is 340 m/s. Summarize all the possible solutions to this exercise.

44. As shown in Figure 21.40, a child is swinging back and forth on a swing. The child is near a speaker that is broadcasting a pure (single-frequency) tone. The child is shown in five different positions during a swing. In which position will the child hear (a) the highest-frequency sound, and (b) the lowest-frequency sound? Briefly justify your answers.

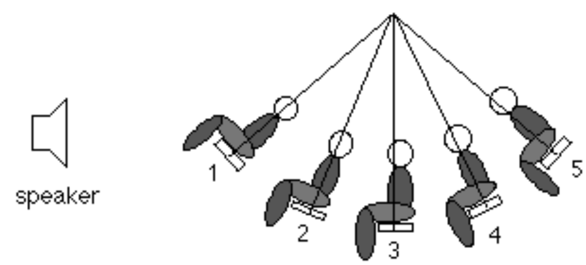


Figure 21.40: A child swinging back and forth on a string near a speaker that is broadcasting a pure tone, for Exercise 44.

45. The flow of blood through the heart can be studied with Doppler ultrasound. Ultrasonic waves are sent toward the heart, and by looking at the frequency of the waves that reflect from a particular spot in the heart, you can determine how fast blood is traveling in that region, and whether the blood is flowing toward or away from the ultrasound probe. An image is usually created from this data, with the colors of the various regions in the image reflecting the velocity of blood in those regions. If the probe sends out ultrasound with a frequency of 3.00 MHz, what is the frequency of waves that reflect back to the probe from an area of the heart (a) that is at rest? (b) where blood is traveling away from the probe with a speed that is 0.5% of the speed of sound in the medium? (c) where blood is traveling toward the probe at a speed of 0.7% of the speed of sound in the medium?

46. An ultrasonic sonar system emits ultrasonic waves that have a frequency of 600 kHz. The waves reflect from a plane that is moving at 50% of the speed of sound, directly toward the sonar system. (a) Find the frequency at which the waves reach the plane. (b) Find the frequency of the waves that are detected by the sonar system, after reflecting from the plane.

47. Repeat Exercise 46, but now have the plane moving directly away from the sonar system.

48. The pattern of sound waves emitted by a source traveling at constant velocity is shown in Figure 21.41. (a) In what direction is the source moving? (b) At what fraction of the speed of sound is the source traveling? If you are at rest, and the source is emitting waves that have a frequency of 480 Hz, what frequency do you observe if you are (c) at point A? (d) at point B?

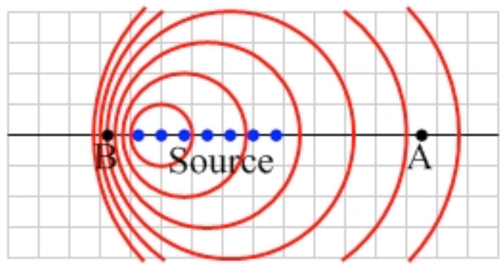


Figure 21.41: The pattern of circular waves emitted by a source that is traveling at a constant velocity. Each of the dots shows the position of the source when it emitted one of the wave peaks. For Exercise 48.

49. Repeat parts (a) – (c) of Exercise 48, but now base your answers on the pattern shown in Figure 21.42.

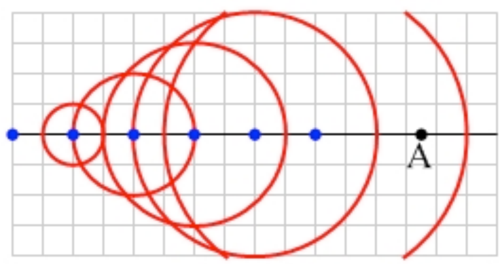


Figure 21.42: The pattern of circular waves emitted by a source that is traveling at a constant velocity. Each of the dots shows the position of the source when it emitted one of the wave peaks. For Exercise 49.

50. Do some research about what causes the loud sound when someone cracks a whip, and write a couple of paragraphs explaining the physics of whip-cracking.

51. Two speakers, which are separated by a distance of 2.4 m, broadcast identical single-frequency sound waves. The speakers are in phase with one another. If you stand at a location that is 1.7 m farther from one speaker than the other, what are the lowest three frequencies at which (a) completely constructive interference occurs at your location, and (b) completely destructive interference occurs at your location?

52. Return to the situation described in Exercise 51. The speed of sound is 340 m/s, and the frequency of the waves emitted by the speakers is 340 Hz. You are initially right next to one of the speakers, and you then walk steadily away from it in a direction that is perpendicular to the line joining the two speakers. (a) At how many locations will you pass through a point at which completely constructive interference occurs? (b) How far are these locations from the speaker that marks your starting point?

53. In Figure 21.43, a pulse is traveling along a string toward the string's right end, which is a fixed end (shown as a dot on the right). Sketch the profile of the string at (a) $t = 4.0$ s, (b) $t = 6.0$ s, and (c) $t = 7.0$ s.

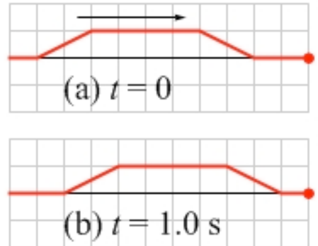


Figure 21.43: A pulse travels along a string toward the right end, which is either a fixed end (Exercise 53) or a free end (Exercise 54).

54. Repeat Exercise 53, but now the right end of the string is a free end instead of a fixed end.

55. In Figure 21.44, a pulse is traveling along a string toward the string's right end, which is a fixed end (shown as a dot on the right). A particular point on the string is shown as a black dot. Plot the displacement as a function of time for this point, over the time interval $t = 0$ to $t = 15.0$ s.

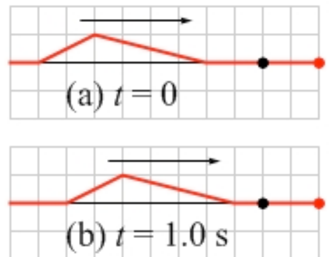


Figure 21.44: A pulse travels along a string toward the right end, which is either a fixed end (Exercise 55) or a free end (Exercises 56 and 57).

56. Repeat Exercise 55, if the right end of the string is a free end instead of a fixed end.

57. Repeat Exercise 56, except now plot the displacement as a function of time for the right end of the string, with the end being a free end.

58. Two stretched strings are placed next to one another, one with a length of 50 cm and the other with a length of 60 cm. The two strings have the same mass per unit length. You pluck the shorter one so that it vibrates at its fundamental frequency. You then adjust the tension in the longer string until it resonates with the first one. To resonate, the two strings must have the same frequency, so that vibrations on one string can cause the second string to vibrate. (a) What is the ratio of the speed of waves on the shorter string to the speed of waves on the longer string? (b) What is the ratio of the tension in the shorter string to the tension in the longer string?

59. A particular guitar string is under a tension of 38.5 N, and has a fundamental frequency of 320 Hz. If you want to tune the string so that it has a fundamental frequency of 330 Hz, to what value should you adjust the tension in the string?

60. A particular pipe that is open at both ends has a fundamental frequency of 442 Hz. When it, and a second pipe, have their fundamental frequencies excited simultaneously, a beat frequency of 8 Hz is observed. What is the ratio of the length of the first pipe to that of the second pipe if the second pipe is (a) also open at both ends, and (b) closed at one end.

61. As shown in Figure 21.45, a string passing over a pulley supports the weight of a 25 N block that hangs from the string. The other end of the string is fixed to a wall. The string has a mass per unit length of 75 grams per meter. The part of the string between the wall and the pulley is observed to oscillate with a fundamental frequency of 44 Hz. (a) What is the speed of waves on the string? (b) What is the distance, L, from the wall to the pulley? (c) If the weight hanging from the string is doubled, what will be the fundamental frequency of the part of the string between the wall and the pulley?

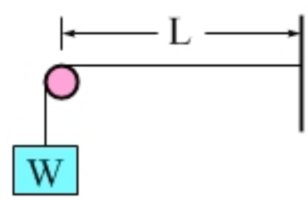


Figure 21.45: One end of a string is tied to a wall. The other end passes over a pulley, and supports a weight tied to the other end of the string. For Exercises 61 and 62.