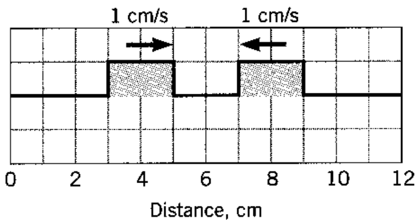
PROBLEMS

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

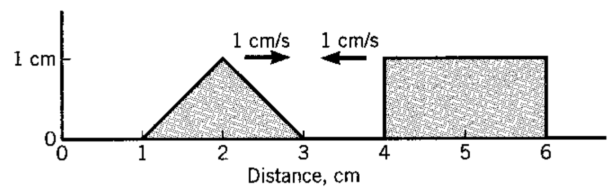
Section 17.1 The Principle of Linear Superposition, Section 17.2 Constructive and Destructive Interference of Sound Waves

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.

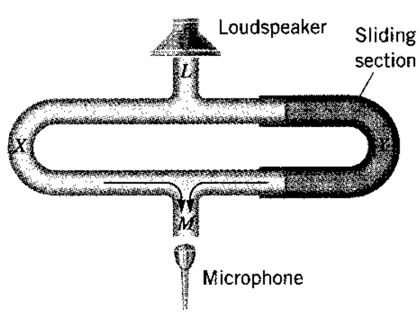


2. Repeat problem 1, assuming that the pulse on the right is pointing downward rather than upward.

3. Two pulses are traveling toward each other, each having a speed of 1 cm/s. At $t = 0$, their positions are shown in the drawing. When $t = 1$ s, what is the height of the resultant pulse at (a) $x = 3$ cm and at (b) $x = 4$ cm?



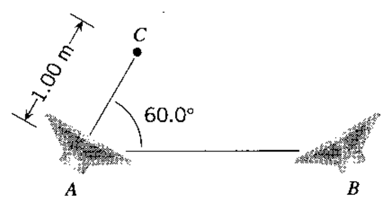
4. The sound produced by the loudspeaker in the drawing has a frequency of 12 000 Hz and arrives at the microphone via two different paths. The sound travels through the left tube *LXM*, which has a fixed length. Simultaneously, the sound travels through the right tube *LYM*, the length of which can 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.



5. **ssm** Review Example 1 in the text. Speaker *A* is moved further to the left, while *ABC* remains a right triangle. What is the separation between the speakers when constructive interference occurs again at point *C*?

6. In Figure 17.7, suppose that the separation between speakers *A* and *B* is 5.00 m and the speakers are vibrating in-phase. They are playing identical 125-Hz tones, and the speed of sound is 343 m/s. What is the largest possible distance between speaker B and the observer at *C*, such that he observes destructive interference?

7. **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?



***8.** Review Conceptual Example 2 in preparation for this problem. Assume that the two loudspeakers in Figure 17.7 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.** 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*?

Section 17.3 Diffraction

10. Sound emerges through a doorway, as in Figure 17.11. The width of the doorway is 77 cm, and the speed of sound is 343 m/s. Find the diffraction angle θ when the frequency of the sound is (a) 5.0 kHz and (b) 5.0×10^2 Hz.

11. **ssm** A speaker has a diameter of 0.30 m. (a) Assuming that the speed of sound is 343 m/s, find the diffraction angle θ for a 2.0-kHz tone. (b) What speaker diameter *D* should be used to generate a 6.0-kHz tone whose diffraction angle is as wide as that for the 2.0-kHz tone in part (a)?

12. In a diffraction horn loudspeaker, the sound exits through a rectangular opening, like a small doorway. The width *D* of a diffraction horn and the diameter of a circular speaker are equal.

The sound produced by the two speakers has the same diffraction angle θ. What is the ratio of the wavelength of the sound produced by the diffraction horn to that produced by the circular speaker?

13. Sound exits a diffraction horn loudspeaker through a rectangular opening, like a small doorway. A person is sitting at an angle θ off to the side of a diffraction horn that has a width D of 0.060 m. The speed of sound is 343 m/s. This individual does not hear a sound wave that has a frequency of 8100 Hz. When she is sitting at an angle $\theta/2$, there is a different frequency that she does not hear. What is it?

***14.** A 3.00-kHz tone is being produced by a speaker with a diameter of 0.175 m. The air temperature changes from 0 to 29 °C. Assuming air to be an ideal gas, find the *change* in the diffraction angle θ.

***15.** A row of seats is parallel to a stage at a distance of 8.7 m from it. At the center and front of the stage is a diffraction horn loudspeaker. This speaker sends out its sound through an opening that is like a small doorway with a width D of 7.5 cm. The speaker is playing a tone that has a frequency of 1.0×10^4 Hz. The speed of sound is 343 m/s. What is the separation between two seats, located on opposite sides of the center of the row, at which the tone cannot be heard?

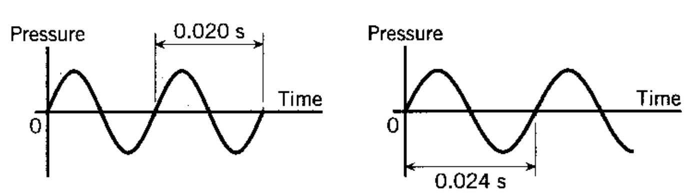
Section 17.4 Beats

16. When a tuning fork is sounded together with a 492-Hz tone, a beat frequency of 2 Hz is heard. Then a small piece of putty is stuck to the tuning fork, and the tuning fork is again sounded along with the 492-Hz tone. The beat frequency decreases. What is the frequency of the tuning fork?

17. ssm Two ultrasonic sound waves combine and form a beat frequency that is in the range of human hearing. The frequency of one of the ultrasonic waves is 70 kHz. What is (a) the smallest possible and (b) the largest possible value for the frequency of the other ultrasonic wave?

18. Two out-of-tune flutes play the same note. One produces a tone that has a frequency of 262 Hz, while the other produces 266 Hz. When a tuning fork is sounded together with the 262-Hz tone, a beat frequency of 1 Hz is produced. When the same tuning fork is sounded together with the 266-Hz tone, a beat frequency of 3 Hz is produced. What is the frequency of the tuning fork?

19. ssm Two pure tones are sounded together. The drawing shows the pressure variations of the two sound waves, measured with respect to atmospheric pressure. What is the beat frequency?



20. When a guitar string is sounded along with a 440-Hz tuning fork, a beat frequency of 5 Hz is heard. When the same string is sounded along with a 436-Hz tuning fork, the beat frequency is 9 Hz. What is the frequency of the string?

***21.** A sound wave is traveling in seawater, where the adiabatic bulk modulus and density are 2.31×10^9 Pa and 1025 kg/m^3, respectively. The wavelength of the sound is 3.35 m. A tuning fork is struck underwater and vibrates at 440.0 Hz. What would be the beat frequency heard by an underwater swimmer?

****22.** Two tuning forks X and Y have different frequencies and produce an 8-Hz beat frequency when sounded together. When X is sounded along with a 392-Hz tone, a 3-Hz beat frequency is detected. When Y is sounded along with the 392-Hz tone, a 5-Hz beat frequency is heard. What are the frequencies f_X and f_Y when (a) f_X is greater than f_Y and (b) f_X is less than f_Y?

Section 17.5 Transverse Standing Waves

23. 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?

24. If the string in Figure 17.18 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?

25. 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 17.20*b*)?

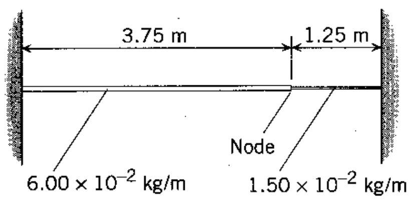
26. The fundamental frequency of a string fixed at both ends is 256 Hz. How long does it take for a wave to travel the length of this string?

27. ssm Ideally, the strings on a violin are stretched with the same tension. Each has the same length between its two fixed ends. The musical notes and corresponding fundamental frequencies of two of these strings are G (196.0 Hz) and E (659.3 Hz). The linear density of the E string is 3.47×10^{-4} kg/m. What is the linear density of the G string?

28. A 41-cm length of wire has a mass of 6.0 g. It is stretched between two fixed supports and is under a tension of 160 N. What is the fundamental frequency of this wire?

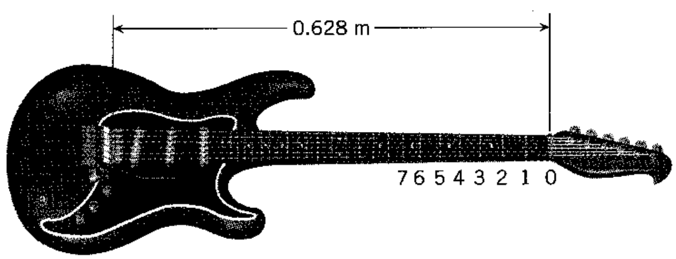
29. A string of length 2.50 m is fixed at both ends. When the string vibrates at a frequency of 85.0 Hz, a standing wave with five loops is formed. (a) What is the wavelength of the waves that travel on the string? (b) What is the speed of the waves? (c) What would be the fundamental frequency of this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

***30.** 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.

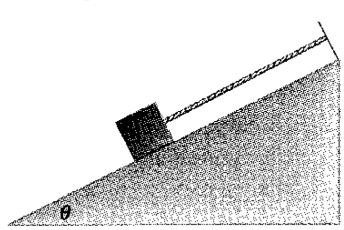


***31. ssm** The E string on an electric bass guitar has a length of 0.628 m and, when producing the note E, vibrates at a fundamental frequency of 41.2 Hz. Players sometimes add to their instruments a device called a "D-tuner." This device allows the E string to be used to produce the note D, which 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?

****32.** Review Conceptual Example 5 before attempting this problem. As the drawing shows, the length of a guitar string is 0.628 m. The frets are numbered for convenience. A performer can play a musical scale on a single string because the spacing *between the frets* is designed according to the following rule: When the string is pushed against any fret j, the fundamental frequency of the shortened string is larger by a factor of the twelfth root of two $(\sqrt[12]{2})$ than it is when the string is pushed against the fret $j - 1$. Assuming that the tension in the string is the same for any note, find the spacing (a) between fret 1 and fret 0 and (b) between fret 7 and fret 6.



****33. ssm www** The drawing shows an arrangement in which a block (mass = 15.0 kg) is held in position on a frictionless incline by a cord (length = 0.600 m). The mass per unit length of the cord is 1.20×10^{-2} kg/m, so the mass of the cord is negligible compared to the mass of the block. The cord is being vibrated at a frequency of 165 Hz (vibration source not shown in the drawing). What are the values of the angle θ between 15.0° and 90.0° at which a standing wave exists on the cord?



Section 17.6 Longitudinal Standing Waves,
Section 17.7 Complex Sound Waves

34. Sound enters the ear, travels through the auditory canal, and reaches the eardrum. The auditory canal is approximately a tube open at only one end. The other end is closed by the eardrum. A typical length for the auditory canal in an adult is about 2.9 cm. The speed of sound is 343 m/s. What is the fundamental frequency of the canal? (Interestingly, the fundamental frequency is in the frequency range where human hearing is most sensitive.)

35. 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?

36. 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?

37. 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?

38. A tube with a cap on one end, but open at the other end, produces a standing wave whose fundamental frequency is 130.8 Hz. The speed of sound is 343 m/s. (a) If the cap is removed, what is the new fundamental frequency? (b) How long is the tube?

39. 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?

***40.** 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.

***41.** Two loudspeakers face each other, vibrate in phase, and produce identical 440-Hz tones. A listener walks from one speaker toward the other at a constant speed and hears the loudness change (loud–soft–loud) at a frequency of 3.0 Hz. The speed of sound is 343 m/s. What is the walking speed?

***42.** 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?

***43. 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?

****44.** 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?

ADDITIONAL PROBLEMS

45. A stretched rubber band has a length of 0.10 m and a fundamental frequency of 440 Hz. What is the speed at which waves travel on the rubber band?

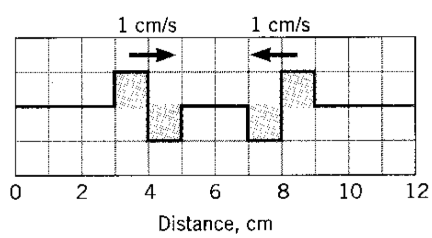
46. The fundamental frequency of a vibrating system is 400 Hz. For each of the following systems, give the three lowest frequencies (excluding the fundamental) at which standing waves can occur: (a) a string fixed at both ends, (b) a cylindrical pipe with both ends open, and (c) a cylindrical pipe with only one end open.

47. ssm Two loudspeakers are vibrating in phase. They are set up as in Figure 17.7, 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*?

48. A tuning fork vibrates at a frequency of 524 Hz. An out-of-tune piano string vibrates at 529 Hz. How much time separates successive beats?

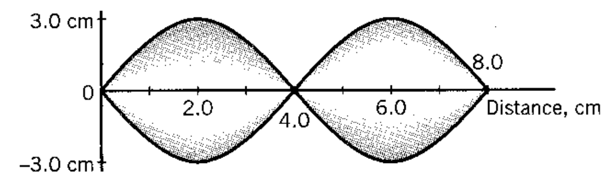
49. The fundamental frequencies of two air columns are the same. Column A is open at both ends, while column B is open at only one end. The length of column A is 0.60 m. What is the length of column B?

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



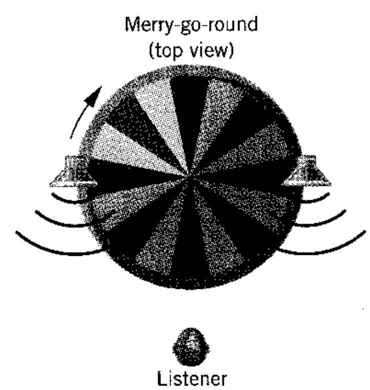
51. ssm On a cello, the string with the largest linear density (1.56×10^{-2} kg/m) is the C string. This string produces a fundamental frequency of 65.4 Hz and has a length of 0.800 m between the two fixed ends. Find the tension in the string.

***52.** 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.



***53.** 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.

****54.** Two loudspeakers are mounted on a merry-go-round whose radius is 9.01 m. When stationary, the speakers both play a tone whose frequency is 100.0 Hz. As the drawing illustrates, they are situated at opposite ends of a diameter. The speed of sound is 343.00 m/s, and the merry-go-round revolves once every 20.0 s. What is the beat frequency that is detected by the listener when the merry-go-round is near the position shown?



****55. ssm www** The note that is three octaves above middle C is supposed to have a fundamental frequency of 2093 Hz. On a certain piano the steel wire that produces this note has a cross-sectional area of 7.85×10^{-7} m^2. The wire is stretched between two pegs. When the piano is tuned properly to produce the correct frequency at 25.0 °C, the wire is under a tension of 818.0 N. Suppose the temperature drops to 20.0 °C. In addition, as an approximation, assume that the wire is kept from contracting as the temperature drops. Consequently, the tension in the wire changes. What beat frequency is produced when this piano and another instrument (properly tuned) sound the note simultaneously?

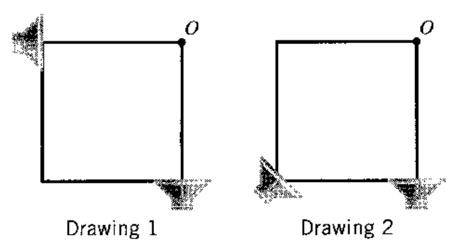
CONCEPTS & CALCULATIONS

GROUP LEARNING PROBLEMS

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

56. Concept Questions Both drawings show the same square, at one corner of which an observer O is stationed. Two loudspeakers are located at corners of the square, either as in drawing 1 or as in drawing 2. The speakers produce the same single-frequency tone in either drawing and are in phase. Constructive interference occurs in drawing 1, but destructive interference occurs in drawing 2. (a) Will only certain frequencies lead to the constructive interference in drawing 1, or will it occur for any frequency at all? (b) Will only certain frequencies lead to the destructive interference in drawing 2, or will it occur for any frequency at all? Justify your answers.

Problem One side of the square has a length of $L = 0.75$ m. The speed of sound is 343 m/s. Find the single smallest frequency that will produce both constructive interference in drawing 1 and destructive interference in drawing 2.



57. Concept Questions (a) When sound emerges from a loudspeaker, is the diffraction angle determined by the wavelength, the diameter of the speaker, or a combination of these two factors? (b) How is the wavelength of a sound related to its frequency? Explain your answers.

Problem The following two lists give diameters and sound frequencies for three loudspeakers. Pair each diameter with a frequency, so that the diffraction angle is the same for each of the speakers. The speed of sound is 343 m/s. Find the common diffraction angle.

Diameter, D	Frequency, f
0.050 m	6.0 kHz
0.10 m	4.0 kHz
0.15 m	12.0 kHz

58. Concept Questions Two cars have identical horns, each emitting a frequency f_s. One of the cars is moving toward a bystander waiting at a corner, and the other is parked. The two horns sound simultaneously. (a) From the moving horn, does the bystander hear a frequency that is greater than, less than, or equal to f_s? (b) From the stationary horn, does the bystander hear a frequency that is greater than, less than, or equal to f_s? (c) Does the bystander hear a beat frequency from the combined sound of the two horns? Account for your answers.

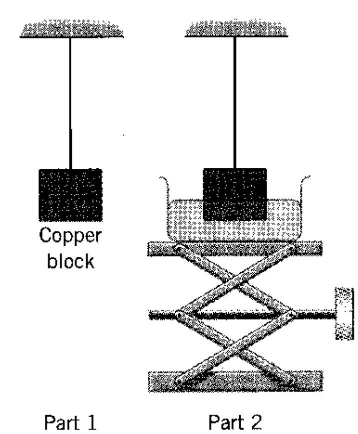
Problem The frequency that the horns emit is $f_s = 395$ Hz. The speed of the moving car is 12.0 m/s and the speed of sound is 343 m/s. What is the beat frequency heard by the bystander?

59. Concept Questions Two wires are stretched between two fixed supports and have the same length. On wire A there is a second-harmonic standing wave whose frequency is 660 Hz. However, the same frequency of 660 Hz is the third harmonic on wire B. (a) Is the fundamental frequency of wire A greater than, less than, or equal to the fundamental frequency of wire B? Explain. (b) How is the fundamental frequency related to the length L of the wire and the speed v at which individual waves travel back and forth on the wire? (c) Do the individual waves travel on wire A with a greater, smaller, or the same speed as on wire B? Give your reasoning.

Problem The common length of the wires is 1.2 m. Find the speed at which individual waves travel on each wire. Verify that your answer is consistent with your answers to the Concept Questions.

60. Concept Questions A copper block is suspended in air from a wire in Part 1 of the drawing. A container of mercury is then raised up around the block as in Part 2. (a) The fundamental freqeuncy of the wire is given by Equation 17.3 with $n = 1$: $f_1 = v/(2L)$. How is the speed v at which individual waves travel on the wire related to the tension in the wire? (b) Is the tension in the wire in Part 2 less than, greater than, or equal to the tension in Part 1? (c) Is the fundamental frequency of the wire in Part 2 less than, greater than, or equal to the fundamental frequency in Part 1? Justify each of your answers.

Problem In Part 2 of the drawing one-half of the block's volume is submerged in the mercury. The density of copper is 8890 kg/m^3, and the density of mercury is 13 600 kg/m^3. Find the ratio of the fundamental frequency of the wire in Part 2 to the fundamental



frequency in Part 1. Check to see that your answer is consistent with your answers to the Concept Questions.

61. Concept Questions One method for measuring the speed of sound uses standing waves. A cylindrical tube is open at both ends, and one end admits sound from a tuning fork. A movable plunger is inserted into the other end. The distance between the end of the tube where the tuning fork is and the plunger is L. For a fixed frequency, the plunger is moved until the smallest value of L is measured that allows a standing wave to be formed. (a) When a standing wave is formed in the tube, is there a node or an antinode at the end of the tube where the tuning fork is? (b) When a standing wave is formed, is there a node or an antinode at the plunger? (c) How is the smallest value of L related to the wavelength of the sound? Explain your answers.

Problem The tuning fork produces a 485-Hz tone, and the smallest value observed for L is 0.264 m. What is the speed of the sound in the gas in the tube?