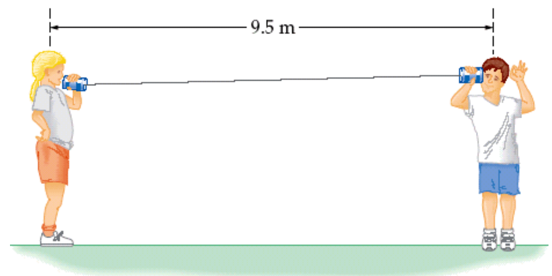
Discussion Examples
Chapter 14: Waves and Sound

14. A brother and sister try to communicate with a string tied between two tin cans (**Figure 14–33xx34**). If the string is 9.5 m long, has a mass of 32 g, and is pulled taut with a tension of 8.6 N, how much time does it take for a wave to travel from one end of the string to the other?

Picture the Problem: The image shows two people talking on a tin can telephone. The cans are connected by a 9.5-meter-long string weighing 32 grams.



Strategy: Set the time equal to the distance divided by the velocity, where the velocity is given by equation 14-2. The linear mass density is the total mass divided by the length.

Solution: 1. Set the time equal to the distance divided by velocity:

$$t = \frac{d}{v} = d\sqrt{\frac{\mu}{F}}$$

2. Substitute $\mu = m/d$ and insert numerical values:

$$t = d\sqrt{\frac{m/d}{F}} = \sqrt{\frac{md}{F}} = \sqrt{\frac{(0.032\text{ kg})(9.5\text{ m})}{8.6\text{ N}}} = \boxed{0.19\text{ s}}$$

Insight: The message travels the same distance in the air in 0.028 seconds, about 7 times faster.

38. In a pig-calling contest, a caller produces a sound with an intensity level of 110 dB. How many such callers would be required to reach the pain level of 120 dB?

Picture the Problem: We are given the sound intensity of one pig caller and are asked to calculate how many pig callers are needed to increase the intensity level by 10 dB.

Strategy: Multiply the intensity in equation 14-8 by *N* callers, setting the intensity level to 120 dB and solve for *N*.

Solution: 1. Write the intensity level for *N* callers:

$$\beta = 10\log\left(\frac{NI}{I_0}\right) = 10\log(N) + 10\log\left(\frac{I}{I_0}\right)$$

2. Insert the intensity levels and solve for *N*:

$$120\text{ dB} = 10\log(N) + 110\text{ dB}$$

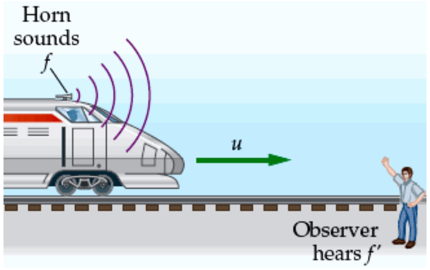
$$10\text{ dB} = 10\log(N)$$

$$N = 10^{10/10} = \boxed{10\text{ callers}}$$

Insight: Increasing the intensity level by 10 dB increases the intensity by a factor of 10. Therefore 10 callers, each with intensity level 110 dB, would produce a net intensity level of 120 db. 100 callers (10 × 10 callers) would be needed to produce an intensity level of 130 dB (120 dB + 10 dB).

45. A train moving with a speed of 31.8 m/s sounds a 136-Hz horn. What frequency is heard by an observer standing near the tracks as the train approaches?

Picture the Problem: The train, a moving source, sounds its horn. We wish to calculate the frequency heard by a person standing near the tracks.



Strategy: Solve equation 14-10 for the observed frequency, using the negative sign because the train is moving toward the observer.

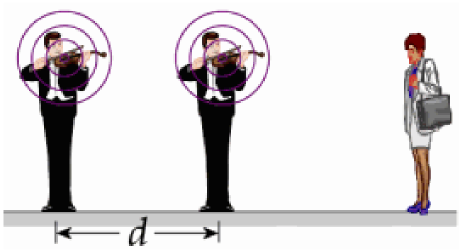
Solution: Insert the given data into equation 14-10:

$$f' = \left(\frac{1}{1-u/v}\right) f = \left[\frac{1}{1-(31.8\text{ m/s})/(343\text{ m/s})}\right](136\text{ Hz})$$
$$= \boxed{1.50\times10^2\text{ Hz}}$$

Insight: If the train were moving away from the observer, he would hear a frequency of 124 Hz.

62. **IP** Two violinists, one directly behind the other, play for a listener directly in front of them. Both violinists sound concert A (440 Hz). **(a)** What is the smallest separation between the violinists that will produce destructive interference for the listener? **(b)** Does this smallest separation increase or decrease if the violinists produce a note with a higher frequency? **(c)** Repeat part (a) for violinists who produce sounds of 540 Hz.

Picture the Problem: Two violinists separated by a distance *d*, as shown in the figure, play a 440-Hz note.



Strategy: We want to calculate the smallest distance *d*, for which the listener will hear destructive interference. Assume that the violins are in phase with each other. The smallest separation that will produce destructive interference occurs when the separation is equal to one-half of a wavelength. Set the distance to half a wavelength and use equation 14-1 to write the wavelength in terms of the frequency and speed of sound.

Solution: 1. (a) Set the distance equal to half a wavelength:

$$d = \frac{\lambda}{2} = \frac{v}{2f} = \frac{343\text{ m/s}}{2(440\text{ Hz})} = \boxed{0.390\text{ m}}$$

2. (b) The frequency is inversely proportional to the separation distance. Therefore, higher frequency means $\boxed{\text{shorter minimum separation}}$.

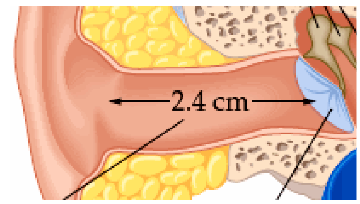
3. (c) Solve for the distance at 540 Hz:

$$d = \frac{\lambda}{2} = \frac{343\text{ m/s}}{2(540.0\text{ Hz})} = \boxed{0.318\text{ m}}$$

Insight: In order for the destructive interference to occur, the violins' notes must be coherent and in phase with each other. This typically does not occur during a concert.

71. **IP BIO Standing Waves in the Human Ear** The human ear canal is much like an organ pipe that is closed at one end (at the tympanic membrane or eardrum) and open at the other (see the figure below). A typical ear canal has a length of about 2.4 cm. **(a)** What is the fundamental frequency and wavelength of the ear canal? **(b)** Find the frequency and wavelength of the ear canal's third harmonic. (Recall that the third harmonic in this case is the standing wave with the second-lowest frequency.) **(c)** Suppose a person has an ear canal that is shorter than 2.4 cm. Is the fundamental frequency of that person's ear canal greater than, less than, or the same as the value found in part (a)? Explain. (Note that the frequencies found in parts (a) and (b) correspond closely to the frequencies of enhanced sensitivity in Figure 14–28.)

Picture the Problem: The image shows an ear canal of length 2.4 cm.



Strategy: Treating the ear canal as a pipe closed at one end, we wish to calculate the fundamental and third harmonic frequencies and wavelengths. Use equation 14-14 to calculate the frequencies and wavelengths. For the fundamental use $n = 1$, and for the third harmonic use $n = 3$.

Solution: 1. (a) Calculate the fundamental frequency and wavelength using equation 14-14 with $n = 1$:

$$f_1 = \frac{nv}{4L} = \frac{1(343\text{ m/s})}{4(2.4\times10^{-2}\text{ m})} = \boxed{3.6\text{ kHz}}$$

$$\lambda_1 = 4L/n = 4(2.4\text{ cm})/1 = \boxed{9.6\text{ cm}}$$

2. (b) Calculate the third harmonic frequency and wavelength using equation 14-14 with $n = 3$:

$$f_3 = \frac{nv}{4L} = \frac{3(343\text{ m/s})}{4(2.4\times10^{-2}\text{ m})} = \boxed{11\text{ kHz}}$$

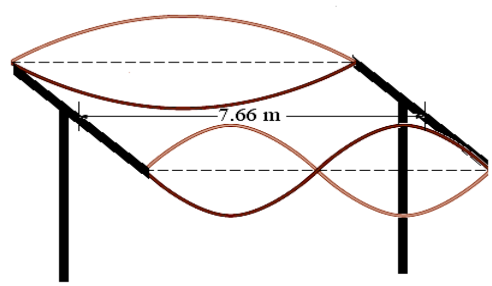
$$\lambda_3 = 4L/n = 4(2.4\text{ cm})/3 = \boxed{3.2\text{ cm}}$$

3. (c) The fundamental frequency is inversely proportional to the length of the ear canal. Therefore, if an ear canal is shorter than 2.4 cm, the fundamental frequency of that person's ear canal is $\boxed{\text{greater than}}$ the value found in part (a).

Insight: For an ear canal of length 2.2 cm the fundamental frequency will be 3.9 kHz.

73. **IP** A 12.5-g clothesline is stretched with a tension of 22.1 N between two poles 7.66 m apart. What is the frequency of **(a)** the fundamental and **(b)** the second harmonic? **(c)** If the tension in the clothesline is increased, do the frequencies in parts (a) and (b) increase, decrease, or stay the same? Explain.

Picture the Problem: The image shows two clotheslines that are 7.66 m long. One line is oscillating at the fundamental frequency and the other at the second harmonic.



Strategy: First use the tension and mass to calculate the speed of the waves, using equation 14-2. Then use equation 14-13 to calculate the frequencies.

Solution: 1. (a) Solve equation 14-2 for the wave speed:

$$v = \sqrt{\frac{F}{\mu}} = \sqrt{\frac{22.1\text{ N}}{0.0125\text{ kg}/7.66\text{ m}}} = \underline{\underline{116.4\text{ m/s}}}$$

2. Set $n = 1$ in equation 14-13 to calculate the fundamental frequency:

$$f_1 = \frac{nv}{2L} = \frac{1(116.4\text{ m/s})}{2(7.66\text{ m})} = \boxed{7.60\text{ Hz}}$$

3. (b) Set $n = 2$ in equation 14-13 to calculate the second harmonic frequency:

$$f_2 = \frac{nv}{2L} = \frac{2(116.4\text{ m/s})}{2(7.66\text{ m})} = \boxed{15.2\text{ Hz}}$$

4. (c) The wave speed is proportional to the square root of the tension, and the frequency is proportional to the wave speed. We conclude that if the tension in the clothesline is increased, the frequencies in parts (a) and (b) will $\boxed{\text{increase}}$.

Insight: If the tension were doubled to 44.2 N, the frequencies would increase by a factor of $\sqrt{2}$ to $f_1 = 10.7\text{ Hz}$ and $f_2 = 21.5\text{ Hz}$. We bent the rules for significant figures a little in step 1 in order to avoid rounding error.

83. **IP** Two strings that are fixed at each end are identical, except that one is 0.560 cm longer than the other. Waves on these strings propagate with a speed of 34.2 m/s, and the fundamental frequency of the shorter string is 212 Hz. **(a)** What beat frequency is produced if each string is vibrating with its fundamental frequency? **(b)** Does the beat frequency in part (a) increase or decrease if the longer string is increased in length? **(c)** Repeat part (a), assuming that the longer string is 0.761 cm longer than the shorter string.

Picture the Problem: Two strings, one slightly longer than the other, produce a beat wave when sounded together.

Strategy: We are given the fundamental frequency of the shorter string, the wave speed of both strings, and the difference in lengths of the two strings and want to calculate the beat frequency. Use equation 14-12 to calculate the length L of the shorter string. Then add the difference in lengths to obtain the length L' of the longer string. Calculate the beat frequency from equation 14-18, using equation 14-12 to write the frequencies in terms of the string lengths.

Solution: 1. (a) Calculate L for the shorter string from equation 14-12:

$$L = \frac{v}{2f_1} = \frac{34.2\text{ m/s}}{2(212\text{ Hz})} = 8.066\text{ cm}$$

2. Calculate $L' = L + \Delta L$:

$$L' = 8.066\text{ cm} + 0.560\text{ cm} = 8.626\text{ cm.}$$

3. Use equation 14-18 to calculate the beat frequency:

$$f_{\text{beat}} = \left|f_1 - f_1'\right| = \left|\frac{v}{2L} - \frac{v}{2L'}\right| = \left|\frac{34.2\text{ m/s}}{2\left(8.066\times10^{-2}\text{m}\right)} - \frac{34.2\text{ m/s}}{2\left(8.626\times10^{-2}\text{ m}\right)}\right|$$

$$= \boxed{13.8\text{ Hz}}$$

4. (b) If the longer string is lengthened, its fundamental frequency will decrease and the beat frequency will $\boxed{\text{increase}}$.

5. (c) Calculate the beat frequency using the new length:

$$f_{\text{beat}} = \left|\frac{34.2\text{ m/s}}{2\left(8.066\times10^{-2}\text{m}\right)} - \frac{34.2\text{ m/s}}{2\left(8.066+0.761\right)\times10^{-2}\text{ m}}\right| = \boxed{18.3\text{ Hz}}$$

Insight: Shortening the longer string will bring its frequency closer to 212 Hz, decreasing the beat frequency.