Summary

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DEFINITIONS

The **intensity** of a periodic sound wave, which is the power per unit area, is

$$I \equiv \frac{\mathcal{P}}{A} = \frac{(\Delta P_{\max})^2}{2\rho v} \qquad \textbf{(17.5, 17.6)}$$

The **sound level** of a sound wave in decibels is

$$\beta \equiv 10 \log\left(\frac{I}{I_0}\right) \qquad \textbf{(17.8)}$$

The constant I_0 is a reference intensity, usually taken to be at the threshold of hearing ($1.00 \times 10^{-12}\ \mathrm{W/m^2}$), and I is the intensity of the sound wave in watts per square meter.

CONCEPTS AND PRINCIPLES

Sound waves are longitudinal and travel through a compressible medium with a speed that depends on the elastic and inertial properties of that medium. The speed of sound in a liquid or gas having a bulk modulus B and density ρ is

$$v = \sqrt{\frac{B}{\rho}} \qquad \textbf{(17.1)}$$

For sinusoidal sound waves, the variation in the position of an element of the medium is

$$s(x, t) = s_{\max} \cos(kx - \omega t) \qquad \textbf{(17.2)}$$

and the variation in pressure from the equilibrium value is

$$\Delta P = \Delta P_{\max} \sin(kx - \omega t) \qquad \textbf{(17.3)}$$

where $\Delta P_{\max}$ is the **pressure amplitude**. The pressure wave is 90° out of phase with the displacement wave. The relationship between $s_{\max}$ and $\Delta P_{\max}$ is

$$\Delta P_{\max} = \rho v \omega s_{\max} \qquad \textbf{(17.4)}$$

The change in frequency heard by an observer whenever there is relative motion between a source of sound waves and the observer is called the **Doppler effect**. The observed frequency is

$$f' = \left(\frac{v + v_O}{v - v_S}\right) f \qquad \textbf{(17.13)}$$

In this expression, the signs for the values substituted for v_O and v_S depend on the direction of the velocity. A positive value for the velocity of the observer or source is substituted if the velocity of one is toward the other, whereas a negative value represents a velocity of one away from the other.

In digital recording of sound, the sound waveform is sampled 44 100 times per second. The pressure of the wave for each sampling is measured and converted to a binary number. In playback, these binary numbers are read and used to build the original waveform.

Questions

☐ denotes answer available in *Student Solutions Manual/Study Guide;* **O** denotes objective question

1. **O** Table 17.1 shows that the speed of sound is typically an order of magnitude larger in solids than in gases. To what can this higher value be most directly attributed? (a) the difference in density between solids and gases (b) the difference in compressibility between solids and gases (c) the limited size of a solid object compared to a free gas (d) the impossibility of holding a gas under significant tension

2. If an alarm clock is placed in a good vacuum and then activated, no sound is heard. Explain.

3. A sonic ranger is a device that determines the distance to an object by sending out an ultrasonic sound pulse and measuring the time interval required for the wave to return by reflection from the object. Typically these devices cannot reliably detect an object that is less than half a meter from the sensor. Why is that?

4. A friend sitting in her car far down the road waves to you and beeps her horn at the same moment. How far away must she be for you to calculate the speed of sound to two significant figures by measuring the time interval required for the sound to reach you?

5. **O** Assume a change at the source of sound reduces the wavelength of a sound wave in air by a factor of 2. **(i)** What happens to its frequency? (a) It increases by a

factor of 4. (b) It increases by a factor of 2. (c) It is unchanged. (d) It decreases by a factor of 2. (e) It changes by an unpredictable factor. **(ii)** What happens to its speed? Choose from the same possibilities.

6. **O** A sound wave travels in air with a frequency of 500 Hz. If the wave travels from the air into water, **(i)** what happens to its frequency? (a) It increases. (b) It decreases. (c) It is unchanged. **(ii)** What happens to its wavelength? Choose from the same possibilities.

7. By listening to a band or orchestra, how can you determine that the speed of sound is the same for all frequencies?

8. **O** A point source broadcasts sound into a uniform medium. If the distance from the source is tripled, how does the intensity change? (a) It becomes one-ninth as large. (b) It becomes one-third as large. (c) It is unchanged. (d) It becomes three times larger. (e) It becomes nine times larger.

9. **O** A church bell in a steeple rings once. At 300 m in front of the church, the maximum sound intensity is 2 μW/m^2. At 950 m behind the church, the maximum intensity is 0.2 μW/m^2. What is the main reason for the difference in the intensity? (a) Most of the sound is absorbed by the air before it gets far away from the source. (b) Most of the sound is absorbed by the ground as it travels away from the source. (c) The bell broadcasts the sound mostly toward the front. (d) At a larger distance, the power is spread over a larger area. (e) At a larger distance, the power is spread throughout a larger spherical volume.

10. **O** Of the following sounds, which is most likely to have a sound level of 60 dB? (a) a rock concert (b) the turning of a page in this textbook (c) dinner-table conversation (d) a cheering crowd at a football game

11. **O** With a sensitive sound level meter you measure the sound of a running spider as -10 dB. What does the negative sign imply? (a) The spider is moving away from you. (b) The frequency of the sound is too low to be audible to humans. (c) The intensity of the sound is too faint to be audible to humans. (d) You have made a mistake; negative signs do not fit with logarithms.

12. *The Tunguska event.* On June 30, 1908, a meteor burned up and exploded in the atmosphere above the Tunguska River valley in Siberia. It knocked down trees over thousands of square kilometers and started a forest fire, but produced no crater and apparently caused no human casualties. A witness sitting on his doorstep outside the zone of falling trees recalled events in the following sequence. He saw a moving light in the sky, brighter than the sun and descending at a low angle to the horizon. He felt his face become warm. He felt the ground shake. An invisible agent picked him up and immediately dropped him about a meter farther away from where the light had been. He heard a very loud protracted rumbling. Suggest an explanation for these observations and for the order in which they happened.

13. Explain what happens to the frequency of the echo of your car horn as you drive toward the wall of a canyon. What happens to the frequency as you move away from the wall?

14. **O** A source of sound vibrates with constant frequency. Rank the frequency of sound observed in the following cases from the highest to the lowest. If two frequencies are equal, show their equality in your ranking. Only one thing is moving at a time, and all the motions mentioned have the same speed, 25 m/s. (a) Source and observer are stationary in stationary air. (b) The source is moving toward the observer in still air. (c) The source is moving away from the observer in still air. (d) The observer is moving toward the source in still air. (e) The observer is moving away from the source in still air. (f) Source and observer are stationary, with a steady wind blowing from the source toward the observer. (g) Source and observer are stationary, with a steady wind blowing from the observer toward the source.

15. **O** Suppose an observer and a source of sound are both at rest and a strong wind is blowing away from the source toward the observer. **(i)** What effect does the wind have on the observed frequency? (a) It causes an increase. (b) It causes a decrease. (c) It causes no change. **(ii)** What effect does the wind have on the observed wavelength? Choose from the same possibilities. **(iii)** What effect does the wind have on the observed speed of the wave? Choose from the same possibilities.

16. How can an object move with respect to an observer so that the sound from it is not shifted in frequency?

Problems

WebAssign The Problems from this chapter may be assigned online in WebAssign.

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1, 2, 3 denotes straightforward, intermediate, challenging; ☐ denotes full solution available in *Student Solutions Manual/Study Guide;* ▲ denotes coached solution with hints available at **www.thomsonedu.com;** denotes developing symbolic reasoning; ● denotes asking for qualitative reasoning; denotes computer useful in solving problem

Section 17.1 Speed of Sound Waves

Problem 60 in Chapter 2 can also be assigned with this section.

1. ● Suppose you hear a clap of thunder 16.2 s after seeing the associated lightning stroke. The speed of sound in air is 343 m/s, and the speed of light in air is 3.00×10^8 m/s. How far are you from the lightning stroke? Do you need to know the value of the speed of light to answer? Explain.