CHAPTER 12 Summary

BIG IDEA Sound waves transfer energy through vibrations. Characteristics of the sounds we perceive are due to properties of the sound waves and the medium through which they travel.

SECTION 1 Sound Waves

- The frequency of a sound wave determines its pitch.
- The speed of sound depends on the medium.
- The relative motion between the source of waves and an observer creates an apparent frequency shift known as the Doppler effect.

KEY TERMS

compression
rarefaction
pitch
Doppler effect

SECTION 2 Sound Intensity and Resonance

- The sound intensity of a spherical wave is the power per area.
- Sound intensity is inversely proportional to the square of the distance from the source because the same energy is spread over a larger area.
- Intensity and frequency determine which sounds are audible.
- Decibel level is a measure of relative intensity on a logarithmic scale.
- A given difference in decibels corresponds to a fixed difference in perceived loudness.
- A forced vibration at the natural frequency produces resonance.
- The human ear transmits vibrations that cause nerve impulses. The brain interprets these impulses as sounds of varying frequencies.

KEY TERMS

intensity
decibel
resonance

SECTION 3 Harmonics

- Harmonics are integral multiples of the fundamental frequency.
- A vibrating string or a pipe open at both ends produces all harmonics.
- A pipe closed at one end produces only odd harmonics.
- The number and intensity of harmonics account for the sound quality of an instrument, also known as timbre.

KEY TERMS

fundamental frequency
harmonic series
timbre
beat

VARIABLE SYMBOLS

Quantities		Units	
	sound intensity	W/m^2	watts/meters squared
	decibel level	dB	decibels
f_n	frequency of the *n*th harmonic	Hz	Hertz $= s^{-1}$
L	length of a vibrating string or an air column	m	meters

Problem Solving

See **Appendix D: Equations** for a summary of the equations introduced in this chapter. If you need more problem-solving practice, see **Appendix I: Additional Problems.**

CHAPTER 12 Review

Sound Waves

REVIEWING MAIN IDEAS

1. Why are sound waves in air characterized as longitudinal?
2. Draw the sine curve that corresponds to the sound wave depicted below.

3. What is the difference between frequency and pitch?
4. What are the differences between infrasonic, audible, and ultrasonic sound waves?
5. Explain why the speed of sound depends on the temperature of the medium. Why is this temperature dependence more noticeable in a gas than in a solid or a liquid?
6. You are at a street corner and hear an ambulance siren. Without looking, how can you tell when the ambulance passes by?
7. Why do ultrasound waves produce images of objects inside the body more effectively than audible sound waves do?

CONCEPTUAL QUESTIONS

8. If the wavelength of a sound source is reduced by a factor of 2, what happens to the wave's frequency? What happens to its speed?
9. As a result of a distant explosion, an observer first senses a ground tremor and then hears the explosion. What accounts for this time lag?
10. By listening to a band or an orchestra, how can you determine that the speed of sound is the same for all frequencies?
11. A fire engine is moving at 40 m/s and sounding its horn. A car in front of the fire engine is moving at 30 m/s, and a van in front of the car is stationary. Which observer hears the fire engine's horn at a higher pitch, the driver of the car or the driver of the van?
12. A bat flying toward a wall emits a chirp at 40 kHz. Is the frequency of the echo received by the bat greater than, less than, or equal to 40 kHz?

Sound Intensity and Resonance

REVIEWING MAIN IDEAS

13. What is the difference between intensity and decibel level?
14. Using **Figure 2.3** as a guide, estimate the decibel levels of the following sounds: a cheering crowd at a football game, background noise in a church, the pages of this textbook being turned, and light traffic.
15. Why is the threshold of hearing represented as a curve in **Figure 2.2** rather than as a single point?
16. Under what conditions does resonance occur?

CONCEPTUAL QUESTIONS

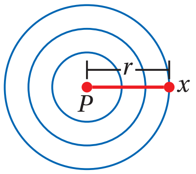
17. The decibel level of an orchestra is 90 dB, and a single violin achieves a level of 70 dB. How does the sound intensity from the full orchestra compare with that from the violin alone?
18. A noisy machine in a factory produces a decibel rating of 80 dB. How many identical machines could you add to the factory without exceeding the 90 dB limit set by federal regulations?
19. Why is the intensity of an echo less than that of the original sound?
20. Why are pushes given to a playground swing more effective if they are given at certain, regular intervals than if they are given at random positions in the swing's cycle?
21. Although soldiers are usually required to march together in step, they must break their march when crossing a bridge. Explain the possible danger of crossing a rickety bridge without taking this precaution.

PRACTICE PROBLEMS

For problems 22–23, see Sample Problem A.

22. A baseball coach shouts loudly at an umpire standing 5.0 m away. If the sound power produced by the coach is 3.1×10^{-3} W, what is the decibel level of the sound when it reaches the umpire? (Hint: Use **Figure 2.3** in this chapter.)

23. A stereo speaker represented by P in the figure on the right emits sound waves with a power output of 100.0 W. What is the intensity of the sound waves at point x when $r = 10.0$ m?

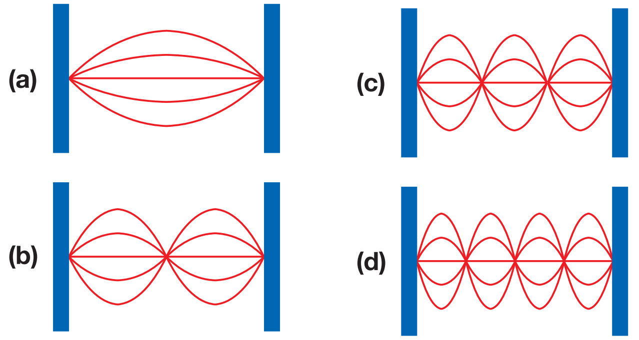


Harmonics

REVIEWING MAIN IDEAS

24. What is fundamental frequency? How are harmonics related to the fundamental frequency?

25. The figures below show a stretched string vibrating in several of its modes. If the length of the string is 2.0 m, what is the wavelength of the wave on the string in (**a**), (**b**), (**c**), and (**d**)?



26. Why does a pipe closed at one end have a different harmonic series than an open pipe?

27. Explain why a saxophone sounds different from a clarinet, even when they sound the same fundamental frequency at the same decibel level.

CONCEPTUAL QUESTIONS

28. Why does a vibrating guitar string sound louder when it is on the instrument than it does when it is stretched on a workbench?

29. Two violin players tuning their instruments together hear six beats in 2 s. What is the frequency difference between the two violins?

30. What is the purpose of the slide on a trombone and the valves on a trumpet?

31. A student records the first 10 harmonics for a pipe. Is it possible to determine whether the pipe is open or closed by comparing the difference in frequencies between the adjacent harmonics with the fundamental frequency? Explain.

32. A flute is similar to a pipe open at both ends, while a clarinet is similar to a pipe closed at one end. Explain why the fundamental frequency of a flute is about twice that of the clarinet, even though the length of these two instruments is approximately the same.

33. The fundamental frequency of any note produced by a flute will vary slightly with temperature changes in the air. For any given note, will an increase in temperature produce a slightly higher fundamental frequency or a slightly lower one?

PRACTICE PROBLEMS

For problems 34–35, see Sample Problem B.

34. What are the first three harmonics of a note produced on a 31.0 cm long violin string if waves on this string have a speed of 274.4 m/s?

35. The human ear canal is about 2.8 cm long and can be regarded as a tube open at one end and closed at the eardrum. What is the frequency around which we would expect hearing to be best when the speed of sound in air is 340 m/s? (Hint: Find the fundamental frequency for the ear canal.)

Mixed Review

REVIEWING MAIN IDEAS

36. A pipe that is open at both ends has a fundamental frequency of 320 Hz when the speed of sound in air is 331 m/s.
- **a.** What is the length of this pipe?
- **b.** What are the next two harmonics?

37. When two tuning forks of 132 Hz and 137 Hz, respectively, are sounded simultaneously, how many beats per second are heard?

38. The range of human hearing extends from approximately 20 Hz to 20 000 Hz. Find the wavelengths of these extremes when the speed of sound in air is equal to 343 m/s.

39. A dolphin in 25°C seawater emits a sound directed toward the bottom of the ocean 150 m below. How much time passes before it hears an echo? (See **Figure 1.3** in this chapter for the speed of the sound.)

40. An open organ pipe is 2.46 m long, and the speed of the air in the pipe is 345 m/s.
- **a.** What is the fundamental frequency of this pipe?
- **b.** How many harmonics are possible in the normal hearing range, 20 Hz to 20 000 Hz?

41. The fundamental frequency of an open organ pipe corresponds to the note middle C ($f = 261.6$ Hz on the chromatic musical scale). The third harmonic (f_3) of another organ pipe that is closed at one end has the same frequency. Compare the lengths of these two pipes.

42. Some studies indicate that the upper frequency limit of hearing is determined by the diameter of the eardrum. The wavelength of the sound wave and the diameter of the eardrum are approximately equal at this upper limit. If this is so, what is the diameter of the eardrum of a person capable of hearing 2.0×10^4 Hz? Assume 378 m/s is the speed of sound in the ear.

43. The decibel level of the noise from a jet aircraft is 130 dB when measured 20.0 m from the aircraft.
- **a.** How much sound power does the jet aircraft emit?
- **b.** How much sound power would strike the eardrum of an airport worker 20.0 m from the aircraft? (Use the diameter found in item 42 to calculate the area of the eardrum.)

GRAPHING CALCULATOR PRACTICE

Doppler Effect

As you learned earlier in this chapter, relative motion between a source of sound and an observer can create changes in the observed frequency. This frequency shift is known as the *Doppler effect.* The frequencies heard by the observer can be described by the following two equations, where f' represents the apparent frequency and f represents the actual frequency.

$$f' = f\left(\frac{v_{sound}}{v_{sound} - v_{source}}\right)$$

$$f' = f\left(\frac{v_{sound}}{v_{sound} + v_{source}}\right)$$

The first equation applies when the source of sound is approaching the observer, and the second equation applies when the source of sound is moving away from the observer.

In this graphing calculator activity, you will graph these two equations and will analyze the graphs to determine the apparent frequencies for various situations.

Go online to HMHScience.com to find the skillsheet and program for this graphing calculator activity.

ALTERNATIVE ASSESSMENT

1. A new airport is being built 750 m from your school. The noise level 50 m from planes that will land at the airport is 130 dB. In open spaces, such as the fields between the school and the airport, the level decreases by 20 dB each time the distance increases tenfold. Work in a cooperative group to research the options for keeping the noise level tolerable at the school. How far away would the school have to be moved to make the sound manageable? Research the cost of land near your school. What options are available for soundproofing the school's buildings? How expensive are these options? Have each member in the group present the advantages and disadvantages of such options.

2. Use soft-drink bottles and water to make a musical instrument. Adjust the amount of water in different bottles to create musical notes. Play them as percussion instruments (by tapping the bottles) or as wind instruments (by blowing over the mouths of individual bottles). What media are vibrating in each case? What affects the fundamental frequency? Use a microphone and an oscilloscope to analyze your performance and to demonstrate the effects of tuning your instrument.

3. Interview members of the medical profession to learn about human hearing. What are some types of hearing disabilities? How are hearing disabilities related to disease, age, and occupational or environmental hazards? What procedures and instruments are used to test hearing? How do hearing aids help? What are the limitations of hearing aids? Present your findings to the class.

4. Do research on the types of architectural acoustics that would affect a restaurant. What are some of the acoustics problems in places where many people gather? How do odd-shaped ceilings, decorative panels, draperies, and glass windows affect echo and noise? Find the shortest wavelengths of sounds that should be absorbed, considering that conversation sounds range from 500 to 5000 Hz. Prepare a plan or a model of your school cafeteria, and show what approaches you would use to keep the level of noise to a minimum.

5. Doppler radar systems use the Doppler effect to identify the speed of objects such as aircraft, ships, automobiles, and weather systems. For example, meteorologists use Doppler radar to track the movement of storm systems. Police use Doppler radar to determine whether a motorist is speeding. Doppler radar systems use electromagnetic waves, rather than sound waves. Choose an application of Doppler radar to research. Create a poster showing how the application works.

6. How does a piano produce sound? Why do grand pianos sound different from upright pianos? How are harpsichords and early pianos different from modern pianos? What types of tuning systems were used in the past, and which are used today? Use library and/or Internet sources to answer these questions. If possible, try playing notes on different pianos, and compare the resulting sounds. Create a presentation to share your results with the class.

7. Research the speed of sound in different media (including solids, liquids, and gases) and at different temperatures. Also investigate the concept of *supersonic* speed, and find some examples of objects that can move at supersonic speeds. Create a bar chart to compare your results.

8. Bats rely on echolocation to find and track prey. Conduct research to find out how this works. Which species of bats use echolocation? What type of sounds do bats emit? What can a bat learn from reflected sounds, and how do bats process the information? Write a paper with the results of your research.