The Nature of Sound

Chapter 21 • The Nature of Sound

PACING • 90 min
Chapter Opener

Section 1 What Is Sound?
- Describe how vibrations cause sound.
- Explain how sound is transmitted through a medium.
- Explain how the human ear works, and identify its parts.
- Identify ways to protect your hearing.

Section 2 Properties of Sound
- Compare the speed of sound in different media.
- Explain how frequency and pitch are related.
- Describe the Doppler effect, and give examples of it.
- Explain how amplitude and loudness are related.
- Describe how amplitude and frequency can be "seen" on an oscilloscope.

Section 3 Interactions of Sound Waves
- Explain how echoes are made, and describe their use in locating objects.
- List examples of constructive and destructive interference of sound waves.
- Explain what resonance is.

Section 4 Sound Quality
- Explain why different instruments have different sound qualities.
- Describe how each family of musical instruments produces sound.
- Explain how noise is different from music.

PACING • 45 min
PACING • 90 min

LABS, DEMONSTRATIONS, AND ACTIVITIES

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CRF Standardized Test Preparation* GENERAL
CRF Performance-Based Assessment* GENERAL
OSP Test Generator, Test Item Listing

CD Student Edition on CD-ROM
CD Guided Reading Audio CD
TR Chapter Starter Transparency*
VID Brain Food Video Quiz

OSP Lesson Plans (also in print)
TR Bellringer Transparency*
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TR P86 How the Human Ear Works*
SE Internet Activity, p. 604

CRF SciLinks Activity* GENERAL
CD Science Tutor

CD Science Tutor

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**sciLinks**

[www.scilinks.org](http://www.scilinks.org)

Maintained by the National Science Teachers Association. See Chapter Enrichment pages that follow for a complete list of topics.

Check out Current Science articles and activities by visiting the HRW Web site at [go.hrw.com](http://go.hrw.com). Just type in the keyword HP5CS21T.

**Classroom Videos**
- Lab Videos demonstrate the chapter lab.
- Brain Food Video Quizzes help students review the chapter material.

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- Visual Concepts
- Science Tutor

**Holt Lab Generator CD-ROM**
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Chapter 21 • The Nature of Sound

Planning Resources

**LEsson Plans**

**Lesson Plan**

- **Lesson Objectives**
  - Define amplitude and frequency.
  - Understand the process of sound production and reception.
- **Materials**
  - Sound-producing devices (e.g., tuning forks, metronomes).
  - Recording equipment (e.g., microphones, sound cards).
- **Assessment**
  - Pre- and post-tests on sound properties.
  - Peer evaluations on sound production projects.

**Parent Letter**

- **Parent Information**
  - Discussion of sound science and its relevance to everyday life.
  - Guidance on how to support children's learning at home.
- **Home Activities**
  - Listening exercises to identify different sound sources.
  - Experimentation with sound-producing devices.

**Test Item Listing**

- **Test Content**
  - Calculating amplitude and frequency of sounds.
  - Identifying the effects of sound on living organisms.
- **Test Format**
  - Multiple choice questions.
  - Short answer questions.
  - Essay questions.

One-Stop Planner CD-ROM

- **Resources Included**
  - Lab Materials QuickList Software.
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Chapter Enrichment

This Chapter Enrichment provides relevant and interesting information to expand and enhance your presentation of the chapter material.

Section 1

What Is Sound?

Robert Boyle (1627–1691)

• Robert Boyle, a British scientist who lived in Ireland, performed a famous experiment in 1660. When a bell was suspended in a vacuum, the clapper could be seen striking the bell, but no sound was heard. This demonstration proved that sound requires a medium to propagate.

Properties of Sound

Loudness

• Loudness is expressed in decibels. An increase of 10 dB multiplies the intensity of a sound by 10 times. An increase of 20 dB is $10 \times 10$, or 100 times more intense. The human ear, however, responds logarithmically, not linearly, to intensity.

Doppler Effect

• In 1842, the Doppler effect was explained by the Austrian physicist Christian Doppler (1803–1853). He noted that there is a change in wavelength of both light and sound when either the source or the receiver (or both, if they move at different velocities) moves.

• In acoustical Doppler effects, the frequency depends on the velocity of the observer and the velocity of the source.

Is That a Fact!

◆ Singing sand dunes can make two very different sounds: some dunes “whistle” or “squeak” in the 500 Hz to 2,500 Hz range, but others “boom” at frequencies of 50 Hz to 300 Hz. Interestingly, the booming sands can be felt as well; the dune trembles noticeably as it booms.

◆ Only sand grains with certain sizes and shapes whistle or squeal. Sands in many locations, including beach sands in a variety of places, can be induced to whistle. Scientists are less certain what factors create booming dunes, although grains of a certain size and shape seem to be required.

◆ The longest recorded distance traveled by any audible sound in air is about 4,600 km. The volcanic explosion on the Indonesian island of Krakatau, in 1883, propelled a column of smoke and ash more than 80 km into the air. The explosion sounded like distant cannon fire to people in Australia, Singapore, and Rodriguez Island—4,600 km away in the Indian Ocean. Waves reached the Pacific coastline of Colombia 19 h later, and tsunamis were recorded in other parts of South America.

◆ Sound travels 1.7 km in about 5 s in air that is 20°C. Sound travels the same distance (1.7 km) in just over 1 s underwater and in only 0.3 s in steel.
Section 3

Interactions of Sound Waves

Bat Sonar and Human Technology

• Experiments conducted at Brown University found that bat sonar can detect the difference between echoes just 2- to 3-millionths of a second apart. The best naval sonar could differentiate between echoes about 5- to 10-millionths of a second apart.

Is That a Fact!

◆ Nikola Tesla, a Croatian inventor, once created a human-made earthquake by making a steam-driven oscillator vibrate at the resonant frequency of the ground. Tesla had accurately determined the resonant frequency of the Earth! In a similar experiment, Tesla proved theories of seismic wave activity by sending waves of energy through the Earth. As these waves of energy returned, Tesla added electric current to them and thereby created a human-made bolt of lightning that measured 40 m. The accompanying thunder was heard for more than 35 km!

Section 4

Sound Quality

Recording Sound

• The two basic methods of recording sound are analog and digital recording. In analog recording, the recording medium varies continuously with the incoming signal. In digital recording, the signal is recorded as a rapid sequence of coded measurements.

Is That a Fact!

◆ Notes on a musical scale are set by exact frequencies. Although humans can hear frequencies as low as 20 Hz, the lowest frequency heard as a note is about 30 Hz. The highest frequency audible to humans is about 20,000 Hz. Middle C on the piano has a frequency of 263 Hz.

◆ Little was known about the science of sound until the 1600s. The Greeks were more interested in music than in the scientific aspects of sound. However, the Greek philosopher and mathematician Pythagoras (c. 580–500 BCE) discovered that doubling the frequency of a pitch produces a pitch one octave higher.

◆ Both methods preserve the varying voltage of the sound signal, but digital recording eliminates the hiss or electrical noise. Analog recordings can be improved by a noise reduction system, such as the Dolby®-system.
Overview
Tell students that this chapter will help them learn about the nature of sound. The chapter begins with a description of sound as longitudinal waves made by vibrations and carried through a medium, such as air. Properties like speed, pitch, and amplitude are then discussed. Students will then learn about interactions of sound waves, such as echoes, interference, and the Doppler effect. Differences in production of sound between musical instruments and the meaning of the term sound quality will then be discussed.

Assessing Prior Knowledge
Students should be familiar with the following topics:
• particles
• energy
• waves

Identifying Misconceptions
Many students wrongly intuit that sound cannot travel through solids and liquids and can travel through a vacuum and space. They also may believe that sound can be produced without any materials. Many students will also guess that hitting an object harder will change the pitch of the sound produced.

Standards Correlations

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A Homemade Guitar

In this chapter, you will learn about sound. You can start by making your own guitar. It won't sound as good as a real guitar, but it will help you explore the nature of sound.

**Procedure**

1. Stretch a rubber band lengthwise around an empty shoe box. Place the box hollow side up. Pluck the rubber band gently. Describe what you hear.
2. Stretch another rubber band of a different thickness around the box. Pluck both rubber bands. Describe the differences in the sounds.

3. Put a pencil across the center of the box and under the rubber bands, and pluck again. Compare this sound with the sound you heard before the pencil was used.
4. Move the pencil closer to one end of the shoe box. Pluck on both sides of the pencil. Describe the differences in the sounds you hear.

**Analysis**

1. How did the thicknesses of the rubber bands affect the sound?
2. In steps 3 and 4, you changed the length of the vibrating part of the rubber bands. What is the relationship between the vibrating length of the rubber band and the sound that you hear?

**Materials**

- pencil
- rubber band, thin
- rubber band, thick
- shoe box

**Teacher’s Notes:**

1. Students should hear a sound and see the rubber band vibrate.
2. Students should hear a higher pitch or note from the thinner rubber band. They might not use the words *pitch* or *note* at this point, but they should be able to notice and describe the differences between the two sounds.
3. When the pencil is used, the pitch of the sound is higher.
4. A high pitch is produced by the short part of the rubber band, and a low pitch is produced by the longer part of the rubber band.

**Answers**

1. The thicker the rubber band is, the lower the pitch.
2. The shorter the rubber band is, the higher the pitch.

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**Chapter Starter Transparency**

Use this transparency to help students begin thinking about the nature of sound.

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**Chapter Resources**

**Technology**

- Transparencies
- Chapter Starter Transparency
- Student Edition on CD-ROM
- Guided Reading Audio CD
- Classroom Videos
- Brain Food Video Quiz

**Workbooks**

- Science Puzzlers, Twisters & Teasers
- The Nature of Sound
What Is Sound?

You are in a restaurant, and without warning, you hear a loud crash. A waiter dropped a tray of dishes. What a mess! But why did dropping the dishes make such a loud sound?

In this section, you’ll find out what causes sound and what characteristics all sounds have in common. You’ll also learn how your ears detect sound and how you can protect your hearing.

Sound and Vibrations

As different as they are, all sounds have some things in common. One characteristic of sound is that it is created by vibrations. A vibration is the complete back-and-forth motion of an object. Figure 1 shows one way sound is made by vibrations.

**Figure 1 Sounds from a Stereo Speaker**

- Electrical signals make the speaker vibrate. As the speaker cone moves forward, it pushes the air particles in front of it closer together, creating a region of higher density and pressure called a compression.
- As the speaker cone moves backward, air particles close to the cone become less crowded, creating a region of lower density and pressure called a rarefaction.
- For each vibration, a compression and a rarefaction are formed. As the compressions and rarefactions travel away from the speaker, sound is transmitted through the air.

**Reading Strategy**

**Prediction Guide** Before reading this section, predict whether each of the following statements is true or false:

- Sound waves are made by vibrations.
- Sound waves push air particles along until they reach your ear.

**Vocabulary**

- sound wave
- medium

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**Auditory/Visual**

**Demonstration**

**Vibrations of Stereo Speakers**

Set up a stereo system with speakers—these must have woofers that reproduce low-frequency sounds—in the classroom, and remove the outer cover of the speakers. Play music that has a strong bass beat or bass notes. Students will be able to see the woofers vibrating with the bass sounds. Challenge them to explain why the vibrations of the woofers can be seen but the vibrations of the tweeters are almost imperceptible.

**Bellringer**

Tell students that if they’ve ever been near a large fireworks display, they may have felt the sound of the explosions. Ask them to think of other times they might feel sound and to describe them in their science journal.
Sound Waves

Longitudinal (lahn juh TOOD’n uhl) waves are made of compressions and rarefactions. A sound wave is a longitudinal wave caused by vibrations and carried through a substance. The particles of the substance, such as air particles, vibrate back and forth along the path that the sound wave travels. Sound is transmitted through the vibrations and collisions of the particles. Because the particles vibrate back and forth along the paths that sound travels, sound travels as longitudinal waves.

Sound waves travel in all directions away from their source, as shown in Figure 2. However, air or other matter does not travel with the sound waves. The particles of air only vibrate back and forth. If air did travel with sound, wind gusts from traveling sound waves would blow you over at a school dance!

Answer to Reading Check

What do sound waves consist of? (See the Appendix for answers to Reading Checks.)

Quick Lab

Good Vibrations

1. Gently strike a tuning fork on a rubber eraser. Watch the prongs, and listen for a sound. Describe what you see and what you hear.
2. Lightly touch the fork with your fingers. What do you feel?
3. Grasp the prongs of the fork firmly with your hand. What happens to the sound?
4. Strike the tuning fork on the eraser again, and dip the prongs in a cup of water. Describe what happens to the water.
5. Record your observations.

Materials

For Each Group
• eraser, rubber
• plastic cup of water, small
• tuning fork

Safety Caution: Remind students that the tuning forks should not touch their eyes or eyeglasses.

Answers

1. Students should hear a faint sound and they may or may not see the tuning fork vibrate, depending on how hard the fork was struck.
2. Students should feel the prongs vibrate.
3. The sound will immediately stop.
4. The vibrations of the prongs will create waves in the water in the cup.
Sound in Space?

Some science fiction movies are full of scenes of roaring spacecraft, loud drilling on asteroids, or deafening explosions during fictional space battles. Discuss with students why these movies are not scientifically accurate.

Sound Samples

Have groups of students search the school and grounds to record a variety of sounds. If possible, use a tape recorder or video camera. Instruct them to find the following sounds:

- high-pitched sound
- sound from above or overhead
- repeating sound
- sound that would startle
- irritating sound
- sound made by an animal
- sound made by wind
- sound made by something moving

Students should record what the sound is and where it was made. Compare and discuss what different groups found.

Answer to Reading Check

Sound needs a medium in order to travel.

Homework

Hearing Aids

Because so many young people listen to very loud music through headphones, one of the next major industries may be the manufacturing of hearing aids. Have students research the different kinds of hearing aids available, how they work, and their costs.

Another characteristic of sound is that all sound waves require a medium (plural, media). A medium is a substance through which a wave can travel. Most of the sounds that you hear travel through air at least part of the time. But sound waves can also travel through other materials, such as water, glass, and metal.

In a vacuum, however, there are no particles to vibrate. So, no sound can be made in a vacuum. This fact helps to explain the effect described in Figure 3. Sound must travel through air or some other medium to reach your ears and be detected.

How You Detect Sound

Imagine that you are watching a suspenseful movie. Just before a door is opened, the background music becomes louder. You know that there is something scary behind that door! Now, imagine watching the same scene without the sound. You would have more difficulty figuring out what’s going on if there were no sound.

Figure 4 shows how your ears change sound waves into electrical signals that allow you to hear. First, the outer ear collects sound waves. The vibrations then go to your middle ear. Very small organs increase the size of the vibrations here. These vibrations are then picked up by organs in your inner ear. Your inner ear changes vibrations into electrical signals that your brain interprets as sound.

A cricket hears through its front legs and produces a series of chirps, or trills, by rubbing its two front wings together. And the pistol shrimp makes a sound much like a gunshot by snapping shut its enlarged claw.
The inner ear contains the organs that are responsible for maintaining balance. These organs are located in a hollow region called the vestibule. Therefore, the sense of balance is sometimes referred to as the vestibular sense.
Have you heard this riddle? If a tree falls in the forest and no one is around to hear it, does the tree make a sound? Think about the situation pictured in Figure 5. When a tree falls and hits the ground, the tree and the ground vibrate. These vibrations make compressions and rarefactions in the surrounding air. So, there would be a sound!

Making Sound Versus Hearing Sound
Have you heard this riddle? If a tree falls in the forest and no one is around to hear it, does the tree make a sound? Think about the situation pictured in Figure 5. When a tree falls and hits the ground, the tree and the ground vibrate. These vibrations make compressions and rarefactions in the surrounding air. So, there would be a sound!

Making sound is separate from detecting sound. The fact that no one heard the tree fall doesn’t mean that there wasn’t a sound. A sound was made—it just wasn’t heard.

Hearing Loss and Deafness
The many parts of the ear must work together for you to hear sounds. If any part of the ear is damaged or does not work properly, hearing loss or deafness may result.

One of the most common types of hearing loss is called tinnitus (ti NIET us), which results from long-term exposure to loud sounds. Loud sounds can cause damage to the hair cells and nerve endings in the cochlea. Once these hairs are damaged, they do not grow back. Damage to the cochlea or any other part of the inner ear usually results in permanent hearing loss.

People who have tinnitus often say they have a ringing in their ears. They also have trouble understanding other people and hearing the difference between words that sound alike. Tinnitus can affect people of any age. Fortunately, tinnitus can be prevented.

Answer to Reading Check
Tinnitus is caused by long-term exposure to loud sounds.
Protecting Your Hearing

Short exposures to sounds that are loud enough to be painful can cause hearing loss. Your hearing can also be damaged by loud sounds that are not quite painful, if you are exposed to them for long periods of time. There are some simple things you can do to protect your hearing. Loud sounds can be blocked out by earplugs. You can listen at a lower volume when you are using headphones, as in Figure 6. You can also move away from loud sounds. If you are near a speaker playing loud music, just move away from it. When you double the distance between yourself and a loud sound, the sound’s intensity to your ears will be one-fourth of what it was before.

Figure 6 Turning your radio down can help prevent hearing loss, especially when you use headphones.

Using Key Terms

1. Use the following terms in the same sentence: sound wave and medium.

Understanding Key Ideas

2. Sound travels as
   a. transverse waves.
   b. longitudinal waves.
   c. shock waves.
   d. airwaves.

3. Which part of the ear increases the size of the vibrations of sound waves entering the ear?
   a. outer ear
   b. ear canal
   c. middle ear
   d. inner ear

4. Name two ways of protecting your hearing.

Critical Thinking

5. Analyzing Processes Explain why a person at a rock concert will not feel gusts of wind coming out of the speakers.

6. Analyzing Ideas If a meteorite crashed on the moon, would you be able to hear it on Earth? Why, or why not?

7. Identifying Relationships Recall the breaking dishes mentioned at the beginning of this section. Why was the sound that they made so loud?

8. What kind of wave is this?

9. Draw a sketch of the diagram on a separate sheet of paper, and label the compressions and rarefactions.

10. How do vibrations make these kinds of waves?

Answers to Section Review

1. Sample answer: A sound wave is carried through a medium by longitudinal waves.
2. b
3. c
4. waring ear protection devices and keeping a distance between your ears and loud sounds
5. All sounds are carried by longitudinal waves: In a wave, the particles themselves do not move forward with the wave.
6. no; There is no medium between the moon and Earth to carry sound waves.
7. The breaking of dishes involves a high energy of vibrations, so the sound is loud.
8. a longitudinal wave
9. Diagrams should label the areas dense with particles as “compressions,” and sparse areas as “rarefactions.”
10. The back-and-forth motion of a vibrating object forms compressions and rarefactions in the air around it.
Properties of Sound

Imagine that you are swimming in a neighborhood pool. You can hear the high, loud laughter of small children and the soft splashing of the waves at the edge of the pool.

Why are some sounds loud, soft, high, or low? The differences between sounds depend on the properties of the sound waves. In this section, you will learn about properties of sound.

The Speed of Sound

Suppose you are standing at one end of a pool and two people from the opposite end of the pool yell at the same time. You would hear their voices at the same time. The reason is that the speed of sound depends only on the medium in which the sound is traveling. So, you would hear them at the same time—even if one person yelled louder!

How the Speed of Sound Can Change

Table 1 shows how the speed of sound varies in different media. Sound travels quickly through air, but it travels even faster in liquids and even faster in solids.

Temperature also affects the speed of sound. In general, the cooler the medium is, the slower the speed of sound. Particles of cool materials move more slowly and transmit energy more slowly than particles do in warmer materials. In 1947, pilot Chuck Yeager became the first person to travel faster than the speed of sound. Yeager flew the airplane shown in Figure 1 at 293 m/s (about 480 mi/h) at 12,000 m above sea level. At that altitude, the temperature of the air is so low that the speed of sound is only 290 m/s.

\[ \text{Table 1 Speed of Sound in Different Media} \]

<table>
<thead>
<tr>
<th>Medium</th>
<th>Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air (0°C)</td>
<td>331</td>
</tr>
<tr>
<td>Air (20°C)</td>
<td>343</td>
</tr>
<tr>
<td>Air (100°C)</td>
<td>366</td>
</tr>
<tr>
<td>Water (20°C)</td>
<td>1,482</td>
</tr>
<tr>
<td>Steel (20°C)</td>
<td>5,200</td>
</tr>
</tbody>
</table>

Figure 1 The X-1 airplane was the first vehicle to move faster than the speed of sound.

Is That a Fact!

In some western movies, a character would be shown putting an ear to the hard ground to find out if someone was coming. This technique actually works because sound travels faster and with less loss of energy through the ground than through air.
Pitch and Frequency

How low or high a sound seems to be is the pitch of that sound. The frequency of a wave is the number of crests or troughs that are made in a given time. The pitch of a sound is related to the frequency of the sound wave, as shown in Figure 2. Frequency is expressed in hertz (Hz), where 1 Hz = 1 wave per second. For example, the lowest note on a piano is about 40 Hz. The screech of a bat is 10,000 Hz or higher.

Reading Check | What is frequency? (See the Appendix for answers to Reading Checks.)

Frequency and Hearing

If you see someone blow a dog whistle, the whistle seems silent to you. The reason is that the frequency of the sound wave is out of the range of human hearing. But the dog hears the whistle and comes running! Table 2 compares the range of frequencies that humans and animals can hear. Sounds that have a frequency too high for people to hear are called ultrasonic.

Table 2 | Frequencies Heard by Different Animals

<table>
<thead>
<tr>
<th>Animal</th>
<th>Frequency range (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bat</td>
<td>2,000 to 110,000</td>
</tr>
<tr>
<td>Porpoise</td>
<td>75 to 150,000</td>
</tr>
<tr>
<td>Cat</td>
<td>45 to 64,000</td>
</tr>
<tr>
<td>Beluga whale</td>
<td>1,000 to 125,000</td>
</tr>
<tr>
<td>Elephant</td>
<td>16 to 12,000</td>
</tr>
<tr>
<td>Human</td>
<td>20 to 20,000</td>
</tr>
<tr>
<td>Dog</td>
<td>67 to 45,000</td>
</tr>
</tbody>
</table>

Answers to Math Practice

- Air: 343 m/s × 5 s = 1,715 m
- Steel: 5,200 m/s × 5 s = 26,000 m

Answer to Reading Check

Frequency is the number of crests or troughs made in a given time.

Is That a Fact?

Studies now show that regions of hair cells within the inner ear are actually “tuned” to specific frequencies. Because of their differences in size and shape, hair cells have a specific resonance at which they vibrate. Thus, certain frequencies will activate some hair cells but not others.

Paper Cup Phones

Have students punch a hole in the bottom of each cup, insert one end of the string into each cup, and tie a knot in the string. Have one student from each pair talk quietly into the cup while the other listens through the second cup. Have each pair experiment with the types of string, the tension of the strings, and lengths of the strings to see which combination works best.

Speed of Sound in Steel

Ask students the following question: “The temperature is 20°C. You are standing next to a railing located in a national park. The railing is 7,700 m long and is made of steel. Your friend is at the other end of the railing, and she hits the railing with a hammer. How long will it take for the sound to get to you through the railing: less than 1 s, between 1 s and 2 s, or more than 2 s? Explain your answer.”

(is between 1 s and 2 s; Sound travels 5,200 m through steel in 1 s. Therefore, sound will take between 1 s and 2 s to travel through the 7,700 m rail.) Logical
Doppler Diagram: Have students use colored pencils to draw a diagram showing the Doppler effect. Have them include a listener, a vehicle, and lines depicting sound waves.

**English Language Learners**

**The Doppler Effect in Action** A demonstration will help students understand the Doppler effect. Find a noisemaker that produces a constant sound (a small buzzer or something similar). Attach the noisemaker to the end of a string approximately 70 cm to 90 cm long. (It may be necessary to do the demonstration outside.) Let students hear the noise from the noisemaker. Stand away from the students and walls. Swing the noisemaker by the string in a wide circle over your head. Ask students to describe what they hear in terms of the Doppler effect. (When the noisemaker is coming toward them, they will hear a higher pitch because the sound waves are closer together. When it is moving away from them they will hear a lower pitch because the sound waves are farther apart.) Call on students to ensure full participation.

**Doppler Effect** The Doppler effect is named after the Austrian mathematician Christian Doppler (1803–1853), who first proposed it in 1842 in a paper describing the colored light of double stars. In 1845, Doppler applied his theory to sound waves and tested it with trumpet players on a train. In 1929, astronomer Edwin Hubble (1889–1953) used Doppler’s theory to interpret his measurements and show that the farther away from Earth a galaxy is, the faster it is moving away from Earth and the more the light from that galaxy is “shifted” toward the red end of the spectrum.
**Loudness and Amplitude**

If you gently tap a drum, you will hear a soft rumbling. But if you strike the drum with a large force, you will hear a much louder sound! By changing the force you use to strike the drum, you change the loudness of the sound that is created. **Loudness** is a measure of how well a sound can be heard.

**Energy and Vibration**

Look at Figure 4. The harder you strike a drum, the louder the boom. As you strike the drum harder, you transfer more energy to the drum. The drum moves with a larger vibration and transfers more energy to the air around it. This increase in energy causes air particles to vibrate farther from their rest positions. **Increasing Amplitude**

When you strike a drum harder, you are increasing the amplitude of the sound waves being made. The amplitude of a wave is the largest distance the particles in a wave vibrate from their rest positions. The larger the amplitude, the louder the sound. And the smaller the amplitude, the softer the sound. One way to increase the loudness of a sound is to use an amplifier, shown in Figure 5. An amplifier receives sound signals in the form of electric current. The amplifier then increases the energy and makes the sound louder.

**Reading Check**  What is the relationship between the amplitude of a sound and its energy of vibration?

**Figure 4** When a drum is struck hard, it vibrates with a lot of energy, making a loud sound.

**Figure 5** An amplifier increases the amplitude of the sound generated by an electric guitar.

**Quick Lab**

**Sounding Board**

1. With one hand, hold a ruler on your desk so that one end of it hangs over the edge.
2. With your other hand, pull the free end of the ruler up a few centimeters, and let go.
3. Try pulling the ruler up different distances. How does the distance affect the sounds you hear? What property of the sound wave are you changing?
4. Change the length of the part that hangs over the edge. What property of the sound wave is affected? Record your answers and observations.

**Safety Caution:** Remind students to wear safety goggles when doing this lab.

**Teacher’s Note:** Any stiff wooden or plastic ruler will work for this lab.

**Answers**

3. The farther up they pull the ruler, the louder the sound will be. Amplitude is changing.

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Measuring Loudness

The most common unit used to express loudness is the decibel (dB). The softest sounds an average human can hear are at a level of 0 dB. Sounds that are at 120 dB or higher can be painful. Table 3 shows some common sounds and their decibel levels.

“Seeing” Amplitude and Frequency

Sound waves are invisible. However, technology can provide a way to “see” sound waves. A device called an oscilloscope (uh SIL uh skope) can graph representations of sound waves, as shown in Figure 6. Notice that the graphs look like transverse waves instead of longitudinal waves.

Answer to Reading Check

An oscilloscope turns sounds into electrical signals and graphs the signals.
From Sound to Electrical Signal

An oscilloscope is shown in Figure 7. A microphone is attached to the oscilloscope and changes a sound wave into an electrical signal. The electrical signal is graphed on the screen in the form of a wave. The graph shows the sound as if it were a transverse wave. So, the sound’s amplitude and frequency are easier to see. The highest points (crests) of these waves represent compressions, and the lowest points (troughs) represent rarefactions. By looking at the displays on the oscilloscope, you can quickly see the differences in amplitude and frequency of different sound waves.

Figure 7 An oscilloscope can be used to represent sounds.

SECTION REVIEW

Summary

- The speed of sound depends on the medium and the temperature.
- The pitch of a sound becomes higher as the frequency of the sound wave becomes higher. Frequency is expressed in units of Hertz (Hz), which is equivalent to waves per second.
- The Doppler effect is the apparent change in frequency of a sound caused by the motion of either the listener or the source of the sound.
- Loudness increases with the amplitude of the sound. Loudness is expressed in decibels.
- The amplitude and frequency of a sound can be measured electronically by an oscilloscope.

Using Key Terms

1. In your own words, write a definition for the term pitch.
2. Use the following terms in the same sentence: loudness and decibel.

Understanding Key Ideas

3. At the same temperature, in which medium does sound travel fastest?
   a. air
   b. liquid
   c. solid
   d. It travels at the same speed through all media.

4. In general, how does the temperature of a medium affect the speed of sound through that medium?
5. What property of waves affects the pitch of a sound?
6. How does an oscilloscope allow sound waves to be “seen”?

Critical Thinking

9. Analyzing Processes Will a listener notice the Doppler effect if both the listener and the source of the sound are traveling toward each other? Explain your answer.
10. Predicting Consequences A drum is struck gently, then is struck harder. What will be the difference in the amplitude of the sounds made? What will be the difference in the frequency of the sounds made?

Math Skills

7. You see a distant flash of lightning, and then you hear a thunderclap 2 s later. The sound of the thunder moves at 343 m/s. How far away was the lightning?
8. In water that is near 0°C, a submarine sends out a sonar signal (a sound wave). The signal travels 1500 m/s and reaches an underwater mountain in 4 s. How far away is the mountain?

Answers to Section Review

1. Sample answer: how low or high a sound seems, which depends on the frequency of the sound waves
2. Loudness is expressed scientifically in units of decibels.
3. c
4. Sound tends to travel fastest in higher-temperature media.
5. Pitch is determined by the frequency of sound waves.
6. An oscilloscope changes sound waves into electronic signals, which are represented on a screen.
7. 343 m/s × 2 s = 686 m
8. 1,500 m/s × 4 s = 6,000 m
9. yes; The sound waves in front of the source will become closer together as the source moves forward. Also, the listener will “meet” the sound waves more rapidly by moving toward the source. The movements of both the source and the listener will make the pitch of the sound higher.
10. The amplitude of the sound will be higher when the drum is struck harder. The frequency will not change.

CHAPTER RESOURCES

Chapter Resource File

- Section Quiz
- Section Review
- Vocabulary and Section Summary
- Reinforcement Worksheet
- Datasheet for Quick Lab

SciLinks

For a variety of links related to this chapter, go to www.scilinks.org

Topic: Properties of Sound
SciLinks code: HSM1235
Overview
In this section students learn about reflection and echolocation. They also learn about constructive and destructive wave interference and resonance.

Bellringer
Put these questions on the board:
• On an oscilloscope, does a wave with a larger amplitude (greater crests and troughs) indicate louder sound or higher pitch? (Louder sound)
• As frequency increases, does pitch get higher or lower? (Higher)
• What is the speed of sound dependent on? (Sample answer: the medium and its temperature)
• What do you think happens when two sound waves interact with each other? (Answers may vary.)

Interactions of Sound Waves
Have you ever heard of a sea canary? It’s not a bird! It’s a whale! Beluga whales are sometimes called sea canaries because of the many different sounds they make.

Dolphins, beluga whales, and many other animals that live in the sea use sound to communicate. Beluga whales also rely on reflected sound waves to find fish, crabs, and shrimp to eat. In this section, you will learn about reflection and other interactions of sound waves. You will also learn how bats, dolphins, and whales use sound to find food.

Reflection of Sound Waves
Reflection is the bouncing back of a wave after it strikes a barrier. You’re probably already familiar with a reflected sound wave, otherwise known as an echo. The strength of a reflected sound wave depends on the reflecting surface. Sound waves reflect best off smooth, hard surfaces. Look at Figure 1. A shout in an empty gymnasium can produce an echo, but a shout in an auditorium usually does not.

The difference is that the walls of an auditorium are usually designed so that they absorb sound. If sound waves hit a flat, hard surface, they will reflect back. Reflection of sound waves doesn’t matter much in a gymnasium. But you don’t want to hear echoes while listening to a musical performance!

Figure 1 Sound Reflection and Absorption
Sound waves easily reflect off the smooth, hard walls of a gymnasium. For this reason, you hear an echo.

In well-designed auditoriums, echoes are reduced by soft materials that absorb sound waves and by irregular shapes that scatter sound waves.

Is That a Fact!
According to Greek mythology, echoes originated when the angry goddess Hera placed a curse on the wood nymph Echo that caused her to repeat whatever was said to her.
Echolocation

Beluga whales use echoes to find food. The use of reflected sound waves to find objects is called echolocation. Other animals—such as dolphins, bats, and some kinds of birds—also use echolocation to hunt food and to find objects in their paths. Figure 2 shows how echolocation works. Animals that use echolocation can tell how far away something is based on how long it takes sound waves to echo back to their ears. Some animals, such as bats, also make use of the Doppler effect to tell if another moving object, such as an insect, is moving toward it or away from it.

Reading Check How is echolocation useful to some animals? (See the Appendix for answers to Reading Checks.)

Echolocation Technology

People use echoes to locate objects underwater by using sonar (which stands for sound navigation and ranging). Sonar is a type of electronic echolocation. Figure 3 shows how sonar works. Ultrasonic waves are used because their short wavelengths give more details about the objects they reflect off. Sonar can also help navigators on ships avoid icebergs and can help oceanographers map the ocean floor.

Answer to Reading Check

Echolocation helps some animals find food.

Is That a Fact!

Dolphins use echolocation by emitting rapid, high-pitched clicks and listening for the returning echo. The closer a dolphin gets to an object, the faster the clicks return. As a dolphin moves its head side to side to scan, it detects both distance and shape. Dolphins can detect an object that is 2 cm in diameter more than 70 m away in open water.
Interference of Sound Waves

Sound waves also interact through interference. Interference happens when two or more waves overlap. Figure 5 shows how two sound waves can combine by both constructive and destructive interference.

Orchestras and bands make use of constructive interference when several instruments of the same kind play the same notes. Interference of the sound waves causes the combined amplitude to increase, resulting in a louder sound. But destructive interference may keep some members of the audience from hearing the concert well. In certain places in an auditorium, sound waves reflecting off the walls interfere destructively with the sound waves from the stage.

**Reading Check**

What are the two kinds of sound wave interference?

**Figure 5 Constructive and Destructive Interference**

Sound waves from two speakers producing sound of the same frequency combine by both constructive and destructive interference.

**Constructive Interference**

As the compressions of one wave overlap the compressions of another wave, the sound will be louder because the amplitude is increased.

**Destructive Interference**

As the compressions of one wave overlap the rarefactions of another wave, the sound will be softer because the amplitude is decreased.

**Is That a Fact!**

Mach number is not a speed. It is the ratio between the speed of an object, usually an airplane, and the speed of sound in the medium in which the object is traveling. A plane traveling at Mach 3.0 is traveling at 3 times whatever the speed of sound is at the plane’s altitude.

**Ultrasonography**

Ultrasonography (UH truh soh NAH rhuh fee) is a medical procedure that uses echoes to “see” inside a patient’s body without doing surgery. A special device makes ultrasonic waves with a frequency that can be from 1 million to 10 million hertz, which reflect off the patient’s internal organs. These echoes are then changed into images that can be seen on a television screen, as shown in Figure 4. Ultrasonography is used to examine kidneys, gallbladders, and other organs. It is also used to check the development of an unborn baby in a mother’s body. Ultrasonic waves are less harmful to human tissue than X rays.

**Real World CONNECTION**

Have students research what sort of building materials have the STC ratings given above. Then, have students design a house and use this rating system to determine what building materials to use. Ask them to explain why they put the materials where they did. 

**SUPPORT FOR**

**English Language Learners**

Ultrasonography Students will benefit from seeing an ultrasound of an organ or an unborn baby. Before you show the ultrasound, describe what they will see and ask them to predict how much detail they will be able to view. Present the ultrasound on an overhead projector, and enlarge to show detail. Point out features of the image. Ask, “Did you see the details you expected to see? Was anything in the picture different from what you expected?” 

**Logical Support**

STC # What can be heard

25 Normal speech can be heard.
30 Loud speech can be heard.
35 Loud speech is audible but not intelligible.
42 Loud speech is audible as a murmur.
45 A person must strain to hear loud speech.
48 Some loud speech is barely audible.
50 Loud speech is inaudible.

**Is That a Fact!**

Sound wave interference can be either constructive or destructive.
**Interference and the Sound Barrier**

As the source of a sound—such as a jet plane—gets close to the speed of sound, the sound waves in front of the jet plane get closer and closer together. The result is constructive interference. **Figure 6** shows what happens as a jet plane reaches the speed of sound.

For the jet in **Figure 6** to go faster than the speed of sound, the jet must overcome the pressure of the compressed sound waves. **Figure 7** shows what happens as soon as the jet reaches supersonic speeds—speeds faster than the speed of sound. At these speeds, the sound waves trail off behind the jet. At their outer edges, the sound waves combine by constructive interference to form a shock wave.

A sonic boom is the explosive sound heard when a shock wave reaches your ears. Sonic booms can be so loud that they can hurt your ears and break windows. They can even make the ground shake as it does during an earthquake.

**Is That a Fact!**

A double sonic boom occurs when the space shuttle enters the atmosphere. Whenever a craft exceeds Mach 1, one shock wave is formed at the nose, and another shock wave is formed at the tail. If the shock waves are more than 0.10 s apart, you hear two sonic booms.

**Interference in Auditoriums**

Destructive interference can make it hard to hear in some parts of a theater or auditorium. To reduce the effects of destructive interference, sounds are usually amplified electronically, and speakers are located in different places. But sound waves from the many speakers can also produce destructive interference. Also, sound waves reflected from the walls and other surfaces can interfere with waves from the speakers. Have students find out how theaters, concert halls, and recording studios are designed and built to reduce destructive interference. Encourage them to use models or posters to show their results.  

**BRAIN FOOD**

The speed of sound is about 343 m/s at sea level at 20°C and is known as Mach 1. As a plane passes through the sound barrier created at this speed, the resulting shock wave increases the drag on the plane. The plane has to be equipped to control this change in airflow.
Reteaching
Brainstorming Section Concepts
Ask students what the two main ideas in this section are.
(reflection and interference of sound waves) If they mention resonance, ask them what more general concept it goes under. (interference) Then, have them name subtopics covered in this chapter and which of the two main ideas each is related to.
(reflection: echoes, echolocation, ultrasonography; interference: constructive interference, destructive interference, sound barrier, sonic boom, standing waves, resonance)

Logical

Quiz

1. Why does everything seem so quiet after a snowfall? (Snow does not reflect sound waves; it absorbs them.)
2. Have you ever sung in the shower? Why does your voice sound so much better there? (The hard, smooth walls of the shower reflect sound waves, and the interactions of the waves make your voice sound fuller.)

Alternative Assessment

Sound Stories Have students write fictional articles for a tabloid newspaper about a strange phenomenon caused by an interaction of sound waves they have learned about in this chapter. The science must be accurate, but they can exaggerate the effects.

Logical

Fundamentals and Harmonics When overtones are exact multiples of the fundamental, they are often called harmonics. However, confusion sometimes results because harmonics are numbered to include the fundamental, but overtones are not. As a result, the first overtone is the second harmonic, the second overtone is the third harmonic, and so on.

Reading Check What is a standing wave?

Resonance

If you have a tuning fork, shown in Figure 9, that vibrates at one of the resonant frequencies of a guitar string, you can make the string make a sound without touching it. Strike the tuning fork, and hold it close to the string. The string will start to vibrate and produce a sound.

Using the vibrations of the tuning fork to make the string vibrate is an example of resonance. Resonance happens when an object vibrating at or near a resonant frequency of a second object causes the second object to vibrate.

Interference and Standing Waves

When you play a guitar, you can make some pleasing sounds, and you might even play a tune. But have you ever watched a guitar string after you’ve plucked it? You may have noticed that the string vibrates as a standing wave. A standing wave is a pattern of vibration that looks like a wave that is standing still. Waves and reflected waves of the same frequency are going through the string. Where you see maximum amplitude, waves are interfering constructively. Where the string seems to be standing still, waves are interfering destructively.

Although you can see only one standing wave, which is at the fundamental frequency, the guitar string actually creates several standing waves of different frequencies at the same time. The frequencies at which standing waves are made are called resonant frequencies. Resonant frequencies and the relationships between them are shown in Figure 8.

Answer to Reading Check
A standing wave is a pattern of vibration that looks like a wave that is standing still.
Resonance in Musical Instruments

Musical instruments use resonance to make sound. In wind instruments, vibrations are caused by blowing air into the mouthpiece. The vibrations make a sound, which is amplified when it forms a standing wave inside the instrument.

String instruments also resonate when they are played. An acoustic guitar, such as the one shown in Figure 10, has a hollow body. When the strings vibrate, sound waves enter the body of the guitar. Standing waves form inside the body of the guitar, and the sound is amplified.

When a vibrating object
Describe a place in which you
Give one example each of
Sound travels through air at
A destructive interference
What causes an echo
Making Com

Summary

- Echoes are reflected sound waves.
- Some animals can use echolocation to find food or to navigate around objects.
- People use echolocation technology in many underwater applications.
- Ultrasonography uses sound reflection for medical applications.
- Sound barriers and shock waves are created by interference.
- Standing waves form at an object’s resonant frequencies.
- Resonance happens when a vibrating object causes a second object to vibrate at one of its resonant frequencies.

Using Key Terms

1. Use the following terms in the same sentence: echo and echolocation.
   Complete each of the following sentences by choosing the correct term from the word bank.
   - interference standing wave sonic boom resonance
2. When you pluck a string on a musical instrument, a(n) _____ forms.
3. When a vibrating object causes a nearby object to vibrate, _____ results.

Understanding Key Ideas

4. What causes an echo?
   a. reflection
   b. resonance
c. constructive interference
d. destructive interference
5. Describe a place in which you would expect to hear echoes.
6. How do bats use echoes to find insects to eat?
7. Give one example each of constructive and destructive interference of sound waves.

Math Skills

8. Sound travels through air at 343 m/s at 20°C. A bat emits an ultrasonic squeak and hears the echo 0.05 s later. How far away was the object that reflected it? (Hint: Remember that the sound must travel to the object and back to the bat.)
9. Applying Concepts Your friend is playing a song on a piano. Whenever your friend hits a certain key, the lamp on top of the piano rattles. Explain why the lamp rattles.
10. Making Comparisons Compare sonar and ultrasonography in locating objects.

Critical Thinking

- Sample answer: Some animals use echolocation to “see” in the dark by listening for the echoes of the sounds they make off reflected objects.
- standing wave
- resonance
- a
- Sample answer: a room with smooth walls
- They use echolocation to find insects by emitting sounds and listening for the echoes, which tell them how far away the insect is and how fast it is moving.
- Sample answer: constructive interference: sonic boom; destructive interference: a “dead spot” in a concert hall
- 343 m/s × 0.05 s = 17 m
- 17 m ÷ 2 = 8.5 m
- Resonance is occurring, because the lamp on top of the piano has a resonant frequency equal to one of the notes being played.
- Both sonar and ultrasonography make use of sound reflection to locate objects. Ultrasonography, however, involves much higher frequency sound waves than used in sonar and allows imaging of objects instead of just locating them.

SciLinks

For a variety of links related to this chapter, go to www.sci links.org
Topic: Interactions of Sound Waves
SciLinks code: HSM0804

Chapter Resource File

- Section Quiz
- Section Review
- Vocabulary and Section Summary

Section 3 • Interactions of Sound Waves 617
Sound Quality

Have you ever been told that the music you really like is just a lot of noise? If you have, you know that people can disagree about the difference between noise and music.

You might think of noise as sounds you don’t like and music as sounds that are pleasant to hear. But the difference between music and noise does not depend on whether you like the sound. The difference has to do with sound quality.

**What Is Sound Quality?**

Imagine that the same note is played on a piano and on a violin. Could you tell the instruments apart without looking? The notes played have the same frequency. But you could probably tell them apart because the instruments make different sounds. The notes sound different because a single note on an instrument actually comes from several different pitches: the fundamental and several overtones. The result of the combination of these pitches is shown in Figure 1. Each instrument has a unique sound quality.

Figure 1 also shows how the sound quality differs when two instruments play the same note.
Sound Quality of Instruments

The difference in sound quality among different instruments comes from their structural differences. All instruments produce sound by vibrating. But instruments vary in the part that vibrates and in the way that the vibrations are made. There are three main families of instruments: string instruments, wind instruments, and percussion instruments.

Reading Check How do musical instruments differ in how they produce sound? (See the Appendix for answers to Reading Checks.)

String Instruments

Violins, guitars, and banjos are examples of string instruments. They make sound when their strings vibrate after being plucked or bowed. Figure 2 shows how two different string instruments produce sounds.

Figure 2  String Instruments

1. Cellos and guitars have strings of different thicknesses. The thicker the string is, the lower the pitch is.
2. The pitch of the string can be changed by pushing the string against the neck of the instrument to change the string’s length. Shorter strings vibrate at higher frequencies.
3. A string vibrates when a bow is pulled across it or when the string is plucked.
4. The vibrations in the cello string make the bridge vibrate, which, in turn, makes the body of the cello vibrate.
5. The body of the cello and the air inside it resonate with the string’s vibration, creating a louder sound.
6. Pickups on the guitar convert the vibration of the guitar string into an electrical signal.
7. An amplifier converts the electrical signal back into a sound wave and increases the loudness of the sound.

Is That a Fact? The pickup on an electric guitar is a set of magnets wrapped by thousands of turns of wire. The vibrations of the guitar strings create disturbances in the magnetic fields. These disturbances produce electrical impulses in the coils of wire, and these impulses are transmitted to an amplifier, where they are converted into sounds.

Answer to Reading Check Musical instruments differ in the part of the instrument that vibrates and in the way that the vibrations are made.

Teach

READING STRATEGY

Prediction Guide Before students read these two pages, ask them to name the three major families of musical instruments and to give as many examples of each family as they can.

SUPPORT FOR

English Language Learners

String Instruments Students may have had little exposure to string instruments such as violins. Ask the orchestra director or students who play a string instrument to demonstrate how their instruments work. Before the demonstration, have groups of students write down questions to ask. Spot check the questions orally for grammar. Ask the demonstrator if students may study the instruments up close after the demonstration.

Homework

The Sound of Music Have students write in their science journal about a sound or some music that is important to them. The sound or music may have changed their perspective about something, or maybe it changed their attitude or mood. Maybe it is just a favorite song. Ask them to explain why they think music can produce a change in a person’s mood.
Reteaching—BASIC

Musical Instruments and Sound Quality Have students name the three classes of musical instruments named in this section. Write each one on the board. Then, have them brainstorm as many examples of each one as they can think of. Write these in a second area on the board underneath each category. Then, have them explain what all instruments of each category have in common in how they produce sound and what determines their particular sound quality. Logical

Quiz—GENERAL

1. What is sound quality? (the result of several pitches blending together through interference)
2. How does noise differ from music? (Music contains repeating melodic patterns. Noise has a complex sound wave with no pattern.)

Alternative Assessment—GENERAL

Instrument Diagrams Have students draw and label members of each instrument family. Instruct them to label the part that vibrates and show where or how pitch can be changed. Verbal

Cultural Awareness—GENERAL

Use of Drums Drums, the most common percussion instruments, have been around since at least 6000 BCE. Drums are found in almost every culture and have been used for a number of purposes, including music. In some African cultures, drums were used to transmit messages over many miles. In Europe, infantry regiments once used snare drums to transmit coded orders to soldiers.
Music or Noise?
Most of the sounds we hear are noises. The sound of a truck roaring down the highway, the slam of a door, and the jingle of keys falling to the floor are all noises. Noise can be described as any sound, especially a nonmusical sound, that is a random mix of frequencies (or pitches). Figure 5 shows on an oscilloscope the difference between a musical sound and noise.

**Figure 5** A note from a French horn produces a sound wave with a repeating pattern, but noise from a clap produces complex sound waves with no regular pattern.

---

**Reading Check** What is the difference between music and noise?

---

**Using Key Terms**

1. Use each of the following terms in a separate sentence: sound quality and noise.

**Interpreting Graphics**

6. Look at the oscilloscope screen below. Do you think the sound represented by the wave on the screen is noise or music? Explain your answer.

---

**Summary**

- Different instruments have different sound qualities.
- Sound quality results from the blending through interference of the fundamental and several overtones.
- The three families of instruments are string, wind, and percussion instruments.
- Noise is a sound consisting of a random mix of frequencies.

**Understanding Key Ideas**

2. What interaction of sound waves determines sound quality?
   - a. reflection 
   - b. diffraction 
   - c. pitch 
   - d. interference

3. Why do different instruments have different sound qualities?

**Critical Thinking**

4. Making Comparisons What do string instruments and wind instruments have in common in how they produce sound?

5. Identifying Bias Someone says that the music you are listening to is “just noise.” Does the person mean that the music is a random mix of frequencies? Explain your answer.

---

**Answer to Reading Check**

Music consists of sound waves that have regular patterns, and noise consists of a random mix of frequencies.

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**SCIlinks**

For a variety of links related to this chapter, go to [www.scilinks.org](http://www.scilinks.org)

Topic: Sound Quality

SciLinks code: HSM1427

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**CHAPTER RESOURCES**

**Chapter Resource File**

- Section Quiz
- Section Review
- Vocabulary and Section Summary
- Critical Thinking

**Technology**

- Interactive Explorations CD-ROM
  - Sound Bite!
Easy Listening

Teacher’s Notes

Time Required
One or two 45-minute class periods

Lab Ratings

Teacher Prep □
Student Set-Up □
Concept Level □
Clean Up □

MATERIALS

For Each Group of 3 to 4 Students
• eraser, hard rubber (or tuning fork mallet)
• meterstick
• paper, graph
• tuning forks, different frequencies (4)

Form a Hypothesis

2. Sample answer: Most of the students in the class will hear mid-frequency sounds better. (Accept any testable hypothesis.)

Lab Notes

You may wish to use the classroom graph to have students practice interpreting a graph. For instance, you could ask students to try and pinpoint the distances at which other frequencies might be heard based on the graph.

Easy Listening

Pitch describes how low or high a sound is. A sound’s pitch is related to its frequency—the number of waves per second. Frequency is measured in hertz (Hz), where 1 Hz equals 1 wave per second. Most humans can hear frequencies in the range from 20 Hz to 20,000 Hz. But not everyone detects all pitches equally well at all distances. In this activity, you will collect data to see how well you and your classmates hear different frequencies at different distances.

Ask a Question

1. Do most of the students in your classroom hear low, mid-, or high-frequency sounds best?

Form a Hypothesis

2. Write a hypothesis that answers the question above. Explain your reasoning.

Test the Hypothesis

3. Choose one member of your group to be the sound maker. The others will be the listeners.

4. Copy the data table below onto another sheet of paper. Be sure to include a column for every listener in your group.

<table>
<thead>
<tr>
<th>Data Collection Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
</tr>
<tr>
<td>1 (____ Hz)</td>
</tr>
<tr>
<td>2 (____ Hz)</td>
</tr>
<tr>
<td>3 (____ Hz)</td>
</tr>
<tr>
<td>4 (____ Hz)</td>
</tr>
</tbody>
</table>

5. The sound maker will choose one of the tuning forks, and record the frequency of the tuning fork in the data table.

6. The listeners should stand 1 m from the sound maker with their backs turned.

CHAPTER RESOURCES

Chapter Resource File

• Datasheet for Chapter Lab
• Lab Notes and Answers

Technology

Classroom Videos

• Lab Video

• The Speed of Sound
• Tuneful Tube
• The Energy of Sound
The sound maker will create a sound by striking the tip of the tuning fork gently with the eraser.

Listeners who hear the sound should take one step away from the sound maker. The listeners who do not hear the sound should stay where they are.

Repeat steps 7 and 8 until none of the listeners can hear the sound or the listeners reach the edge of the room.

Using the meterstick, the sound maker should measure the distance from his or her position to each of the listeners. All group members should record this data.

Repeat steps 5 through 10 with a tuning fork of a different frequency.

Continue until all four tuning forks have been tested.

### Analyze the Results

1. **Organizing Data** Calculate the average distance for each frequency. Share your group’s data with the rest of the class to make a data table for the whole class.

2. **Analyzing Data** Calculate the average distance for each frequency for the class.

3. **Constructing Graphs** Make a graph of the class results, plotting average distance (y-axis) versus frequency (x-axis).

### Draw Conclusions

4. **Drawing Conclusions** Was everyone in the class able to hear all of frequencies equally? (Hint: Was the average distance for each frequency the same?)

5. **Evaluating Data** If the answer to question 4 is no, which frequency had the longest average distance? Which frequency had the shortest final distance?

6. **Analyzing Graphs** Based on your graph, do your results support your hypothesis? Explain your answer.

7. **Evaluating Methods** Do you think your class sample is large enough to confirm your hypothesis for all people of all ages? Explain your answer.

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**Holt Lab Generator CD-ROM**

Search for any lab by topic, standard, difficulty level, or time. Edit any lab to fit your needs, or create your own labs. Use the Lab Materials QuickList software to customize your lab materials list.

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**CLASSROOM TESTED & APPROVED**

**Terry Rakes**

Elmwood Junior High

Rogers, Arkansas

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**Chapter 21 • Chapter Lab 623**
ANSWERS

Using Key Terms
1. loudness
2. echoes
3. sound quality

Understanding Key Ideas

Multiple Choice
4. If a fire engine is traveling toward you, the Doppler effect will cause the siren to sound
   a. higher.
   b. lower.
   c. louder.
   d. softer.
5. Sound travels fastest through
   a. a vacuum.
   b. sea water.
   c. air.
   d. glass.

Short Answer
10. Describe how the Doppler effect helps a beluga whale determine whether a fish is moving away from it or toward it.
11. How do vibrations cause sound waves?
12. Briefly describe what happens in the different parts of the ear.

Math Skills
13. A submarine that is not moving sends out a sonar sound wave traveling 1,500 m/s, which reflects off a boat back to the submarine. The sonar crew detects the reflected wave 6 s after it was sent out. How far away is the boat from the submarine?

You will hear a sonic boom when
a. an object breaks the sound barrier.
b. an object travels at supersonic speeds.
c. a shock wave reaches your ears.
d. the speed of sound is 290 m/s.

Resonance can happen when an object vibrates at another object's
a. resonant frequency.
b. fundamental frequency.
c. second overtone frequency.
d. All of the above

A technological device that can be used to see sound waves is a(n)
a. sonar.
b. oscilloscope.
c. ultrasound.
d. amplifier.

Using Key Terms

Complete each of the following sentences by choosing the correct term from the word bank.

loudness echoes pitch noise sound quality

1. The _____ of a sound wave depends on its amplitude.
2. Reflected sound waves are called _____.
3. Two different instruments playing the same note sound different because of _____.
4. If a fire engine is traveling toward you, the Doppler effect will cause the siren to sound
   a. higher.
   b. lower.
   c. louder.
   d. softer.
5. Sound travels fastest through
   a. a vacuum.
   b. sea water.
   c. air.
   d. glass.
6. If two sound waves interfere constructively, you will hear
   a. a high-pitched sound.
   b. a softer sound.
   c. a louder sound.
   d. no change in sound.
7. You will hear a sonic boom when
   a. an object breaks the sound barrier.
   b. an object travels at supersonic speeds.
   c. a shock wave reaches your ears.
   d. the speed of sound is 290 m/s.
8. Resonance can happen when an object vibrates at another object’s
   a. resonant frequency.
   b. fundamental frequency.
   c. second overtone frequency.
   d. All of the above
9. A technological device that can be used to see sound waves is a(n)
   a. sonar.
   b. oscilloscope.
   c. ultrasound.
   d. amplifier.
10. If a fish is moving away from the whale, the echo off the fish that the whale hears will have a lower pitch than the original sound. If the fish is moving toward the whale, the echo off the fish heard by the whale will have a higher pitch than the original sound.
11. The back-and-forth motions of vibrations of an object cause compressions and rarefactions in the air around it, which is carried outward as sound waves.

12. In the outer ear, sound waves are funneled into the ear canal. In the middle ear, the hammer, anvil, and stirrup increase the size of the vibrations. In the inner ear, these vibrations are changed into electrical signals for the brain to interpret.

13. \(1,500 \text{ m/s} \times 6 \text{ s} = 9,000 \text{ m} \)
   \[9,000 \text{ m} \div 2 = 4,500 \text{ m}\]
14 Concept Mapping Use the following terms to create a concept map:
sound waves, pitch, loudness, decibels, frequency, amplitude, oscilloscope, hertz, and interference.

15 Analyzing Processes An anechoic chamber is a room where there is almost no reflection of sound waves. Anechoic chambers are often used to test sound equipment, such as stereos. The walls of such chambers are usually covered with foam triangles. Explain why this design eliminates echoes in the room.

16 Applying Concepts Would the pilot of an airplane breaking the sound barrier hear a sonic boom? Explain why or why not.

17 Forming Hypotheses After working in a factory for a month, a man you know complains about a ringing in his ears. What might be wrong with him? What do you think may have caused his problem? What can you suggest to him to prevent further hearing loss?

14 Use the oscilloscope screens below to answer the questions that follow:

1 Which sound is noise?

2 Which represents the softest sound?

3 Which represents the sound with the lowest pitch?

4 Which two sounds were produced by the same instrument?

Critical Thinking
14. An answer to this exercise can be found at the end of this book.

15. This design eliminates echoes because the surfaces of the walls absorb most sound waves instead of reflecting them.

16. No; a sonic boom is only audible to an observer behind the plane along the shock wave. Once the airplane breaks the sound barrier, the plane outruns the sonic boom, so the pilot does not hear it.

17. The worker may be suffering from tinnitus, caused by long exposure to loud sounds. Further hearing loss could be prevented by wearing hearing protection while on the job.

Interpreting Graphics
18. d
19. a
20. c
21. b, c

CHAPTER RESOURCES

Chapter Resource File
- Chapter Review
- Chapter Test A
- Chapter Test B
- Chapter Test C
- Vocabulary Activity

Workbooks
- Study Guide
  - Study Guide is also available in Spanish.
Teacher’s Note
To provide practice under more realistic testing conditions, give students 20 minutes to answer all of the questions in this Standardized Test Preparation.

MISCONCEPTION ALERT
Answers to the standardized test preparation can help you identify student misconceptions and misunderstandings.

READING
Read each of the passages below. Then, answer the questions that follow each passage.

Passage 1
Centuries ago, Marco Polo wrote about the booming sand dunes of the Asian desert. He wrote that the booming sands filled the air with the sounds of music, drums, and weapons of war. Booming sands are most often found in the middle of large deserts. They have been discovered all over the world, including the United States. Booming sands make loud, low-pitched sounds when the top layers of sand slip over the layers below, producing vibrations. The sounds have been compared to foghorns, cannon fire, and moaning. The sounds can last from a few seconds to 15 min and can be heard more than 10 km away!

1. Which is a fact in this passage?
   A. Marco Polo loved traveling.
   B. Booming sands always sound like moaning people.
   C. Booming sands are the most interesting thing in Asia.
   D. Some booming sands are found in the United States.

2. Which of the following phrases best describes booming sands?
   F. found in Asia
   G. noisy
   H. slippery
   I. discovered by Marco Polo

3. What causes booming sands?
   A. vibrations caused by top layers of sand slipping over layers below
   B. battles in the desert
   C. animals that live beneath sand dunes
   D. there is not enough information to determine the answer.

Passage 2
People who work in the field of architectural acoustics are concerned with controlling sound that travels in a closed space. Their goal is to make rooms and buildings quiet yet suitable for people to enjoy talking and listening to music. One major factor that affects the acoustical quality of a room is the way the room reflects sound waves. Sound waves bounce off surfaces such as doors, ceilings, and walls. Using materials that absorb sound reduces the reflection of sound waves. Materials that have small pockets of air that can trap the sound vibrations and keep them from reflecting are the most sound absorbent. Sound-absorbing floor and ceiling tiles, curtains, and upholstered furniture all help to control the reflection of sound waves.

1. The field of architectural acoustics is concerned with which of the following?
   A. making buildings earthquake safe
   B. controlling sound in closed spaces
   C. designing sound-absorbing materials
   D. making buildings as quiet as possible

2. Which of the following is a major factor in the acoustical quality of a room?
   F. the size of the room
   G. the furnishings in the room
   H. the walls of the room
   I. the noise level in the room

3. Which of the following materials is most likely to absorb sounds the best?
   A. materials that have small pockets of air
   B. surfaces such as doors, ceilings, and walls
   C. materials that keep the room as quiet as possible
   D. furniture that is made of wood

Question 2: The key to this question is zeroing in on the one most defining aspect of booming sands among the descriptors shown. Although they are found in Asia, this is not a defining aspect of booming sands: they are found elsewhere. Booming sands can be caused by slippery sand over sand dunes, but “slippery” is not the best way to describe them. Booming sands were described by Marco Polo, but this is, again, not a defining aspect of booming sands. The best answer choice is G, “noisy,” because this is the one quality referred to most throughout the passage.

Question 3: Students may be tempted to select answer C, but it is not an actual description of the types of materials that are likely to absorb sound. Furniture is mentioned in the passage as a minor factor in room acoustics, but the passage names materials that have small pockets of air as the best sound-absorbing material. Answer A is therefore correct.
INTERPRETING GRAPHICS

Use the pictures of standing waves below to answer the questions that follow.

(a) | (c)
(b) | (d)

1. Which of the standing waves has the lowest frequency?
   A a
   B b
   C c
   D d

2. Which of the standing waves has the highest frequency?
   F a
   G b
   H c
   I d

3. Which of the standing waves represents the first overtone?
   A a
   B b
   C c
   D d

4. In which of the following pairs of standing waves is the frequency of the second wave twice the frequency of the first?
   F a, b
   G a, c
   H b, c
   I c, d

MATH

Read each question below, and choose the best answer.

1. The speed of sound in copper is 3,560 m/s. Which is another way to express this measure?
   A $3.56 \times 10^3$ m/s
   B $0.356 \times 10^4$ m/s
   C $3.56 \times 10^4$ m/s
   D $3.56 \times 10^5$ m/s

2. The speed of sound in sea water is 1,522 m/s. How far can a sound wave travel underwater in 10 s?
   F 152.2 m
   G 1,522 m
   H 15,220 m
   I 152,220 m

3. Claire likes to go swimming after work. She warms up for 120 s before she begins swimming, and it takes her an average of 55 s to swim one lap. Which equation could be used to find $w$, the number of seconds it takes for Claire to warm up and swim 15 laps?
   A $w = (15 \times 120) + 55$
   B $w = (15 \times 55) + 120$
   C $w = 120 + 55 + 15$
   D $w = (15 \times 55) \times 120$

4. The Vasquez family went bowling. They rented 6 pairs of shoes for $3 a pair and bowled for 2 h at a rate of $8.80/h. Which is the best estimate of the total cost of the shoes and bowling?
   F $24
   G $30
   H $36
   I $45

INTERPRETING GRAPHICS

Question 3: The first overtone should not be confused with the first harmonic, which is the same as the fundamental. The first overtone is the standing wave with twice the frequency (and half the wavelength) of the fundamental.

MATH

Question 3: If students recognize that the order of operations for addition is not important, they will recognize B as the correct answer. If they do not, they may think that the fact that the 120 s of warmup is mentioned first in the passage means they should look for the 120 s to come first in the equation, and they may be tempted to choose C.
Science, Technology, and Society

Background
Computed axial tomography (CAT scanning), which has been used for many years in medicine, is now being used by paleontologists to study the internal structure of fossils. CAT scanning can provide interior views of a fossil without touching the fossil’s surface. If a paleontologist needs to reconstruct an entire skull, a series of two-dimensional “slice” shots are taken and combined through computer imaging to produce a three-dimensional image of the skull—inside and out!

Science Fiction

Background
As a Caldecott Award winner, National Book nominee, and Nebula finalist, Jane Yolen knows how to write successful stories. Her work spans a wide range of topics—from imaginative alphabet books for the youngest reader to serious novels for the young-adult and adult audience. The inspiration for much of Yolen’s work comes from folktales and stories with rich histories.

Science Fiction

“Ear” by Jane Yolen

Jily and her friends, Sanya and Feeny, live in a time not too far in the future. It is a time when everyone’s hearing is damaged. People communicate using sign language—unless they put on their Ear. Then, the whole world is filled with sounds.

Jily and her friends visit a club called The Low Down. It is too quiet for Jily’s tastes, and she wants to leave. But Sanya is dancing by herself, even though there is no music. When Jily finds Feeny, they notice some Earless kids their own age. Earless people never go to clubs, and Jily finds their presence offensive. But Feeny is intrigued.

Everyone is given an Ear at the age of 12 but has to give it up at the age of 30. Why would these kids want to go out without their Ears before the age of 30? Jily thinks the idea is ridiculous and doesn’t stick around to find out the answer to such a question. But it is an answer that will change her life by the end of the next day.

Math Activity

Imagine that a standing wave with a frequency of 80 Hz is made inside the crest of a Parasaurolophus. What would be the frequency of the first overtone of this standing wave? the second? the third?

Answer to Math Activity

The first overtone would be twice the frequency of the fundamental, so the frequency would be \(80 \text{ Hz} \times 2 = 160 \text{ Hz}\). The second overtone would be \(80 \text{ Hz} \times 3 = 240 \text{ Hz}\). The third overtone would be \(80 \text{ Hz} \times 4 = 320 \text{ Hz}\).

Language Arts Activity

Read “Ear,” by Jane Yolen, in the Holt Anthology of Science Fiction. Write a one-page report that discusses how the story made you think about the importance of hearing in your everyday life.

Answer to Language Arts Activity

Answers may vary.
Careers

Adam Dudley

Sound Engineer  Adam Dudley uses the science of sound waves every day at his job. He is the audio supervisor for the Performing Arts Center of the University of Texas at Austin. Dudley oversees sound design and technical support for campus performance spaces, including an auditorium that seats over 3,000 people.

To stage a successful concert, Dudley takes many factors into account. The size and shape of the room help determine how many speakers to use and where to place them. It is a challenge to make sure people seated in the back row can hear well enough and also to make sure that the people up front aren’t going deaf from the high volume.

Adam Dudley loves his job—he enjoys working with people and technology and prefers not to wear a coat and tie. Although he is invisible to the audience, his work backstage is as crucial as the musicians and actors on stage to the success of the events.

Social Studies Activity

Research the ways in which concert halls were designed before the use of electric amplification. Make a model or diorama, and present it to the class, explaining the acoustical factors involved in the design.

Answer to Social Studies Activity

Answers may vary.

Careers

Background

The physics of sound is very important in the field of sound engineering. For instance, speakers placed in different locations in a concert hall must be placed in such a way that destructive interference does not create dead spots. Also, sometimes extra speakers are placed in the balcony to reinforce the sound coming from the speakers near the stage. But because of the difference in speed between the signal coming through the wire and the sound traveling through air, people in the balcony may hear a delay between the sound coming from the balcony speakers and that coming from speakers near the stage. This problem requires a correction in the signal to the balcony speakers, delaying it by a fraction of a second to compensate.