chapter 11

Sound

BIG Idea
Sound waves are compressional waves produced by something that vibrates.

11.1 The Nature of Sound

MAIN Idea Sound waves are compressional waves that can only travel through matter.

11.2 Properties of Sound

MAIN Idea The loudness of a sound depends on its intensity and its pitch depends on its frequency.

11.3 Music

MAIN Idea A musical instrument produces combinations of frequencies that determine how the instrument sounds.

11.4 Using Sound

MAIN Idea Sound waves are used to locate objects, form images, and to treat medical problems.

Cracking the Sound Barrier

Have you ever heard the crack of a sonic boom? A sonic boom occurs when a plane exceeds the speed of sound. Sound waves create a cone-shaped shock wave coming from the aircraft. Behind the cone are low-pressure regions that can cause water vapor to condense, forming the cloud you see here.

Science Journal

Write three things you would like to learn about sound.

Start-Up Activities

Launch LAB

What sound does a ruler make?

Think of the musical instruments you've seen and heard. Some have strings, some have hollow tubes, and others have keys or pedals. Musical instruments come in many shapes and sizes and are played with various techniques. These differences give each instrument a unique sound. What would an instrument made from a ruler sound like?

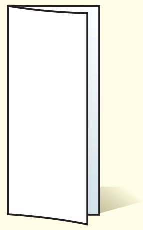
1. Hold one end of a thin ruler firmly down on a desk, allowing the free end to extend beyond the edge of the desk.
2. Gently pull up on and release the end of the ruler. What do you see and hear?
3. Vary the length of the overhanging portion and repeat the experiment several times.
4. **Think Critically** In your Science Journal, write instructions for playing a song with the ruler. Explain how the length of the overhanging part of the ruler affects the sound.

Science Online — Preview this chapter's content and activities at gpscience.com

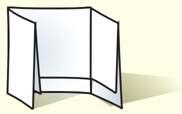
FOLDABLES™ Study Organizer

Sound Make the following Foldable to help identify what you already know, what you want to know, and what you learned about sound.

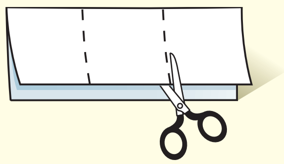
STEP 1 **Fold** a vertical sheet of paper from side to side. Make the front edge about 1.25 cm shorter than the back edge.



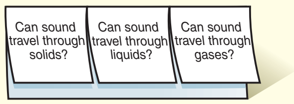
STEP 2 **Turn** lengthwise and **fold** into thirds.



STEP 3 **Unfold and cut** only the top layer along both folds to make three tabs.



STEP 4 **Label** each tab as shown.



Identify Questions As you read the chapter, write what you learn about sound traveling through solids under the left tab of your Foldable, what you learn about sound traveling through liquids under the center tab, and what you learn about sound traveling through gases under the right tab.

AFP/CORBIS

Section 1

The Nature of Sound

Reading Guide

What You'll Learn

- **Explain** how sound travels through different mediums.
- **Identify** what influences the speed of sound.
- **Describe** how the ear enables you to hear.

Why It's Important

The nature of sound affects how you hear and interpret sounds.

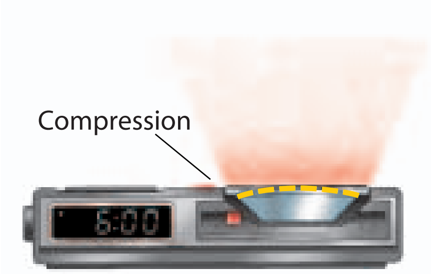
Review Vocabulary

vibration: rhythmic back-and-forth motion

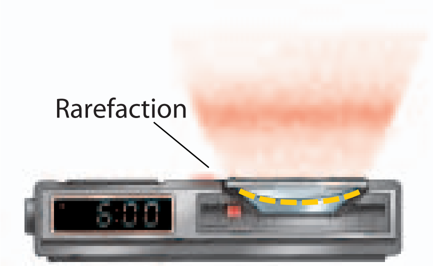
New Vocabulary

- eardrum
- cochlea

Figure 1 The vibration of a speaker produces compressional waves.



When the speaker vibrates outward, molecules in the air next to it are pushed together to form a compression.



When the speaker vibrates inward, the molecules spread apart to form a rarefaction.

What causes sound?

An amusement park can be a noisy place. With all the racket of carousel music and booming loudspeakers, it can be hard to hear what your friends say. These sounds are all different, but they do have something in common—each sound is produced by an object that vibrates. For example, your friends' voices are produced by the vibrations of their vocal cords, and music from a carousel and voices from a loudspeaker are produced by vibrating speakers. All sounds are created by something that vibrates.

Sound Waves

When an object like a radio speaker vibrates, it collides with nearby molecules in the air, transferring some of its energy to them. These molecules then collide with other molecules in the air and pass the energy on to them. The energy originally transferred by the vibrating object continues to pass from one molecule to another. This process of collisions and energy transfer forms a sound wave.

Sound waves are compressional waves. Remember that a compressional wave is made up of two types of regions called compressions and rarefactions. If you look at **Figure 1,** you'll see that when a radio speaker vibrates outward, the nearby molecules in the air are pushed together to form compressions. As the figure shows, when the speaker moves inward, the nearby molecules in the air have room to spread out, and a rarefaction forms. As long as the speaker continues to vibrate back and forth, compressions and rarefactions are formed.

Traveling as a Wave Compressions and rarefactions move away from the speaker as molecules in the air collide with their neighbors. As the speaker continues to vibrate, more molecules in the air are alternately pushed together and spread apart. A series of compressions and rarefactions forms that travels from the speaker to your ear. This sound wave is what you hear.

The Speed Of Sound

Most sounds you hear travel through air to reach your ears. However, if you've ever been swimming underwater and heard garbled voices, you know that sound also travels through water. In fact, sound waves can travel through any type of matter—solid, liquid, or gas. The matter that a wave travels through is called a medium. Sound waves create compressions and rarefactions in any medium they travel through.

What would happen if no matter existed to form a medium? Could sound be transmitted without particles of matter to compress, expand, and collide? On the Moon, which has no atmosphere, the energy in sound waves cannot be transmitted from particle to particle because no particles exist. Sound waves cannot travel through empty space. Astronauts must talk to each other using electronic communication equipment.

The Speed of Sound in Different Materials The speed of a sound wave through a medium depends on the substance the medium is made of and whether it is solid, liquid, or gas. For example, **Table 1** shows that at room temperature, sound travels at 347 m/s through air, at 1,498 m/s through water, and at 4,877 m/s through aluminum. In general, sound travels the slowest through gases, faster through liquids, and even faster through solids.

Reading Check *What are two things that affect the speed of sound?*

Sound travels faster in liquids and solids than in gases because the individual molecules in a liquid or solid are closer together than the molecules in a gas. When molecules are close together, they can transmit energy from one to another more rapidly. However, the speed of sound doesn't depend on the loudness of the sound. Loud sounds travel through a medium at the same speed as soft sounds.

Table 1 Speed of Sound in Different Mediums

Medium	Speed of Sound (in m/s)
Air	347
Cork	500
Water	1,498
Brick	3,650
Aluminum	4,877

Mini LAB

Listening to Sound Through Different Materials

Procedure

1. Tie the middle of a length of **string** onto a **metal object,** such as a wire hanger or a spoon, so that the string has two long ends.
2. Wrap each string end around a finger on each hand.
3. Gently placing your fingers in your ears, swing the object until it bumps against the edge of a **chair** or **table.** Listen to the sound.
4. Take your fingers out of your ears and listen to the sound made by the collisions.

Analysis

1. Compare and contrast the sounds you hear when your fingers are and are not in your ears.
2. Do sounds travel better through air or the string?

Figure 2 A line of people passing a bucket is a model for molecules transferring the energy of a sound wave.

When the people are far away from each other, like the molecules in a gas, it takes longer to transfer the bucket of water from person to person.

The bucket travels quickly down the line when the people stand close together.

Explain *why sound would travel more slowly in cork than in steel.*

A Model for Transmitting Sound You can understand why solids and liquids transmit sound well by picturing a large group of people standing in a line. Imagine that they are passing a bucket of water from person to person. If everyone stands far apart, each person has to walk a long distance to transfer the bucket, as in the top photo of **Figure 2.** However, if everyone stands close together, as in the bottom photo of **Figure 2,** the bucket quickly moves down the line.

The people standing close to each other are like particles in solids and liquids. Those standing far apart are like gas particles. The closer the particles, the faster they can transfer energy from particle to particle.

Temperature and the Speed of Sound The speed of sound waves also depends on the temperature of a medium. As the temperature of a substance increases, its molecules move faster. This makes them more likely to collide with each other. Remember that sound waves depend on the collisions of particles to transfer energy through a medium. If the particles in a medium are colliding with each other more often, more energy can be transferred in a shorter amount of time. Then sound waves move faster. For example, when the temperature is 0°C, sound travels through the air at only 331 m/s, but at a temperature of 20°C, it speeds up to 343 m/s.

Human Hearing

INTEGRATE Life Science

Think of the last conversation you had. Vocal cords and mouths move in many different ways to produce various kinds of compressional waves, but you were somehow able to make sense of these different sound waves. Your ears and brain work together to turn the compressional waves caused by speech, music, and other sources into something that has meaning. Making sense of these waves involves four stages. First, the ear gathers the compressional waves. Next, the ear amplifies the waves. In the ear, the amplified waves are converted to nerve impulses that travel to the brain. Finally, the brain decodes and interprets the nerve impulses.

Gathering Sound Waves—The Outer Ear When you think of your ear, you probably picture just the fleshy, visible, outer part. But, as shown in **Figure 3,** the human ear has three sections called the outer ear, the middle ear, and the inner ear.

The visible part of your ear, the ear canal, and the eardrum make up the outer ear. The outer ear is where sound waves are gathered. The gathering process starts with the outer part of your ear, which is shaped to help capture and direct sound waves into the ear canal. The ear canal is a passageway that is 2-cm to 3-cm long and is a little narrower than your index finger. The sound waves travel along this passageway, which leads to the eardrum. The **eardrum** is a tough membrane about 0.1 mm thick. When incoming sound waves reach the eardrum, they transfer their energy to it and it vibrates.

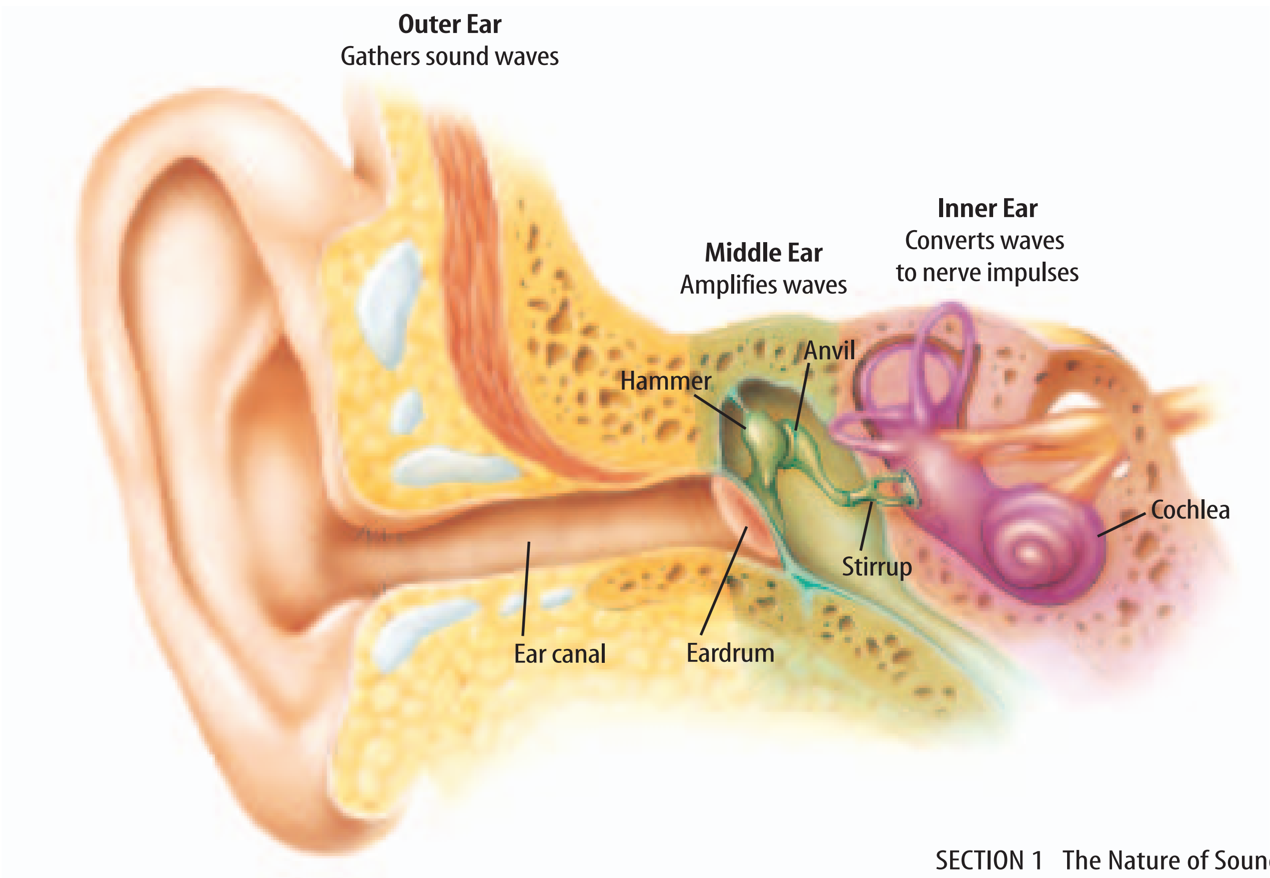
Reading Check *What makes the eardrum vibrate?*

Amplifying Sound Waves—The Middle Ear When the eardrum vibrates, it passes the sound vibrations into the middle ear, where three tiny bones start to vibrate. These bones are called the hammer, the anvil, and the stirrup. They make a lever system that multiplies the force and pressure exerted by the sound wave. The bones amplify the sound wave. The stirrup is connected to a membrane on a structure called the oval window, which vibrates as the stirrup vibrates.

INTEGRATE Career

Audiology Some types of hearing loss involve damage to the inner ear. The use of a hearing aid often can improve hearing. Audiologists diagnose and treat people with hearing loss. Research the field of audiology. Find out what education is required for people to gain certification as audiologists, and the settings in which they work.

Figure 3 The ear has three regions that perform specific functions in hearing.



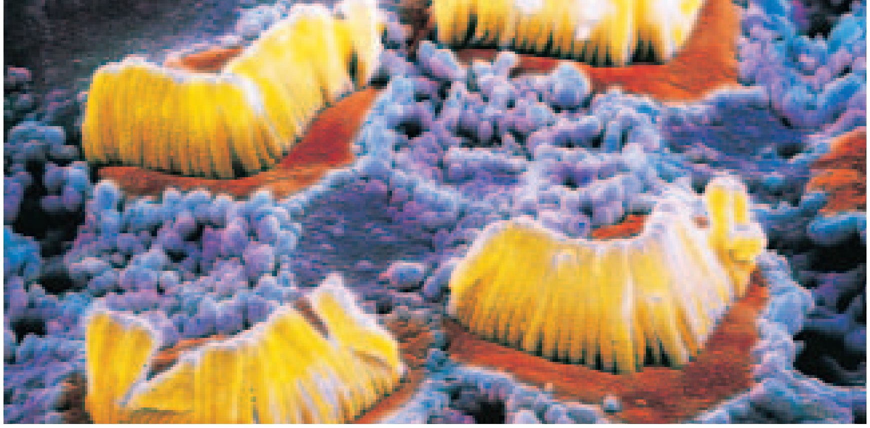


Figure 4 These hair cells in the human ear send nerve impulses to the brain when sound waves cause them to vibrate. In this photo the hair cells are magnified 3,900 times.

Converting Sound Waves—The Inner Ear When the membrane in the oval window vibrates, the sound vibrations are transmitted into the inner ear. The inner ear contains the **cochlea** (KOH klee uh), which is a spiral-shaped structure that is filled with liquid and contains tiny hair cells like those shown in **Figure 4.** When these tiny hair cells in the cochlea begin to vibrate, nerve impulses are sent through the auditory nerve to the brain. It is the cochlea that converts sound waves to nerve impulses.

When someone's hearing is damaged, it's usually because the tiny hair cells in the cochlea are damaged or destroyed, often by loud sounds. New research suggests that these hair cells may be able to repair themselves.

section 1 review

Summary

Sound Waves and Their Causes

- Sound results from compressional waves emanating from vibrating objects.
- The compressions and rarefactions of sound waves transfer energy.

Moving Through Materials

- Sound waves can travel through any matter.
- Sound travels fastest through solids, slower through liquids, and slowest through gases.
- Sound travels faster in warmer mediums.

Human Hearing

- The outer ear gathers sound waves and directs them to the eardrum.
- The middle ear contains three tiny bones that multiply the force and pressure of the vibrating eardrum.
- The inner ear's cochlea converts sound waves to nerve impulses.

Self Check

1. **Explain** how sound travels from your vocal cords to your friend's ears when you talk.
2. **Summarize** the physical reasons that sound waves travel at different speeds through liquids and gases.
3. **Explain** why sound speeds up when the temperature rises.
4. **Describe** in detail each section of the human ear and its role in hearing.
5. **Think Critically** Some people hear ringing in their ears, called tinnitus, even in the absence of sound. Form a hypothesis to explain why this occurs.

Applying Math

6. **Calculate Time** How long would it take a sound wave from a car alarm to travel 1 km if the temperature were 0°C?
7. **Calculate Time** How long would it take the same wave to travel 1 km if the temperature were 20°C?

Science Online gpscience.com/self_check_quiz

section 2

Properties of Sound

Reading Guide

What You'll Learn

- **Recognize** how amplitude, intensity, and loudness are related.
- **Describe** how sound intensity is measured and what levels can damage hearing.
- **Explain** the relationship between frequency and pitch.
- **Discuss** the Doppler effect.

Why It's Important

Each property of a sound wave affects how things sound to you—from your blaring CD player to someone's whisper.

Review Vocabulary

potential energy: energy that is stored in an object's position

New Vocabulary

- intensity
- loudness
- decibel
- pitch
- ultrasonic
- Doppler effect

Intensity and Loudness

If the phone rings while you're listening to a stereo, you might have to turn down the volume on the stereo to be able to hear the person on the phone. What happens to the sound waves from your radio when you adjust the volume? The notes sound the same as when the volume was higher, but something about the sound changes. The difference is that quieter sound waves do not carry as much energy as louder sound waves do.

Recall that the amount of energy a wave carries corresponds to its amplitude. For a compressional wave, amplitude is related to the density of the particles in the compressions and rarefactions. Look at **Figure 5.** For a sound wave that carries less energy and has a lower amplitude, particles in the medium are less compressed in the compressions and less spread out in the rarefactions. For a sound wave that has a higher amplitude, particles in the medium are closer together, or more compressed, in the compressions and more spread out in the rarefactions.

To produce a wave that carries more energy, more energy is transferred from the vibrating object to the medium. More energy is transferred to the medium when the particles of the medium are forced closer together in the compressions and spread farther apart in the rarefactions.

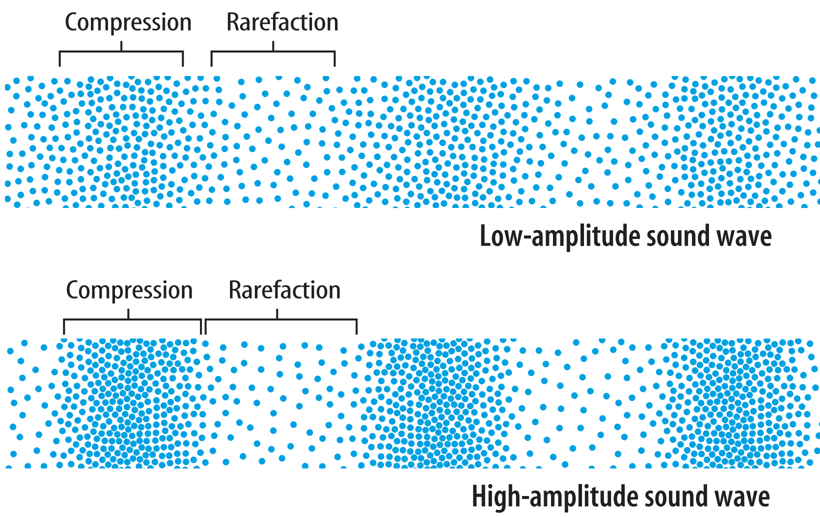


Figure 5 The amplitude of a sound wave depends on how tightly packed molecules are in the compressions and rarefactions.

Intensity Imagine sound waves moving through the air from your radio to your ear. If you held a square loop between you and the radio, as in **Figure 6,** and could measure how much energy passed through the loop in 1 s, you would measure intensity. **Intensity** is the amount of energy that flows through a certain area in a specific amount of time. When you turn down the volume of your radio, you reduce the energy carried by the sound waves, so you also reduce their intensity.

Intensity influences how far away a sound can be heard. If you and a friend whisper a conversation, the sound waves you create have low intensity and do not travel far. You have to sit close together to hear each other. However, when you shout to each other, you can be much farther apart. The sound waves made by your shouts have high intensity and can travel far.

Intensity Decreases With Distance Intensity influences how far a wave will travel because some of a wave's energy is converted to other forms of energy when it is passed from particle to particle. Think about what happens when you drop a basketball. The ball has potential energy as you hold it above the ground. This potential energy is converted into energy of motion as the ball falls. When the ball hits the ground and bounces up, a small amount of that energy has been transferred to the ground. The ball no longer has enough energy to bounce back to the original level. The ball transfers a small amount of energy with each bounce, until finally the ball has no more energy. If you held the ball higher above the ground, it would have more energy and would bounce for a longer time before it came to a stop. In a similar way, a sound wave of low intensity loses its energy more quickly, and travels a shorter distance than a sound wave of higher intensity.

Figure 6 The intensity of the sound waves from the CD player is related to the amount of energy that passes through the loop in a certain amount of time.
Describe *how the intensity would change if the loop were 10 m away from the radio.*

Michael Newman/PhotoEdit, Inc.

Loudness When you hear different sounds, you do not need special equipment to know which sounds have greater intensity. Your ears and brain can tell the difference. **Loudness** is the human perception of sound intensity. Sound waves with high intensity carry more energy. When sound waves of high intensity reach your ear, they cause your eardrum to move back and forth a greater distance than sound waves of low intensity do. The bones of the middle ear convert the increased movement of the eardrum into increased movement of the hair cells in the inner ear. As a result, you hear a loud sound. As the intensity of a sound wave increases, the loudness of the sound you hear increases.

Reading Check *How are intensity and loudness related?*

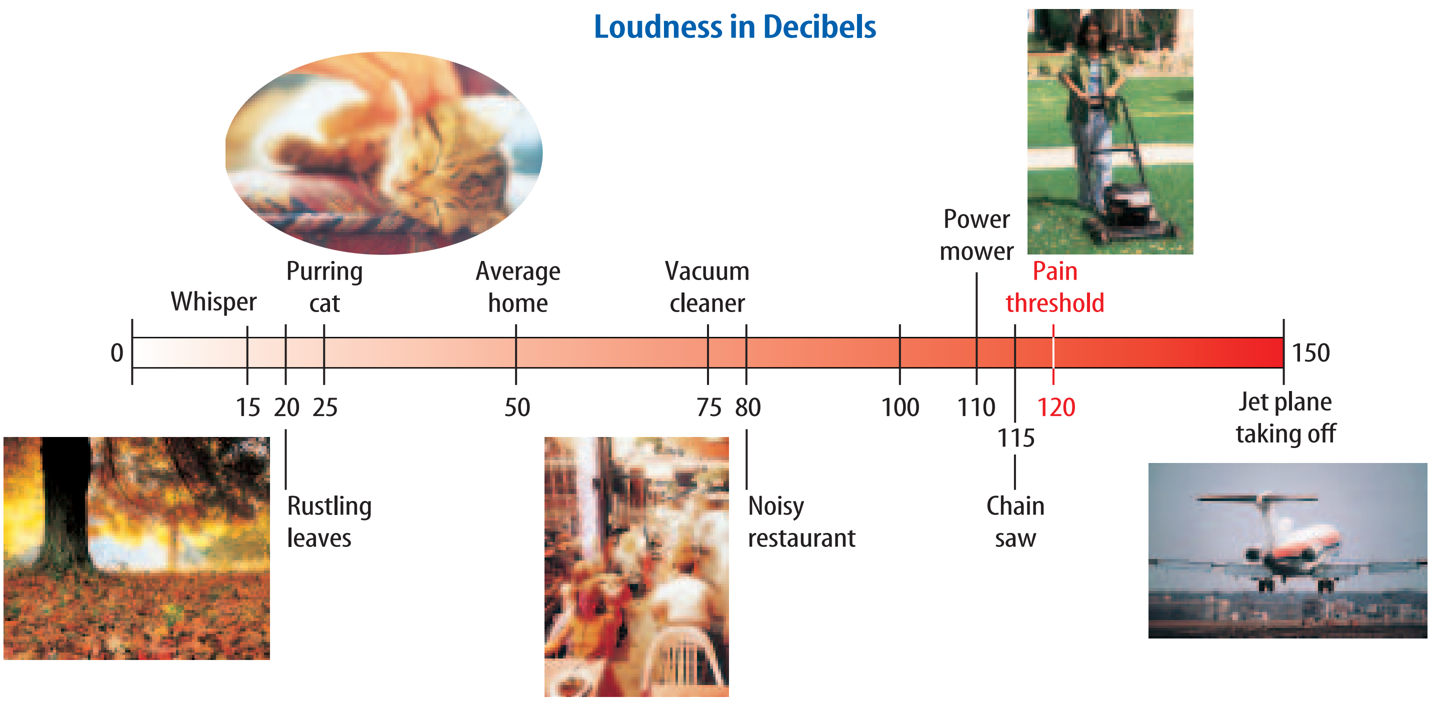
The Decibel Scale It's hard to say how loud too loud is. Two people are unlikely to agree on what is too loud, because people vary in their perception of loudness. A sound that seems fine to you may seem earsplitting to your teacher. Even so, the intensity of sound can be described using a measurement scale. Each unit on the scale for sound intensity is called a **decibel** (DE suh bel), abbreviated dB. On this scale, the faintest sound that most people can hear is 0 dB. Sounds with intensity levels above 120 dB may cause pain and permanent hearing loss. During some rock concerts, sounds reach this damaging intensity level. Wearing ear protection, such as earplugs, around loud sounds can help protect against hearing loss. **Figure 7** shows some sounds and their intensity levels in decibels.

Science Online

Topic: Sound Intensity
Visit gpscience.com for Web links to information about sound as well as a list of sounds and their intensities in decibels.

Activity Make a table that lists some sounds you heard today, in order from loudest to quietest. In another column, write the intensity level of each sound.

Figure 7 The decibel scale measures the intensity of sound.
Identify *where a normal speaking voice would fall on the scale.*



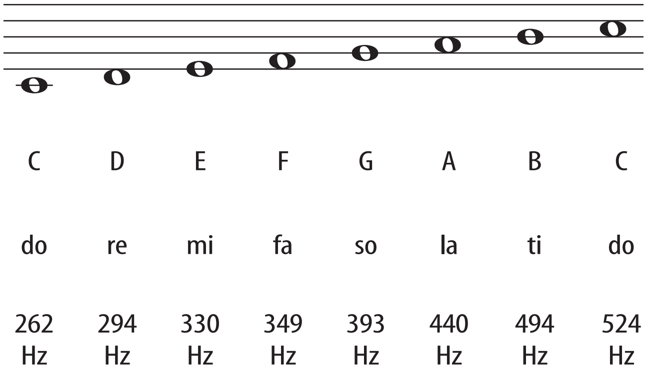


Figure 8 Every note has a different frequency, which gives it a distinct pitch.
Describe *how pitch changes when frequency increases.*

Pitch

If you have ever taken a music class, you are probably familiar with the musical scale do, re, mi, fa, so, la, ti, do. If you were to sing this scale, your voice would start low and become higher with each note. You would hear a change in **pitch,** which is how high or low a sound seems to be. The pitch of a sound is related to the frequency of the sound waves.

Frequency and Pitch Frequency is a measure of how many wavelengths pass a particular point each second. For a compressional wave, such as sound, the frequency is the number of compressions or the number of rarefactions that pass by each second. Frequency is measured in hertz (Hz)—1 Hz means that one wavelength passes by in 1 s.

When a sound wave with high frequency hits your ear, many compressions hit your eardrum each second. The wave causes your eardrum and all the other parts of your ear to vibrate more quickly than if a sound wave with a low frequency hit your ear. Your brain interprets these fast vibrations caused by high-frequency waves as a sound with a high pitch. As the frequency of a sound wave decreases, the pitch becomes lower. **Figure 8** shows different notes and their frequencies. For example, a whistle with a frequency of 1,000 Hz has a high pitch, but low-pitched thunder has a frequency of less than 50 Hz.

A healthy human ear can hear sound waves with frequencies from about 20 Hz to 20,000 Hz. The human ear is most sensitive to sounds in the range of 440 Hz to about 7,000 Hz. In this range, most people can hear much fainter sounds than at higher or lower frequencies.

Ultrasonic and Infrasonic Waves Most people can't hear sound frequencies above 20,000 Hz, which are called **ultrasonic** waves. Dogs can hear sounds with frequencies up to about 35,000 Hz, and bats can detect frequencies higher than 100,000 Hz. Even though humans can't hear ultrasonic waves, they use them for many things. Ultrasonic waves are used in medical diagnosis and treatment. They also are used to estimate the size, shape, and depth of underwater objects.

Infrasonic, or subsonic, waves have frequencies below 20 Hz—too low for most people to hear. These waves are produced by sources that vibrate slowly, such as wind, heavy machinery, and earthquakes. Although you can't hear infrasonic waves, you may feel them as a rumble inside your body.

Mini LAB

Simulating Hearing Loss

Procedure

1. Tune a **radio** to a news station. Turn the volume down to the lowest level you can hear and understand.
2. Turn the bass to maximum and the treble to minimum. If the radio does not have these controls, hold thick wads of **cloth** over your ears.
3. Observe which sounds are hardest and easiest to hear.

Analysis

1. Are high or low pitches harder to hear? Are vowel or consonant sounds harder to hear?
2. How could you help a person with hearing loss understand what you say?

Try at Home

The Doppler Effect

Imagine that you are standing at the side of a racetrack with race cars zooming past. As they move toward you, the different pitches of their engines become higher. As they move away from you, the pitches become lower. The change in pitch or wave frequency due to a moving wave source is called the **Doppler effect. Figure 9** shows how the Doppler effect occurs.

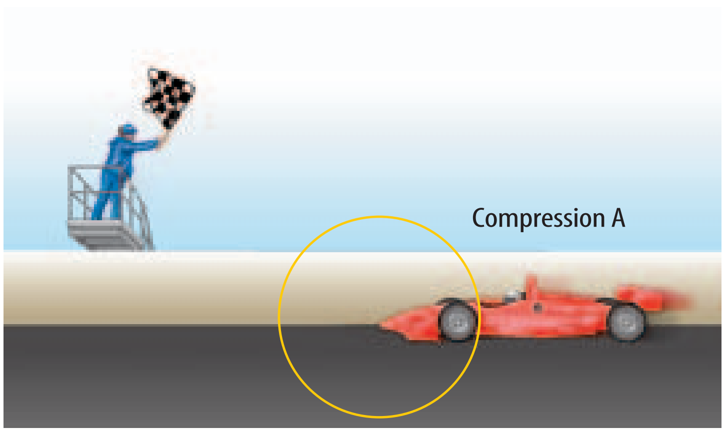
Reading Check *What is the Doppler effect?*

Moving Sound As a race car moves, it sends out sound waves in the form of compressions and rarefactions. In **Figure 9A,** the race car creates a compression, labeled A. Compression A moves through the air toward the flagger standing at the finish line. By the time compression B leaves the race car in **Figure 9B,** the car has moved forward. Because the car has moved since the time it created compression A, compressions A and B are closer together than they would be if the car had stayed still. Because the compressions are closer together, more compressions pass by the flagger each second than if the car were at rest. As a result, the flagger hears a higher pitch. You also can see from **Figure 9B** that the compressions behind the moving car are farther apart, resulting in a lower frequency and a lower pitch after the car passes and moves away from the flagger.

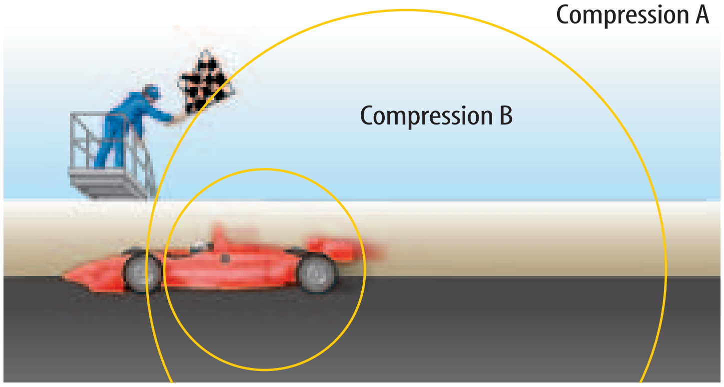
INTEGRATE Astronomy

Red Shift The Doppler effect can also be observed in light waves emanating from moving sources—although the sources must be moving at tremendous speeds. Astronomers have learned that the universe is expanding by observing the Doppler effect in light waves. Research the phenomenon known as red shift and explain in your Science Journal how it relates to the Doppler effect.

Figure 9 The Doppler effect occurs when the source of a sound wave is moving relative to a listener.



A The race car creates compression A.



B The car is closer to the flagger when it creates compression B. Compressions A and B are closer together in front of the car, so the flagger hears a higher-pitched sound.

Figure 10 Doppler radar can show the movement of winds in storms, and, in some cases, can detect the wind rotation that leads to the formation of tornadoes, like the one shown here. This can help provide early warning and reduce the injuries and loss of life caused by tornadoes.

A Moving Observer You also can observe the Doppler effect when you are moving past a sound source that is standing still. Suppose you were riding in a school bus and passed a building with a ringing bell. The pitch would sound higher as you approached the building and lower as you rode away from it. The Doppler effect happens any time the source of a sound is changing position compared with the observer. It occurs no matter whether it is the sound source or the observer that is moving. The faster the change in position, the greater the change in frequency and pitch.

Using the Doppler Effect The Doppler effect also occurs for other waves besides sound waves. For example, the frequency of electromagnetic waves, such as radar waves, changes if an observer and wave source are moving relative to each other. Radar guns use the Doppler effect to measure the speed of cars. The radar gun sends radar waves toward a moving car. The waves are reflected from the car and their frequency is shifted, depending on the speed and direction of the car. From the Doppler shift of the reflected waves, the radar gun determines the car's speed. Weather radar also uses the Doppler shift to show the movement of winds in storms, such as the tornado in **Figure 10.**

section 2 review

Summary

Intensity and Loudness

- Tight, dense compressions in a sound wave mean high intensity, loudness, and more energy.
- Sound intensity is measured in decibels.

Pitch

- High frequency sound waves have closer compressions and rarefactions and higher pitch than those of low frequency.
- Ultrasonic waves are too high for people to hear, but are useful for medical purposes.

The Doppler Effect

- The Doppler effect occurs when a moving object emits sounds that change pitch as the object moves past you.
- Police radar uses the Doppler effect to detect speeding cars.

Self Check

1. **Determine** which will change if you turn up a radio's volume: wave velocity, intensity, pitch, amplitude, frequency, wavelength, or loudness.
2. **Describe** the range of human hearing in decibels, and the level at which sound can damage human ears.
3. **Contrast** frequency and pitch.
4. **Draw and label** a diagram that explains the Doppler effect.
5. **Think Critically** Why would a passing race car display more Doppler effect than a passing police siren?

Applying Math

6. **Make a Table** Using the musical scale in **Figure 8,** make a table that shows how many wavelengths will pass you in 1 min for each musical note. What is the relationship between frequency and the number of wavelengths that pass you in 1 min?

Science Online gpscience.com/self_check_quiz

section 3

Music

Reading Guide

What You'll Learn

- **Distinguish** between noise and music.
- **Describe** why different instruments have different sound qualities.
- **Explain** how string, wind, and percussion instruments produce music.
- **Describe** the formation of beats.

Why It's Important

Music makes life more enjoyable, but noise pollution is unpleasant.

Review Vocabulary

frequency: the number of vibrations occurring in 1 s

New Vocabulary

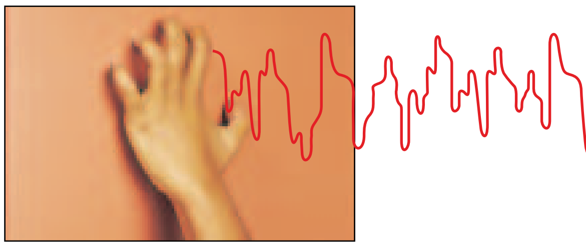
- music
- sound quality
- overtone
- resonator

What is music?

To someone else, your favorite music might sound like a jumble of noise. Music and noise are caused by vibrations—with some important differences, as shown in **Figure 11.** Noise has random patterns and pitches. **Music** is made of sounds that are deliberately used in a regular pattern.

Figure 11 These wave patterns represent the sound waves created by the piano and the scraping fingernails.
Determine *which of these has a regularly repeating pattern.*

Piano



Scraping fingernails

Natural Frequencies Every material or object has a particular set of frequencies at which it vibrates. This set of frequencies are its natural frequencies. When you pluck a guitar string the pitch you hear depends on the string's natural frequencies. Each string on a guitar has a different set of natural frequencies. The natural frequencies of a guitar string depend on the string's thickness, its length, the material it is made from, and how tightly it is stretched. Musical instruments contain strings, membranes, or columns of air that vibrate at their natural frequencies to produce notes with different pitches.

Resonance The sound produced by musical instruments is amplified by resonance. Recall that resonance occurs when a material or an object is made to vibrate at its natural frequencies by absorbing energy from something that is also vibrating at those frequencies. The vibrations of the mouthpiece or the reed in a wind instrument cause the air inside the instrument to absorb energy and vibrate at its natural frequencies. The vibrating air makes the sound of the instrument louder.

Sound Quality

Suppose your classmate played a note on a flute and then a note of the same pitch and loudness on a piano. Even if you closed your eyes, you could tell the difference between the two instruments. Their sounds wouldn't be the same. Each of these instruments has a unique sound quality. **Sound quality** describes the differences among sounds of the same pitch and loudness. Objects can be made to vibrate at other frequencies besides their natural frequency. This produces sound waves with more than one frequency. The specific combination of frequencies produced by a musical instrument is what gives it a distinctive quality of sound.

Reading Check *What does sound quality describe and how is it created?*

Overtones Even though an instrument vibrates at many different frequencies at once, you still hear just one note. All of the frequencies are not at the same intensity. The main tone that is played and heard is called the fundamental frequency. On a guitar, for example, the fundamental frequency is produced by the entire string vibrating back and forth, as in **Figure 12.** In addition to vibrating at the fundamental frequency, the string also vibrates to produce overtones. An **overtone** is a vibration whose frequency is a multiple of the fundamental frequency. The first two guitar-string overtones also are shown in **Figure 12.** These overtones create the rich sounds of a guitar. The number and intensity of overtones vary with each instrument. These overtones produce an instrument's distinct sound quality.

Musical Instruments

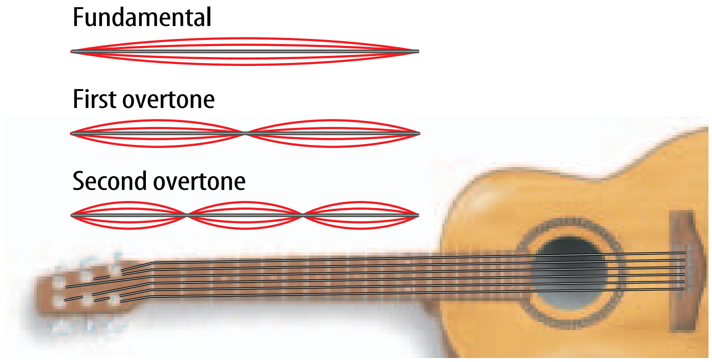
A musical instrument is any device used to produce a musical sound. Violins, cello, oboes, bassoons, horns, and kettledrums are musical instruments that you might have seen and heard in your school orchestra. These familiar examples are just a small sample of the diverse assortment of instruments people play throughout the world. For example, Australian Aborigines accompany their songs with a woodwind instrument called the didgeridoo (DIH juh ree dew). Caribbean musicians use rubber-tipped mallets to play steel drums, and a flutelike instrument called the nay is played throughout the Arab world.

Science Online

Topic: Noise Pollution
Visit gpscience.com for Web links to information about noise pollution.

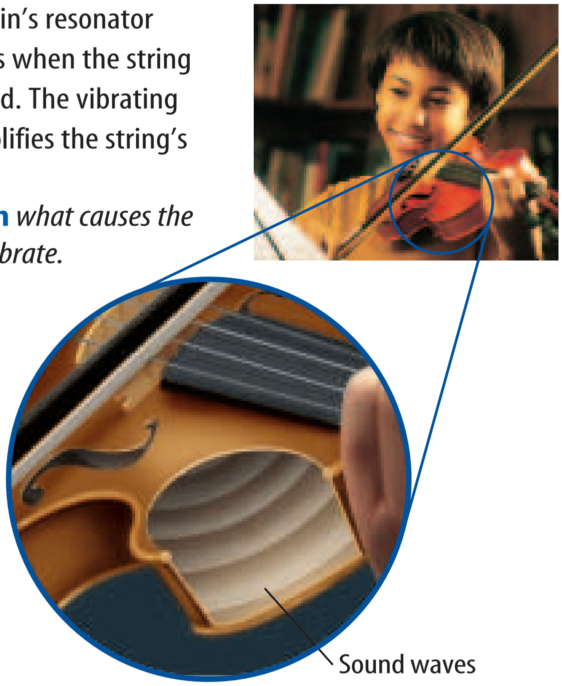
Activity Identify sources of noise pollution that you can help eliminate. Write your findings in your Science Journal.

Figure 12 A guitar string can vibrate at more than one frequency at the same time. Here the guitar string vibrations produce the fundamental frequency, and first and second overtones are shown.
Infer *how the string would vibrate to produce the third overtone.*



Strings Soft violins, screaming electric guitars, and elegant harps are types of string instruments. In string instruments, sound is produced by plucking, striking, or drawing a bow across tightly stretched strings. Because the sound of a vibrating string is soft, string instruments usually have a resonator, like the violin in **Figure 13.** A **resonator** (RE zuh nay tur) is a hollow chamber filled with air that amplifies sound when the air inside of it vibrates. For example, if you pluck a guitar string that is stretched tightly between two nails on a board, the sound is much quieter than if the string were on a guitar. When the string is attached to a guitar, the guitar frame and the air inside the instrument begin to vibrate as they absorb energy from the vibrating string. The vibration of the guitar body and the air inside the resonator makes the sound of the string louder and also affects the quality of the sound.

Figure 13 The air inside the violin's resonator vibrates when the string is played. The vibrating air amplifies the string's sound.
Explain *what causes the air to vibrate.*



Brass and Woodwinds Brass and woodwind instruments rely on the vibration of air to make music. The many different brass and wind instruments—such as horns, oboes, and flutes—use various methods to make air vibrate inside the instrument. For example, brass instruments have cone-shaped mouthpieces like the one in **Figure 14.** This mouthpiece is inserted into metal tubing, which is the resonator in a brass instrument. As the player blows into the instrument, his or her lips vibrate against the mouthpiece. The air in the resonator also starts to vibrate, producing a pitch. On the other hand, to play a flute, a musician blows a stream of air against the edge of the flute's mouth hole. This causes the air inside the flute to vibrate.

In brass and wind instruments, the length of the vibrating tube of air determines the pitch of the sound produced. For example, in flutes and trumpets, the musician changes the length of the resonator by opening and closing finger holes or valves. In a trombone, however, the tubing slides in and out to become shorter or longer.

Figure 14 When the trumpeter makes the mouthpiece vibrate, the air in the trumpet resonates to amplify the sound.

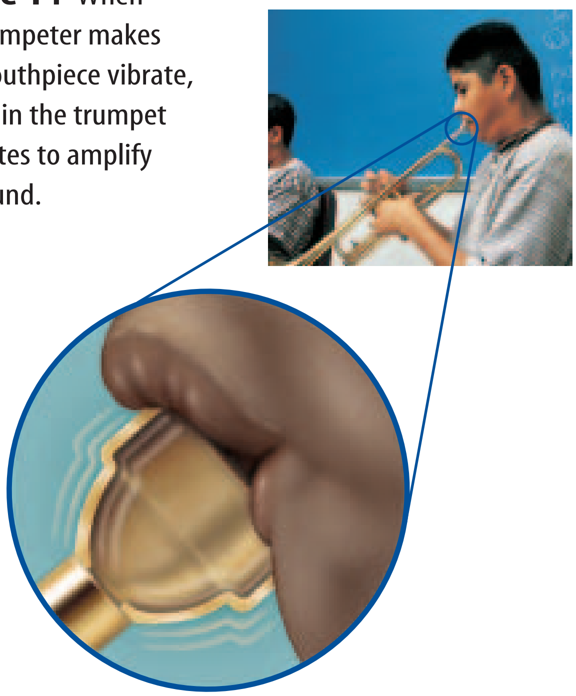


Figure 15 The air inside the resonator of the drum amplifies the sound created when the musician strikes the membrane's surface. **Describe** *how the natural frequency of the air in the drum affects the sound it creates.*

(t)Nick Rowe/PhotoDisc, (b)Derick A. Thomas, Dat's Jazz/CORBIS

Percussion Does the sound of a bass drum make your heart start to pound? Since ancient times, people have used drums and other percussion instruments to send signals, accompany important rituals, and entertain one another. Percussion instruments are struck, shaken, rubbed, or brushed to produce sound. Some, such as kettledrums or the drum shown in **Figure 15,** have a membrane stretched over a resonator. When the drummer strikes the membrane with sticks or hands, the membrane vibrates and causes the air inside the resonator to vibrate. The resonator amplifies the sound made when the membrane is struck. Some drums have a fixed pitch, but others have a pitch that can be changed by tightening or loosening the membrane.

Figure 16 Xylophones are made with many wooden bars that each have their own resonator tubes. **Explain** *why the resonators and bars on a xylophone are different sizes.*

Caribbean steel drums were developed in the 1940s in Trinidad. As many as 32 different striking surfaces hammered from the ends of 55-gallon oil barrels create different pitches of sound. The side of a drum acts as the resonator.

Reading Check *How have people used drums?*

The xylophone shown in **Figure 16** is another type of percussion instrument. It has a series of wooden bars, each with its own tube-shaped resonator. The musician strikes the bars with mallets, and the type of mallet affects the sound quality. Hard mallets make crisp sounds, while softer rubber mallets make duller sounds. Other types of percussion instruments include cymbals, rattles, and even old-fashioned washboards.

Beats

Have you ever heard two flutes play the same note when they weren't properly tuned? The sounds they produce have slightly different frequencies. You may have heard a pulsing variation in loudness, called beats.

When two instruments play at the same time, the sound waves produced by each instrument interfere. The amplitudes of the waves add together when compressions overlap and rarefactions overlap, causing an increase in loudness. When compressions and rarefactions overlap each other, the loudness decreases. Look at **Figure 17.** If two waves of different frequencies interfere, a new wave is produced that has a different frequency. The frequency of this wave is actually the difference in the frequencies of the two waves. The frequency of the beats that you hear decreases as the two waves become closer in frequency. If two flutes that are in tune play the same note, no beats are heard.

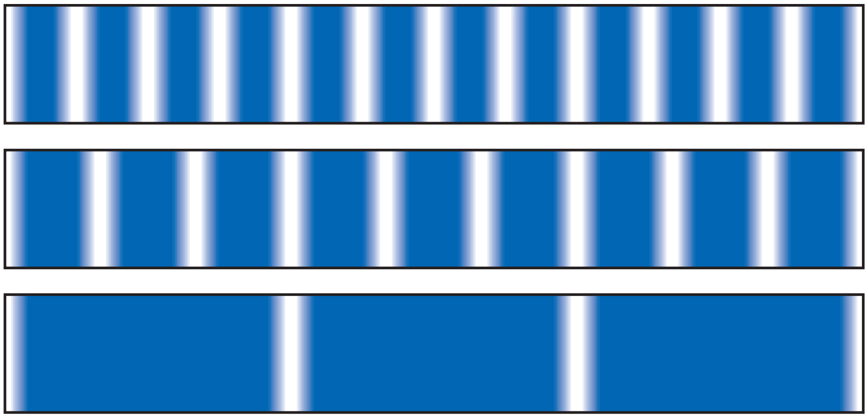


Figure 17 Beats can occur when sound waves of different frequencies, shown in the top two panels, combine. These sound waves interfere with each other, forming a wave with a lower frequency, shown in the bottom panel. This wave causes a listener to hear beats.

Reading Check *How are beats produced?*

section 3 review

Summary

Nature of Music

- Music is sound used in regular patterns.
- Every material has a set of natural frequencies at which it will vibrate.
- Resonance helps amplify the sound produced by musical instruments.

Sound Quality

- Quality of sound describes the differences among sounds of the same pitch and loudness.
- Sound quality results from specific combinations of frequencies produced in various musical instruments.

Beats

- The interference of two waves with different frequencies produces beats.

Self Check

1. **Compare and contrast** music and noise.
2. **Explain** how an instrument's overtones contribute to its sound quality.
3. **Explain** how a flute, violin, and kettledrum produce sound.
4. **Describe** what occurs when two out-of-tune instruments play the same note.
5. **Think Critically** Why do musical instruments vary in different regions of the world?

Applying Math

6. **Calculate Frequencies** A string on a guitar vibrates with a frequency of 440 Hz. Two beats are heard when this string and a string on another guitar are played at the same time. What are the possible frequencies of vibration of the second string?

LAB

Making Music

There are many different types of musical instruments. Early instruments were made from materials that were easily obtained such as clay, shells, skins, wood, and reeds. These materials were fashioned into various instruments that produced pleasing sounds. In this lab, you are going to create a musical instrument using materials that are available to you—just as your ancestors did.

Real-World Question

How can you make different tones using only test tubes and water?

Goals

- **Demonstrate** how to make music using water and test tubes.
- **Predict** how the tones will change when there is more or less water in a test tube.

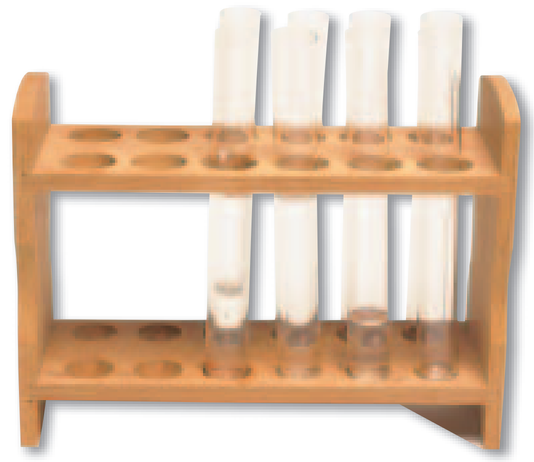
Materials

test tubes
test-tube rack

Safety Precautions

Procedure

1. Put different amounts of water into each of the test tubes.
2. **Predict** any differences you expect in how the tones from the different test tubes will sound.
3. Blow across the top of each test tube.
4. **Record** any differences that you notice in the tones that you hear from each test tube.



Conclude and Apply

1. **Describe** how the tones change depending on the amount of water in the test tube.
2. **Explain** why the pitch depends on the height of the water.
3. **Summarize** why each test tube produces a different tone.
4. **Explain** how resonance amplifies the sound from a test tube.
5. **Explain** how the natural frequencies of the air columns in each of the tubes differ.
6. **Compare and contrast** the way the test tubes make music with the way a flute makes music.

Communicating Your Data

When you are listening to music with family or friends, describe to them what you have learned about how musical instruments produce sound.

Doug Martin

section 4 Using Sound

Reading Guide

What You'll Learn

- **Recognize** some of the factors that determine how a concert hall or theater is designed.
- **Describe** how some animals use sound waves to hunt and navigate.
- **Discuss** the uses of sonar.
- **Explain** how ultrasound is useful in medicine.

Why It's Important

Sound waves have many uses, from discovering sunken treasures to diagnosing and treating diseases.

Review Vocabulary

echo: the reflection of a sound from a surface

New Vocabulary

- acoustics
- echolocation
- sonar

Acoustics

When an orchestra stops playing, does it seem as if the sound of its music lingers for a couple of seconds? The sounds and their reflections reach your ears at different times, so you hear echoes. This echoing effect produced by many reflections of sound is called reverberation (rih vur buh RAY shun).

During an orchestra performance, reverberation can ruin the sound of the music. To prevent this problem, scientists and engineers who design concert halls must understand how the size, shape, and furnishings of the room affect the reflection of sound waves. These scientists and engineers specialize in **acoustics** (uh KEW stihks), which is the study of sound. They know that soft, porous materials can reduce excess reverberation, so they might recommend that the walls of concert halls be lined with carpets and draperies. **Figure 18** shows a concert hall that has been designed to create a good listening environment.

Figure 18 This concert hall uses cloth drapes to help reduce reverberations.
Explain *how the drapes absorb or reflect sound waves.*

Echolocation

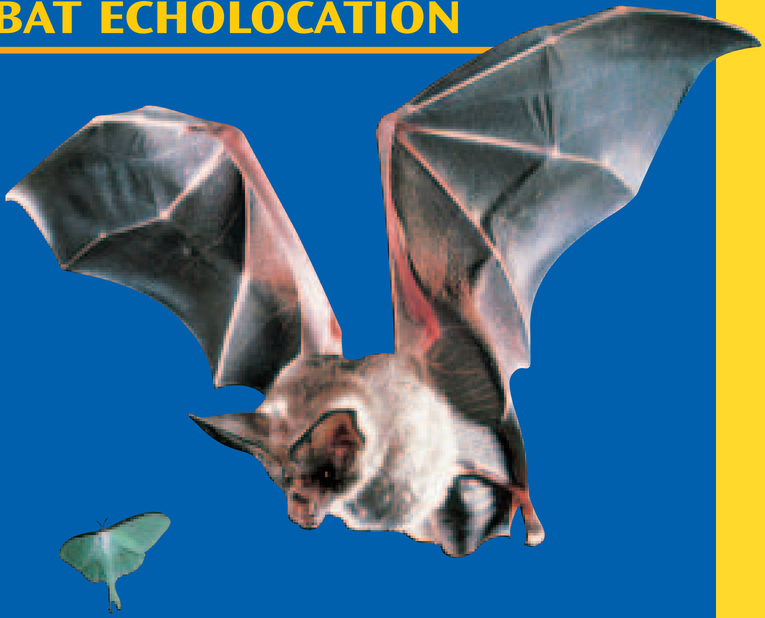
At night, bats swoop around in darkness without bumping into anything. They even manage to find insects and other prey in the dark. Their senses of sight and smell help them navigate. Many species of bats also depend on echolocation. **Echolocation** is the process of locating objects by emitting sounds and interpreting the sound waves that are reflected back. Look at **Figure 19** to learn how echolocation works.

NATIONAL GEOGRAPHIC

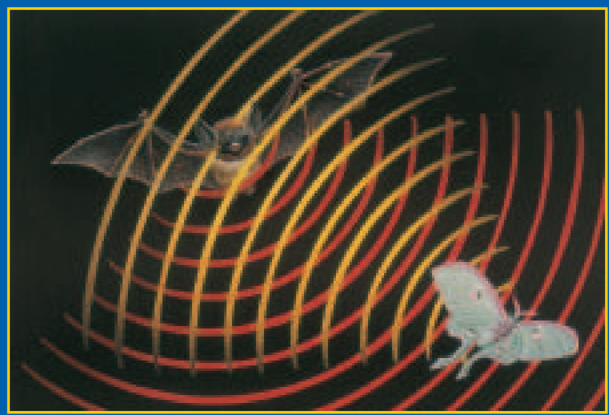
VISUALIZING BAT ECHOLOCATION

Figure 19

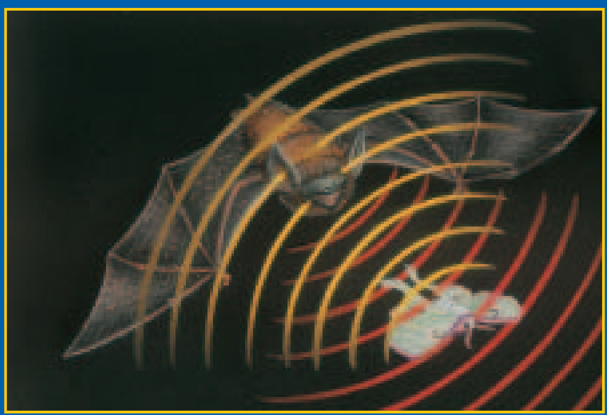
Many bats emit ultrasonic—very high-frequency—sounds. The sound waves bounce off objects, and bats locate prey by using the returning echoes. Known as echolocation, this technique is also used by dolphins, which produce clicking sounds as they hunt. The diagrams below show how a bat uses echolocation to capture a flying insect.



A Sound waves from a bat's ultrasonic cries spread out in front of it.



B Some of the waves strike a moth and bounce back to the bat.



C The bat determines the moth's location by continuing to emit cries, then changes its course to catch the moth.

D By emitting a continuous stream of ultrasonic cries, the bat homes in on the moth and captures its prey.

(tr)Merlin D. Tuttle, (bl)Gary W. Carter/CORBIS

Sonar

More than 140 years ago, a ship named the *Central America* disappeared in a hurricane off the coast of South Carolina. In its hold lay 21 tons of newly minted gold coins and bars that would be worth $1 billion or more in today's market. When the shipwreck occurred, there was no way to search for the ship in the deep water where it sank. The *Central America* and its treasures lay at the bottom of the ocean until 1988, when crews used sonar to locate the wreck under 2,400 m of water. **Sonar** is a system that uses the reflection of underwater sound waves to detect objects. First, a sound pulse is emitted toward the bottom of the ocean. The sound travels through the water and is reflected when it hits something solid, as shown in **Figure 20.** A sensitive underwater microphone called a hydrophone picks up the reflected signal. Because the speed of sound in water is known, the distance to the object can be calculated by measuring how much time passes between emitting the sound pulse and receiving the reflected signal.

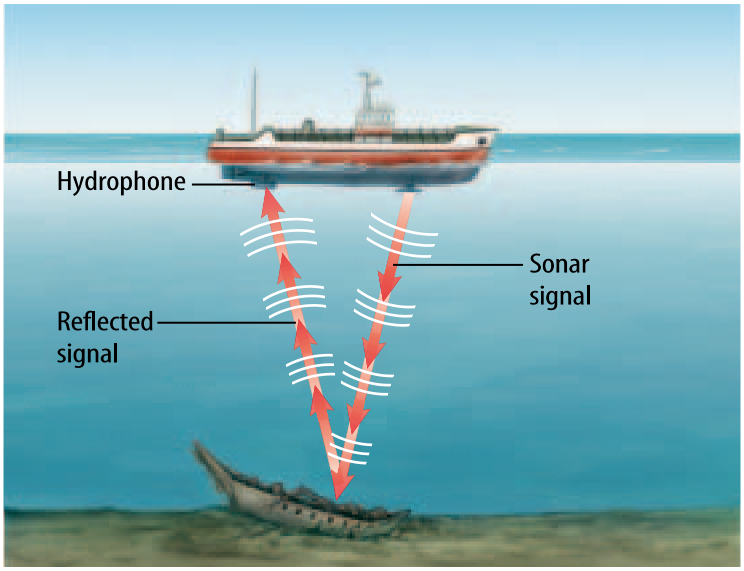


Figure 20 Sonar uses sound waves to find objects that are underwater.
Describe *how sonar is like echolocation.*

Reading Check ***How does sonar detect underwater objects?***

The idea of using sonar to detect underwater objects was first suggested as a way of avoiding icebergs, but many other uses have been developed for it. Navy ships use sonar for detecting, identifying, and locating submarines. Fishing crews also use sonar to find schools of fish, and scientists use it to map the ocean floor. More detail can be revealed by using sound waves of high frequency. As a result, most sonar systems use ultrasonic frequencies.

Ultrasound in Medicine

High-frequency sound waves are used in more than just echolocation and sonar. Ultrasonic waves also are used to break up and remove dirt buildup from jewelry. Chemists sometimes use ultrasonic waves to clean glassware. One of the important uses of ultrasonic waves, though, is in medicine. Using special instruments, medical professionals can send ultrasonic waves into a specific part of a patient's body. Reflected ultrasonic waves are used to detect and monitor conditions such as pregnancy, certain types of heart disease, and cancer.

Figure 21 Ultrasonic waves are directed into a pregnant woman's uterus to form images of her fetus.

Ultrasound Imaging Like X rays, ultrasound can be used to produce images of internal structures. A medical ultrasound technician directs the ultrasound waves toward a target area of a patient's body. The sound waves reflect off the targeted organs or tissues, and the reflected waves are used to produce electrical signals. A computer program converts these electrical signals into video images, called sonograms. Physicians trained to interpret sonograms can use them to detect a variety of medical problems.

Reading Check *How does ultrasound imaging use reflected waves?*

Medical professionals use ultrasound to examine many parts of the body, including the heart, liver, gallbladder, pancreas, spleen, kidneys, breast, and eye. Ultrasound also is used to monitor the development of a fetus, as shown in **Figure 21.** However, ultrasound does not produce good images of the bones and lungs, because hard tissues and air absorb the ultrasonic waves instead of reflecting them.

SONAR EQUATION

Solve for depth A sonar pulse takes 3.00 s to return from a sunken ship directly below. Find the depth of the sunken ship if the speed of the pulse is 1,440 m/s. Hint: the sonar pulse travels a total distance equal to twice the depth of the sunken ship. Use the equation $d = st/2$ to find the depth, where s is the speed of the pulse and t is the time for the pulse to return.

1. **This is what you know:** speed of pulse: $s = 1{,}440\ \text{m/s}$; time for pulse to return: $t = 3.00\ \text{s}$
2. **This is what you need to find:** depth: d
3. **Use this formula:** $d = \frac{st}{2}$
4. **Substitute:** the values of t and s into the formula, multiply and divide by 2. $d = \frac{(1{,}440)(3.00)}{2} = 2{,}160$
5. **Determine the units:** units of d = (units of s) $\times$ (units of t) $= \frac{\text{m}}{\text{s}} \times \text{s} = \frac{\text{m}}{\cancel{\text{s}}} \times \cancel{\text{s}} = \text{m}$

Answer: The depth of the sunken ship is 2,160 m.

Practice Problems

1. A wave traveling in water has a frequency of 500.0 Hz and a wavelength of 3.00 m. What is the speed of the wave?
2. **Challenge** How long will it take a sonar pulse that travels at a speed of 1,500 m/s to return from a sunken ship that is at a depth of 3,750 m?

Science Online
For more practice problems, go to page 834, and visit gpscience.com/extra_problems.

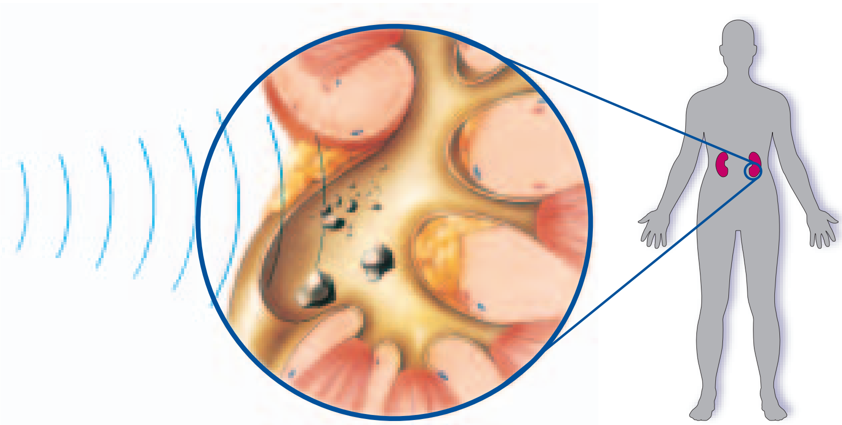


Figure 22 Ultrasonic waves can be used to break up kidney stones. **Explain** *why ultrasound therapy is beneficial for treating kidney stones.*

Treating with Ultrasound High-frequency sound waves can be used to treat certain medical problems. For example, sometimes small, hard deposits of calcium compounds or other minerals form in the kidneys, making kidney stones. In the past, physicians had to perform surgery to remove kidney stones. But now ultrasonic treatments are commonly used to break them up instead. Bursts of ultrasound create vibrations that cause the stones to break into small pieces, as shown in **Figure 22.** These fragments then pass out of the body with the urine. A similar treatment is available for gallstones. Patients who are treated successfully with ultrasound recover more quickly than those who must have surgery.

INTEGRATE Health

Doppler Waves Physicians can measure blood flow by studying the Doppler effect in ultrasonic waves. Brainstorm how the Doppler-shifted waves could help doctors diagnose diseases of the arteries and monitor their healing.

section 4 review

Summary

Acoustics

- Acoustics is a field in which scientists and engineers work to control the quality of sound in spaces.

Echolocation

- Bats locate objects by emitting sounds and then interpreting their reflected sound waves.

Sonar

- Humans using sonar can interpret reflected sound to locate objects underwater.

Ultrasound in Medicine

- High-frequency sound waves are useful for detecting and monitoring certain medical conditions.
- Medical ultrasound is also used to cure problems like kidney stones and gallstones.

Self Check

1. **Describe** some differences between a gym and a concert hall that might affect the amount of reverberation in each.
2. **Explain** how echolocation helps bats to find food and avoid obstacles.
3. **Explain** how sound waves can be used to find underwater objects.
4. **Describe** at least three uses of ultrasonic technology in medicine.
5. **Think Critically** How is sonar technology useful in locating deposits of oil and minerals?

Applying Math

6. **Calculate Distance** Sound travels at about 1,500 m/s in seawater. How far will a sonar pulse travel in 45 s?
7. **Calculate Time** How long will it take for an undersea sonar pulse to travel 3 km?

LAB Design Your Own

John Wang/PhotoDisc

Blocking Noise Pollution

Goals

- **Design** an experiment that tests the effectiveness of various types of barriers and materials for blocking out noise pollution.
- **Test** different types of materials and barriers to determine the best noise blockers.

Possible Materials

radio, CD player, horn, drum, or other loud noise source
shrubs, trees, concrete walls, brick walls, stone walls, wooden fences, parked cars, or hanging laundry
sound meter
meterstick or metric tape measure

Real-World Question

What loud noises do you enjoy, and which ones do you find annoying? Most people enjoy a music concert performed by their favorite artist, booming displays of fireworks on the Fourth of July, and the roar of a crowd when their team scores a goal or touchdown. Although these are loud noises, most people enjoy them for short periods of time. Most people find certain loud noises, such as traffic, sirens, and loud talking, annoying. Constant, annoying noises are called noise pollution. What can be done to reduce noise pollution? What types of barriers best block out loud noises? What types of barriers will best block out noise pollution?

Form a Hypothesis

Based on your experiences with loud noises, form a hypothesis that predicts the effectiveness of different types of barriers at blocking out noise pollution.

Test Hypothesis

Make a Plan

1. **Decide** what type of barriers or materials you will test.
2. **Describe** exactly how you will use these materials.

3. **Identify** the controls and variables you will use in your experiment.
4. **List** the steps you will use and describe each step precisely.
5. **Prepare** a data table in your Science Journal to record your measurements.
6. **Organize** the steps of your experiment in logical order.

Follow Your Plan

1. Ask your teacher to approve your plan and data table before you start.
2. **Conduct** your experiment as planned.
3. **Test** each barrier two or three times.
4. **Record** your test results in your data table in your Science Journal.

Analyze Your Data

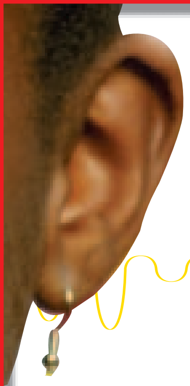
1. **Identify** the barriers that most effectively reduced noise pollution.
2. **Identify** the barriers that least effectively reduced noise pollution.
3. **Compare** the effective barriers and identify common characteristics that might explain why they reduced noise pollution.
4. **Compare** the natural barriers you tested with the artificial barriers. Which type of barrier best reduced noise pollution?
5. **Compare** the different types of materials the barriers were made of. Which type of material best reduced noise pollution?

Conclude and Apply

1. **Evaluate** whether your results support your hypothesis.
2. **Predict** how your results would differ if you use a louder source of noise such as a siren.
3. **Infer** from your results how people living near a busy street could reduce noise pollution.
4. **Identify** major sources of noise pollution in or near your home. How could this be reduced?
5. **Research** how noise pollution can be unhealthy.

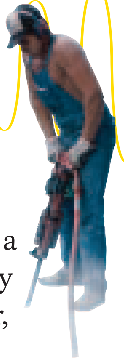
Communicating Your Data

Draw a poster illustrating how builders and landscapers could use certain materials to better insulate a home or office from excess noise pollution.



Noise Pollution

AND HEARING LOSS



Now hear this: More than 28 million Americans have hearing loss. Twelve million more people have a condition called tinnitus (TIN uh tus), or ringing in the ears. In at least 10 million of the 28 million cases mentioned above, hearing loss could have been prevented, because it was caused by noise pollution.

People take their music very seriously in the United States. And a lot of people like it loud. So loud, in fact, that it can damage their hearing. The medical term is *auditory overstimulation.* You may have experienced a high-pitched ringing in your ears for days after standing too close to a loudspeaker at a concert. That's how hearing loss starts.

Music isn't the only cause of hearing loss caused by noise pollution. Other kinds of environmental noise can be strong enough to damage the ears, too. Intense, short-duration noise, like the sound of a gunshot or even a thunderclap, can cause some hearing loss. All of the structures of the inner ear can be damaged this way.

A less intense but longer duration noise, like the sound of a lawn mower, a low-flying plane, or a drill blasting away at cement, can possibly damage the ear, as well.

All the Better to Hear You

There are 20,000 to 30,000 sensory receptors, or hair cells, located in the inner ear, or the cochlea. When vibrations reach these hair cells, electrical impulses are triggered.

The impulses send messages to the auditory center of the brain. But the human ear was not made to withstand all the very loud sounds of the modern world. Once hair cells are damaged, they don't grow back.

What can you do to avoid hearing damage? Well, the first thing is to turn the volume down on the stereo and TV. And keep the volume low when you've got your earphones on, no matter how tempting it is to blast it. Also, if you go to a rock concert, you can wear earplugs to muffle the sound. You'll still hear everything, but you won't damage your ears. And earplugs are now small enough that they're pretty much undetectable. So enjoy all that music and the street sounds of urban life, but mind your ears.

Test **Put on a blindfold and have a friend test your hearing. Have your friend choose several noise-making objects. (Not too loud, please, and make sure you have your teacher's permission.) Guess what object is making each sound.**

Science Online
For more information, visit gpscience.com/time

(tl)Australian Picture Library/CORBIS, (tr)Zig Leszczynski/Earth Scenes, (bl)David Sacks

Reviewing Main Ideas

Section 1 The Nature of Sound

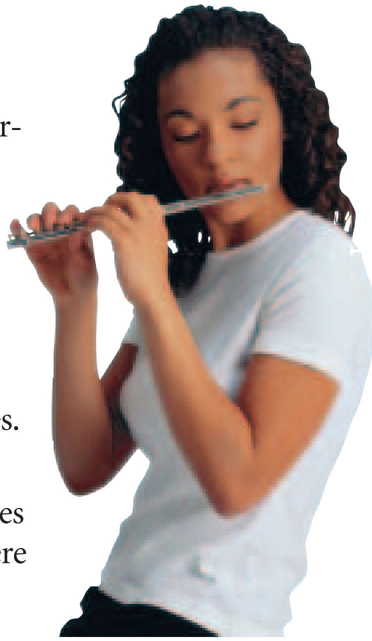
1. Sound is a compressional wave created by something that is vibrating.
2. Sound travels fastest through solids and slowest through gases. You see the flash of lightning before you hear the clap of thunder because light travels faster than sound.

3. The human ear can be divided into three sections—the outer ear, the middle ear, and the inner ear. Each section plays a specific role in hearing.
4. Hearing involves four stages: gathering sound waves, amplifying them, converting them to nerve impulses, and interpreting the signals in the brain.

Section 2 Properties of Sound

1. Intensity is a measure of how much energy a wave carries. Humans interpret the intensity of sound waves as loudness.
2. The pitch of a sound becomes higher as the frequency increases.
3. The Doppler effect is a change in frequency that occurs when a source of sound is moving relative to a listener.

Section 3 Music



1. Music is made of sounds used deliberately in a regular pattern.
2. Instruments, such as this flute, use a variety of methods to produce and amplify sound waves.
3. When sound waves of similar frequencies overlap, they interfere with each other to form beats.

Section 4 Using Sound

1. Acoustics is the study of sound. This gym is great for playing basketball, but the sound quality would be poor for a concert.
2. Sonar uses reflected sound waves to detect objects.
3. Ultrasound waves can be used for imaging body tissues or treating medical conditions.

FOLDABLES™ Use the Foldable that you made at the beginning of this chapter to help you review sound.

chapter 11 Review

Using Vocabulary

acoustics p. 339	music p. 333
cochlea p. 326	overtone p. 334
decibel p. 329	pitch p. 330
Doppler effect p. 331	resonator p. 335
eardrum p. 325	sonar p. 341
echolocation p. 339	sound quality p. 334
intensity p. 328	ultrasonic p. 330
loudness p. 329	

Fill in the blanks with the correct vocabulary word or words.

1. The _________ is filled with fluid and contains tiny hair cells that vibrate.
2. _________ is the study of sound.
3. A change in pitch or wave frequency due to a moving wave source is called _________.
4. _________ is a combination of sounds and pitches that follows a specified pattern.
5. Differences among sounds of the same pitch and loudness are described as _________.
6. _________ is how humans perceive the intensity of sound.
7. _________ is a scale for sound intensity.

Checking Concepts

Choose the word or phrase that best answers the question.

8. For a sound with a low pitch, what else is always low?
   A) amplitude C) wavelength
   B) frequency D) wave velocity
9. Sound intensity decreases when which of the following decreases?
   A) wave velocity C) quality
   B) wavelength D) amplitude
10. When specific pitches and sounds are put together in a pattern, what are they called?
    A) overtones C) white noise
    B) music D) resonance
11. Sound can travel through all but which of the following?
    A) solids C) gases
    B) liquids D) empty space
12. What is the term for variations in the loudness of sound caused by wave interference?
    A) beats
    B) standing waves
    C) pitch
    D) forced vibrations
13. What does the outer ear do to sound waves?
    A) scatter them C) gather them
    B) amplify them D) convert them
14. Which of the following occurs when a sound source moves away from you?
    A) The sound's velocity decreases.
    B) The sound's loudness increases.
    C) The sound's frequency decreases.
    D) The sound's frequency increases.
15. Sounds with the same pitch and loudness traveling in the same medium may differ in which of these properties?
    A) frequency C) quality
    B) amplitude D) wavelength
16. What part of a musical instrument amplifies sound waves?
    A) resonator C) mallet
    B) string D) finger hole
17. What is the name of the method used to find objects that are underwater?
    A) sonogram
    B) ultrasonic bath
    C) sonar
    D) percussion

Science Online gpscience.com/vocabulary_puzzlemaker

Interpreting Graphics

18. Copy and complete the following table on musical instruments.

Characteristics of Musical Instruments

	Guitar	Flute	Bongo Drum
How Played	plucked	blown into	
Role of Resonator	amplifies sound		amplifies sound
Type of Instrument		wind	percussion

Use the table below to answer question 19.

Federally Recommended Noise Exposure Limits

Sound Level (dB)	Time Permitted (hours per day)
90	8
95	4
100	2
105	1
110	0.5

19. You use a lawn mower with a sound level of 100 dB. Using the table above, determine the maximum number of hours a week you can safely work mowing lawns without ear protection.

Thinking Critically

20. Infer A car comes to a railroad crossing. The driver hears a train's whistle and its pitch becomes lower. What can be assumed about how the train is moving?

21. Form Hypotheses Sound travels slower in air at high altitudes than at low altitudes. Form a hypothesis to explain this.

22. Apply Acoustic scientists sometimes do research in rooms that absorb all sound waves. How could such a room be used to study how bats find their food?

23. Explain why windows might begin to rattle when an airplane flies overhead.

24. Communicate Some people enjoy using snowmobiles. Others object to the noise that they make. Write a proposal for a policy that seems fair to both groups for the use of snowmobiles in a state park.

Applying Math

Use the wave speed equation $v = f\lambda$ to answer questions 25–27.

25. Calculate Frequency A sonar pulse has a wavelength of 3.0 cm. If the pulse has a speed in water of 1,500 m/s, calculate its frequency.

26. Calculate Wavelength What is the wavelength of a sound wave with a frequency of 440 Hz if the speed of sound in air is 340 m/s?

27. Calculate Wave Speed An earthquake produces a seismic wave that has a wavelength of 650 m and a frequency of 10 Hz. How fast does the wave travel?

28. Calculate Distance The sound of thunder travels at a speed of 340 m/s and reaches you in 2.6 s. How far away is the storm?

29. Calculate Time The shipwrecked Central America was discovered lying beneath 2,400 m of water. If the speed of sound in seawater is 1,500 m/s, how long will it take a sonar pulse to travel to the shipwreck and return?

chapter 11 Standardized Test Practice

Part 1 Multiple Choice

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

1. What does a sound's frequency determine?
A. pitch
B. amplitude
C. intensity
D. energy

2. Which medium does sound travel fastest through?
A. empty space
B. liquids
C. gases
D. solids

Use the table below to answer questions 3 and 4.

Sound	Loudness (dB)
Jet taking off	150
Pain threshold	120
Chain saw	115
Power mower	110
Vacuum cleaner	75
Average home	50
Purring cat	25

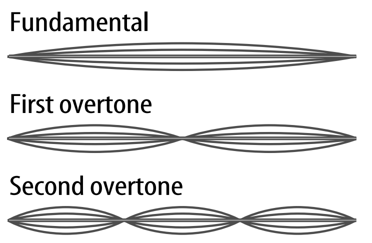
3. Which of the following would sound the loudest?
A. vacuum cleaner
B. chain saw
C. power mower
D. purring cat

4. Which of the following statements is true about a sound of 65 decibels?
A. It causes intense pain.
B. It can cause permanent hearing loss.
C. It cannot be heard by anyone.
D. It can be heard without discomfort or damage.

5. To which group of instruments does a clarinet belong?
A. electronic
B. percussion
C. stringed
D. wind

6. Which of the following will lower the pitch of the sound made by a guitar string?
A. shortening the vibrating string
B. tightening the string
C. plucking the string harder
D. loosening the string

Use the illustration below to answer questions 7 and 8.



7. If the fundamental frequency of a guitar string is 262 Hz, what is the frequency of the first overtone?
A. 262 Hz
B. 524 Hz
C. 786 Hz
D. 1048 Hz

8. What is the frequency of the second overtone if the fundamental frequency is 294 Hz?
A. 294 Hz
B. 588 Hz
C. 882 Hz
D. 1176 Hz

9. If you were on a moving train, what would happen to the pitch of the bell at a crossing as you approached and then passed by the crossing?
A. pitch would increase and then decrease
B. pitch would remain the same
C. pitch would decrease and then increase
D. pitch would keep decreasing

10. On what does a guitar string's natural frequency depend?
A. thickness
B. tightness
C. length
D. all of these

Part 2 Short Response/Grid In

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

Use the table below to answer questions 11–13.

Medium	Speed of Sound (m/s)
Air	347
Water	1,498
Iron	5,103

11. A "fishfinder" sends out a pulse of ultrasound and measures the time needed for the sound to travel to a school of fish and back to the boat. If the fish are 16 m below the surface, how long would it take sound to make the round trip in the water?

12. Suppose you are sitting in the bleachers at a baseball game 150 m from home plate. How long after the batter hits the ball do you hear the "crack" of the ball and bat?

13. Suppose a friend is 500 m away along a railroad track while you have your ear to the track. He drops a stone on the tracks. How long will the sound take to reach your ear?

14. Explain why placing your hand on a bell that has just been rung will stop the sound immediately.

15. Why do different musical instruments have different sound qualities?

Test-Taking Tip

Make Sure the Units Match Read carefully and make note of the units used in any measurement.

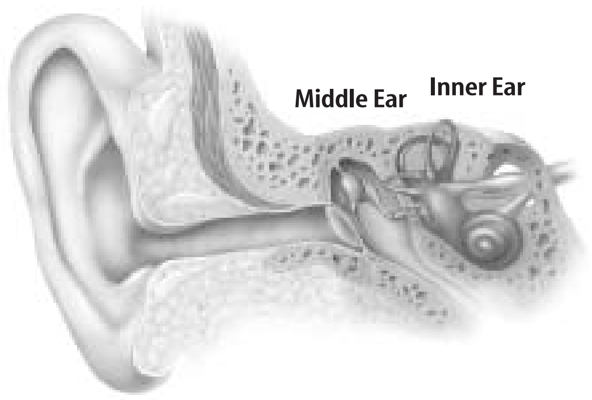
Question 11 Compare the units given in the table with those in the problem. If the units do not match, you will have to do unit conversions.

Part 3 Open Ended

Record your answers on a sheet of paper.

16. Explain why people who work on the ground near jet runways wear big ear muffs filled with a sound insulator.

Use the illustration below to answer questions 17 and 18.



17. Describe the path of sound from the time it enters the ear until a message reaches the brain.

18. Would sound waves traveling through the outer ear travel faster or slower that those traveling through the inner ear? Explain.

19. Science-fiction movies often show battles in space where an enemy spaceship explodes with a very loud sound. Explain whether or not this scenario is accurate.

20. Compare the way a violin, a flute, and drum produce sound waves. What acts as a resonator in each instrument?

21. How can interference produce a sound with decreased loudness? How can interference produce a sound with increased loudness?

22. Imagine you have been hired by a school to reduce the amount of reverberation that occurs in the classrooms. What recommendations would you make?