chapter 2

Sound

The BIG Idea

Sound waves are compressional waves produced by something that vibrates.

SECTION 1
What is sound?

Main Idea A vibrating object produces compressions and rarefactions that travel away from the object.

SECTION 2
Music

Main Idea The sound of a musical instrument depends on the natural frequencies of the materials it is made from.

An Eerie Silence

You probably have never experienced complete silence unless you've been in a room like this one. The room is lined with special materials that absorb sound waves and eliminate sound reflections.

Science Journal Write a paragraph about the quietest place you've ever been.

Tom Wagner/CORBIS SABA

Start-Up Activities

Launch LAB

Making Human Sounds

When you speak or sing, you push air from your lungs past your vocal cords, which are two flaps of tissue inside your throat. When you tighten your vocal cords, you can make the sound have a higher pitch. Do this lab to explore how you change the shape of your throat to vary the pitch of sound.

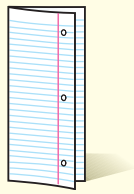
1. Hold your fingers against the front of your throat and say *Aaaah.* Notice the vibration against your fingers.
2. Now vary the pitch of this sound from low to high and back again. How do the vibrations in your throat change? Record your observations.
3. Change the sound to an *Ooooh.* What do you notice as you listen? Record your observations.
4. **Think Critically** In your Science Journal, describe how the shape of your throat changed the pitch.

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

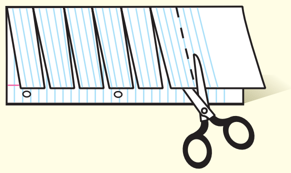
FOLDABLES™ Study Organizer

Sound Make the following Foldable to help you answer questions about sound.

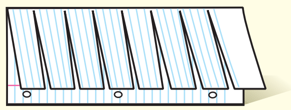
STEP 1 **Fold** a vertical sheet of notebook paper from side to side.



STEP 2 **Cut** along every third line of only the top layer to form tabs.



STEP 3 **Write** a question about sound on each tab.



Answer Questions Before you read the chapter, write some questions you have about sound on the front of the tabs. As you read the chapter, write the answer beneath the question. You may add questions as you read.

Tom Wagner/CORBIS SABA

Get Ready to Read

Monitor

1 Learn It! An important strategy to help you improve your reading is monitoring, or finding your reading strengths and weaknesses. As you read, monitor yourself to make sure the text makes sense. Discover different monitoring techniques you can use at different times, depending on the type of test and situation.

2 Practice It! The paragraph below appears in Section 1. Read the passage and answer the questions that follow. Discuss your answers with other students to see how they monitor their reading.

> The diffraction of lower frequencies in the human voice allows you to hear someone talking even when the person is around the corner. This is different from an echo. Echoes occur when sound waves bounce off a reflecting surface. Diffraction occurs when a wave spreads out after passing through an opening or when a wave bends around an obstacle.
>
> — *from page 44*

- What questions do you still have after reading?
- Do you understand all of the words in the passage?
- Did you have to stop reading often? Is the reading level appropriate for you?

3 Apply It! Identify one paragraph that is difficult to understand. Discuss it with a partner to improve your understanding.

Reading Tip

Monitor your reading by slowing down or speeding up, depending on your understanding of the text.

Target Your Reading

Use this to focus on the main ideas as you read the chapter.

1. **Before you read** the chapter, respond to the statements below on your worksheet or on a numbered sheet of paper.
   - Write an **A** if you **agree** with the statement.
   - Write a **D** if you **disagree** with the statement.

2. **After you read** the chapter, look back to this page to see if you've changed your mind about any of the statements.
   - If any of your answers changed, explain why.
   - Change any false statements into true statements.
   - Use your revised statements as a study guide.

Before You Read A or D		Statement	After You Read A or D
	1	Sound waves transfer energy only in matter.	
	2	The loudness of a sound wave increases as the frequency of a wave increases.	
	3	Sound travels faster in warm air than in cold air.	
	4	Sound usually travels faster in gases than in solids.	
	5	The pitch of a sound you hear depends on whether the source of the sound is moving relative to you.	
	6	Sound waves do not spread out when they pass through an opening.	
	7	A vibrating string whose length is fixed can produce sound waves of more than one frequency.	
	8	The body of a guitar helps make the sound of the vibrating strings louder.	
	9	Changing the length of a vibrating air column changes the pitch of the sound produced.	

Science Online
Print out a worksheet of this page at booko.msscience.com

section 1

What is sound?

as you read

What You'll Learn

- **Identify** the characteristics of sound waves.
- **Explain** how sound travels.
- **Describe** the Doppler effect.

Why It's Important

Sound gives important information about the world around you.

Review Vocabulary

frequency: number of wavelengths that pass a given point in one second, measured in hertz (Hz)

New Vocabulary

- loudness
- pitch
- echo
- Doppler effect

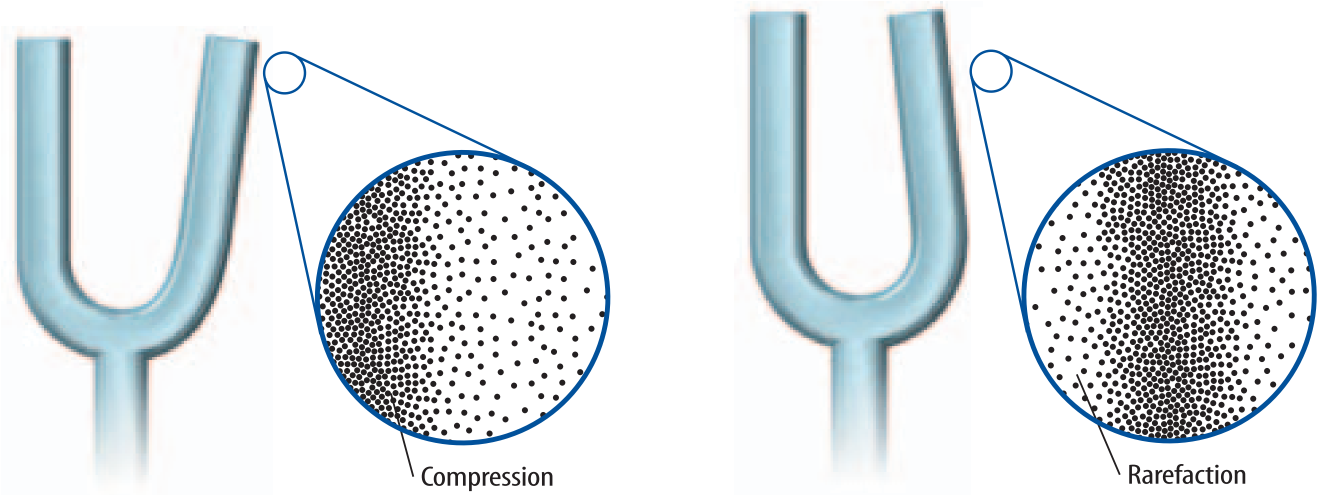
Sound and Vibration

Think of all the sounds you've heard since you awoke this morning. Did you hear your alarm clock blaring, car horns honking, or locker doors slamming? Every sound has something in common with every other sound. Each is produced by something that vibrates.

Sound Waves How does an object that is vibrating produce sound? When you speak, the vocal cords in your throat vibrate. These vibrations cause other people to hear your voice. The vibrations produce sound waves that travel to their ears. The other person's ears interpret these sound waves.

A wave carries energy from one place to another without transferring matter. An object that is vibrating in air, such as your vocal cords, produces a sound wave. The vibrating object causes air molecules to move back and forth. As these air molecules collide with those nearby, they cause other air molecules to move back and forth. In this way, energy is transferred from one place to another. A sound wave is a compressional wave, like the wave moving through the coiled spring toy in **Figure 1.** In a compressional wave, particles in the material move back and forth along the direction the wave is moving. In a sound wave, air molecules move back and forth along the direction the sound wave is moving.

Figure 1 When the coils of a coiled spring toy are squeezed together, a compressional wave moves along the spring. The coils move back and forth as the compressional wave moves past them.



When the tuning fork vibrates outward, it forces molecules in the air next to it closer together, creating a region of compression.

When the tuning fork moves back, the molecules in the air next to it spread farther apart, creating a region of rarefaction.

Figure 2 A tuning fork makes a sound wave as the ends of the fork vibrate in the air.
Explain *why a sound wave cannot travel in a vacuum.*

Making Sound Waves When an object vibrates, it exerts a force on the surrounding air. For example, as the end of the tuning fork moves outward into the air, it pushes the molecules in the air together, as shown on the left in **Figure 2.** As a result, a region where the molecules are closer together, or more dense, is created. This region of higher density is called a compression. When the end of the tuning fork moves back, it creates a region of lower density called a rarefaction, as shown on the right in **Figure 2.** As the tuning fork continues to vibrate, a series of compressions and rarefactions is formed. The compressions and rarefactions move away from the tuning fork as molecules in these regions collide with other nearby molecules.

Like other waves, a sound wave can be described by its wavelength and frequency. The wavelength of a sound wave is shown in **Figure 3.** The frequency of a sound wave is the number of compressions or rarefactions that pass by a given point in one second. An object that vibrates faster forms a sound wave with a higher frequency.

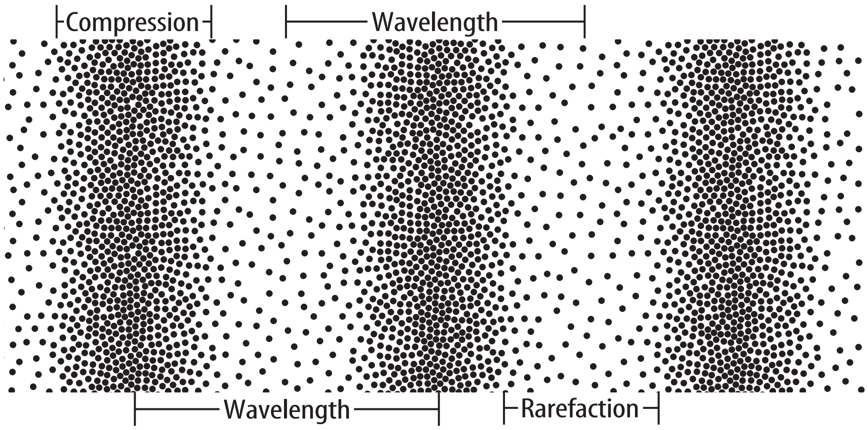


Figure 3 Wavelength is the distance from one compression to another or one rarefaction to another.

Mini LAB

Comparing and Contrasting Sounds

Procedure

1. Strike a **block of wood** with a **spoon** and listen carefully to the sound. Then press the block of wood to your ear and strike it with the spoon again. Listen carefully to the sound.
2. Tie the middle of a length of **cotton string** to a metal spoon. Strike the spoon on something to hear it ring. Now press the ends of the string against your ears and repeat the experiment. What do you hear?

Analysis

1. Did you hear sounds transmitted through wood and through string? Describe the sounds.
2. Compare and contrast the sounds in wood and in air.

Try at Home

The Speed of Sound

Sound waves can travel through other materials besides air. In fact, sound waves travel in the same way through different materials as they do in air, although they might travel at different speeds. As a sound wave travels through a material, the particles in the material collide with each other. In a solid, molecules are closer together than in liquids or gases, so collisions between molecules occur more rapidly than in liquids or gases. The speed of sound is usually fastest in solids, where molecules are closest together, and slowest in gases, where molecules are farthest apart. **Table 1** shows the speed of sound through different materials.

The Speed of Sound and Temperature The temperature of the material that sound waves are traveling through also affects the speed of sound. As a substance heats up, its molecules move faster, so they collide more frequently. The more frequent the collisions are, the faster the speed of sound is in the material. For example, the speed of sound in air at 0°C is 331 m/s; at 20°C, it is 343 m/s.

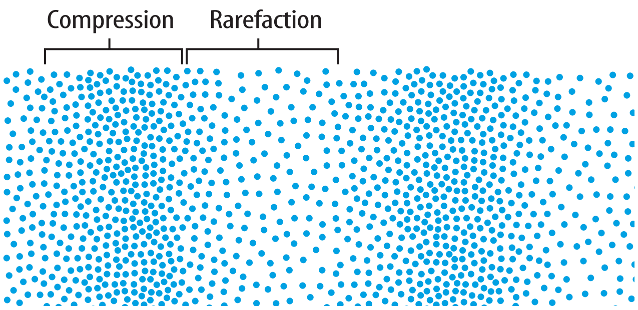
Amplitude and Loudness

What's the difference between loud sounds and quiet sounds? When you play a song at high volume and low volume, you hear the same instruments and voices, but something is different. The difference is that loud sound waves generally carry more energy than soft sound waves do.

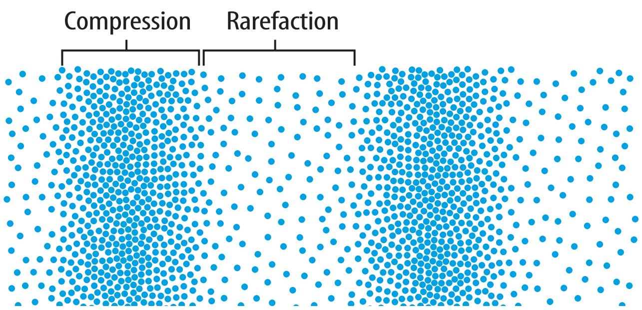
Loudness is the human perception of how much energy a sound wave carries. Not all sound waves with the same energy are as loud. Humans hear sounds with frequencies between 3,000 Hz and 4,000 Hz as being louder than other sound waves with the same energy.

Table 1 Speed of Sound Through Different Materials

Material	Speed (m/s)
Air	343
Water	1,483
Steel	5,940
Glass	5,640



This sound wave has a lower amplitude.



This sound wave has a higher amplitude. Particles in the material are more compressed in the compressions and more spread out in the rarefactions.

Amplitude and Energy The amount of energy a wave carries depends on its amplitude. For a compressional wave such as a sound wave, the amplitude is related to how spread out the molecules or particles are in the compressions and rarefactions, as **Figure 4** shows. The higher the amplitude of the wave is, the more compressed the particles in the compression are and the more spread out they are in the rarefactions. More energy had to be transferred by the vibrating object that created the wave to force the particles closer together or spread them farther apart. Sound waves with greater amplitude carry more energy and sound louder. Sound waves with smaller amplitude carry less energy and sound quieter.

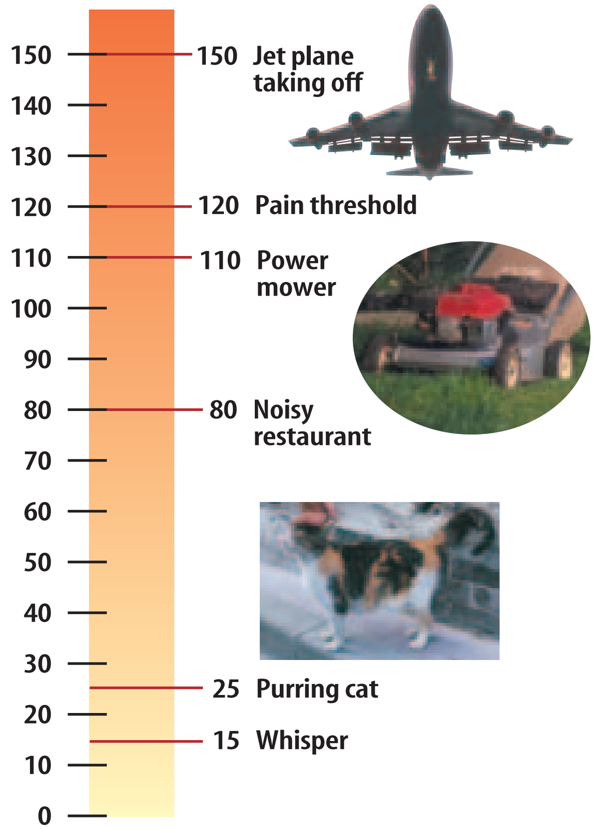
Figure 4 The amplitude of a sound wave depends on how spread out the particles are in the compressions and rarefactions of the wave.

Reading Check *What determines the loudness of different sounds?*

The Decibel Scale Perhaps an adult has said to you, "Turn down your music, it's too loud! You're going to lose your hearing!" Although the perception of loudness varies from person to person, the energy carried by sound waves can be described by a scale called the decibel (dB) scale. **Figure 5** shows the decibel scale. An increase in the loudness of a sound of 10 dB means that the energy carried by the sound has increased ten times, but an increase of 20 dB means that the sound carries 100 times more energy.

Hearing damage begins to occur at sound levels of about 85 dB. The amount of damage depends on the frequencies of the sound and the length of time a person is exposed to the sound. Some music concerts produce sound levels as high as 120 dB. The energy carried by these sound waves is about 30 billion times greater than the energy carried by sound waves that are made by whispering.

Figure 5 The loudness of sound is measured on the decibel scale.



(t)Joe Towers/The Stock Market/CORBIS, (c)Bob Daemmrich/Stock Boston/PictureQuest, (b)Jean-Paul Thomas/Jacana Scientific Control/Photo Researchers

Frequency and Pitch

The **pitch** of a sound is how high or low it sounds. For example, a piccolo produces a high-pitched sound or tone, and a tuba makes a low-pitched sound. Pitch corresponds to the frequency of the sound. The higher the pitch is, the higher the frequency is. A sound wave with a frequency of 440 Hz, for example, has a higher pitch than a sound wave with a frequency of 220 Hz.

The human ear can detect sound waves with frequencies between about 20 Hz and 20,000 Hz. However, some animals can detect even higher and lower frequencies. For example, dogs can hear frequencies up to almost 50,000 Hz. Dolphins and bats can hear frequencies as high as 150,000 Hz, and whales can hear frequencies higher than those heard by humans.

Recall that frequency and wavelength are related. If two sound waves are traveling at the same speed, the wave with the shorter wavelength has a higher frequency. If the wavelength is shorter, then more compressions and rarefactions will go past a given point every second than for a wave with a longer wavelength, as shown in **Figure 6.** Sound waves with a higher pitch have shorter wavelengths than those with a lower pitch.

The Human Voice When you make a sound, you exhale past your vocal cords, causing them to vibrate. The length and thickness of your vocal cords help determine the pitch of your voice. Shorter, thinner vocal cords vibrate at higher frequencies than longer or thicker ones. This explains why children, whose vocal cords are still growing, have higher voices than adults. Muscles in the throat can stretch the vocal cords tighter, letting people vary their pitch within a limited range.

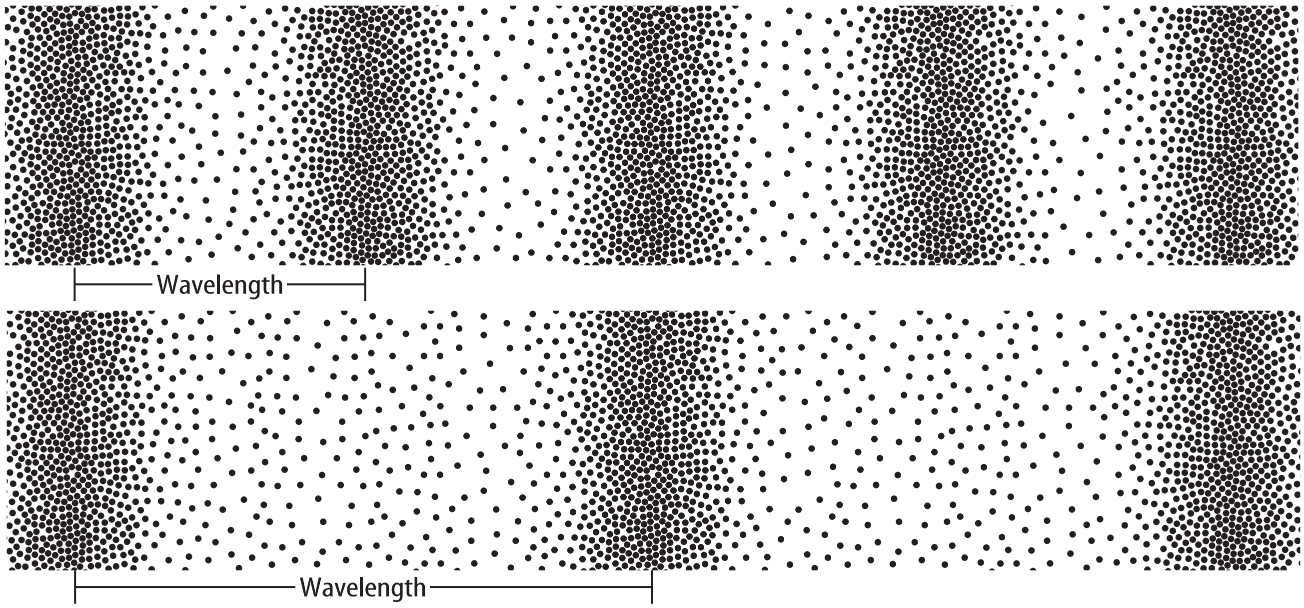


Figure 6 The upper sound wave has a shorter wavelength than the lower wave. If these two sound waves are traveling at the same speed, the upper sound wave has a higher frequency than the lower one. For this wave, more compressions and rarefactions will go past a point every second than for the lower wave.
Identify *the wave that has a higher pitch.*

Figure 7 Sonar uses reflected sound waves to determine the location and shape of an object.

Echoes

Sound reflects off of hard surfaces, just like a water wave bounces off the side of a bath tub. A reflected sound wave is called an **echo.** If the distance between you and a reflecting surface is great enough, you might hear the echo of your voice. This is because it might take a few seconds for the sound to travel to the reflecting surface and back to your ears.

Sonar systems use sound waves to map objects underwater, as shown in **Figure 7.** The amount of time it takes an echo to return depends on how far away the reflecting surface is. By measuring the length of time between emitting a pulse of sound and hearing its echo off the ocean floor, the distance to the ocean floor can be measured. Using this method, sonar can map the ocean floor and other undersea features. Sonar also can be used to detect submarines, schools of fish, and other objects.

Reading Check *How do sonar systems measure distance?*

INTEGRATE Life Science

Echolocation Some animals use a method called echolocation to navigate and hunt. Bats, for example, emit high-pitched squeaks and listen for the echoes. The type of echo it hears helps the bat determine exactly where an insect is, as shown in **Figure 8.** Dolphins also use a form of echolocation. Their high-pitched clicks bounce off of objects in the ocean, allowing them to navigate in the same way.

People with visual impairments also use echolocation. For example, they can interpret echoes to estimate the size and shape of a room by using their ears.

Science Online

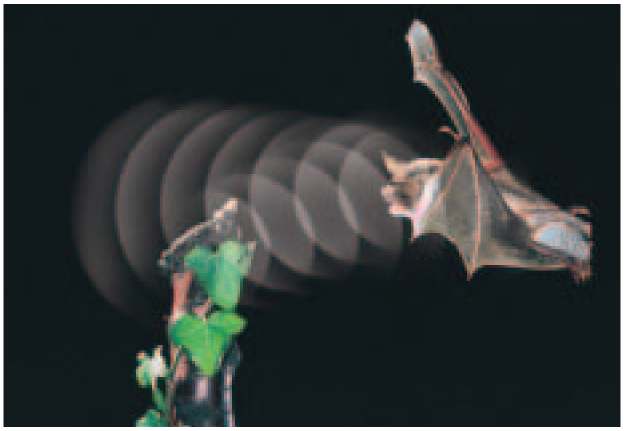
Topic: Sonar

Visit booko.msscience.com for Web links to information about how sonar is used to detect objects underwater.

Activity List and explain how several underwater discoveries were made using sonar.

Figure 8 Bats use echolocation to hunt.

Explain *why this is a good technique for hunting at night.*



INTEGRATE Astronomy

Doppler Shift of Light
The frequency of light waves is also changed by the Doppler shift. If a light source is moving away from an observer, the frequencies of the emitted light waves decrease. Research how the Doppler shift is used by astronomers to determine how other objects in the universe are moving relative to Earth.

The Doppler Effect

Perhaps you've heard an ambulance siren as the ambulance speeds toward you, then goes past. You might have noticed that the pitch of the siren gets higher as the ambulance moves toward you. Then as the ambulance moves away, the pitch of the siren gets lower. The change in frequency that occurs when a source of sound is moving relative to a listener is called the **Doppler effect**. **Figure 9** shows why the Doppler effect occurs.

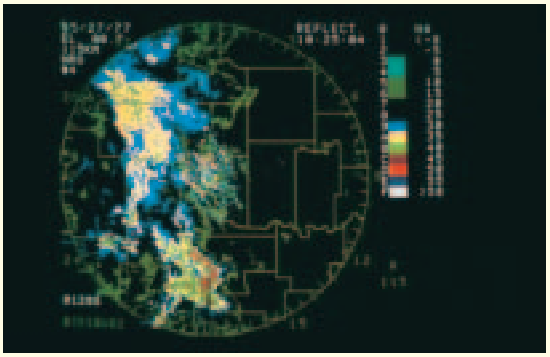
The Doppler effect occurs whether the sound source or the listener is moving. If you drive past a factory as its whistle blows, the whistle will sound higher pitched as you approach. As you move closer you encounter each sound wave a little earlier than you would if you were sitting still, so the whistle has a higher pitch. When you move away from the whistle, each sound wave takes a little longer to reach you. You hear fewer wavelengths per second, which makes the sound lower in pitch.

Radar guns that are used to measure the speed of cars and baseball pitches also use the Doppler effect. Instead of a sound wave, the radar gun sends out a radio wave. When the radio wave is reflected, its frequency changes depending on the speed of the object and whether it is moving toward the gun or away from it. The radar gun uses the change in frequency of the reflected wave to determine the object's speed.

Applying Science

How does Doppler radar work?

Doppler radar is used by the National Weather Service to detect areas of precipitation and to measure the speed at which a storm moves. Because the wind moves the rain, Doppler radar can "see" into a strong storm and expose the winds. Tornadoes that might be forming in the storm then can be identified.



Identify the Problem

An antenna sends out pulses of radio waves as it rotates. The waves bounce off raindrops and return to the antenna at a different frequency, depending on whether the rain is moving toward the antenna or away from it. The change in frequency is due to the Doppler shift.

Solving the Problem

1. If the frequency of the reflected radio waves increases, how is the rain moving relative to the radar station?
2. In a tornado, winds are rotating. How would the radio waves reflected by rotating winds be Doppler-shifted?

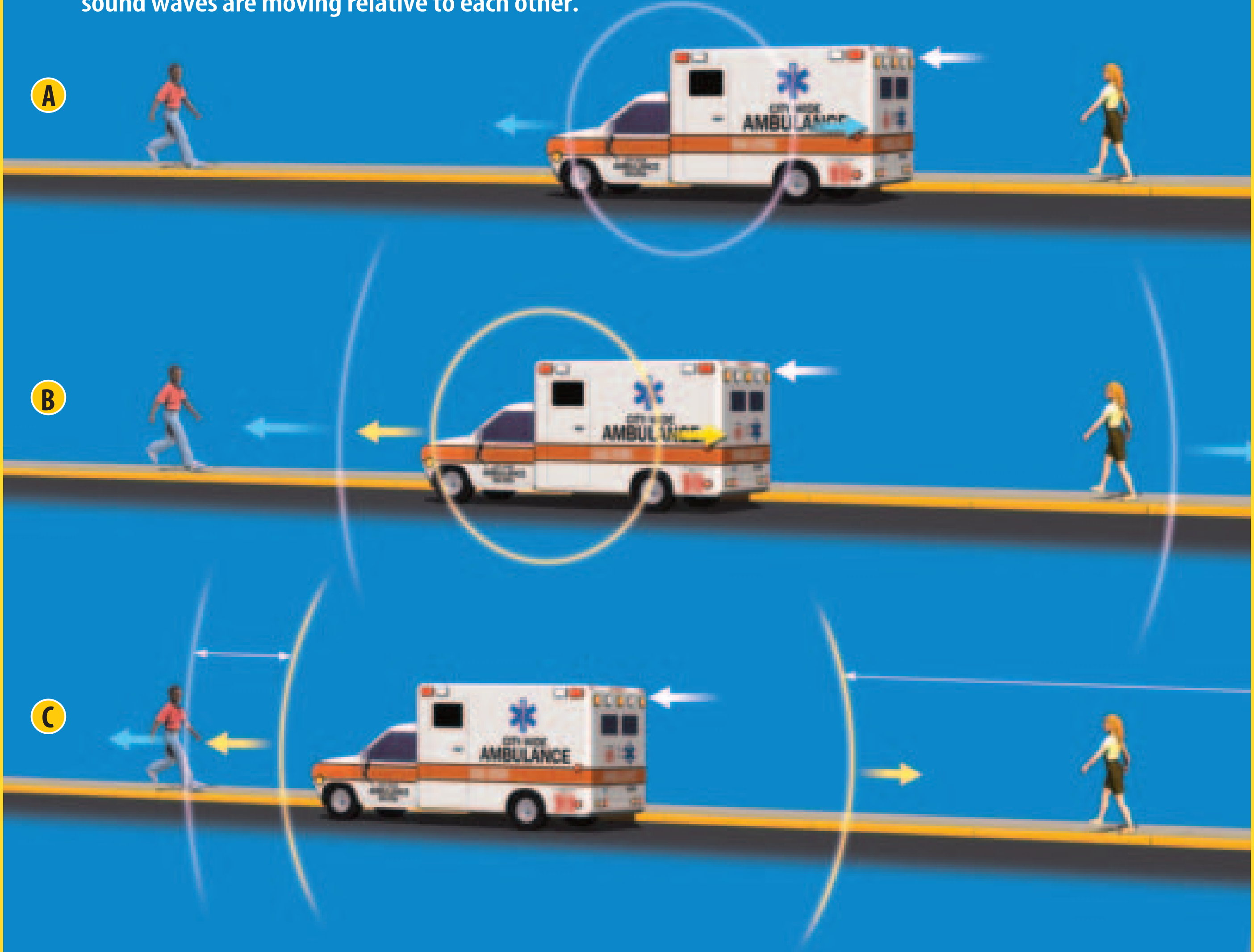
NOAA

NATIONAL GEOGRAPHIC

VISUALIZING THE DOPPLER EFFECT

Figure 9

You've probably heard the siren of an ambulance as it races through the streets. The sound of the siren seems to be higher in pitch as the ambulance approaches and lower in pitch as it moves away. This is the Doppler effect, which occurs when a listener and a source of sound waves are moving relative to each other.



A As the ambulance speeds down the street, its siren emits sound waves. Suppose the siren emits the compression part of a sound wave as it goes past the girl.

B As the ambulance continues moving, it emits another compression. Meanwhile, the first compression spreads out from the point from which it was emitted.

C The waves traveling in the direction that the ambulance is moving have compressions closer together. As a result, the wavelength is shorter and the boy hears a higher frequency sound as the ambulance moves toward him. The waves traveling in the opposite direction have compressions that are farther apart. The wavelength is longer and the girl hears a lower frequency sound as the ambulance moves away from her.

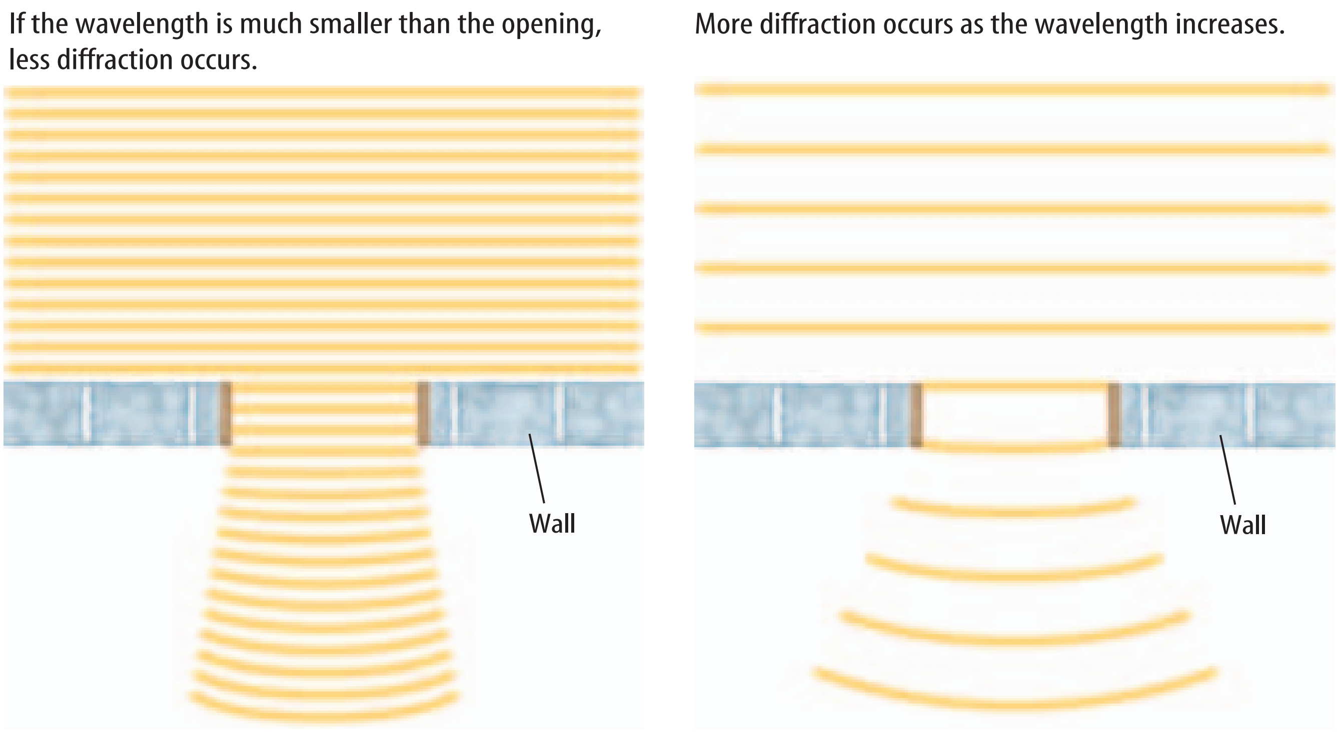


Figure 10 The spreading of a wave by diffraction depends on the wavelength and the size of the opening.

Diffraction of Sound Waves

Like other waves, sound waves diffract. This means they can bend around obstacles or spread out after passing through narrow openings. The amount of diffraction depends on the wavelength of the sound wave compared to the size of the obstacle or opening. If the wavelength is much smaller than the obstacle, almost no diffraction occurs. As the wavelength becomes closer to the size of the obstacle, the amount of diffraction increases.

You can observe diffraction of sound waves by visiting the school band room during practice. If you stand in the doorway, you will hear the band normally. However, if you stand to one side outside the door or around a corner, you will hear the lower-pitched instruments better. **Figure 10** shows why this happens. The sound waves that are produced by the lower-pitched instruments have lower frequencies and longer wavelengths. These wavelengths are closer to the size of the door opening than the higher-pitched sound waves are. As a result, the longer wavelengths diffract more, and you can hear them even when you're not standing in the doorway.

The diffraction of lower frequencies in the human voice allows you to hear someone talking even when the person is around the corner. This is different from an echo. Echoes occur when sound waves bounce off a reflecting surface. Diffraction occurs when a wave spreads out after passing through an opening, or when a wave bends around an obstacle.

Using Sound Waves

Sound waves can be used to treat certain medical problems. A process called ultrasound uses high-frequency sound waves as an alternative to some surgeries. For example, some people develop small, hard deposits in their kidneys or gallbladders. A doctor can focus ultrasound waves at the kidney or gallbladder. The ultrasound waves cause the deposits to vibrate rapidly until they break apart into small pieces. Then, the body can get rid of them.

Ultrasound can be used to make images of the inside of the body. One common use of ultrasound is to examine a developing fetus. Also, ultrasound along with the Doppler effect can be used to examine the functioning of the heart. An ultrasound image of the heart is shown in **Figure 11.** This technique can help determine if the heart valves and heart muscle are functioning properly, and how blood is flowing through the heart.

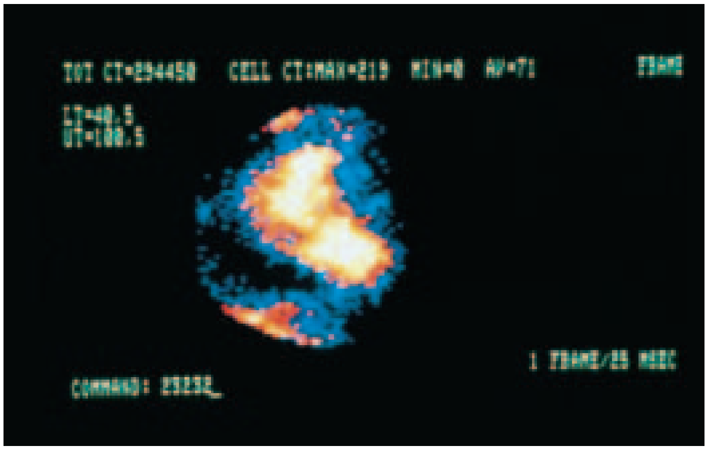


Figure 11 Ultrasound is used to make this image of the heart.
Describe *other ways ultrasound is used in medicine.*

section 1 review

Summary

Sound Waves

- Sound waves are compressional waves produced by vibrations.
- Sound travels fastest in solids and slowest in gases.
- Sound travels faster as the temperature of the medium increases.
- The energy carried by a sound wave increases as its amplitude increases.

Loudness and Pitch

- Loudness is the human perception of the energy carried by a sound wave.
- The pitch of a sound becomes higher as the frequency of the sound increases.

The Doppler Effect and Diffraction

- In the Doppler effect, the frequency of a sound wave changes if the source of the sound is moving relative to the listener.
- Diffraction occurs when sound waves bend around objects or spread out after passing through an opening.

Self Check

1. **Describe** how the loudness of a sound wave changes when the amplitude of the wave is increased.
2. **Explain** how the wavelength of a sound wave affects the diffraction of the sound wave through an open window.
3. **Describe** how echolocation could be used to measure the distance to the bottom of a lake.
4. **Discuss** how the spacing of particles in a sound wave changes as the amplitude of the wave decreases.
5. **Describe** how the wavelength of a sound wave changes if the frequency of the wave increases.
6. **Think Critically** You hear the pitch of the sound from an ambulance siren get lower, then get higher. Describe the motion of the ambulance relative to you.

Applying Math

7. **Calculate Distance** Sound travels through water at a speed of 1,483 m/s. Use the equation

$$\text{distance} = \text{speed} \times \text{time}$$

to calculate how far a sound wave in water will travel in 5 s.

Science Online booko.msscience.com/self_check_quiz

Spencer Grant/PhotoEdit, Inc.

Observe and Measure Reflection of Sound

Real-World Question

Like all waves, sound waves can be reflected. When sound waves strike a surface, in what direction does the reflected sound wave travel? In this activity, you'll focus sound waves using cardboard tubes to help answer this question. How are the angles made by incoming and reflected sound waves related?

Goals

- **Observe** reflection of sound waves.
- **Measure** the angles incoming and reflected sound waves make with a surface.

Materials

20-cm to 30-cm-long cardboard tubes (2)
watch that ticks audibly
protractor

Safety Precautions

Procedure

1. Work in groups of three. Each person should listen to the watch—first without a tube and then through a tube. The person who hears the watch most easily is the listener.
2. One person should hold one tube at an angle with one end above a table. Hold the watch at the other end of the tube.
3. The listener should hold the second tube at an angle, with one end near his or her ear and the other end near the end of the first tube that is just above the table. The tubes should be in the same vertical plane.
4. Move the first tube until the watch sounds loudest. The listener might need to cover the other ear to block out background noises.
5. The third person should measure the angle that each tube makes with the table.

Conclude and Apply

1. **Compare** the angles the incoming and reflected waves make with the table.
2. The normal is a line at 90 degrees to the table at the point where reflection occurs. Determine the angles the incoming and reflected waves make with the normal.
3. The law of reflection states that the angles the incoming and reflected waves make with the normal are equal. Do sound waves obey the law of reflection?

Communicating Your Data

Make a scientific illustration to show how the experiment was done. Describe your results using the illustration.

section 2

Music

What is music?

What do you like to listen to—rock 'n' roll, country, blues, jazz, rap, or classical? Music and noise are groups of sounds. Why do humans hear some sounds as music and other sounds as noise?

The answer involves patterns of sound. **Music** is a group of sounds that have been deliberately produced to make a regular pattern. Look at **Figure 12.** The sounds that make up music usually have a regular pattern of pitches, or notes. Some natural sounds such as the patter of rain on a roof, the sound of ocean waves splashing, or the songs of birds can sound musical. On the other hand, noise is usually a group of sounds with no regular pattern. Sounds you hear as noise are irregular and disorganized such as the sounds of traffic on a city street or the roar of a jet aircraft.

However, the difference between music and noise can vary from person to person. What one person considers to be music, another person might consider noise.

Natural Frequencies Music is created by vibrations. When you sing, your vocal cords vibrate. When you beat a drum, the drumhead vibrates. When you play a guitar, the strings vibrate.

If you tap on a bell with a hard object, the bell produces a sound. When you tap on a bell that is larger or smaller or has a different shape you hear a different sound. The bells sound different because each bell vibrates at different frequencies. A bell vibrates at frequencies that depend on its shape and the material it is made from. Every object will vibrate at certain frequencies called its **natural frequencies.**

as you read

What You'll Learn

- **Explain** the difference between music and noise.
- **Describe** how different instruments produce music.
- **Explain** how you hear.

Why It's Important

Music is made by people in every part of the world.

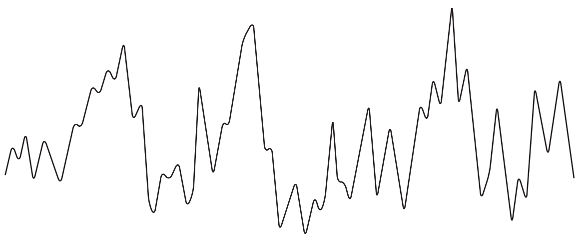
Review Vocabulary

compressional wave: a type of mechanical wave in which matter in the medium moves forward and backward in the same direction the wave travels

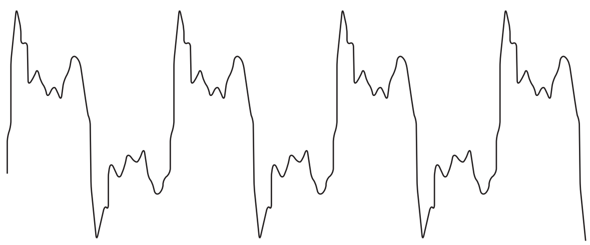
New Vocabulary

- music
- natural frequencies
- resonance
- fundamental frequency
- overtone
- reverberation
- eardrum

Figure 12 Music and noise have different types of sound patterns.



Noise has no specific or regular sound wave pattern.



Music is organized sound. Music has regular sound wave patterns and structures.

INTEGRATE Social Studies

Reducing Earthquake Damage The shaking of the ground during an earthquake can cause buildings to resonate. The increased vibration of a building due to resonance could result in the collapse of the building, causing injuries and loss of life. To reduce damage during earthquakes, buildings are designed to resonate at frequencies different than those that occur during earthquakes. Research how buildings are designed to reduce damage caused by earthquakes.

Musical Instruments and Natural Frequencies Many objects vibrate at one or more natural frequencies when they are struck or disturbed. Like a bell, the natural frequencies of any object depend on the size and shape of the object and the material it is made from. Musical instruments use the natural frequencies of strings, drumheads, or columns of air contained in pipes to produce various musical notes.

Reading Check *What determines the natural frequencies?*

Resonance You may have seen the comedy routine in which a loud soprano sings high enough to shatter glass. Sometimes sound waves cause an object to vibrate. When a tuning fork is struck, it vibrates at its natural frequency and produces a sound wave with the same frequency. Suppose you have two tuning forks with the same natural frequency. You strike one tuning fork, and the sound waves it produces strike the other tuning fork. These sound waves would cause the tuning fork that wasn't struck to absorb energy and vibrate. This is an example of resonance. **Resonance** occurs when an object is made to vibrate at its natural frequencies by absorbing energy from a sound wave or another object vibrating at these frequencies.

Musical instruments use resonance to amplify their sounds. Look at **Figure 13.** The vibrating tuning fork might cause the table to vibrate at the same frequency, or resonate. The combined vibrations of the table and the tuning fork increase the loudness of the sound waves produced.

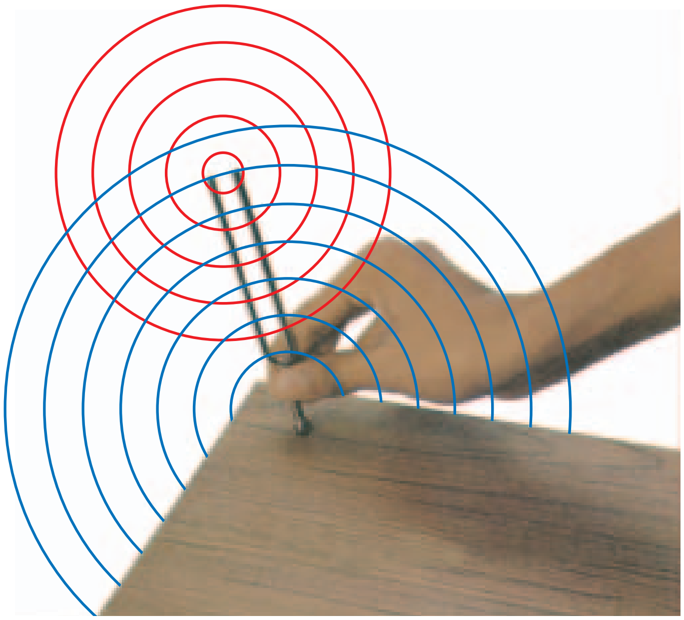


Figure 13 When a vibrating tuning fork is placed against a table, resonance might cause the table to vibrate.

Overtones

Before a concert, all orchestra musicians tune their instruments by playing the same note. Even though the note has the same pitch, it sounds different for each instrument. It also sounds different from a tuning fork that vibrates at the same frequency as the note.

A tuning fork produces a single frequency, called a pure tone. However, the notes produced by musical instruments are not pure tones. Most objects have more than one natural frequency at which they can vibrate. As a result, they produce sound waves of more than one frequency.

If you play a single note on a guitar, the pitch that you hear is the lowest frequency produced by the vibrating string. The lowest frequency produced by a vibrating object is the **fundamental frequency.** The vibrating string also produces higher frequencies. These higher frequencies are **overtones.** Overtones have frequencies that are multiples of the fundamental frequency, as in **Figure 14.** The number and intensity of the overtones produced by each instrument are different and give instruments their distinctive sound quality.

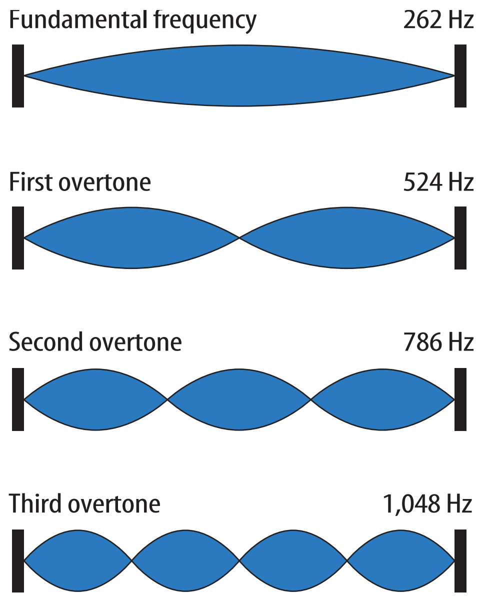


Figure 14 A string vibrates at a fundamental frequency, as well as at overtones. The overtones are multiples of that frequency.

Musical Scales

A musical instrument is a device that produces musical sounds. These sounds are usually part of a musical scale that is a sequence of notes with certain frequencies. For example, **Figure 15** shows the sequence of notes that belong to the musical scale of C. Notice that the frequency produced by the instrument doubles after eight successive notes of the scale are played. Other musical scales consist of a different sequence of frequencies.

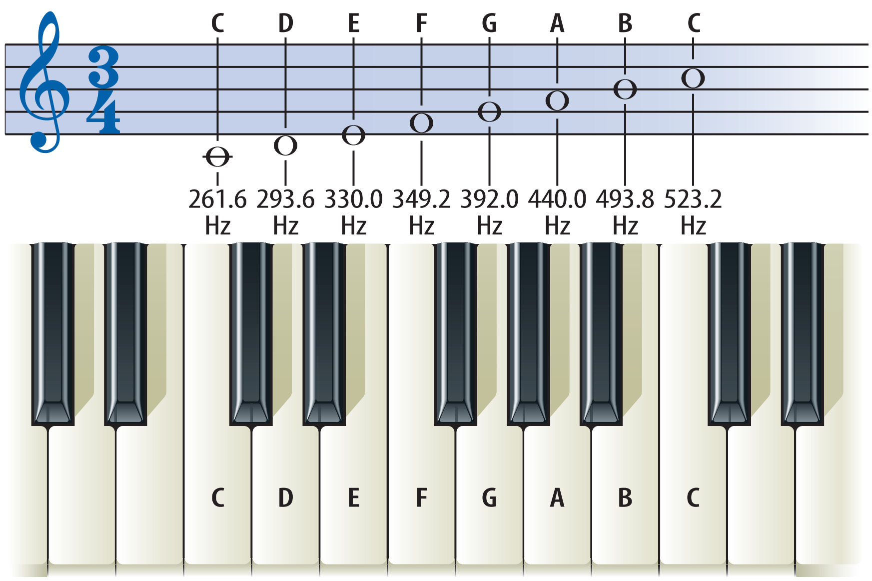


Figure 15 A piano produces a sequence of notes that are a part of a musical scale.
Describe *how the frequencies of the two C notes on this scale are related.*

Stringed Instruments

Stringed instruments, like the cello shown in **Figure 16,** produce music by making strings vibrate. Different methods are used to make the strings vibrate—guitar strings are plucked, piano strings are struck, and a bow is slid across cello strings. The strings often are made of wire. The pitch of the note depends on the length, diameter, and tension of the string—if the string is shorter, narrower, or tighter, the pitch increases. For example, pressing down on a vibrating guitar string shortens its length and produces a note with a higher pitch. Similarly, the thinner guitar strings produce a higher pitch than the thicker strings.

Amplifying Vibrations The sound produced by a vibrating string usually is soft. To amplify the sound, stringed instruments usually have a hollow chamber, or box, called a resonator, which contains air. The resonator absorbs energy from the vibrating string and vibrates at its natural frequencies. For example, the body of a guitar is a resonator that amplifies the sound that is produced by the vibrating strings. The vibrating strings cause the guitar's body and the air inside it to resonate. As a result, the vibrating guitar strings sound louder, just as the tuning fork that was placed against the table sounded louder.

Mini LAB

Modeling a Stringed Instrument

Procedure

1. Stretch a **rubber band** between your fingers.
2. Pluck the rubber band. Listen to the sound and observe the shape of the vibrating band. Record what you hear and see.
3. Stretch the band farther and repeat step 2.
4. Shorten the length of the band that can vibrate by holding your finger on one point. Repeat step 2.
5. Stretch the rubber band over an open box, such as a **shoe box.** Repeat step 2.

Analysis

1. How did the sound change when you stretched the rubber band? Was this what you expected? Explain.
2. How did the sound change when you stretched the band over the box? Did you expect this? Explain.

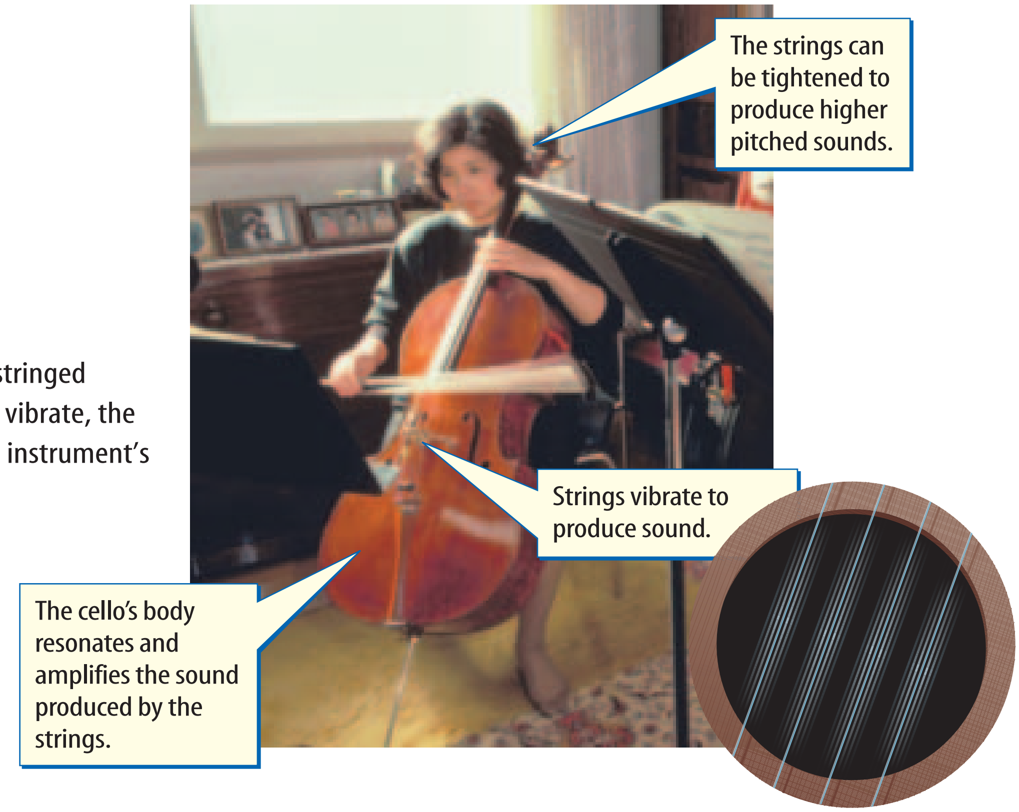


Figure 16 A cello is a stringed instrument. When strings vibrate, the natural frequencies of the instrument's body amplify the sound.

Percussion

Percussion instruments, such as the drum shown in **Figure 17,** are struck to make a sound. Striking the top surface of the drum causes it to vibrate. The vibrating drumhead is attached to a chamber that resonates and amplifies the sound.

Drums and Pitch Some drums have a fixed pitch, but some can be tuned to play different notes. For example, if the drumhead on a kettledrum is tightened, the natural frequency of the drumhead is increased. As a result, the pitches of the sounds produced by the kettledrum get higher. A steel drum, shown in **Figure 17,** plays different notes in the scale when different areas in the drum are struck. In a xylophone, wood or metal bars of different lengths are struck. The longer the bar is, the lower the note that it produces is.

Figure 17 The sounds produced by drums depend on the material that is vibrating.

The vibrating drumhead of this drum is amplified by the resonating air in the body of the drum.

The vibrating steel surface in a steel drum produces loud sounds that don't need to be amplified by an air-filled chamber.

Brass and Woodwinds

Just as the bars of a xylophone have different natural frequencies, so do the air columns in pipes of different lengths. Brass and woodwind instruments, such as those in **Figure 18,** are essentially pipes or tubes of different lengths that sometimes are twisted around to make them easier to hold and carry. To make music from these instruments, the air in the pipes is made to vibrate at various frequencies.

Different methods are used to make the air column vibrate. A musician playing a brass instrument, such as a trumpet, makes the air column vibrate by vibrating the lips and blowing into the mouthpiece. Woodwinds such as clarinets, saxophones, and oboes contain one or two reeds in the mouthpiece that vibrate the air column when the musician blows into the mouthpiece. Flutes also are woodwinds, but a flute player blows across a narrow opening to make the air column vibrate.

Figure 18 Brass and woodwind instruments produce sounds by causing a column of air to vibrate.

Figure 19 A flute changes pitch as holes are opened and closed.

Changing Pitch in Woodwinds To change the note that is being played in a woodwind instrument, a musician changes the length of the resonating column of air. By making the length of the vibrating air column shorter, the pitch of the sound produced is made higher. In a woodwind such as a flute, saxophone, or clarinet, this is done by closing and opening finger holes along the length of the instrument, as shown in **Figure 19.**

Changing Pitch in Brass In brass instruments, musicians vary the pitch in other ways. One is by blowing harder to make the air resonate at a higher natural frequency. Another way is by pressing valves that change the length of the tube.

Beats

Recall that interference occurs when two waves overlap and combine to form a new wave. The new wave formed by interference can have a different frequency, wavelength, and amplitude than the two original waves.

Suppose two notes close in frequency are played at the same time. The two notes interfere to form a new sound whose loudness increases and decreases several times a second. If you were listening to the sound, you would hear a series of beats as the sound got louder and softer. The beat frequency, or the number of beats you would hear each second, is equal to the difference in the frequencies of the two notes.

For example, if the two notes have frequencies of 329 Hz and 332 Hz, the beat frequency would be 3 Hz. You would hear the sound get louder and softer—a beat—three times each second.

Figure 20 A piano can be tuned by using beats.

Beats Help Tune Instruments Beats are used to help tune instruments. For example, a piano tuner, like the one shown in **Figure 20,** might hit a tuning fork and then the corresponding key on the piano. Beats are heard when the difference in pitch is small. The piano string is tuned properly when the beats disappear. You might have heard beats while listening to an orchestra tune before a performance. You also can hear beats produced by two engines vibrating at slightly different frequencies.

Reverberation

Sound is reflected by hard surfaces. In an empty gymnasium, the sound of your voice can be reflected back and forth several times by the floor, walls, and ceiling. Repeated echoes of sound are called **reverberation.** In a gym, reverberation makes the sound of your voice linger before it dies out. Some reverberation can make voices or music sound bright and lively. Too little reverberation makes the sound flat and lifeless. However, reverberation can produce a confusing mess of noise if too many sounds linger for too long.

Concert halls and theaters, such as the one in **Figure 21,** are designed to produce the appropriate level of reverberation. Acoustical engineers use soft materials to reduce echoes. Special panels that are attached to the walls or suspended from the ceiling are designed to reflect sound toward the audience.

Science Online

Topic: Controlling Reverberation

Visit booko.msscience.com for Web Links to information about how acoustical engineers control reverberation.

Activity Make a list of the materials engineers use to reduce and enhance reverberation.

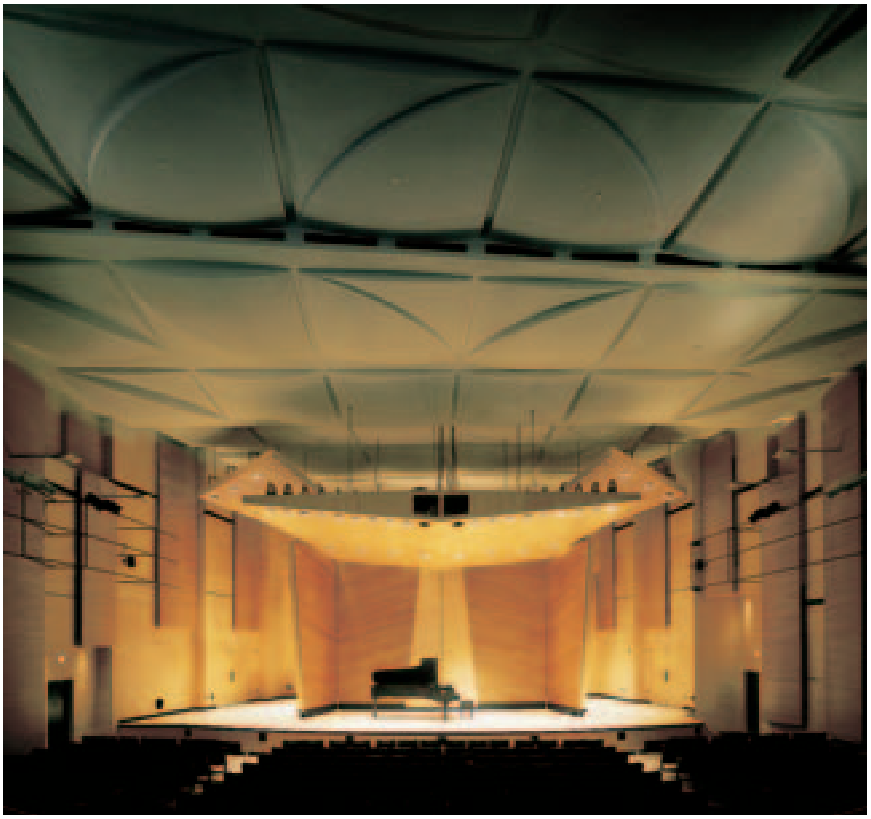


Figure 21 The shape of a concert hall and the materials it contains are designed to control the reflection of sound waves.

SuperStock

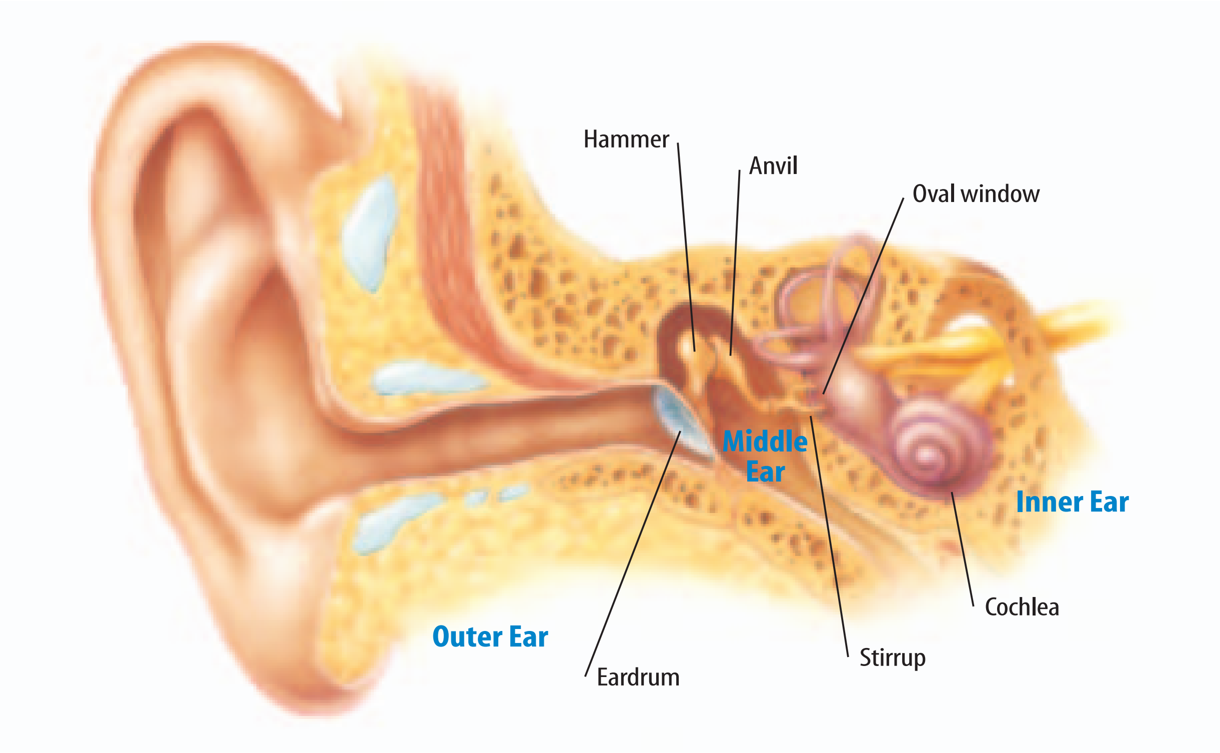


Figure 22 The human ear has three different parts—the outer ear, the middle ear, and the inner ear.

The Ear

You hear sounds with your ears. The ear is a complex organ that is able to detect a wide range of sounds. The ear can detect frequencies ranging from about 20 Hz to about 20,000 Hz. The ear also can detect a wide range of sound intensities. The faintest sounds you can hear carry about one trillionth the amount of energy as the loudest sounds you can hear. The human ear is illustrated in **Figure 22.** It has three parts—the outer ear, the middle ear, and the inner ear.

The Outer Ear—Sound Collector Your outer ear collects sound waves and directs them into the ear canal. Notice that your outer ear is shaped roughly like a funnel. This shape helps collect sound waves.

Animals that rely on hearing to locate predators or prey often have larger, more adjustable ears than humans, as shown in **Figure 23.** A barn owl, which relies on its excellent hearing for hunting at night, does not have outer ears made of flesh. Instead, the arrangement of its facial feathers helps direct sound to its ears. Some sea mammals, on the other hand, have only small holes for outer ears, even though their hearing is good.

Figure 23 Animals, such as rabbits and owls, have ears that are adapted to their different needs.

The Middle Ear—Sound Amplifier When sound waves reach the middle ear, they vibrate the **eardrum,** which is a membrane that stretches across the ear canal like a drumhead. When the eardrum vibrates, it transmits vibrations to three small connected bones—the hammer, anvil, and stirrup. The bones amplify the vibrations, just as a lever can change a small movement at one end into a larger movement at the other.

(t)Geostock/PhotoDisc, (b)SuperStock

The Inner Ear—Sound Interpreter The stirrup vibrates a second membrane called the oval window. This marks the start of the inner ear, which is filled with fluid. Vibrations in the fluid are transmitted to hair-tipped cells lining the cochlea, as shown in **Figure 24.** Different sounds vibrate the cells in different ways. The cells generate signals containing information about the frequency, intensity, and duration of the sound. The nerve impulses travel along the auditory nerve and are transmitted to the part of the brain that is responsible for hearing.

Reading Check *Where are waves detected and interpreted in the ear?*

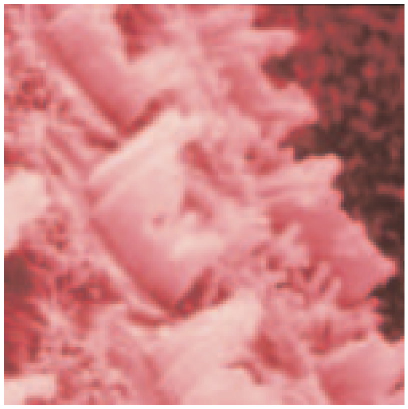


Figure 24 The inner ear contains tiny hair cells that convert vibrations into nerve impulses that travel to the brain.

Hearing Loss

The ear can be damaged by disease, age, and exposure to loud sounds. For example, constant exposure to loud noise can damage hair cells in the cochlea. If damaged mammalian hair cells die, some loss of hearing results because mammals cannot make new hair cells. Also, some hair cells and nerve fibers in the inner ear degenerate and are lost as people age. It is estimated that about 30 percent of people over 65 have some hearing loss due to aging.

section 2 review

Summary

What is music?

- Music is sound that is deliberately produced in a regular pattern.
- Objects vibrate at certain natural frequencies.
- The lowest frequency produced by a vibrating object is the object's fundamental frequency.
- The overtones produced by a vibrating object are multiples of the fundamental frequency.

Musical Instruments and Hearing

- In stringed instruments the sounds made by vibrating strings are amplified by a resonator.
- Percussion instruments produce sound by vibrating when they are struck.
- Brass and woodwind instruments produce sound by vibrating a column of air.
- The ear collects sound waves, amplifies the sound, and interprets the sound.

Self Check

1. **Describe** how music and noise are different.
2. **Infer** Two bars on a xylophone are 10 cm long and 14 cm long. Identify which bar produces a lower pitch when struck and explain why.
3. **Describe** the parts of the human ear and the function of each part in enabling you to hear sound.
4. **Predict** how the sound produced by a guitar string changes as the length of the string is made shorter.
5. **Diagram** the fundamental and the first two overtones for a vibrating string.
6. **Think Critically** How does reverberation explain why your voice sounds different in a gym than it does in your living room?

Applying Math

7. **Calculate Overtone Frequency** A guitar string has a fundamental frequency of 440 Hz. What is the frequency of the second overtone?

Science Online booko.msscience.com/self_check_quiz

Fred E. Hossler/Visuals Unlimited

LAB

Design Your Own

Music

Goals

- **Design** an experiment to compare the changes that are needed in different instruments to produce a variety of different notes.
- **Observe** which changes are made when playing different notes.
- **Measure and record** these changes whenever possible.

Possible Materials

musical instruments
measuring tape
tuning forks

Safety Precautions

Properly clean the mouthpiece of any instrument before it is used by another student.

Real-World Question

The pitch of a note that is played on an instrument sometimes depends on the length of the string, the air column, or some other vibrating part. Exactly how does sound correspond to the size or length of the vibrating part? Is this true for different instruments? What causes different instruments to produce different notes?

Form a Hypothesis

Based on your reading and observations, make a hypothesis about what changes in an instrument to produce different notes.

Test Your Hypothesis

Make a Plan

1. You should do this lab as a class, using as many instruments as possible. You might want to go to the music room or invite friends and relatives who play an instrument to visit the class.

(t)Will McIntyre/Photo Researchers, (b)Oliver Benn/Stone/Getty Images

2. As a group, decide how you will measure changes in instruments. For wind instruments, can you measure the length of the vibrating air column? For stringed instruments, can you measure the length and thickness of the vibrating string?
3. Refer to the table of wavelengths and frequencies for notes in the scale. Note that no measurements are given—if you measure C to correspond to a string length of 30 cm, for example, the note G will correspond to two thirds of that length.
4. Decide which musical notes you will compare. Prepare a table to collect your data. List the notes you have selected.

Ratios of Wavelengths and Frequencies of Musical Notes

Note	Wavelength	Frequency
C	1	1
D	8/9	9/8
E	4/5	5/4
F	3/4	4/3
G	2/3	3/2
A	3/5	5/3
B	8/15	15/8
C	1/2	2

Follow Your Plan

1. Make sure your teacher approves your plan before you start.
2. Carry out the experiment as planned.
3. While doing the experiment, record your observations and complete the data table.

Analyze Your Data

1. **Compare** the change in each instrument when the two notes are produced.
2. **Compare and contrast** the changes between instruments.
3. What were the controls in this experiment?
4. What were the variables in this experiment?
5. How did you eliminate bias?

Conclude and Apply

1. How does changing the length of the vibrating column of air in a wind instrument affect the note that is played?
2. Describe how you would modify an instrument to increase the pitch of a note that is played.

Communicating Your Data

Demonstrate to another teacher or to family members how the change in the instrument produces a change in sound.

It's a Wrap!

No matter how quickly or slowly you open a candy wrapper, it always will make a noise

You're at the movies and it's the most exciting part of the film. The audience is silent and intent on what is happening on the screen. At that moment, you decide to unwrap a piece of candy. CRACKLE! POP! SNAP! No matter how you do it, the candy wrapper makes a lot of noise.

Why can't you unwrap candy without making a racket? To test this plastics problem, researchers put some crinkly wrappers in a silent room. Then they stretched out the wrappers and recorded the sounds they made. Next, the sounds were analyzed by a computer. The research team discovered that the wrapper didn't make a continuous sound. Instead, it made many separate little popping noises, each taking only a thousandth of a second. They found that whether you open the wrapper quickly or slowly the amount of noise made by the pops will be the same. "And there's nothing you can do about it," said a member of the research team.

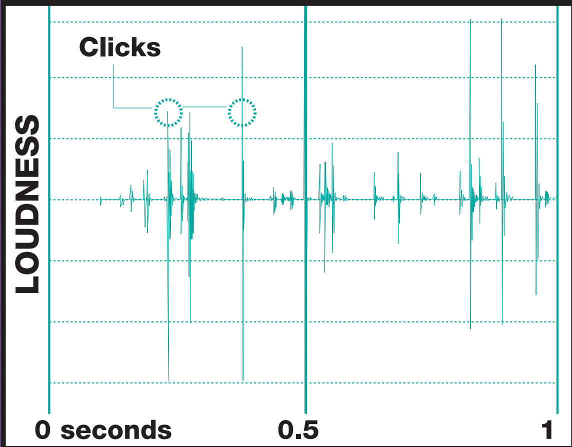
By understanding what makes a plastic wrapper snap when it changes shape, doctors can better understand molecules in the human body that also change shape.

The pop chart

SOUND LEVEL OVER TIME

The sound that a candy wrapper makes is emitted as a series of pulses or clicks. So, opening a wrapper slowly only increases the length of time in between clicks, but the amount of noise remains the same.

(TALLER SPIKES SIGNIFY LOUDER CLICKS)



Source: Eric Kramer, Simon's Rock College, 2000

Recall and Retell Have you ever opened a candy wrapper in a quiet place? Did it bother other people? If so, did you try to open it more slowly? What happened?

Science Online
For more information, visit booko.msscience.com/time

Douglas Whyte/The Stock Market/CORBIS

Reviewing Main Ideas

Section 1 What is sound?

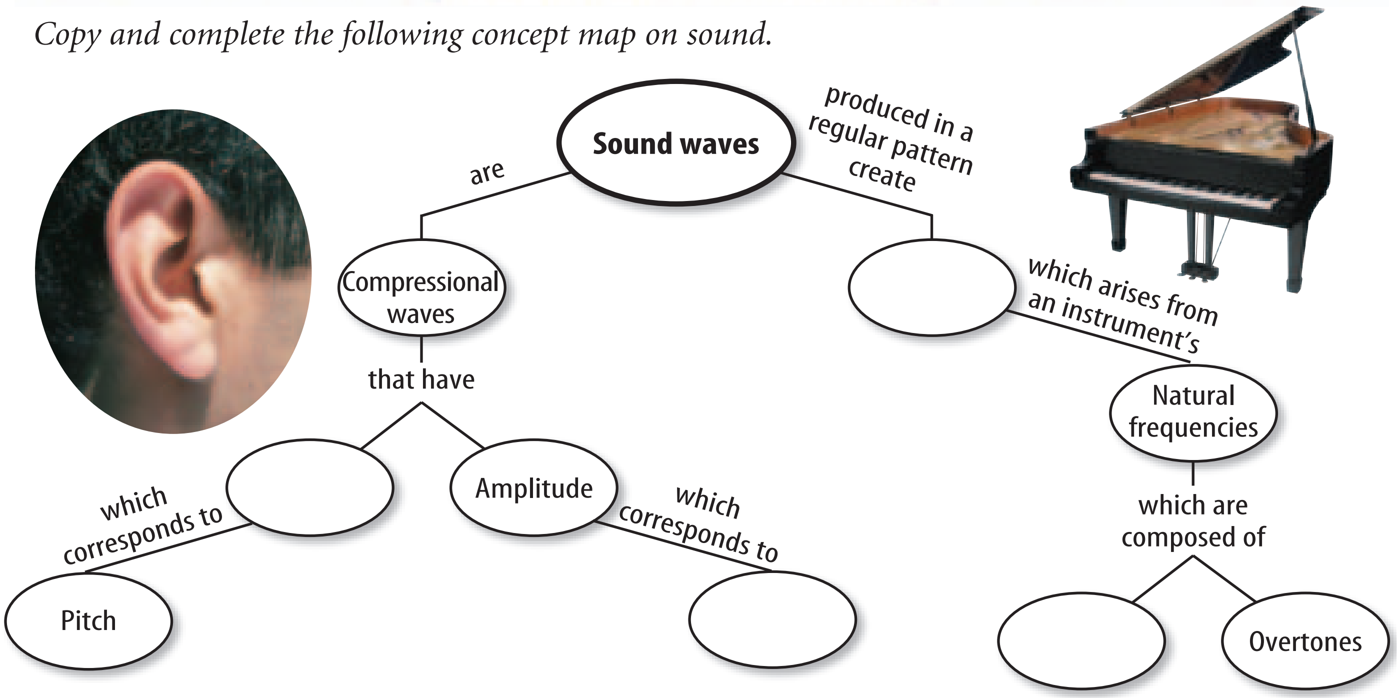
1. Sound is a compressional wave that travels through matter, such as air. Sound is produced by something that vibrates.
2. The speed of sound depends on the material in which it is traveling.
3. The larger the amplitude of a sound wave, the more energy it carries and the louder the sound.
4. The pitch of a sound wave becomes higher as its frequency increases. Sound waves can reflect and diffract.
5. The Doppler effect occurs when a source of sound and a listener are in motion relative to each other. The pitch of the sound heard by the listener changes.

Section 2 Music

1. Music is made of sounds that are used in a regular pattern. Noise is made of sounds that are irregular and disorganized.
2. Objects vibrate at their natural frequencies. These depend on the shape of the object and the material it's made of.
3. Resonance occurs when an object is made to vibrate by absorbing energy at one of its natural frequencies.
4. Musical instruments produce notes by vibrating at their natural frequencies.
5. Beats occur when two waves of nearly the same frequency interfere.
6. The ear collects sound waves and converts sound waves to nerve impulses.

Visualizing Main Ideas

Copy and complete the following concept map on sound.



(l)The Photo Works/Photo Researchers, (r)PhotoDisc

chapter 2 Review

Using Vocabulary

Doppler effect p. 42	music p. 47
eardrum p. 54	natural frequency p. 47
echo p. 41	overtone p. 49
fundamental frequency p. 49	pitch p. 40
loudness p. 38	resonance p. 48
	reverberation p. 53

Distinguish between the terms in the following pairs.

1. overtones—fundamental frequency
2. pitch—sound wave
3. pitch—Doppler effect
4. loudness—resonance
5. fundamental frequency—natural frequency
6. loudness—amplitude
7. natural frequency—overtone
8. reverberation—resonance

Checking Concepts

Choose the word or phrase that best answers the question.

9. A tone that is lower in pitch is lower in what characteristic?
   A) frequency **C)** loudness
   B) wavelength **D)** resonance

10. If the wave speed stays the same, which of the following decreases as the frequency increases?
    A) pitch **C)** loudness
    B) wavelength **D)** resonance

11. What part of the ear is damaged most easily by continued exposure to loud noise?
    A) eardrum **C)** oval window
    B) stirrup **D)** hair cells

12. What is an echo?
    A) diffracted sound
    B) resonating sound
    C) reflected sound
    D) an overtone

13. A trumpeter depresses keys to make the column of air resonating in the trumpet shorter. What happens to the note being played?
    A) Its pitch is higher.
    B) Its pitch is lower.
    C) It is quieter.
    D) It is louder.

14. When tuning a violin, a string is tightened. What happens to a note being played on the string?
    A) Its pitch is higher.
    B) Its pitch is lower.
    C) It is quieter.
    D) It is louder.

15. As air becomes warmer, how does the speed of sound in air change?
    A) It increases. **C)** It doesn't change.
    B) It decreases. **D)** It oscillates.

16. Sound waves are which type of wave?
    A) slow **C)** compressional
    B) transverse **D)** electromagnetic

17. What does the middle ear do?
    A) focuses sound
    B) interprets sound
    C) collects sound
    D) transmits and amplifies sound

18. An ambulance siren speeds away from you. What happens to the pitch of the siren?
    A) It becomes softer.
    B) It becomes louder.
    C) It decreases.
    D) It increases.

Science Online booko.msscience.com/vocabulary_puzzlemaker

Thinking Critically

19. Explain Some xylophones have open pipes of different lengths hung under each bar. The longer a bar is, the longer the pipe beneath it. Explain how these pipes help amplify the sound of the xylophone.

20. Infer why you don't notice the Doppler effect for a slow moving train.

21. Predict Suppose the movement of the bones in the middle ear were reduced. Which would be more affected—the ability to hear quiet sounds or the ability to hear high frequencies? Explain your answer.

22. Explain The triangle is a percussion instrument consisting of an open metal triangle hanging from a string. A chiming sound is heard when the triangle is struck by a metal rod. If the triangle is held in the hand, a quiet dull sound is heard when it is struck. Why does holding the triangle make the sound quieter?

Use the table below to answer question 23.

Speed of Sound Through Different Materials

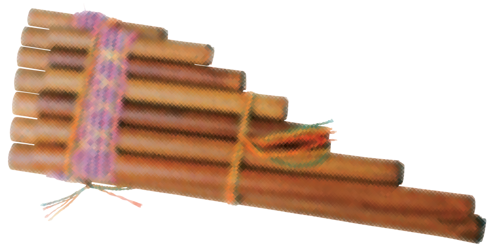
Material	Speed (m/s)
Air	343
Water	1,483
Steel	5,940
Glass	5,640

23. Calculate Using the table above, determine the total amount of time needed for a sound wave to travel 3.5 km through air and then 100.0 m through water.

24. Predict If the holes of a flute are all covered while playing, then all uncovered, what happens to the length of the vibrating air column? What happens to the pitch of the note?

25. Identify Variables and Controls Describe an experiment to demonstrate that sound is diffracted.

26. Interpret Scientific Illustrations The picture below shows pan pipes. How are different notes produced by blowing on pan pipes?



Performance Activities

27. Recital Perform a short musical piece on an instrument. Explain how your actions changed the notes that were produced.

28. Pamphlet Make a pamphlet describing how a hearing aid works.

29. Interview Interview several people over 65 with some form of hearing loss. Create a table that shows the age of each person and how their hearing has changed with age.

Applying Math

30. Beats Two flutes are playing at the same time. One flute plays a note with a frequency of 524 Hz. If two beats per second are heard, what are the possible frequencies the other flute is playing?

31. Overtones Make a table showing the first three overtones of C, which has a frequency of 262 Hz, and G, which has a frequency of 392 Hz.

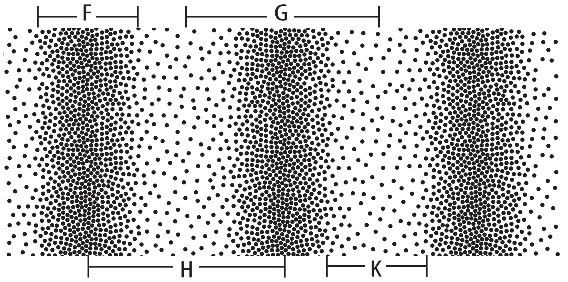
Part 1 Multiple Choice

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

1. In which of the following materials does sound travel the fastest?
A. empty space **C.** air
B. water **D.** steel

2. How can the pitch of the sound made by a guitar string be lowered?
A. by shortening the part of the string that vibrates
B. by tightening the string
C. by replacing the string with a thicker string
D. by plucking the string harder

Use the figure below to answer questions 3 and 4.



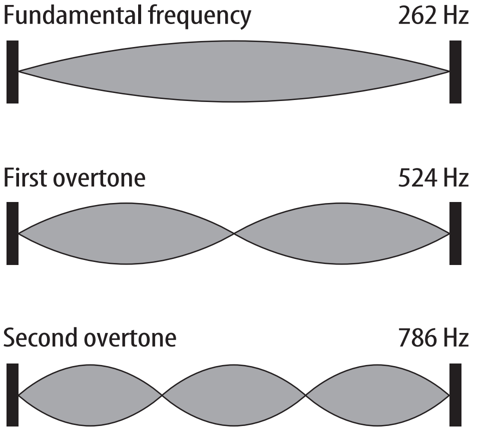
3. What part of the wave is shown at F?
A. rarefaction **C.** wavelength
B. compression **D.** amplitude

4. What part of the wave is shown at H?
A. rarefaction **C.** wavelength
B. compression **D.** amplitude

5. What happens to the particles of matter when a compressional wave moves through the matter?
A. The particles do not move.
B. The particles move back and forth along the wave direction.
C. The particles move back and forth and are carried along with the wave.
D. The particles move at right angles to the direction the wave travels.

6. If you were on a moving train, what would happen to the pitch of a bell at a crossing as you approached and then passed by the crossing?
A. It would seem higher, then lower.
B. It would remain the same.
C. It would seem lower and then higher.
D. It would keep getting lower.

Use the figure below to answer questions 7 and 8.



7. How are the overtone frequencies of any vibrating object related to the fundamental frequency of vibration?
A. They are multiples of the fundamental.
B. They are not related to the fundamental.
C. They equal twice the fundamental.
D. They are lower than the fundamental.

8. Which of the following is the frequency of the third overtone?
A. 1,572 Hz **C.** 1,048 Hz
B. 1,000 Hz **D.** 786 Hz

9. Which of the following is NOT related to the amplitude of a sound wave?
A. energy carried by the wave
B. loudness of a sound
C. pitch of a sound
D. how spread out the particles are in the compressions and rarefactions

Part 2 Short Response/Grid In

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

10. What is the difference between diffracted sound waves and echoes?

Use the figure below to answer questions 11–13.

Speed of Sound in Different Materials	
Material	**Speed of sound (m/s)**
Air	343
Water	1,483
Steel	5,940

11. A fish locator 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 boat, how long would it take sound to make the round trip in the water?

12. Suppose you are at a baseball game 150 m from home plate. How long after the batter hits the ball do you hear the sound?

13. A friend drops a stone on a steel railroad track. If the sound made by the stone hitting the track reaches you in 0.8 s, how far away is your friend?

14. Why do different objects produce different sounds when they are struck?

15. Explain how one vibrating tuning fork could make a second tuning fork also vibrate. What is this an example of?

Test-Taking Tip

Notice Units Read carefully and make note of the units used in any measurement.

Question 13 Notice the units used for time in the question and the units for speed given in the table.

Part 3 Open Ended

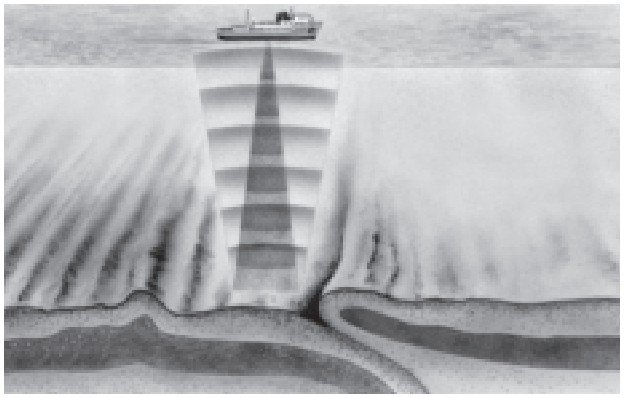
Record your answers on a sheet of paper.

16. Why do different musical instruments sound different even when they play a note with the same pitch?

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

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

Use the figure below to answer questions 19.



19. Describe how the process shown in the figure can be used to map the ocean floor.

20. When a sound wave passes through an opening, what does the amount of diffraction depend on?

21. Describe how a cello produces and amplifies sounds.

22. People who work on the ground near jet runways are required to wear ear protection. Explain why this is necessary.

23. Bats use ultrasound when they echolocate prey. If ultrasound waves bounce off an insect that is flying away from the bat, how would the frequency of the wave be affected? What is this effect called?