CHAPTER 6 Waves

Chapter Outline

This immense wall of moving water gives the surfer an amazing ride. The swelling surf will raise him up and push him forward as though he's as light as a feather. All he needs to do is keep his balance on the surfboard. The incredible power of the wave will do the rest. When you think of waves, ocean waves like this one probably come to mind. But there are many other examples of waves, some that affect all of us in our daily lives. What are waves, and what causes them? What are some other examples of waves? Read on to find out.

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6.1 Characteristics of Waves

Lesson Objectives

- Define mechanical wave.
- Describe transverse waves.
- Identify longitudinal waves.
- Describe surface waves.

Lesson Vocabulary

- longitudinal wave
- mechanical wave
- surface wave
- transverse wave

Introduction

Ocean waves are among the most impressive waves in the world. They clearly show that waves transfer energy. In the case of ocean waves, energy is transferred through matter. But some waves, called electromagnetic waves, can transfer energy without traveling through matter. These waves can travel through space. You can read more about electromagnetic waves in the chapter "Electromagnetic Radiation." Waves that transfer energy through matter are the focus of the present chapter. These waves are called mechanical waves.

Mechanical Waves

A **mechanical wave** is a disturbance in matter that transfers energy from place to place. A mechanical wave starts when matter is disturbed. An example of a mechanical wave is pictured in **Figure** 6.1. A drop of water falls into a pond. This disturbs the water in the pond. What happens next? The disturbance travels outward from the drop in all directions. This is the wave. A source of energy is needed to start a mechanical wave. In this case, the energy comes from the falling drop of water.

The Medium

The energy of a mechanical wave can travel only through matter. This matter is called the medium (*plural*, media). The medium in **Figure** 6.1 is a liquid —the water in the pond. But the medium of a mechanical wave can be any state of matter, including a solid or a gas. It's important to note that particles of matter in the medium don't actually travel along with the wave. Only the energy travels. The particles of the medium just vibrate, or move back-and-forth or

FIGURE 6.1
A drop of water causes a disturbance that travels through the pond as a wave.

up-and-down in one spot, always returning to their original positions. As the particles vibrate, they pass the energy of the disturbance to the particles next to them, which pass the energy to the particles next to them, and so on.

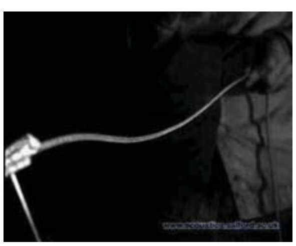
Types of Mechanical Waves

There are three types of mechanical waves. They differ in how they travel through a medium. The three types are transverse, longitudinal, and surface waves. All three types are described in detail below.

Transverse Waves

A **transverse wave** is a wave in which the medium vibrates at right angles to the direction that the wave travels. An example of a transverse wave is a wave in a rope, like the one pictured in **Figure** 6.2. In this wave, energy is provided by a person's hand moving one end of the rope up and down. The direction of the wave is down the length of the rope away from the person's hand. The rope itself moves up and down as the wave passes through it. You can see a brief video of a transverse wave in a rope at this URL: http://www.youtube.com/watch?v=TZIr9mpERbU&NR=1 .

To see a transverse wave in slow motion, go to this URL: http://www.youtube.com/watch?v=g49mahYeNgc (0:22).



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Crests and Troughs

A transverse wave can be characterized by the high and low points reached by particles of the medium as the wave passes through. This is illustrated in **Figure** 6.3. The high points are called crests, and the low points are called troughs.

S Waves

Another example of transverse waves occurs with earthquakes. The disturbance that causes an earthquake sends transverse waves through underground rocks in all directions from the disturbance. Earthquake waves that travel this way are called secondary, or S, waves. An S wave is illustrated in **Figure** 6.4.

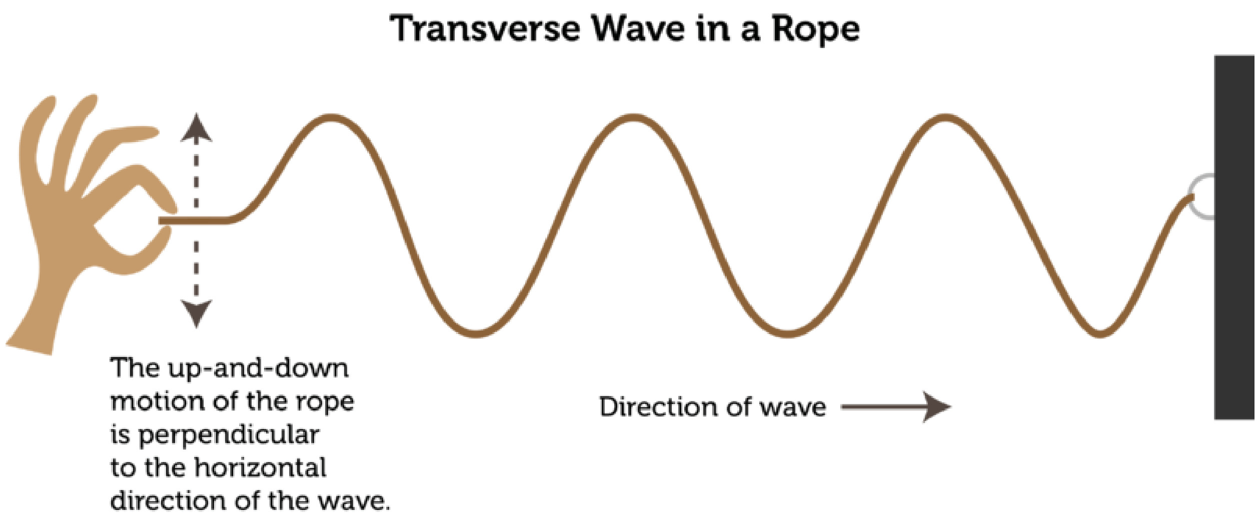


FIGURE 6.2
In a transverse wave, the medium moves at right angles to the direction of the wave.

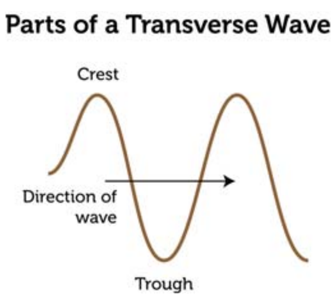


FIGURE 6.3
Crests and troughs are the high and low points of a transverse wave.

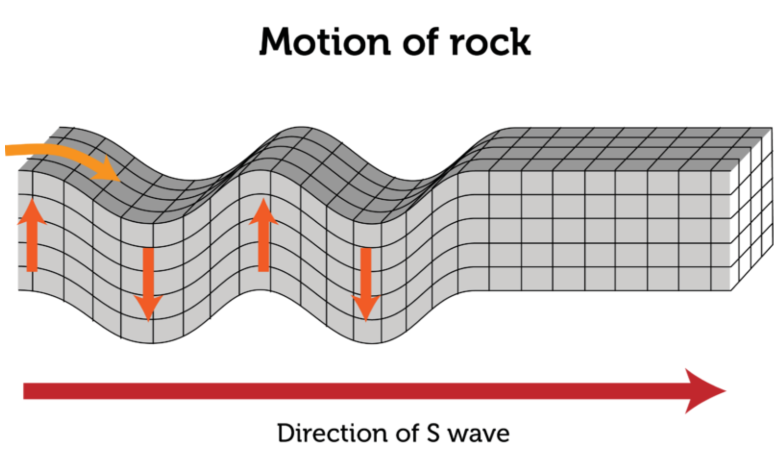


FIGURE 6.4
An S wave is a transverse wave that travels through rocks under Earth's surface.

Longitudinal Waves

A **longitudinal wave** is a wave in which the medium vibrates in the same direction that the wave travels. An example of a longitudinal wave is a wave in a spring, like the one in **Figure** 6.5. In this wave, the energy is provided by a person's hand pushing and pulling the spring. The coils of the spring first crowd closer together and then spread farther apart as the disturbance passes through them. The direction of the wave is down the length of the spring, or the same direction in which the coils move. You can see a video of a longitudinal wave in a spring at this URL: http://www.youtube.com/watch?v=ubRlaCCQfDk&feature=related .

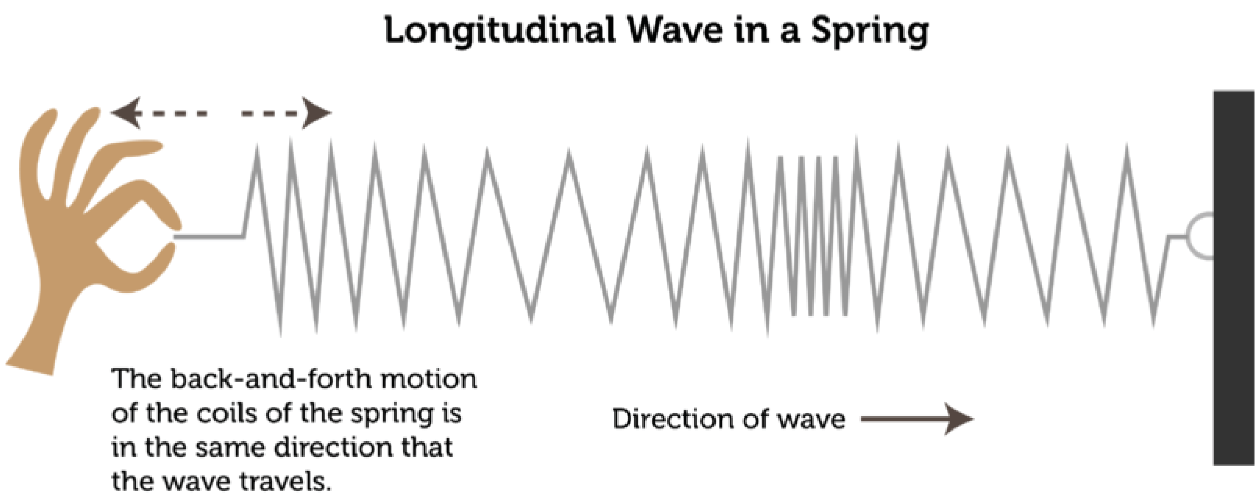


FIGURE 6.5
In a longitudinal wave, the medium moves back and forth in the same direction as the wave.

Compressions and Rarefactions

A longitudinal wave can be characterized by the compressions and rarefactions of the medium. This is illustrated in **Figure** 6.6. Compressions are the places where the coils are crowded together, and rarefactions are the places where the coils are spread apart.

P Waves

Earthquakes cause longitudinal waves as well as transverse waves. The disturbance that causes an earthquake sends longitudinal waves through underground rocks in all directions from the disturbance. Earthquake waves that travel this way are called primary, or P, waves. They are illustrated in **Figure** 6.7.

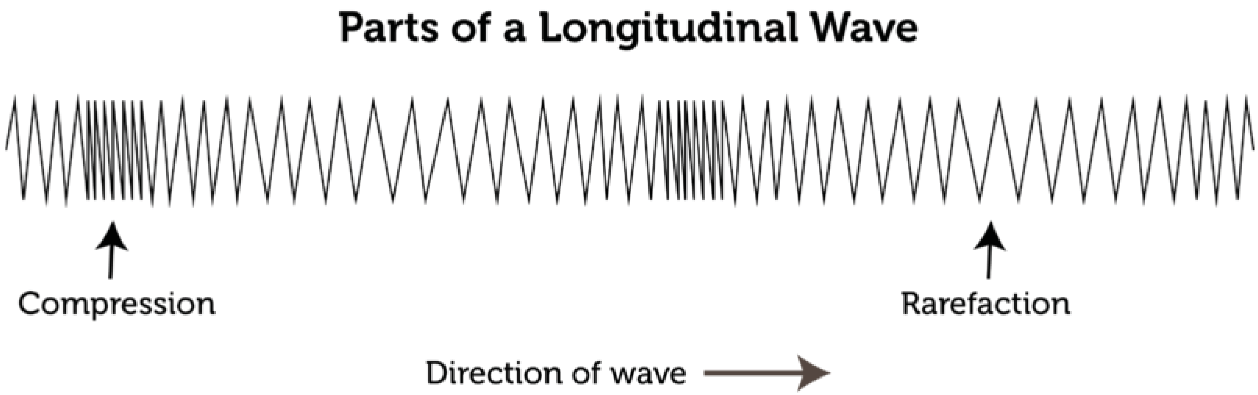


FIGURE 6.6
The compressions and rarefactions of a longitudinal wave are like the crests and troughs of a transverse wave.

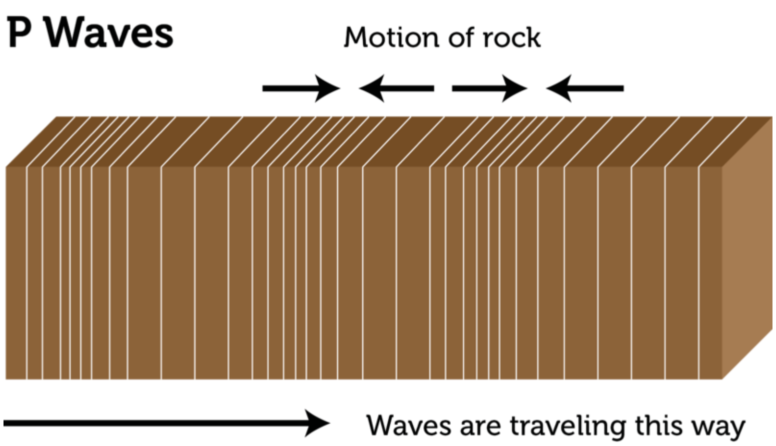
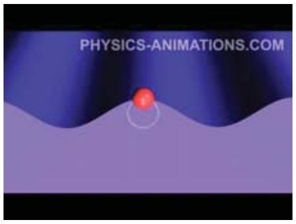


FIGURE 6.7
P waves are longitudinal waves that travel through rocks under Earth's surface.

Surface Waves

A **surface wave** is a wave that travels along the surface of a medium. It combines a transverse wave and a longitudinal wave. Ocean waves are surface waves. They travel on the surface of the water between the ocean and the air. In a surface wave, particles of the medium move up and down as well as back and forth. This gives them an overall circular motion. This is illustrated in **Figure** 6.8 and at the URL below.

http://www.youtube.com/watch?v=7yPTa8qi5X8 (0:57)



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How Particles Move in a Surface Wave

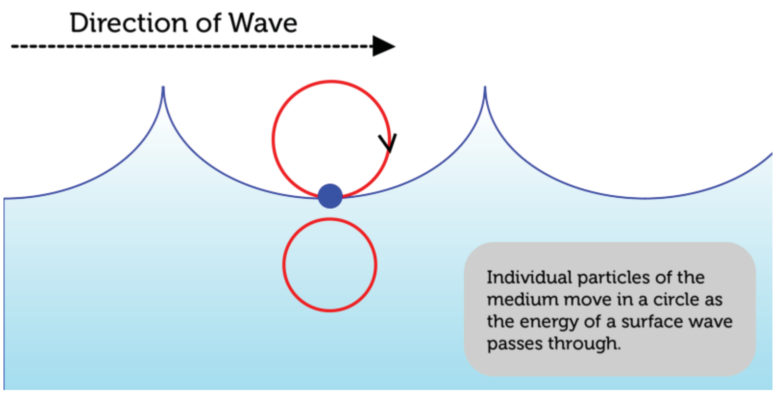


FIGURE 6.8

Surface waves are both transverse and longitudinal waves.

In deep water, particles of water just move in circles. They don't actually move closer to shore with the energy of the waves. However, near the shore where the water is shallow, the waves behave differently. They start to drag on the bottom, creating friction (see **Figure** 6.9). The friction slows down the bottoms of the waves, while the tops of the waves keep moving at the same speed. This causes the waves to get steeper until they topple over and crash on the shore. The crashing waves carry water onto the shore as surf.

Lesson Summary

- Mechanical waves are waves that transfer energy through matter, called the medium. Mechanical waves start when a source of energy causes a disturbance in the medium. Types of mechanical waves include transverse, longitudinal, and surface waves.
- In a transverse wave, such as a wave in a rope, the medium vibrates at right angles to the direction that the wave travels. The high points of transverse waves are called crests, and the low points are called troughs.
- In a longitudinal wave, such as a wave in a spring, the medium vibrates in the same direction that the wave travels. Places where the particles of the medium are closer together are called compressions, and places where they are farther apart are called rarefactions.
- A surface wave, such as an ocean wave, travels along the surface of a medium and combines a transverse wave and a longitudinal wave. Particles of the medium move in a circle as the surface wave passes through them.

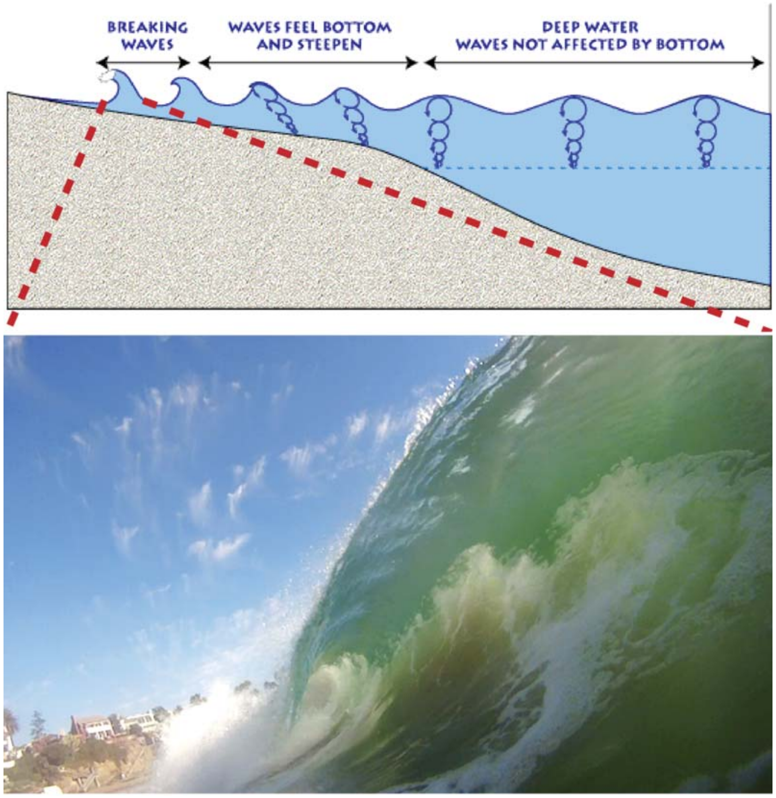


FIGURE 6.9
Waves topple over and break on the shore because of friction with the bottom in shallow water.

Lesson Review Questions

Recall

1. What is a mechanical wave?
2. Identify the medium of the wave in **Figure** 6.1.
3. Describe the compressions and rarefactions of a longitudinal wave.
4. What are surface waves? Give an example.
5. State how a particle of the medium moves when a surface wave passes through it.

Apply Concepts

6. Draw a sketch of a transverse wave. Label the crests and troughs, and add an arrow to show the direction the wave is traveling.

Think Critically

7. Compare and contrast P waves and S waves of earthquakes.

Points to Consider

When an earthquake occurs under the ocean, it sends waves through the water as well as the ground. When the energy of the earthquake reaches shore, it forms a huge wave called a tsunami.

- Do you know how large tsunamis are? How might the size of these and other waves be measured?
- What causes some waves to be bigger than others?

6.2 Measuring Waves

Lesson Objectives

- Define wave amplitude and wavelength.
- Relate wave speed to wave frequency and wavelength.

Lesson Vocabulary

- hertz (Hz)
- wave amplitude
- wave frequency
- wavelength
- wave speed

Introduction

Tsunamis, or the waves caused by earthquakes, are unusually large ocean waves. You can see an example of a tsunami in **Figure** 6.10. Because tsunamis are so big, they can cause incredible destruction and loss of life. The tsunami in the figure crashed into Thailand, sending people close to shore running for their lives. The height of a tsunami or other wave is just one way of measuring its size. You'll learn about this and other ways of measuring waves in this lesson.

FIGURE 6.10
This tsunami occurred in Thailand on December 26, 2004.

Wave Amplitude and Wavelength

The height of a wave is its amplitude. Another measure of wave size is wavelength. Both wave amplitude and wavelength are described in detail below. **Figure** 6.11 shows these wave measures for both transverse and longitudinal waves. You can also simulate waves with different amplitudes and wavelengths by doing the interactive animation at this URL: http://sci-culture.com/advancedpoll/GCSE/sine%20wave%20simulator.html .

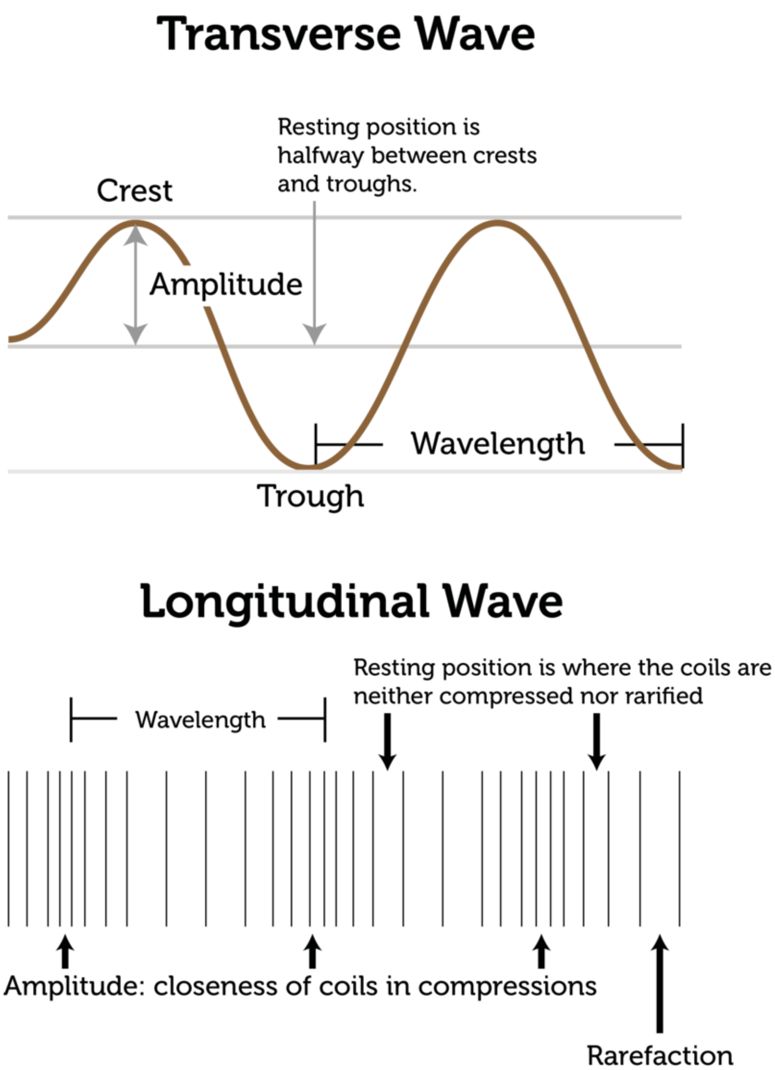


FIGURE 6.11
Wave amplitude and wavelength are two important measures of wave size.

Wave Amplitude

Wave amplitude is the maximum distance the particles of a medium move from their resting position when a wave passes through. The resting position is where the particles would be in the absence of a wave.

- In a transverse wave, wave amplitude is the height of each crest above the resting position. The higher the crests are, the greater the amplitude.
- In a longitudinal wave, amplitude is a measure of how compressed particles of the medium become when the wave passes through. The closer together the particles are, the greater the amplitude.

What determines a wave's amplitude? It depends on the energy of the disturbance that causes the wave. A wave caused by a disturbance with more energy has greater amplitude. Imagine dropping a small pebble into a pond of still water. Tiny ripples will move out from the disturbance in concentric circles, like those in **Figure** 6.1. The ripples are low-amplitude waves. Now imagine throwing a big boulder into the pond. Very large waves will be generated by the disturbance. These waves are high-amplitude waves.

Wavelength

Another important measure of wave size is wavelength. **Wavelength** is the distance between two corresponding points on adjacent waves (see **Figure** 6.11). Wavelength can be measured as the distance between two adjacent crests of a transverse wave or two adjacent compressions of a longitudinal wave. It is usually measured in meters. Wavelength is related to the energy of a wave. Short-wavelength waves have more energy than long-wavelength waves of the same amplitude. You can see examples of waves with shorter and longer wavelengths in **Figure** 6.12.

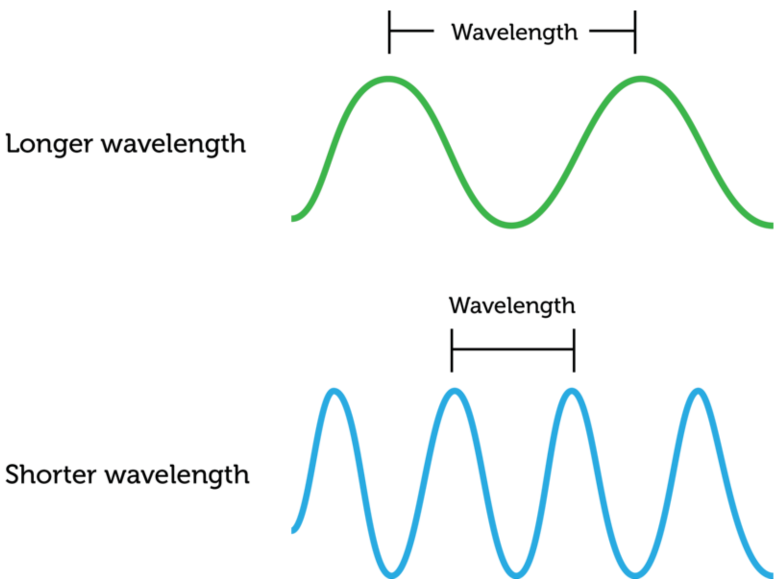


FIGURE 6.12
Both of these waves have the same amplitude, but they differ in wavelength. Which wave has more energy?

Wave Frequency and Speed

Imagine making transverse waves in a rope, like the waves in **Figure** 6.2. You tie one end of the rope to a doorknob or other fixed point and move the other end up and down with your hand. You can move the rope up and down slowly or quickly. How quickly you move the rope determines the frequency of the waves.

Wave Frequency

The number of waves that pass a fixed point in a given amount of time is **wave frequency**. Wave frequency can be measured by counting the number of crests or compressions that pass the point in 1 second or other time period. The higher the number is, the greater is the frequency of the wave. The SI unit for wave frequency is the **hertz (Hz)**, where 1 hertz equals 1 wave passing a fixed point in 1 second. **Figure** 6.13 shows high-frequency and low-frequency transverse waves. You can simulate transverse waves with different frequencies at this URL: http://zonalandeducation.com/mstm/physics/waves/partsOfAWave/waveParts.htm .

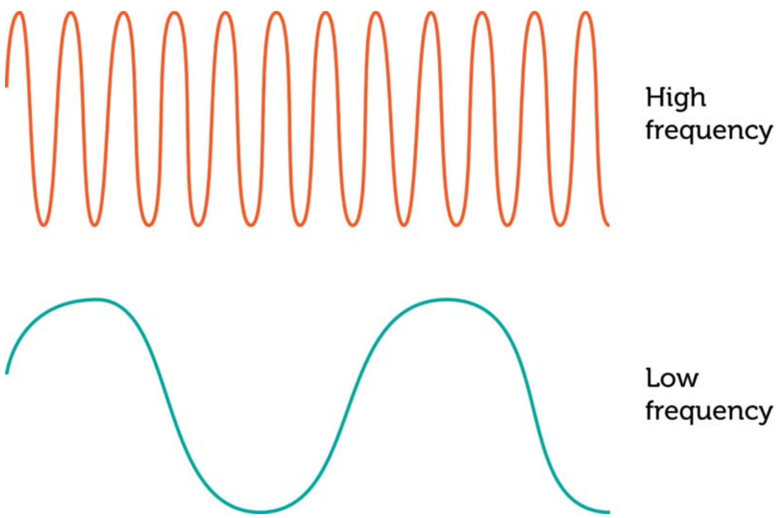


FIGURE 6.13
A transverse wave with a higher frequency has crests that are closer together.

The frequency of a wave is the same as the frequency of the vibrations that caused the wave. For example, to generate a higher-frequency wave in a rope, you must move the rope up and down more quickly. This takes more energy, so a higher-frequency wave has more energy than a lower-frequency wave with the same amplitude.

Wave Speed

Assume that you move one end of a rope up and down just once. How long will take the wave to travel down the rope to the other end? This depends on the speed of the wave. **Wave speed** is how far the wave travels in a given amount of time, such as how many meters it travels per second. Wave speed is not the same thing as wave frequency, but it is related to frequency and also to wavelength. This equation shows how the three factors are related:

$$\text{Speed} = \text{Wavelength} \times \text{Frequency}$$

In this equation, wavelength is measured in meters and frequency is measured in hertz, or number of waves per second. Therefore, wave speed is given in meters per second.

The equation for wave speed can be used to calculate the speed of a wave when both wavelength and wave frequency are known. Consider an ocean wave with a wavelength of 3 meters and a frequency of 1 hertz. The speed of the wave is:

$$\text{Speed} = 3 \text{ m} \times 1 \text{ wave/s} = 3 \text{ m/s}$$

You Try It!

Problem: Jera made a wave in a spring by pushing and pulling on one end. The wavelength is 0.1 m, and the wave frequency is 0.2 m/s. What is the speed of the wave?

If you want more practice calculating wave speed from wavelength and frequency, try the problems at this URL: http://www.physicsclassroom.com/class/waves/u10l2e.cfm .

The equation for wave speed (above) can be rewritten as:

$$\text{Frequency} = \frac{\text{Speed}}{\text{Wavelength}} \text{ or Wavelength} = \frac{\text{Speed}}{\text{Frequency}}$$

Therefore, if you know the speed of a wave and either the wavelength or wave frequency, you can calculate the missing value. For example, suppose that a wave is traveling at a speed of 2 meters per second and has a wavelength of 1 meter. Then the frequency of the wave is:

$$\text{Frequency} = \frac{2 \text{ m/s}}{1 \text{ m}} = 2 \text{ waves/s, or } 2 \text{ Hz}$$

You Try It!

Problem: A wave is traveling at a speed of 2 m/s and has a frequency of 2 Hz. What is its wavelength?

The Medium Matters

The speed of most waves depends on the medium through which they are traveling. Generally, waves travel fastest through solids and slowest through gases. That's because particles are closest together in solids and farthest apart in gases. When particles are farther apart, it takes longer for the energy of the disturbance to pass from particle to particle.

Lesson Summary

- Wave amplitude is the maximum distance the particles of a medium move from their resting positions as a wave passes through. Wavelength is the distance between two corresponding points of adjacent waves. Waves with greater amplitudes or shorter wavelengths have more energy.
- Wave frequency is the number of waves that pass a fixed point in a given amount of time. Higher frequency waves have more energy. Wave speed is calculated as wavelength multiplied by wave frequency. Wave speed is affected by the medium through which a wave travels.

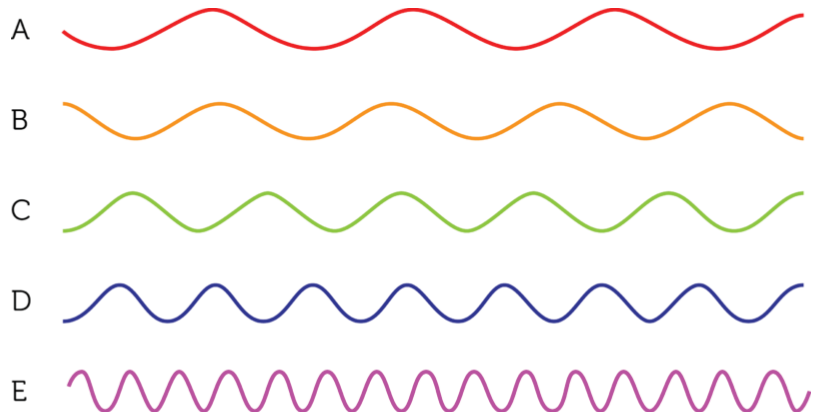
Lesson Review Questions

Recall

1. How is wave amplitude measured in a transverse wave?
2. Describe the wavelength of a longitudinal wave.
3. Define wave frequency.

Apply Concepts

4. All of the waves in the sketch below have the same amplitude and speed. Which wave has the longest wavelength? Which has the highest frequency? Which has the greatest energy?



5. A wave has a wavelength of 0.5 m/s and a frequency of 2 Hz. What is its speed?

Think Critically

6. Relate wave amplitude, wavelength, and wave frequency to wave energy.
7. Waves A and B have the same speed, but wave A has a shorter wavelength. Which wave has the higher frequency? Explain how you know.

Points to Consider

You read in this lesson that waves travel at different speeds in different media.

- When a wave enters a new medium, it may speed up or slow down. What other properties of the wave do you think might change when it enters a new medium?
- What if a wave reaches a type of matter it cannot pass through? Does it just stop moving? If not, where does it go?

6.3 Wave Interactions and Interference

Lesson Objectives

- Describe wave reflection, refraction, and diffraction.
- Explain how wave interference affects the amplitude of waves.

Lesson Vocabulary

- diffraction
- reflection
- refraction
- standing wave
- wave interference

Introduction

Did you ever hear an echo of your own voice? An echo occurs when sound waves bounce back from a hard object. The man in **Figure** 6.14 is trying to create an echo by shouting toward a rock wall. When the sound waves strike the rock wall, they can't pass through. Instead, they bounce back toward the man, and he hears an echo of his voice. An echo is just one example of how waves interact with matter.

Wave Interactions

Waves interact with matter in several ways. The interactions occur when waves pass from one medium to another. Besides bouncing back like an echo, waves may bend or spread out when they strike a new medium. These three ways that waves may interact with matter are called reflection, refraction, and diffraction. Each type of interaction is described in detail below. For animations of the three types of wave interactions, go to this URL: http://www.acoustics.salford.ac.uk/schools/teacher/lesson3/flash/whiteboardcomplete.swf .

Reflection

An echo is an example of wave reflection. Reflection occurs when waves bounce back from a barrier they cannot pass through. **Reflection** can happen with any type of waves, not just sound waves. For example, **Figure** 6.15 shows the reflection of ocean waves off a rocky coast. Light waves can also be reflected. In fact, that's how we see most objects. Light from a light source, such as the sun or a light bulb, shines on the object and some of the light is reflected. When the reflected light enters our eyes, we can see the object.

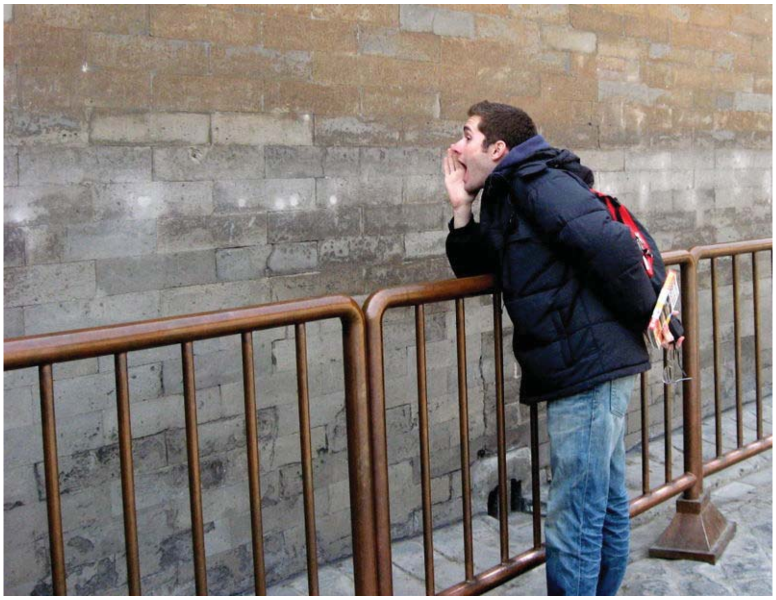


FIGURE 6.14
This man is sending sound waves toward a rock wall so he can hear an echo.

FIGURE 6.15
Ocean waves are reflected by rocks on shore.

Reflected waves have the same speed and frequency as the original waves before they were reflected. However, the direction of the reflected waves is different. When waves strike an obstacle head on, the reflected waves bounce straight back in the direction they came from. When waves strike an obstacle at any other angle, they bounce back at the same angle but in a different direction. This is illustrated in **Figure** 6.16.

Refraction

Refraction is another way that waves interact with matter. **Refraction** occurs when waves bend as they enter a new medium at an angle. You can see an example of refraction in **Figure** 6.17. Light bends when it passes from air to water. The bending of the light causes the pencil to appear broken.

Why do waves bend as they enter a new medium? Waves usually travel at different speeds in different media. For example, light travels more slowly in water than air. This causes it to refract when it passes from air to water.

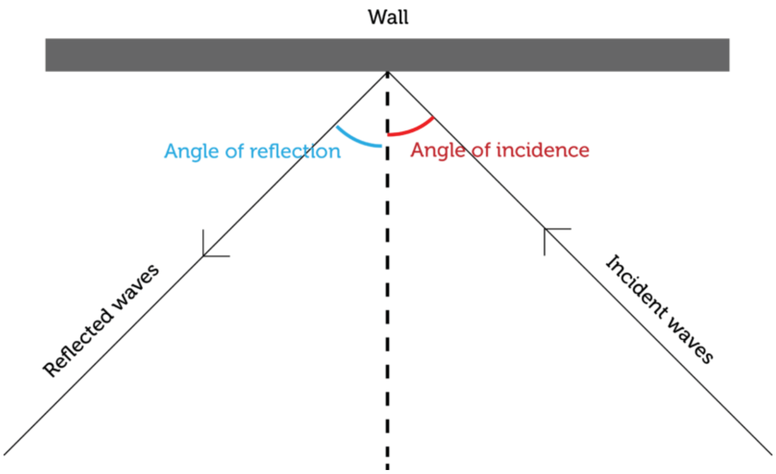


FIGURE 6.16
Waves strike a wall at an angle, called the angle of incidence. The waves are reflected at the same angle, called the angle of reflection, but in a different direction. Both angles are measured relative to a line that is perpendicular to the wall.

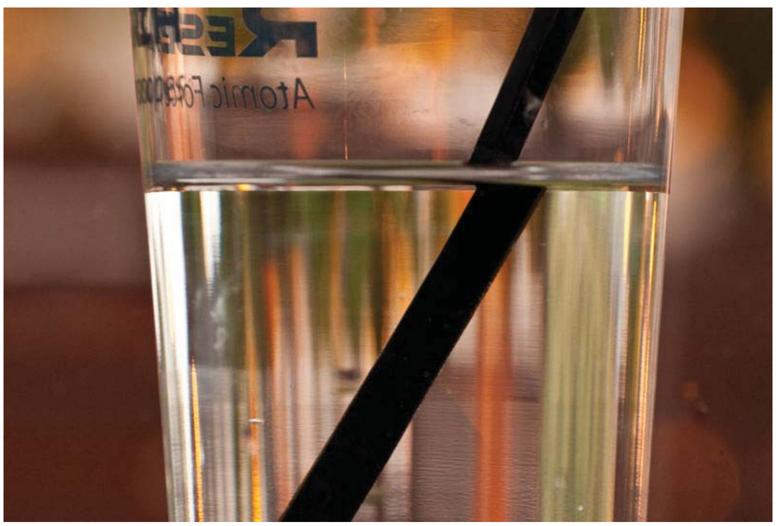


FIGURE 6.17
This pencil looks broken where it enters the water because of refraction of light waves.

Diffraction

Did you ever notice that when you're walking down a street, you can hear sounds around the corners of buildings? **Figure** 6.18 shows why this happens. As you can see from the figure, sound waves spread out and travel around obstacles. This is called **diffraction**. It also occurs when waves pass through an opening in an obstacle. All waves may be diffracted, but it is more pronounced in some types of waves than others. For example, sound waves bend around corners much more than light does. That's why you can hear but not see around corners.

For a given type of waves, such as sound waves, how much the waves diffract depends on two factors: the size of the obstacle or opening in the obstacle and the wavelength. This is illustrated in **Figure** 6.19.

- Diffraction is minor if the length of the obstacle or opening is greater than the wavelength.
- Diffraction is major if the length of the obstacle or opening is less than the wavelength.

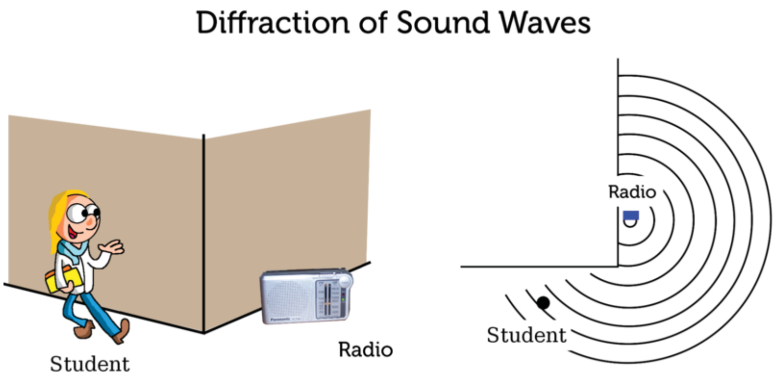


FIGURE 6.18
The person can hear the radio around the corner of the building because of the diffraction of sound waves.

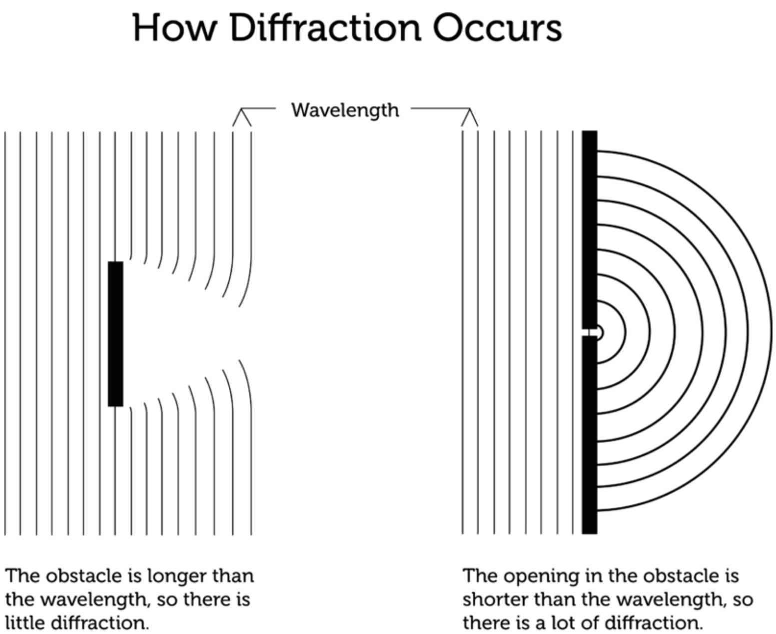


FIGURE 6.19
An obstacle or opening that is shorter than the wavelength causes greater diffraction of waves.

Wave Interference

Waves interact not only with matter in the ways described above. Waves also interact with other waves. This is called **wave interference**. Wave interference may occur when two waves that are traveling in opposite directions meet. The two waves pass through each other, and this affects their amplitude. How amplitude is affected depends on the type of interference. Interference can be constructive or destructive.

Constructive Interference

Constructive interference occurs when the crests of one wave overlap the crests of the other wave. This is illustrated in **Figure** 6.20. As the waves pass through each other, the crests combine to produce a wave with greater amplitude. You can see an animation of constructive interference at this URL: http://phys23p.sl.psu.edu/phys_anim/waves/embederQ1.20100.html .

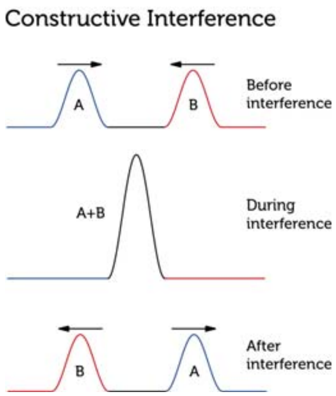


FIGURE 6.20
Constructive interference increases wave amplitude.

Destructive Interference

Destructive interference occurs when the crests of one wave overlap the troughs of another wave. This is illustrated in **Figure** 6.21. As the waves pass through each other, the crests and troughs cancel each other out to produce a wave with less amplitude. You can see an animation of destructive interference at this URL: http://phys23p.sl.psu.edu/phys_anim/waves/embederQ1.20200.html .

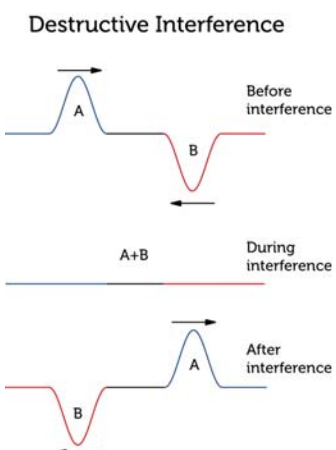


FIGURE 6.21
Destructive interference decreases wave amplitude.

Standing Waves

When a wave is reflected straight back from an obstacle, the reflected wave interferes with the original wave and creates a **standing wave**. This is a wave that appears to be standing still. A standing wave occurs because of a combination of constructive and destructive interference between a wave and its reflected wave. You can see animations of standing waves at the URLs below.

- http://skullsinthestars.com/2008/05/04/classic-science-paper-otto-wieners-experiment-1890/
- http://www.physicsclassroom.com/mmedia/waves/swf.cfm

It's easy to generate a standing wave in a rope by tying one end to a fixed object and moving the other end up and down. When waves reach the fixed object, they are reflected back. The original wave and the reflected wave interfere to produce a standing wave. Try it yourself and see if the wave appears to stand still.

Lesson Summary

- Reflection occurs when waves bounce back from a barrier they cannot pass through. Refraction occurs when waves bend as they enter a new medium at an angle. Diffraction occurs when waves spread out around an obstacle or after passing through an opening in an obstacle.
- Wave interference occurs when waves interact with other waves. Constructive interference increases wave amplitude. Destructive interference decreases wave amplitude.

Lesson Review Questions

Recall

1. What is reflection? Give an example.
2. Define constructive interference.
3. State how destructive interference affects wave amplitude.
4. What is a standing wave?

Apply Concepts

5. Create a sketch of sound waves to show why you can hear a sound on the other side of brick wall.

Think Critically

6. Explain why the pencil in **Figure** 6.17 appears broken.
7. A sound wave meets an obstacle it cannot pass through. Relate the amount of diffraction of the sound wave to the length of the obstacle and the wavelength.

Points to Consider

You were introduced to sound waves in this chapter, and you will learn more about them in the chapter "Sound."

- How do you think we hear sound waves?
- What properties of sound waves might determine how loud a sound is?

6.4 References

1. Tim Fields. http://www.flickr.com/photos/24327829@N04/6737005997/ . CC BY 2.0
2. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
3. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
4. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
5. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
6. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
7. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
8. User:Vargklo/Wikipedia, modified by CK-12 Foundation. http://commons.wikimedia.org/wiki/File:Wave_motion-i18n.svg . Public Domain
9. Top: U.S. Geological Survey; Bottom: Flickr: Axion23. Top: http://geomaps.wr.usgs.gov/parks/sea/gwave.html; Bottom: http://www.flickr.com/photos/gfreeman23/5137640341/ . Top: Public Domain; Bottom: CC BY 2.0
10. David Rydevik. http://commons.wikimedia.org/wiki/File:2004-tsunami.jpg . Public Domain
11. Christopher Auyeung. CK-12 Foundation .
12. Christopher Auyeung. CK-12 Foundation .
13. Christopher Auyeung. CK-12 Foundation .
14. Kyle Taylor. http://www.flickr.com/photos/kyletaylor/394160033/ . CC BY 2.0
15. Flickr:daveynin. http://www.flickr.com/photos/daveynin/7130041653/ . CC BY 2.0
16. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
17. Iain Watson. http://www.flickr.com/photos/dagoaty/4657318099/ . CC BY 2.0
18. Student: Flickr:MaxTorrt; Radio: Flickr:Kansir. Student: http://www.flickr.com/photos/16953895@N05/8299424201/; Radio: http://www.flickr.com/photos/kansirnet/231639326/ . CC BY 2.0
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CHAPTER 7 Sound

Chapter Outline

You can almost hear the sound of this colorful African drum! The drummer must be hitting the drum quickly because his hands are a blur of motion. Each time he strikes the drum, it produces a loud, pounding sound. There are hundreds of different kinds of musical instruments, from drums to horns to stringed instruments. Would it surprise you to learn that all of them make sound in the same basic way? Do you know how sounds are created? You'll learn how when you read this chapter.

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7.1 Characteristics of Sound

Lesson Objectives

- Describe sound waves.
- Identify properties of sound.

Lesson Vocabulary

- decibel (dB)
- Doppler effect
- infrasound
- intensity
- loudness
- pitch
- sound
- ultrasound

Introduction

The tree in **Figure** 7.1 fell to the forest floor in a high wind. Does it make you think of an old riddle? The riddle goes like this:

If a tree falls in the forest and there's no one there to hear it, does it make any sound?

To answer the riddle correctly, you first need to know the scientific definition of sound. In science, **sound** is the transfer of energy from a vibrating object in waves that travel through matter. Most people commonly use the term *sound* to mean what they hear when sound waves enter their ears. The tree creates sound waves when it falls to the ground, so it makes sound according to the scientific definition. But the sound won't be detected by a person's ears if there's no one in the forest. So the answer to the riddle is both yes and no!

Sound Waves

Why does a tree make sound when it crashes to the ground? How does the sound reach people's ears if they happen to be in the forest? And in general, how do sounds get started, and how do they travel? Keep reading to find out.

FIGURE 7.1
This tree cracked and fell to the ground in a storm. Can you imagine what it sounded like when it came crashing down?

How Sounds Begin

All sounds begin with vibrating matter. It could be the ground vibrating when a tree comes crashing down. Or it could be guitar strings vibrating when they are plucked. You can see a guitar string vibrating in **Figure** 7.2. The vibrating string repeatedly pushes against the air particles next to it. The pressure of the vibrating string causes these air particles to vibrate. The air particles alternately push together and spread apart. This starts waves of vibrations that travel through the air in all directions away from the strings. The vibrations pass through the air as longitudinal waves, with individual air particles vibrating back and forth in the same direction that the waves travel. You can see an animation of sound waves moving through air at this URL: http://www.mediacollege.com/audio/01/sound-waves.html .

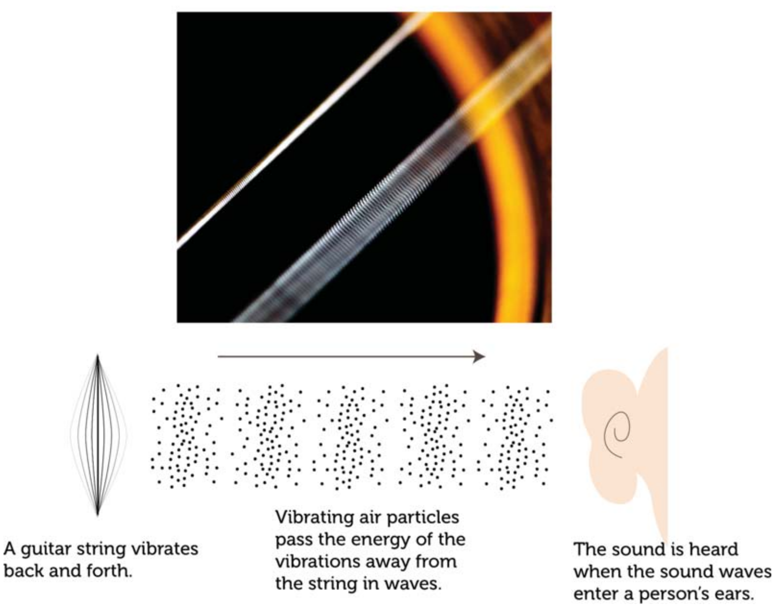

FIGURE 7.2
Plucking a guitar string makes it vibrate. The vibrating string sends sound waves through the air in all directions.

Sound and Matter

Sound waves are mechanical waves, so they can travel only though matter and not through empty space. This was demonstrated in the 1600s by a scientist named Robert Boyle. Boyle placed a ticking clock in a sealed glass jar. The clock could be heard ticking through the air and glass of the jar. Then Boyle pumped the air out of the jar. The clock was still running, but the ticking could no longer be heard. That's because the sound couldn't travel away from the clock without air particles to pass the sound energy along. You can see an online demonstration of the same experiment—with a modern twist—at this URL: http://www.youtube.com/watch?v=b0JQt4u6-XI (4:06).

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Click image to the left for more content.

Sound waves can travel through many different kinds of matter. Most of the sounds we hear travel through air, but sounds can also travel through liquids such as water and solids such as glass and metal. If you swim underwater —or even submerge your ears in bathwater —any sounds you hear have traveled to your ears through water. You can tell that sounds travel through glass and other solids because you can hear loud outdoor sounds such as sirens through closed windows and doors.

Properties of Sound

Sound has certain characteristic properties because of the way sound energy travels in waves. Properties of sound include speed, loudness, and pitch.

Speed of Sound

The speed of sound is the distance that sound waves travel in a given amount of time. You probably already know that sound travels more slowly than light. That's why you usually see the flash of lightning before you hear the boom of thunder. However, the speed of sound isn't constant. It varies depending on the medium of the sound waves. **Table** 7.1 lists the speed of sound in several different media. Generally, sound waves travel fastest through solids and slowest through gases. That's because the particles of solids are close together and can quickly pass the energy of vibrations to nearby particles. You can explore the speed of sound in different media at this URL: http://www.ltscotland.org.uk/resources/s/sound/speedofsound.asp?strReferringChannel=resources&strReferringPageID=tcm:4-248291-64 .

TABLE 7.1: The speed of sound depends on the medium.

Medium (20°C)	Speed of Sound Waves (m/s)
Air	343
Water	1437
Wood	3850
Glass	4540
Aluminum	6320

The speed of sound also depends on the temperature of the medium. For a given medium such as air, sound has a slower speed at lower temperatures. You can compare the speed of sound in air at different temperatures in **Table** 7.2. A lower temperature means that particles of the medium are moving more slowly, so it takes them longer to transfer the energy of the sound waves. The amount of water vapor in the air affects the speed of sound as well. Do you think sound travels faster or slower when the air contains more water vapor? (*Hint:* Compare the speed of sound in water and air in **Table** 7.1.)

TABLE 7.2: Based on the values in this table, predict the speed of sound in air at 10°C.

Temperature of Air	Speed of Sound (m/s)
0°C	331
20°C	343
100°C	386

Loudness

A friend whispers to you in class in a voice so soft that you have to lean very close to hear what he's saying. Later that day, your friend shouts to you across the football field. Now his voice is loud enough for you to hear him clearly even though he's many meters away. Obviously, sounds can vary in loudness. **Loudness** refers to how loud or soft a sound seems to a listener. The loudness of sound is determined, in turn, by the intensity of sound. **Intensity** is a measure of the amount of energy in sound waves. The unit of intensity is the **decibel (dB)**.

You can see typical decibel levels of several different sounds in **Figure** 7.3. As decibel levels get higher, sound waves have greater intensity and sounds are louder. For every 10-decibel increase in the intensity of sound, loudness is 10 times greater. Therefore, a 30-decibel "quiet" room is 10 times louder than a 20-decibel whisper, and a 40-decibel light rainfall is 100 times louder than a 20-decibel whisper. How much louder than a 20-decibel whisper is the 60-decibel sound of a vacuum cleaner?

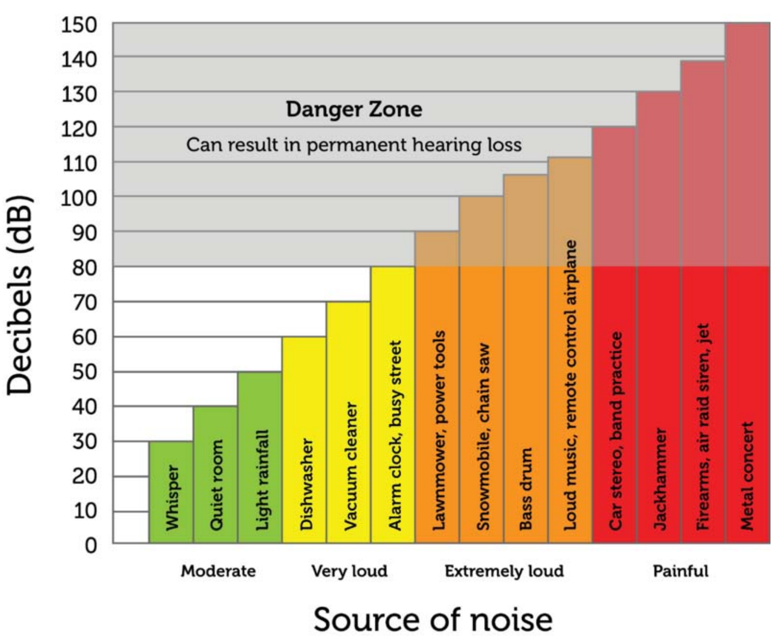

FIGURE 7.3
High-decibel sounds can damage the ears and cause loss of hearing. Which sounds in the graph are dangerously loud?

The intensity of sound waves determines the loudness of sounds, but what determines intensity? Intensity is a function of two factors: the amplitude of the sound waves and how far they have traveled from the source of the sound. Remember that sound waves start at a source of vibrations and spread out from the source in all directions. The farther the sound waves travel away from the source, the more spread out their energy becomes. This is illustrated in **Figure** 7.4. The decrease in intensity with distance from a sound source explains why even loud sounds fade away as you move farther from the source. It also explains why low-amplitude sounds can be heard only over short distances. For a video demonstration of the amplitude and loudness of sounds, go to this URL: http://www.youtube.com/watch?v=irqfGYD2UKw . You can also explore the amplitude of sound waves with the interactive animation at this URL: http://www.ltscotland.org.uk/resources/s/sound/amplitude.asp?strReferringChannel=resources&strReferringPageID=tcm:4-248294-64 .

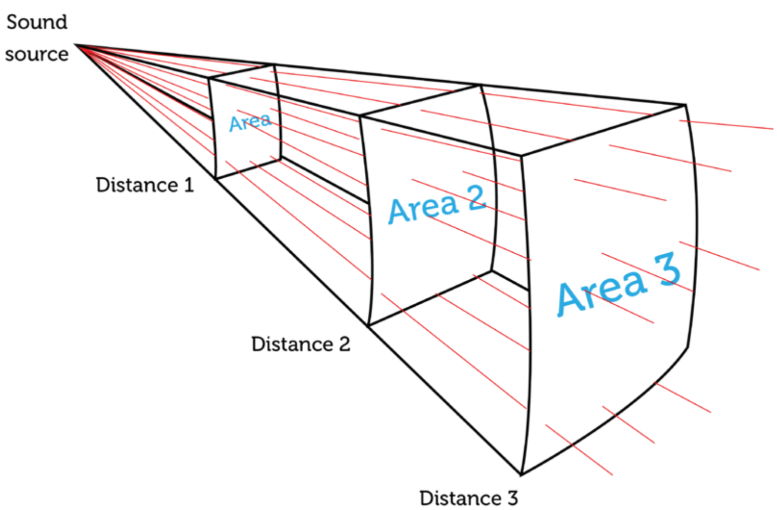

FIGURE 7.4
The energy of sound waves spreads out over a greater area as the waves travel farther from the sound source. This diagram represents just a small section of the total area of sound waves spreading out from the source. Sound waves actually travel away from the source in all directions. As distance from the source increases, the area covered by the sound waves increases, lessening their intensity.

Pitch

A marching band is parading down the street. You can hear it coming from several blocks away. When the different instruments finally pass by you, their distinctive sounds can be heard. The tiny piccolos trill their bird-like high notes, and the big tubas rumble out their booming bass notes (see **Figure** 7.5). Clearly, some sounds are higher or lower than others. But do you know why? How high or low a sound seems to a listener is its **pitch**. Pitch, in turn, depends on the frequency of sound waves. Recall that the frequency of waves is the number of waves that pass a fixed point in a given amount of time. High-pitched sounds, like the sounds of a piccolo, have high-frequency waves. Low-pitched sounds, like the sounds of a tuba, have low-frequency waves. For a video demonstration of frequency and pitch, go to this URL: http://www.youtube.com/watch?v=irqfGYD2UKw (3:20).

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Click image to the left for more content.

To explore an interactive animation of sound wave frequency, go to this URL: http://www.ltscotland.org.uk/resources/s/sound/amplitude.asp?strReferringChannel=resources&strReferringPageID=tcm:4-248294-64 .

The frequency of sound waves is measured in hertz (Hz), or the number of waves that pass a fixed point in a second. Human beings can normally hear sounds with a frequency between about 20 Hz and 20,000 Hz. Sounds

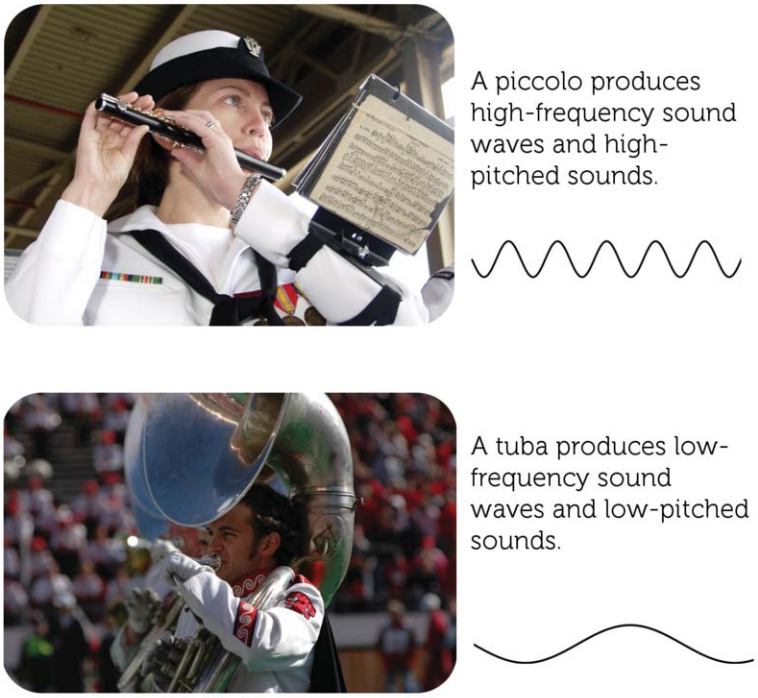

FIGURE 7.5
A piccolo and a tuba sound very different. One difference is the pitch of their sounds.

with frequencies below 20 hertz are called **infrasound**. Sounds with frequencies above 20,000 hertz are called **ultrasound**. Some other animals can hear sounds in the ultrasound range. For example, dogs can hear sounds with frequencies as high as 50,000 Hz. You may have seen special whistles that dogs but not people can hear. The whistles produce a sound with a frequency too high for the human ear to detect. Other animals can hear even higher-frequency sounds. Bats, for example, can hear sounds with frequencies higher than 100,000 Hz.

Doppler Effect

Look at the police car in **Figure** 7.6. The sound waves from its siren travel outward in all directions. Because the car is racing forward (toward the right), the sound waves get bunched up in front of the car and spread out behind it. As the car approaches the person on the right (position B), the sound waves get closer and closer together. In other words, they have a higher frequency. This makes the siren sound higher in pitch. After the car speeds by the person on the left (position A), the sound waves get more and more spread out, so they have a lower frequency. This makes the siren sound lower in pitch. A change in the frequency of sound waves, relative to a stationary listener, when the source of the sound waves is moving is called the **Doppler effect**. You've probably experienced the Doppler effect yourself. The next time a vehicle with a siren races by, listen for the change in pitch. For an online animation of the Doppler effect, go to the URL below.

http://www.astro.ubc.ca/~scharein/a311/Sim/doppler/Doppler.html

Lesson Summary

- Sound is the transfer of energy from a vibrating object in waves that travel through matter.
- Properties of sound include speed, loudness, and pitch. The speed of sound varies in different media. The

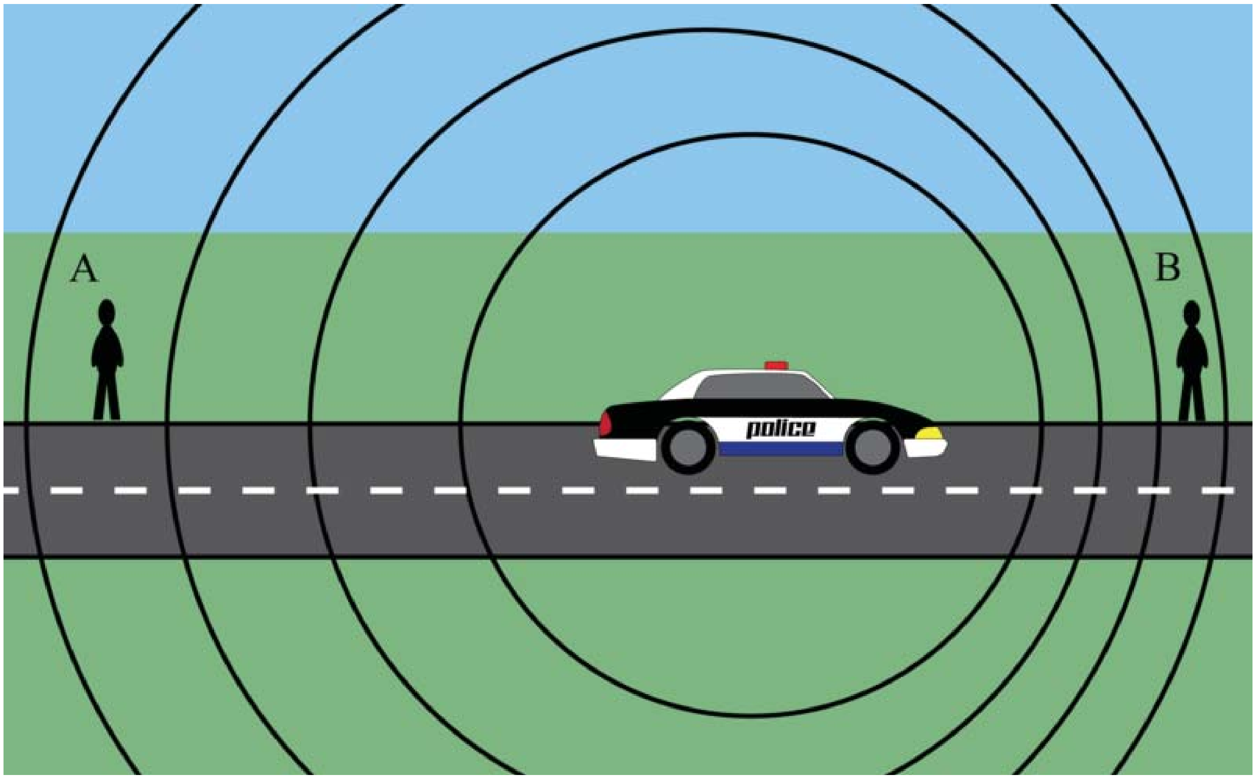

FIGURE 7.6
The siren's pitch changes as the police car zooms by. Can you explain why?

loudness of sound depends on the intensity of sound waves. The pitch of sound depends on the frequency of sound waves.

Lesson Review Questions

Recall

1. How is sound defined in physics?
2. Identify two factors that determine the intensity of sound.
3. What is the pitch of sound?

Apply Concepts

4. A wind chime produces both high-pitched and low-pitched sounds. If you could see the sound waves from the wind chime, what would they look like?
5. Look back at **Figure** 7.6. Does the siren change pitch to the police officer driving the car? Why or why not?

Think Critically

6. Explain why sound tends to travel faster in solids than in liquids or gases.

Points to Consider

In this lesson you learned that high-intensity, high-amplitude sound waves make dangerously loud sounds. In the next lesson, "Hearing Sound," you'll read how loud sounds can cause loss of hearing.

- How do you think loud sounds cause hearing loss?
- What can you do to protect your ears from loud sounds?

7.2 Hearing Sound

Lesson Objectives

- Explain how we hear sound.
- Relate loud sounds to hearing loss.
- State how hearing can be protected.

Introduction

The organ that we use to hear sound is the ear. Almost all the structures in the ear are needed for this purpose. Together, they gather and amplify sound waves and change their energy to electrical signals. The electrical signals travel to the brain, which interprets them as sound.

How We Hear

Figure 7.7 shows the three main parts of the ear: the outer, middle, and inner ear. It also shows the specific structures in each part. The roles of these structures in hearing are described below and in the animations at these URLS:

- http://www.medindia.net/animation/ear_anatomy.asp
- http://www.youtube.com/watch?v=tkPj4IGbmQQ (1:44)

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Outer Ear

The outer ear includes the pinna, ear canal, and eardrum.

- The pinna is the only part of the ear that extends outward from the head. Its position and shape make it good at catching sound waves and funneling them into the ear canal.
- The ear canal is a tube that carries sound waves into the ear. The sound waves travel through the air inside the ear canal to the eardrum.
- The eardrum is like the head of a drum. It's a thin membrane stretched tight across the end of the ear canal. The eardrum vibrates when sound waves strike it, and it sends the vibrations on to the middle ear.

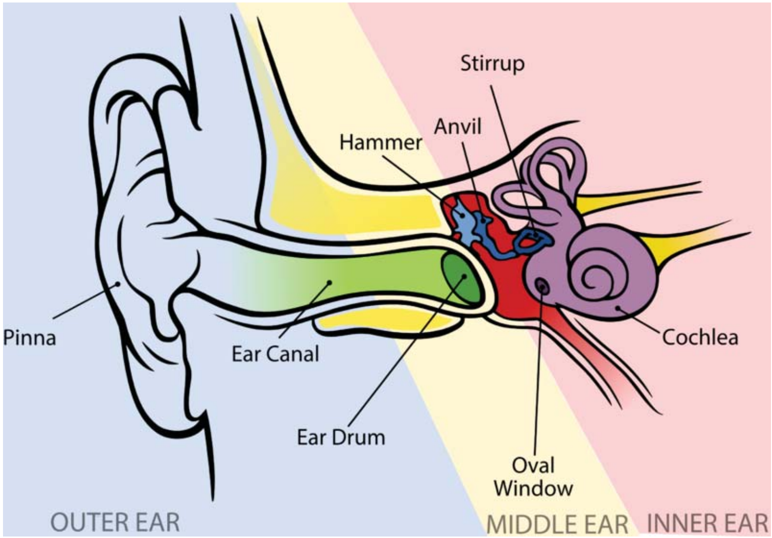

FIGURE 7.7
The three main parts of the ear have different functions in hearing.

Middle Ear

The middle ear contains three tiny bones (ossicles) called the hammer, anvil, and stirrup. If you look at these bones in **Figure** 7.7, you might notice that they resemble the objects for which they are named. The three bones transmit vibrations from the eardrum to the inner ear. They also amplify the vibrations. The arrangement of the three bones allows them to work together as a lever that increases the amplitude of the waves as they pass to the inner ear.

Inner Ear

The stirrup passes the amplified sound waves to the inner ear through the oval window (see **Figure** 7.7). When the oval window vibrates, it causes the cochlea to vibrate as well. The cochlea is a shell-like structure that is full of fluid and lined with nerve cells called hair cells. Each hair cell has tiny hair-like projections, as you can see in **Figure** 7.8. When the cochlea vibrates, it causes waves in the fluid inside. The waves bend the "hairs" on the hair cells, and this triggers electrical impulses. The electrical impulses travel to the brain through nerves. Only after the nerve impulses reach the brain do we hear the sound.

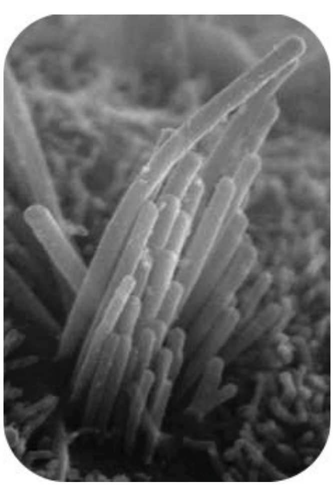

FIGURE 7.8
This highly magnified image of a hair cell shows the tiny hair-like structures on its surface. What function do the "hairs" play in hearing?

Hearing Loss

All these structures of the ear must work well for normal hearing. Damage to any of them, through illness or injury, may cause hearing loss. Total hearing loss is called deafness. To learn more about hearing loss, watch the animations at these URLs:

- http://www.youtube.com/watch?v=lioNIbtFxSY&NR=1 (1:04)

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- http://www.youtube.com/watch?NR=1&v=YpIptQSEEjY (1:39)

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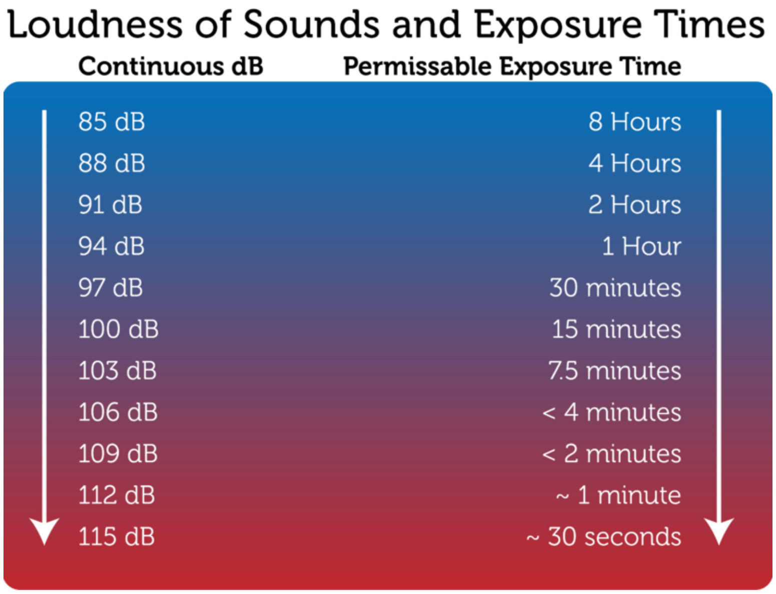
Most adults experience at least some hearing loss as they get older. The most common cause is exposure to loud sounds, which damage hair cells. The louder a sound is, the less exposure is needed for damage to occur. Even a single brief exposure to a sound louder than 115 decibels can cause hearing loss. **Figure** 7.9 shows the relationship between loudness, exposure time, and hearing loss.

Preventing Hearing Loss

Hearing loss caused by loud sounds is permanent. However, this type of hearing loss can be prevented by protecting the ears from loud sounds.

Who Needs Hearing Protection?

People who work in jobs that expose them to loud sounds must wear hearing protectors. Examples include construction workers who work around loud machinery for many hours each day (see **Figure** 7.10). But anyone exposed to loud sounds for longer than the permissible exposure time should wear hearing protectors. Many home and yard chores and even recreational activities are loud enough to cause hearing loss if people are exposed to them for very long.


Loudness of Sounds and Exposure Times

Continuous dB	Permissable Exposure Time
85 dB	8 Hours
88 dB	4 Hours
91 dB	2 Hours
94 dB	1 Hour
97 dB	30 minutes
100 dB	15 minutes
103 dB	7.5 minutes
106 dB	< 4 minutes
109 dB	< 2 minutes
112 dB	~ 1 minute
115 dB	~ 30 seconds

FIGURE 7.9
The louder the sounds are, the less time you should be exposed to them for the sake of your hearing.

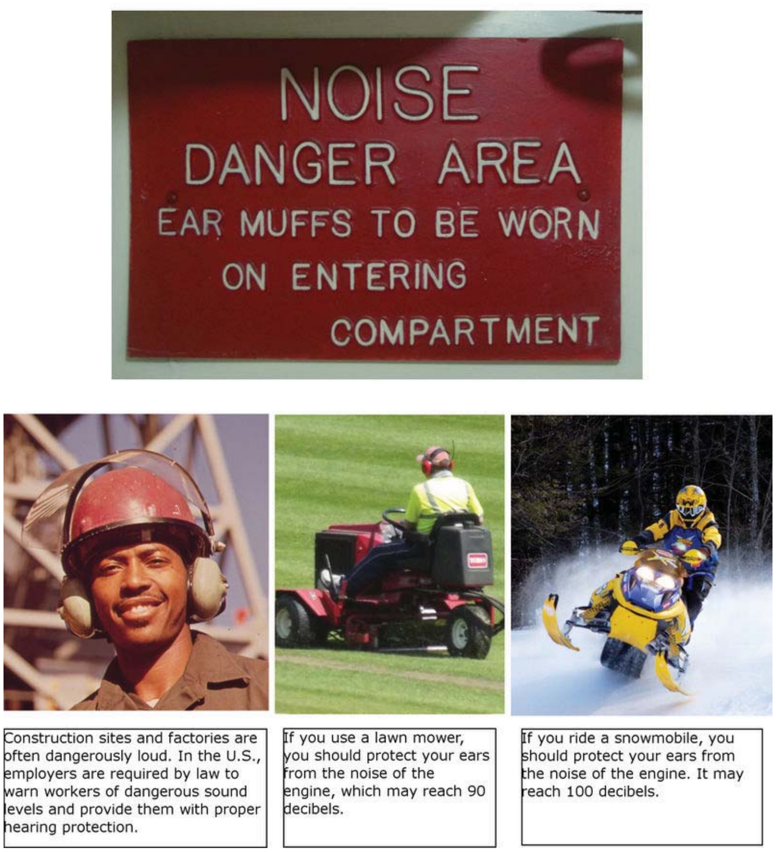


FIGURE 7.10
Many activities expose people to dangerously loud sounds that can cause hearing loss.

How Hearing Protectors Work

You can see two different types of hearing protectors in **Figure** 7.11. Earplugs are simple hearing protectors that just muffle sounds by partially blocking all sound waves from entering the ears. This type of hearing protector is suitable for lower noise levels, such as the noise of a lawnmower or snowmobile engine.

Electronic ear protectors work differently. They identify high-amplitude sound waves and send sound waves through them in the opposite direction. This causes destructive interference with the waves, which reduces their amplitude to zero or nearly zero. This changes even the loudest sounds to just a soft hiss. Sounds that people need to hear, such as the voices of co-workers, are not interfered with in this way and may be amplified instead so they can be heard more clearly. This type of hearing protector is recommended for higher noise levels and situations where it's important to be able to hear lower-decibel sounds.

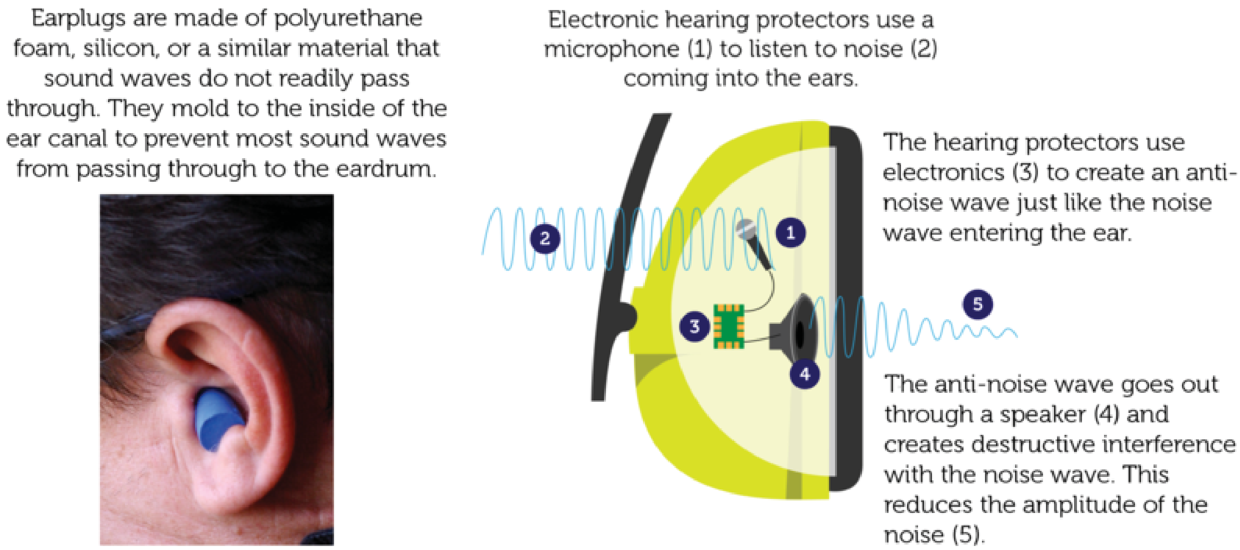


FIGURE 7.11

All types of hearing protectors help reduce the risk of hearing loss, but they don't all work the same way.

Lesson Summary

- The outer ear catches sound waves and funnels them to the middle ear. The middle ear amplifies the sound waves and passes them to the inner ear. The inner ear changes the sound waves to electrical signals. The signals travel to the brain, which interprets the sounds.
- Loud sounds can cause hearing loss by damaging hair cells in the inner ear. The louder the sounds are, the less exposure is needed to cause hearing loss.
- Hearing loss due to loud sounds can be prevented by wearing hearing protectors. They reduce the amplitude of sound waves entering the ears.

Lesson Review Questions

Recall

1. What is the function of the outer ear?
2. How does the middle ear amplify sound?
3. Describe the structure of the cochlea.
4. State how hair cells detect sound waves.

Apply Concepts

5. Write a public service announcement warning people of the dangers of loud sounds. Include tips for protecting the ears from loud sounds.

Think Critically

6. In **Figure** 7.9, how are permissible exposure times related to sound intensity? Create a graph to show the relationship.

Points to Consider

In this lesson, you read about loud sounds and their dangers. Rock concerts often produce very loud sounds. Both the screaming fans and the highly amplified musical instruments contribute to the high decibel levels. Playing musical instruments is one way we use sound. You'll read about musical instruments in "Using Sound," the next lesson.

- How do you think musical instruments produce sound? In other words, how do you think they cause air to vibrate?
- How do musical instruments change the pitch of sound?

7.3 Using Sound

Lesson Objectives

- Explain how musical instruments produce sound.
- Identify uses of ultrasound.

Lesson Vocabulary

- resonance
- sonar

Introduction

If you have normal hearing, it's hard to imagine life without sound. A silent world would seem like an eerie place. Sound is an important part of how we sense the world around us. Whether it's the chirping of a bird, the sigh of a friend, or the whistle of a train, sound gives us important clues about our environment. We also depend on sound to communicate and for many other purposes. One very pleasant way we use sound is to make music.

Making Music

People have been using sound to make music for thousands of years. They have invented many different kinds of musical instruments for this purpose. Despite their diversity, however, musical instruments share certain similarities.

- All musical instruments create sound by causing matter to vibrate. The vibrations start sound waves moving through the air.
- Most musical instruments use resonance to amplify the sound waves and make the sounds louder. **Resonance** occurs when an object vibrates in response to sound waves of a certain frequency. In a musical instrument such as a guitar, the whole instrument and the air inside it may vibrate when a single string is plucked. This causes constructive interference with the sound waves, which increases their amplitude.
- Most musical instruments have a way of changing the frequency of the sound waves they produce. This changes the pitch of the sounds.

There are three basic categories of musical instruments: percussion, wind, and stringed instruments. In **Figure** 7.12, you can see how instruments in each category make sound and how the pitch of the sound can be changed.

FIGURE 7.12

A drum, saxophone, and violin represent the three basic categories of musical instruments. Can you name other instruments in each category?

Using Ultrasound

Ultrasound has frequencies higher than the human ear can detect (higher than 20,000 hertz). Although we can't hear ultrasound, it is very useful. Uses include echolocation, sonar, and ultrasonography.

Echolocation

Animals such as bats, whales, and dolphins send out ultrasound waves and use their echoes, or reflected waves, to identify the locations of objects they cannot see. This is called echolocation. Animals use echolocation to find prey and avoid running into objects in the dark. **Figure** 7.13 and the animation at the URL below show how a bat uses echolocation to locate insect prey.

http://www.bsos.umd.edu/psyc/batlab/headaimmovies/nsf_challenge/nsf4.wmv

Sonar

Sonar uses ultrasound in a way that is similar to echolocation. **Sonar** stands for sound navigation and ranging. It is used to locate underwater objects such as sunken ships or to determine how deep the water is. A sonar device is usually located on a boat at the surface of the water. The device is both a sender and a receiver (see **Figure** 7.14). It sends out ultrasound waves and detects reflected waves that bounce off underwater objects or the bottom of the water. If you watch the video at the URL below, you can see how sonar is used on a submarine.

http://dsc.discovery.com/videos/ultimate-guide-to-submarines-sonar.html

The distance to underwater objects or the bottom of the water can be calculated from the known speed of sound in

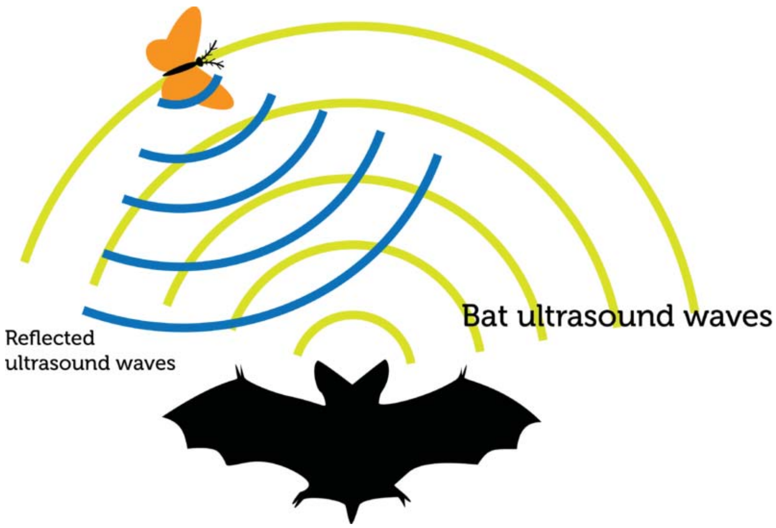


FIGURE 7.13
Bats use ultrasound to find prey.

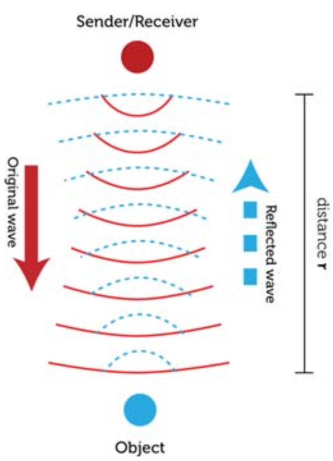


FIGURE 7.14
Sonar works on the same principle as echolocation.

water and the time it takes for the waves to travel to the object. The equation for the calculation is:

$$\text{Distance} = \text{Speed} \times \text{Time}$$

Assume, for example, that a sonar device on a ship sends an ultrasound wave to the bottom of the ocean. The speed of the sound through ocean water is 1437 m/s, and the wave travels to the bottom and back in 2 seconds. What is the distance from the surface to the bottom of the water? The sound wave travels to the bottom and back in 2 seconds, so it travels from the surface to the bottom in 1 second. Therefore, the distance from the surface to the bottom is:

$$\text{Distance} = 1437 \text{ m/s} \times 1 \text{ s} = 1437 \text{ m}$$

You Try It!

Problem: The sonar device on a ship sends an ultrasound wave to the bottom of the water at speed of 1437 m/s. The wave is reflected back to the device in 4 seconds. How deep is the water?

Ultrasonography

Ultrasound can be used to "see" inside the human body. This use of ultrasound is called ultrasonography. Harmless ultrasound waves are sent inside the body, and the reflected waves are used to create an image on a screen. This technology is used to examine internal organs and unborn babies without risk to the patient. You can see an ultrasound image in **Figure** 7.15. You can see an animation showing how ultrasonography works at this URL: http://health.howstuffworks.com/pregnancy-and-parenting/pregnancy/fetal-development/adam-200128.htm .

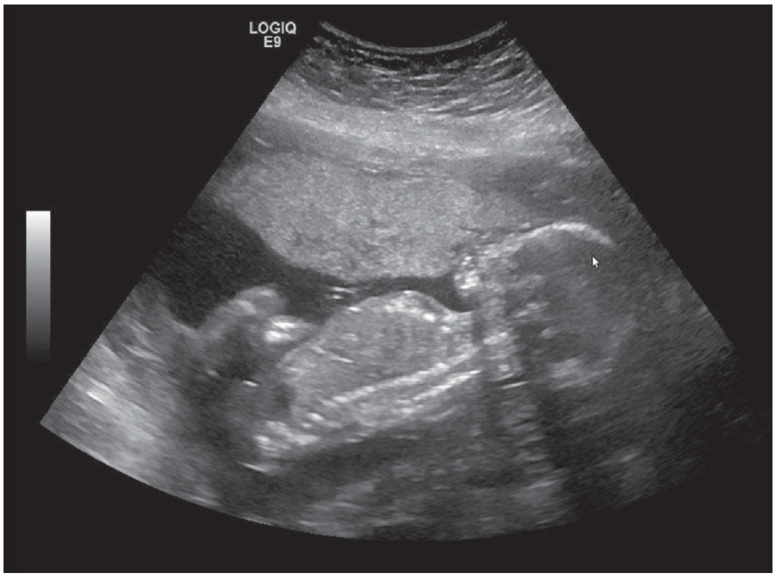


FIGURE 7.15
This ultrasound image shows an unborn baby inside its mother's body. Do you see the baby's face?

Lesson Summary

- All musical instruments make sound by causing something to vibrate and starting sound waves moving through the air. Most instruments use resonance to amplify the sound waves. Most also have a way to change pitch of the sounds. There are three categories of musical instruments: percussion, wind, and stringed instruments.
- Ultrasound has frequencies higher than the human ear can hear. Uses of ultrasound include echolocation, sonar, and ultrasonography.

Lesson Review Questions

Recall

1. Describe ultrasound.
2. How does resonance occur? Give an example.
3. What does sonar stand for?
4. List two uses of sonar.
5. What is ultrasonography?

Apply Concepts

6. Create a sketch to show how a whale might use echolocation to locate a school of fish.

Think Critically

7. Compare and contrast echolocation, sonar, and ultrasonography.

Points to Consider

In this chapter, you read about sound waves, which start with a disturbance of matter and travel through matter as longitudinal waves. In the chapter "Electromagnetic Radiation," you'll read about electromagnetic waves, such as light and X rays, which can travel through empty space.

- How do you think electromagnetic waves might be different from waves that travel through matter?
- How do you think electromagnetic waves get started?

7.4 References

1. Mark Hillary. http://www.flickr.com/photos/markhillary/361796692/ . CC BY 2.0
2. Guitar string photo by Flickr:jar(); illustration by Christopher Auyeung (CK-12 Foundation). Guitar string photo: http://www.flickr.com/photos/jariceiii/5343236121/ . CC BY 2.0
3. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
4. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
5. Piccolo: U.S. Navy photo by Chief Mass Communication Specialist David Rush; Tuba: Bob Fishbeck. Piccolo: http://commons.wikimedia.org/wiki/File:US_Navy_081024-N-0879R-007_A_musician_from_the_U.S._-Pacific_Fleet_Band_plays_a_piccolo.jpg ; Tuba: http://commons.wikimedia.org/wiki/File:Armen_tuba2.jpg . Public Domain
6. Zachary Wilson. CK-12 Foundation . CC BY-NC 3.0
7. Original by Chittka L, Brockmann A; modified by CK-12 Foundation. http://commons.wikimedia.org/wiki/File:Anatomy_of_the_Human_Ear.svg . CC BY 2.5
8. S. Heller and K. Oshima. http://www.nidcd.nih.gov/news/releases/10/Pages/07_02_10.aspx . Public Domain
9. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
10. Sign: Rae Allen; Construction: Photo by John Messina for the Environmental Protection Agency; Lawnmower: Elliot Brown; Snowmobile: Chris Costes; composite by CK-12. Sign: http://www.flickr.com/photos/raeallen/5798295550/; Construction: http://commons.wikimedia.org/wiki/File:AVONDALE_SHIPYARD_WORKER_WEARS_SPECIAL_EAR_MUFFS_FOR_PROTECTION_FROM_THE_HEAVY_LEVEL_-OF_INDUSTRIAL_NOISE_POLLUTION_-_NARA_-_546041.jpg; Lawnmower: http://www.flickr.com/photos/ell-r-brown/8830469870/; Snowmobile: http://www.flickr.com/photos/33852688@N08/3304923489/ . Sign, Lawnmower, Snowmobile: CC BY 2.0; Construction: Public Domain
11. Earplugs: Kevin Dooley; Diagram by Christopher Auyeung (CK-12 Foundation). Earplugs: http://www.flickr.com/photos/pagedooley/3976260597/ . Earplugs: CC BY 2.0; Diagram: CC BY-NC 3.0
12. Drum: Vladimir Morozov; Saxophone player: Flickr:Jim, the Photographer; Sax reed: Daniel Means (Flickr:supa pedro); Violin player: Jim Wall (Flickr:silkolive). Drum: http://www.flickr.com/photos/27429206@N02/4124370796/; Saxophone player: http://www.flickr.com/photos/jcapaldi/9540998932/; Sax reed: http://www.flickr.com/photos/supa_pedro/4296626215/; Violin player: http://www.flickr.com/photos/jimwall/4783029667/ . CC BY 2.0
13. Christopher Auyeung, using bat image by User:Rugby471/Wikimedia Commons. CK-12 Foundation (bat available at http://commons.wikimedia.org/wiki/File:Bat_shadow_black.svg) . CC BY-NC 3.0 (bat image available under public domain)
14. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
15. Glenn J. Mason (Flickr:glennji). http://www.flickr.com/photos/glennji/5566389372/ . CC BY 2.0