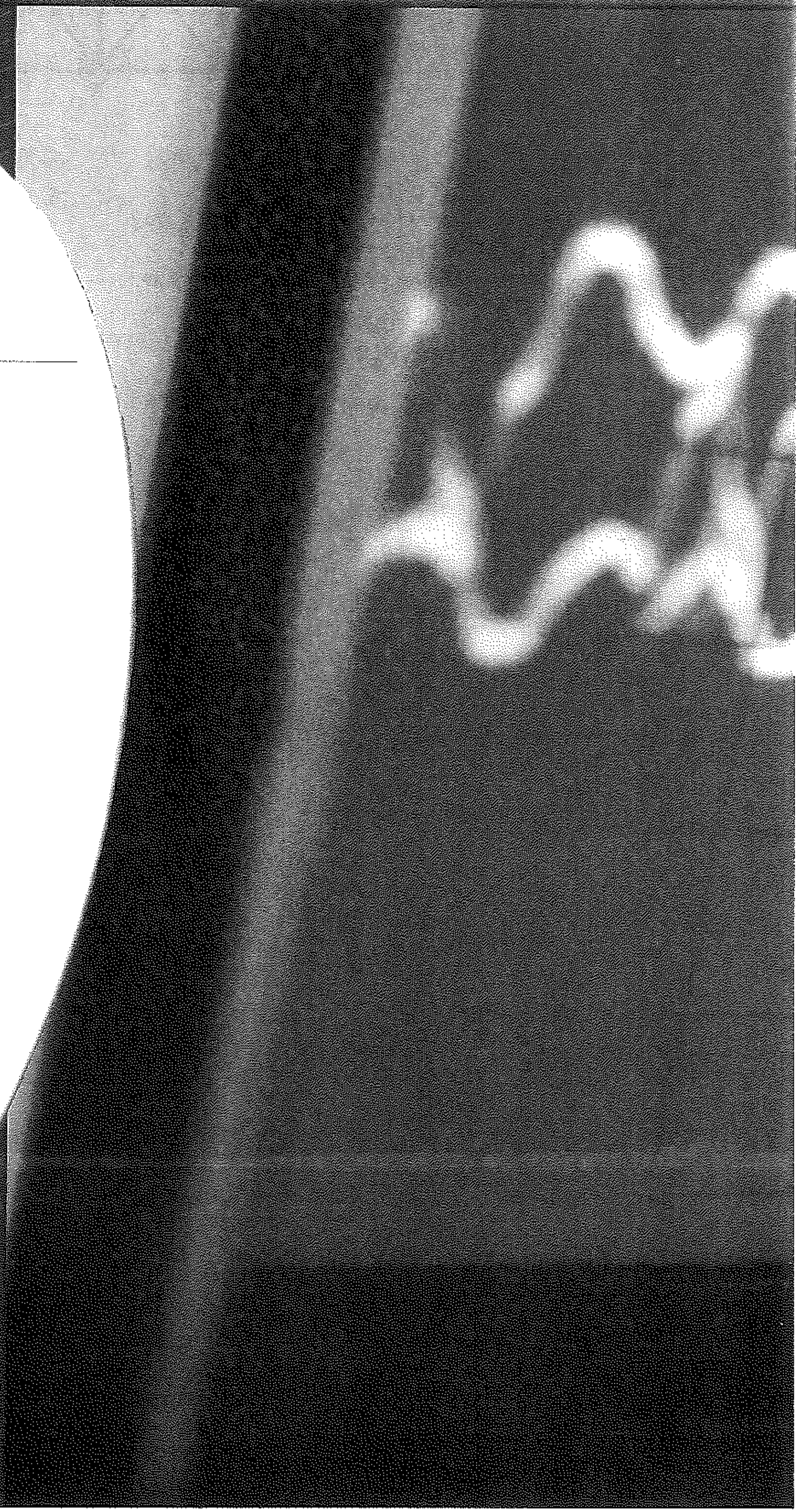
Chapter

15 Characteristics of Waves



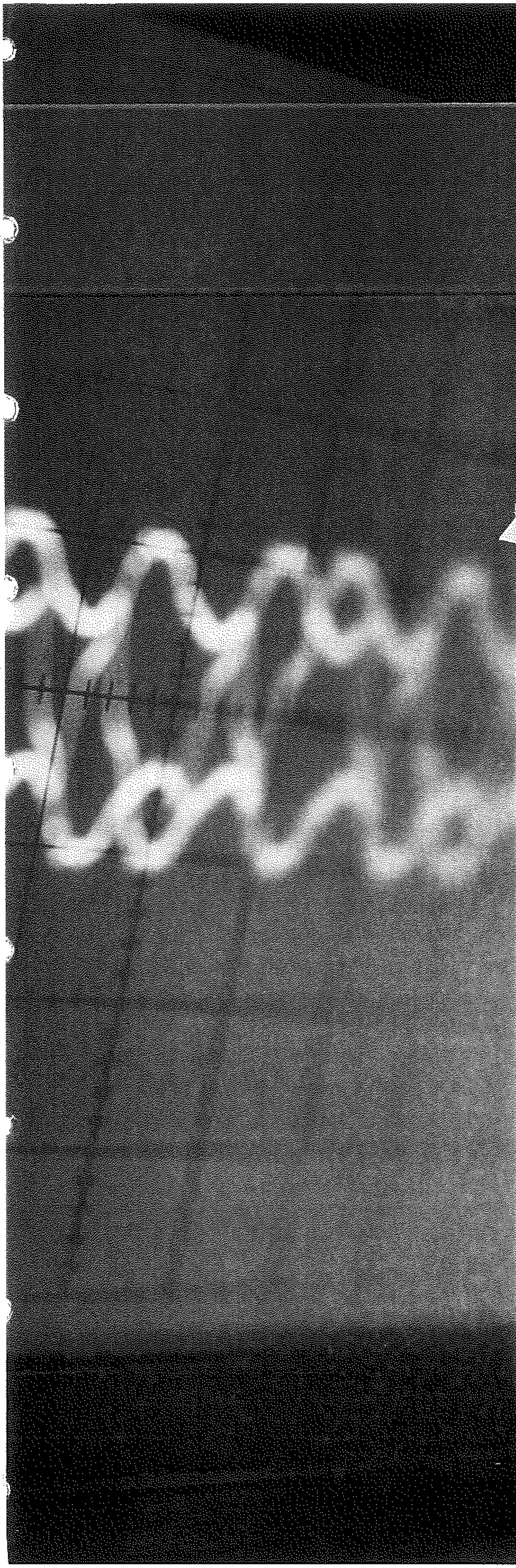
The BIG Idea

Transfer of Energy

How does a mechanical wave transfer energy?

Chapter Preview

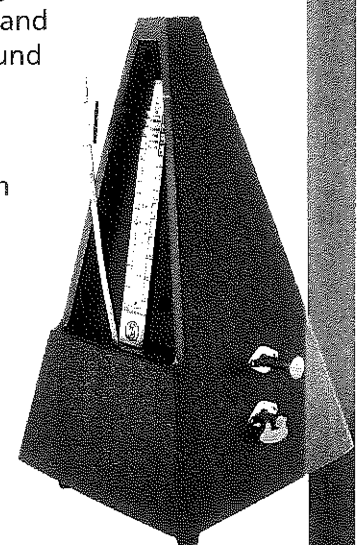
1. **What Are Waves?**
   Discover How Do Waves Travel?
   Math Skills Angles
2. **Properties of Waves**
   Discover Can You Change a Wave?
   Skills Activity Calculating
   Skills Lab Wavy Motions
3. **Interactions of Waves**
   Discover How Does a Ball Bounce?
   Skills Activity Observing
   Active Art Wave Interference
   Try This Interfering Waves
   At-Home Activity Waves in a Sink
   Skills Lab Making Waves
4. **Seismic Waves**
   Discover Can You Find the Sand?
   Analyzing Data Motion of a Tsunami
   At-Home Activity Sounds Solid



Lab zone™ Chapter Project

Over and Over and Over Again

Some waves involve repeating patterns, or cycles. Any motion that repeats itself at regular intervals is called periodic motion. The hands moving on a clock, a child swinging on a swing, and a Ferris wheel going round and round are examples of periodic motion.



Your Goal To find examples of periodic motion and describe them

To complete this project you must

- identify examples of periodic motion or events that have periodic characteristics
- collect and organize data on the frequency and duration of each event
- present your findings as a poster, a display, or a demonstration

Plan It! With your group, brainstorm examples of objects or events that go back and forth or alternate from high to low, dark to light, loud to quiet, or crowded to uncrowded. Select at least two objects or events to observe. Record data such as how long it takes for the event to finish and start again or the highest and lowest point of the object's motion. Finally, organize your findings to present to your class.

Section 1

What Are Waves?

Reading Preview

Key Concepts

- What causes mechanical waves?
- What are two types of waves and how are they classified?

Key Terms

- wave
- energy
- medium
- mechanical wave
- vibration
- transverse wave
- crest
- trough
- longitudinal wave
- compression
- rarefaction

Target Reading Skill

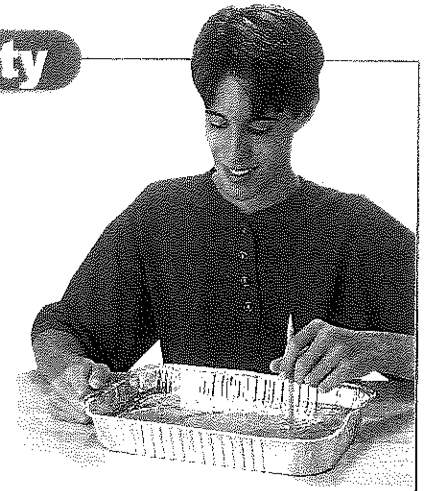
Using Prior Knowledge Before you read, look at the section headings and visuals to see what this section is about. Then write what you know about waves and energy in a graphic organizer like the one below. As you read, continue to write in what you learn.

What You Know
1. Waves are high and low. 2.

What You Learned
1. 2.

Lab zone Discover Activity

How Do Waves Travel?



1. Fill a shallow pan with about 3 cm of water.
2. With a pencil, touch the surface of the water at one end of the pan twice each second for about a minute.
3. Describe the pattern the waves make. Sketch a rough diagram of what you see.
4. Float a cork in the center of the pan. Repeat Step 2 and observe how the cork moves. Draw a diagram of what you see.

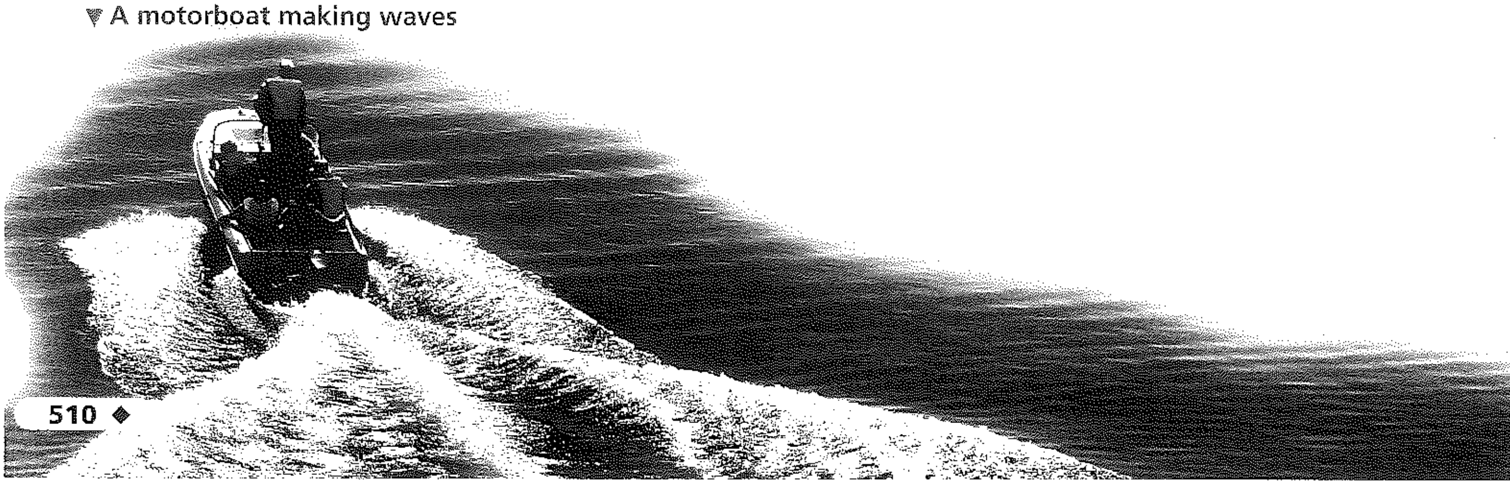
Think It Over

Observing How did the cork move in Step 4? How is its movement similar to the wave's movement? How is it different?

It was a long swim, but now you're resting on the swimming raft in the lake. You hear the water lapping gently against the raft as the sun warms your skin. Suddenly a motorboat zooms by. A few seconds later you're bobbing wildly up and down as the boat's waves hit the raft. Although the speedboat didn't touch the raft, its energy caused waves in the water. Then the waves moved the raft—and you!

You can see and feel the water waves when you're on a swimming raft. But did you know that many kinds of waves affect you every day? Sound is a wave. Sunlight is a different kind of wave. Light, sound, and water waves may seem very different, but they all are waves. What is a wave?

▼ A motorboat making waves



Waves and Energy

A **wave** is a disturbance that transfers energy from place to place. In science, **energy** is defined as the ability to do work. To understand waves, think about the swimming raft. A wave that disturbs the surface of the water also will disturb the raft. The wave's energy lifts the heavy raft as the wave passes under it. But the disturbance caused by the wave is temporary. After the wave passes, the water is calm again and the raft stops bobbing.

What Carries Waves? Most kinds of waves need something to travel through. Sound waves travel through air. Water waves travel along the surface of the water. A wave can even travel along a rope. The material through which a wave travels is called a **medium.** Gases (such as air), liquids (such as water), and solids (such as rope) all act as mediums. Waves that require a medium through which to travel are called **mechanical waves.**

But not all waves require a medium to travel through. Light from the sun, for example, can carry energy through empty space. If light could not travel through empty space, you could not even see the sun! Waves that can travel without a medium are called electromagnetic waves. You will learn more about electromagnetic waves in a later chapter.

FIGURE 1
Motion of a Medium
Waves travel through water, but they do not carry the water (or the duck) with them. Predicting *If you add a sixth stage to the diagram, which earlier stage should it most resemble?*

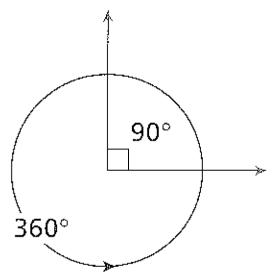
How Do Waves Transfer Energy? Although mechanical waves travel through a medium, they do not carry the medium with them. Look at the duck in Figure 1. When a wave travels under the duck, the duck moves up and down. But the duck does not travel with the wave. After the wave passes, the duck and the water return to where they started.

Why doesn't the medium travel along with the wave? All mediums are made of tiny particles. When a wave enters a medium, it transfers energy to the medium's particles. The particles bump into each other, passing the wave's energy along. To understand this, think about how food is passed at a table. You hand the food to the next person, who passes it to the next person, and so on. The food is transferred, but the people don't move. The food is like the wave's energy, and the people are like particles in a medium.

Math Skills

Angles

An angle is formed when two lines meet at a point. Angles are measured in degrees, indicated by the symbol °. A circle has 360 degrees. A right angle is an angle that contains 90 degrees. Two lines that meet at a point to form a 90° angle are said to be perpendicular to each other.



Practice Problems

1. Draw a circle on a piece of paper. How many right angles can you fit in the circle?
2. How many degrees do two right angles contain?

What Causes Waves? Energy always is required to make a wave. **Mechanical waves are produced when a source of energy causes a medium to vibrate.** A **vibration** is a repeated back-and-forth or up-and-down motion. When a vibration moves through a medium, a wave results.

Moving objects have energy. A moving object can transfer energy to a medium, producing waves. For example, you can make waves by dipping your finger in water. Your finger has energy because it is moving. When your finger touches the water, it transfers energy to the water and makes waves. In the same way, a motorboat slicing through calm water transfers energy to the water and makes waves.

Reading Checkpoint What is a vibration?

Types of Waves

Waves move through mediums in different ways. **Mechanical waves are classified by how they move. There are two types of mechanical waves: transverse waves and longitudinal waves.**

Transverse Waves When you make a wave on a rope, the wave moves from one end of the rope to the other. But the rope itself moves up and down or from side to side, at right angles to the direction in which the wave travels. Waves that move the medium at right angles to the direction in which the waves travel are called **transverse waves.** Transverse means "across." As a transverse wave moves, the particles of the medium move across, or at a right angle to, the direction of the wave.

In Figure 2, you can see that the red ribbon on the rope is first at a low point of the wave. Then it is at a high point. The high part of a transverse wave is called a **crest,** and the low part is called a **trough** (trawf).

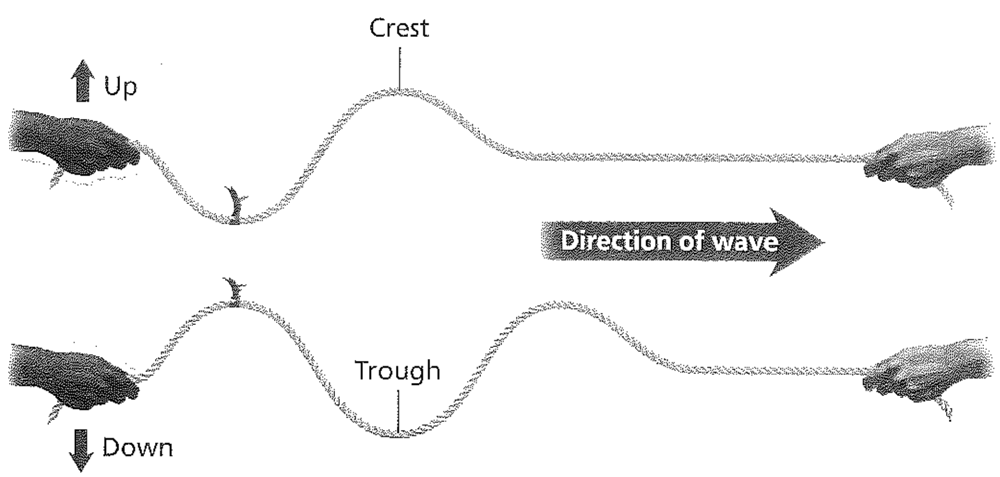


FIGURE 2
Transverse Waves
A transverse wave moves the rope up and down in a direction perpendicular to the direction in which the wave travels.

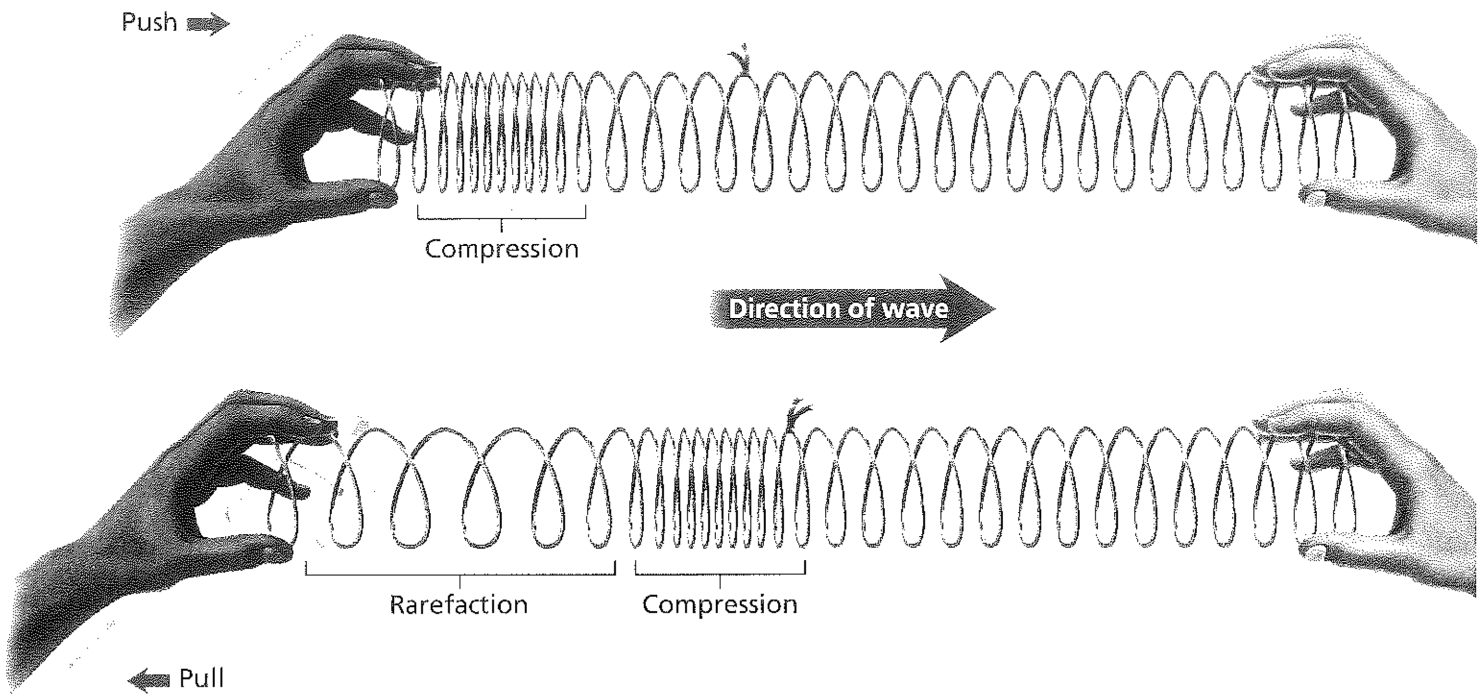


FIGURE 3
Longitudinal Waves
A longitudinal wave moves the coils of a spring toy back and forth in a direction parallel to the direction the wave travels. Comparing and Contrasting *How do the coils in a compression compare to the coils in a rarefaction?*

Longitudinal Waves Figure 3 shows a different kind of wave. If you stretch out a spring toy and push and pull one end, you can produce a longitudinal wave. **Longitudinal waves** (lawn juh TOO duh nul) move the medium parallel to the direction in which the waves travel. The coils in the spring move back and forth parallel to the wave motion.

Notice in Figure 3 that in some parts of the spring, the coils are close together. In other parts of the spring, the coils are more spread out. The parts where the coils are close together are called **compressions** (kum PRESH unz). The parts where the coils are spread out, or rarified, are called **rarefactions** (rair uh FAK shunz).

As compressions and rarefactions travel along the spring toy, each coil moves forward and then back. The energy travels from one end of the spring to the other, creating a wave. After the wave passes, each coil returns to the position where it started.

Sound is also a longitudinal wave. In air, sound waves cause air particles to move back and forth. In areas where the particles are pushed together, compressions form. In between the compressions, particles are spread out. These are rarefactions.

Go Online
SCILINKS NSTA
For: Links on waves
Visit: www.SciLinks.org
Web Code: scn-1511

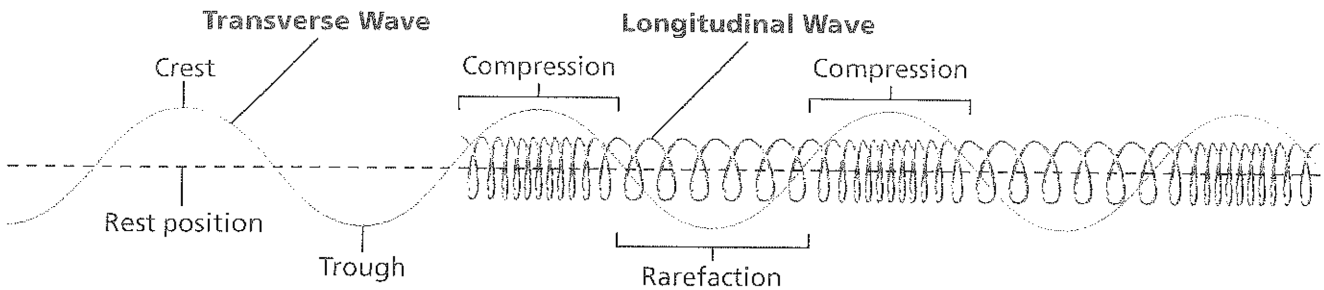


FIGURE 4
Representing Waves
The compressions of a longitudinal wave correspond to the crests of a transverse wave. The troughs correspond to rarefactions.

Representing Types of Waves You can use diagrams to represent transverse and longitudinal waves. Transverse waves like those on a rope are easy to draw. You can draw a transverse wave as shown in Figure 4. Think of the horizontal line as the position of the rope before it is disturbed. This position is called the rest position. As the wave passes, the rope moves above or below the rest position. Remember that the crests are the highest points of the wave and the troughs are the lowest points of the wave.

To draw longitudinal waves, think of the compressions in the spring toy as being similar to the crests of a transverse wave. The rarefactions in the spring toy are like the troughs of a transverse wave. By treating compressions as crests and rarefactions as troughs, you can draw longitudinal waves in the same way as transverse waves.

Reading Checkpoint **How do you draw the rest position of a transverse wave?**

Section 1 Assessment

Target Reading Skill Using Prior Knowledge Revise your graphic organizer about waves based on what you just learned in the section.

Reviewing Key Concepts

1. a. Defining What is a mechanical wave?
   b. Explaining How are mechanical waves produced?
   c. Inferring A wave moves a floating dock up and down several times, but then the dock stops moving. What happened to the wave?
2. a. Identifying What are the two types of mechanical waves?
   b. Describing Use a wave diagram to represent the crests and troughs of a wave. Then describe a crest and trough in your own words.
   c. Comparing and Contrasting How does a transverse wave move a medium? How does a longitudinal wave move a medium?

Writing in Science

Firsthand Account Suppose you are a particle of water in a lake. Describe what happens to you when a motorboat passes by. Be sure to use words like *vibration* and *crest* in your description.

Section 2 Properties of Waves

Reading Preview

Key Concepts

- What are the basic properties of waves?
- How is a wave's speed related to its wavelength and frequency?

Key Terms

- amplitude
- wavelength
- frequency
- hertz (Hz)

Target Reading Skill

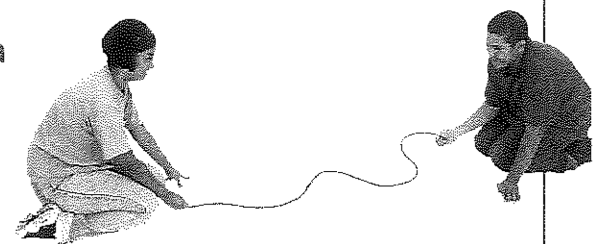
Outlining An outline shows the relationship between main ideas and supporting ideas. As you read, make an outline about the properties of waves that you can use for review. Use the red headings for the main ideas and the blue headings for the supporting ideas.

Properties of Waves

I. Amplitude
   A. Amplitude of transverse waves
   B.
II. Wavelength
III.

Lab zone Discover Activity

Can You Change a Wave?



1. Lay a 3-meter-long rope on the floor. Hold one end of the rope. Have a partner hold the other end.
2. Flick your end left and right about once per second. Observe the waves.
3. Now flick your end about twice per second. Observe the waves.
4. Switch roles with your partner and repeat Steps 2 and 3.

Think It Over

Predicting What happened to the waves when you flicked the rope more often? Predict how the wave will change if you flick the rope less often than once per second. Try it.

One of the most elegant and graceful Olympic sports is rhythmic gymnastics. A ribbon dancer flicks a stick attached to a ribbon, making waves that travel down the ribbon. Some of the waves are longer, while others are shorter. The rate at which the gymnast flicks her hands affects both the length and shape of the waves in the ribbon.

This is just one of many different kinds of waves. Waves can carry a little energy or a lot. They can be short or long. They can be rare or frequent. They can travel fast or slow. All waves, however, share certain properties. **The basic properties of waves are amplitude, wavelength, frequency, and speed.**

A rhythmic gymnast ▲

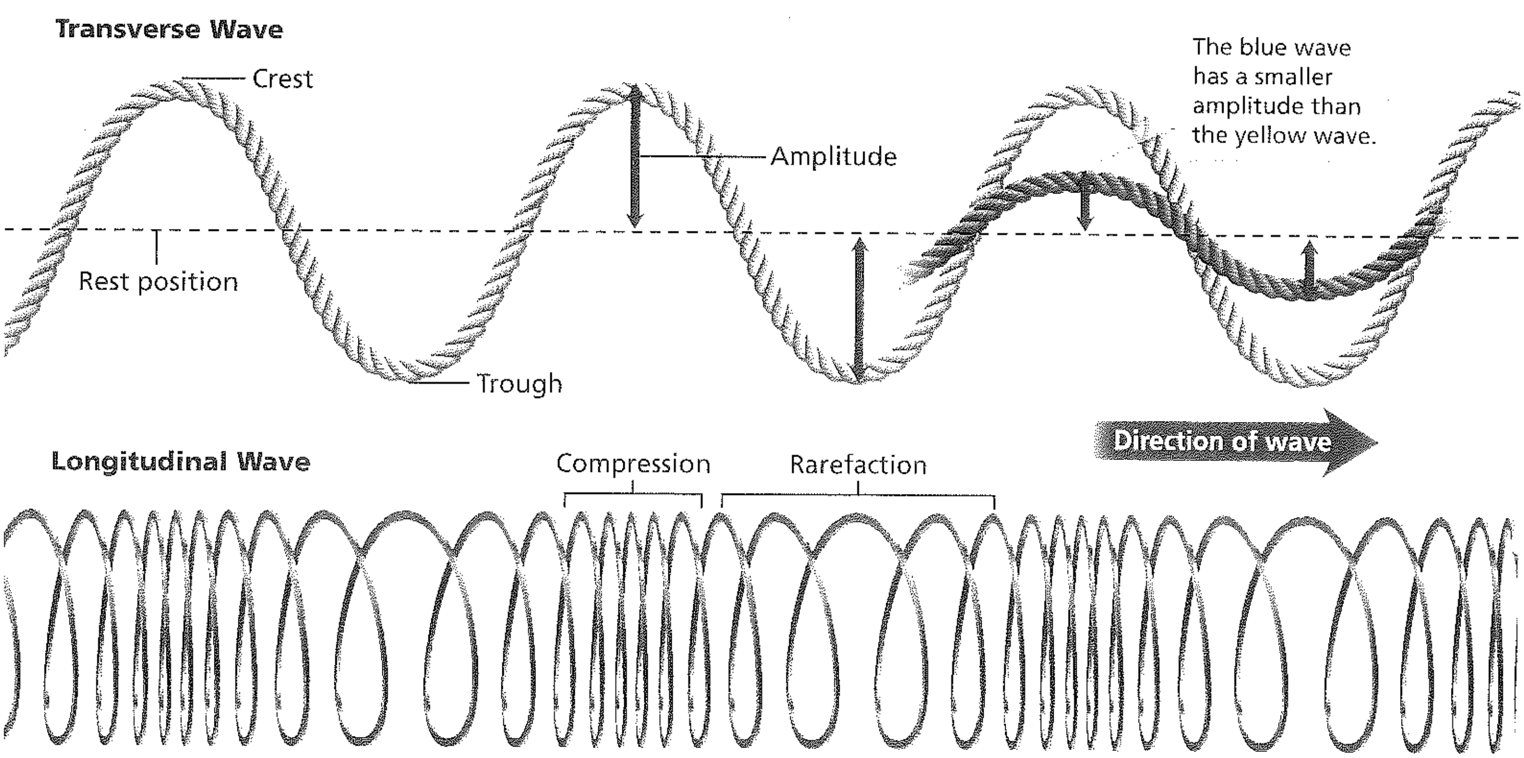
Amplitude

Some crests are very high, while others are very low. The distance the medium rises depends on the amplitude of the wave. **Amplitude** is the maximum distance that the particles of the medium carrying the wave move away from their rest positions. For example, the amplitude of a water wave is the maximum distance a water particle moves above or below the surface level of calm water. You can increase the amplitude of a wave in a rope by moving your hand up and down a greater distance. To do this, you have to use more energy. This energy is transferred to the rope. Thus, the more energy a wave has, the greater its amplitude.

Amplitude of Transverse Waves As shown in Figure 5, the amplitude of a transverse wave is the maximum distance the medium moves up or down from its rest position. You can find the amplitude of a transverse wave by measuring the distance from the rest position to a crest or to a trough.

Amplitude of Longitudinal Waves The amplitude of a longitudinal wave is a measure of how compressed or rarefied the medium becomes. A high-energy wave causes more compression and rarefaction than a low-energy wave. When the compressions are dense, it means that the wave's amplitude is large.

FIGURE 5
Amplitude, Wavelength, and Frequency
The basic properties of all waves include amplitude, wavelength, and frequency.
Developing Hypotheses *How could you increase the amplitude of a wave in a rope? How could you increase the frequency?*



Wavelength

A wave travels a certain distance before it starts to repeat. The distance between two corresponding parts of a wave is its **wavelength.** You can find the wavelength of a transverse wave by measuring the distance from crest to crest, as shown in Figure 5. Or you could measure from trough to trough. The wavelength of a longitudinal wave is the distance between compressions.

Frequency

Wave **frequency** is the number of complete waves that pass a given point in a certain amount of time. For example, if you make waves on a rope so that one wave passes by every second, the frequency is 1 wave per second. How can you increase the frequency? Simply move your hand up and down more quickly, perhaps two or three times per second. To decrease the frequency, move your hand up and down more slowly.

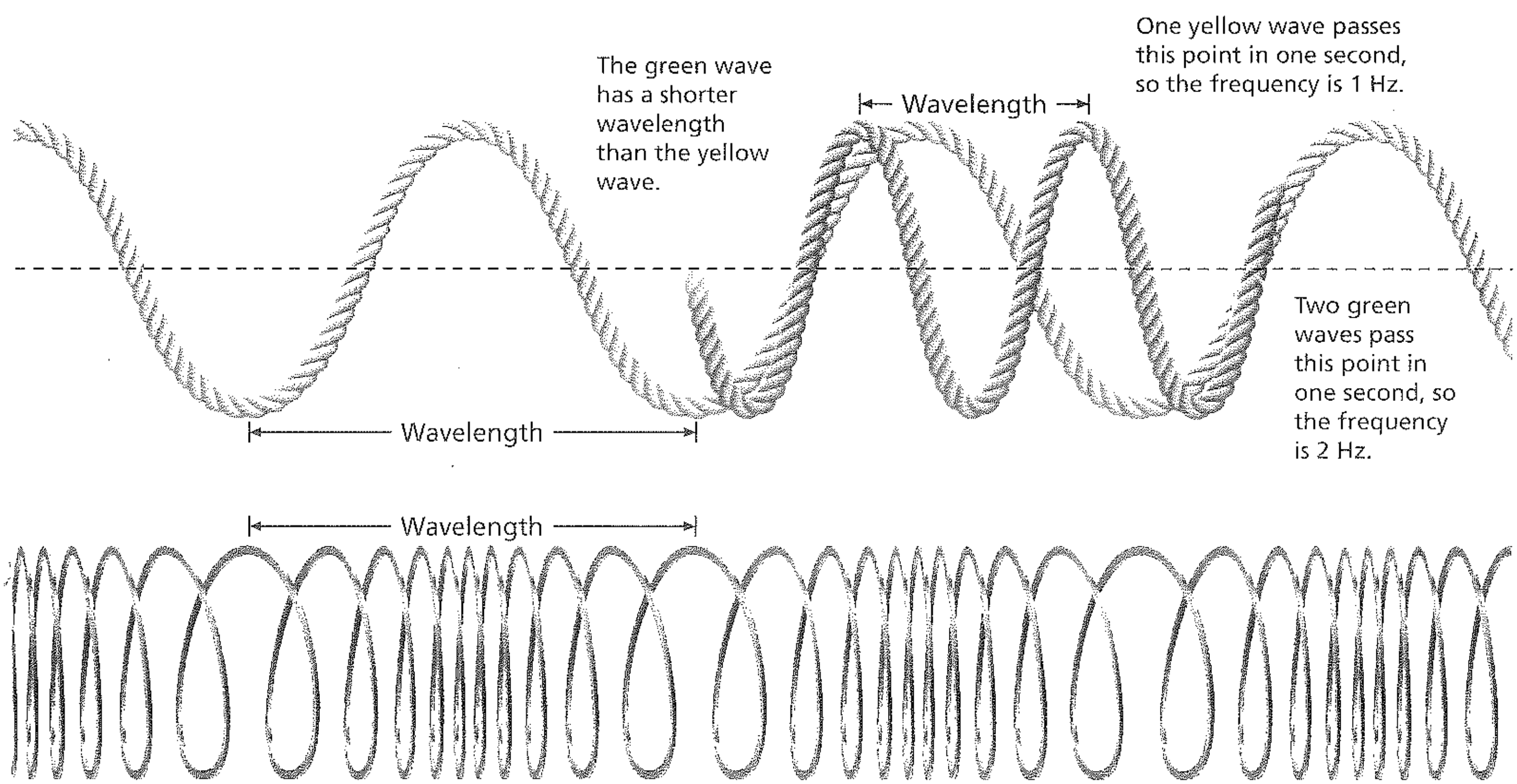
Frequency is measured in units called **hertz (Hz).** A wave that occurs every second has a frequency of 1 Hz. If two waves pass you every second, then the frequency of the wave is 2 per second, or 2 hertz. The hertz was named after Heinrich Hertz, the German scientist who discovered radio waves.

Reading Checkpoint **In what unit is the frequency of a wave measured?**

Lab zone Skills Activity

Calculating

Tie a metal washer to one end of a 25-cm long string. Tape the other end of the string to the edge of a table. Let the washer hang and then pull it about 10 cm to the side and release it. Measure the time it takes the washer to swing through 10 complete cycles. (In 1 cycle, the washer swings forward and back, returning to its starting point.) Calculate the frequency by dividing 10 cycles by the time interval.



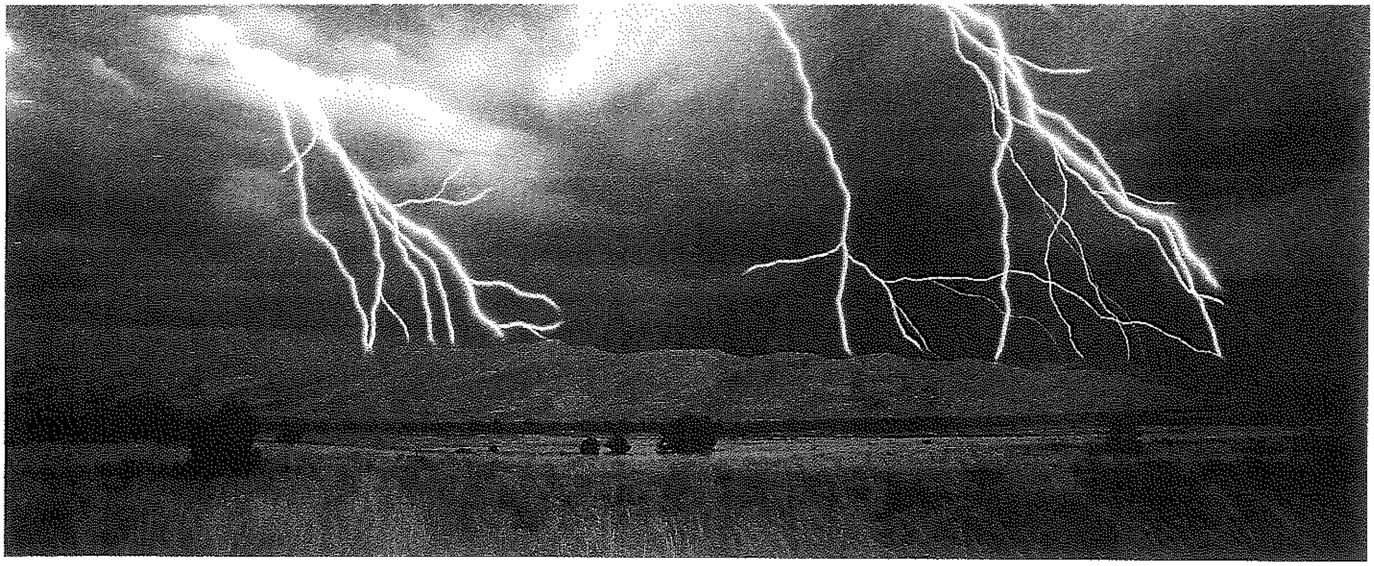


FIGURE 6
Speed of Waves
Light waves travel much faster than sound waves.
Problem Solving *Why do you see lightning before hearing thunder?*

Speed

Imagine watching a distant thunderstorm approach on a hot summer day. First you see a flash of lightning. A few seconds later you hear the thunder rumble. Even though the thunder occurs the instant the lightning flashes, the light and sound reach you seconds apart. This happens because light waves travel much faster than sound waves. In fact, light waves travel about a million times faster than sound waves!

Different waves travel at different speeds. The speed of a wave is how far the wave travels in a given length of time, or its distance divided by the time it took to travel that distance. **The speed, wavelength, and frequency of a wave are related to one another by a mathematical formula:**

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

If you know two of the quantities in the speed formula—speed, wavelength, and frequency—you can calculate the third quantity. For example, if you know a wave's speed and wavelength, you can calculate the frequency. If you know the speed and the frequency, you can calculate the wavelength.

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

If a medium does not change, the speed of a wave is constant. For example, in air at a given temperature and pressure, all sound waves travel at the same speed. If speed is constant, what do you think will happen if the wave's frequency changes? If you multiply wavelength by frequency, you should always get the same speed. Therefore, if you increase the frequency of a wave, the wavelength must decrease.

Reading Checkpoint **What is the speed of a wave?**

Go Online
PHSchool.com
For: More on wave properties
Visit: PHSchool.com
Web Code: cgd-5012

Math Sample Problem

Calculating Frequency

The speed of a wave on a rope is 50 cm/s and its wavelength is 10 cm. What is the wave's frequency?

1 Read and Understand

What information are you given?

Speed = 50 cm/s

Wavelength = 10 cm

2 Plan and Solve

What quantity are you trying to calculate?

The frequency of a wave = ■ Hz

What formula contains the given quantities and the unknown quantity?

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

Perform the calculation.

$$\text{Frequency} = \frac{\text{Speed}}{\text{Wavelength}} = \frac{50\text{ cm/s}}{10\text{ cm}}$$

$$\text{Frequency} = \frac{5}{s} = 5\text{ Hz}$$

3 Look Back and Check

Does your answer make sense?

The wave speed is 50 cm per second. Because the distance from crest to crest is 10 cm, 5 crests will pass a point every second.

Math Practice

1. A wave has a wavelength of 2 mm and a frequency of 3 Hz. At what speed does the wave travel?
2. The speed of a wave on a guitar string is 142 m/s and the frequency is 110 Hz. What is the wavelength of the wave?

Section 2 Assessment

Target Reading Skill Outlining Use the information in your outline to help you answer the questions below.

Reviewing Key Concepts

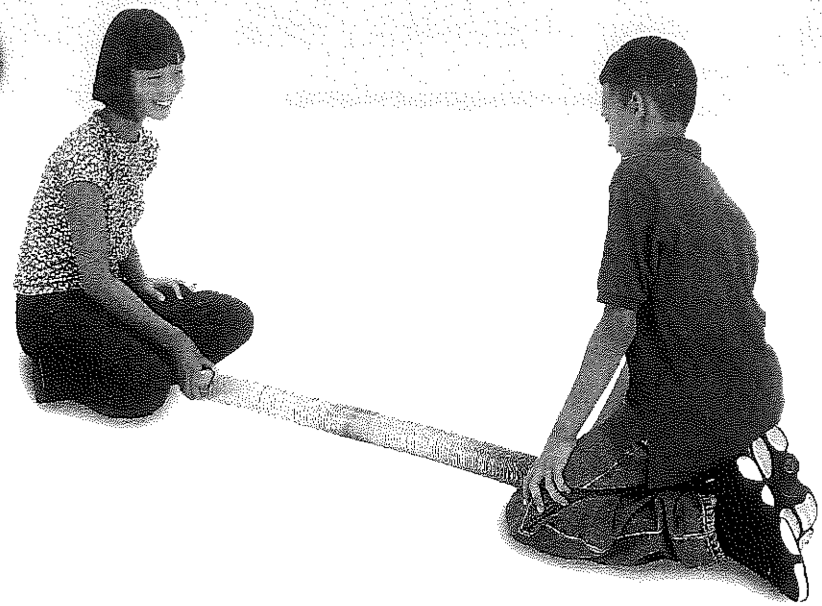
1. a. Listing What are four basic properties of waves?
   b. Explaining Which wave property is directly related to energy?
   c. Comparing and Contrasting Which wave properties are distances? Which are measured relative to time?
2. a. Identifying What formula relates speed, wavelength, and frequency?
   b. Inferring Two waves have the same wavelength and frequency. How do their speeds compare?
   c. Calculating A wave's frequency is 2 Hz and its wavelength is 4 m. What is the wave's speed?

Math Practice

3. Calculating Frequency A wave travels at 3 m/s along a spring toy. If the wavelength is 0.2 m, what is the wave's frequency?

Lab zone **Skills Lab**

Wavy Motions



Problem
How do waves travel in a spring toy?

Skills Focus
comparing and contrasting, classifying

Materials
- spring toy
- meter stick

Procedure
1. On a smooth floor, stretch the spring to about 3 meters. Hold one end while your partner holds the other end. Do not overstretch the spring toy.
2. Pull a few coils of the spring toy to one side near one end of the spring.
3. Release the coils and observe the motion of the spring. What happens when the disturbance reaches your partner? Draw what you observe.
4. Have your partner move one end of the spring toy to the left and then to the right on the floor. Be certain that both ends of the spring are held securely. Draw a diagram of the wave you observe.
5. Repeat Step 4, increasing the rate at which you move the spring toy left and right. Record your observations.
6. Squeeze together several coils of the spring toy, making a compression.
7. Release the compressed section of the spring toy and observe the disturbance as it moves down the spring. Record your observations. Draw and label what you see.

Analyze and Conclude
1. Comparing and Contrasting Compare the waves generated in Steps 1–5 with the waves generated in Steps 6–7.
2. Classifying Were the waves generated in Steps 1–5 transverse or longitudinal? Explain your answer.
3. Comparing and Contrasting In Step 3 of the procedure, compare the original wave to the wave that came back.
4. Classifying Were the waves generated in Steps 6 and 7 transverse or longitudinal? Explain your answer.
5. Interpreting Data What happened to the wavelength and frequency when you increased the rate at which the spring toy moved left and right?
6. Developing Hypotheses How might you change the amplitude of the longitudinal waves you made?
7. Communicating Use your drawings to make a poster that explains your observations.

Design an Experiment
Obtain some different spring toys. Look for different sizes and materials, such as metal and plastic. Design an experiment to test whether the differences of the spring toys result in differences in the waves the springs make. Have your teacher approve your procedure before you carry out the experiment.

Section 3

Interactions of Waves

Reading Preview

Key Concepts

- How do reflection, refraction, and diffraction change a wave's direction?
- What are the different types of interference?
- How do standing waves form?

Key Terms

- reflection • law of reflection
- refraction • diffraction
- interference
- constructive interference
- destructive interference
- standing wave • node
- antinode • resonance

Target Reading Skill

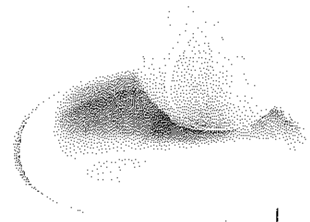
Asking Questions Before you read, preview the red headings. In a graphic organizer like the one below, ask a *what, how, when,* or *where* question for each heading. As you read, write the answers to your questions.

Interactions of Waves

Question	Answer
How are waves reflected?	Waves are reflected . . .

Lab zone Discover Activity

How Does a Ball Bounce?



1. Choose a spot at the base of a wall. From a distance of 1 m, roll a wet ball along the floor straight at the spot you chose. Watch the angle at which the ball bounces by looking at the path of moisture on the floor.
2. Wet the ball again. From a different position, roll the ball at the same spot, but at an angle to the wall. Again, observe the angle at which the ball bounces back.

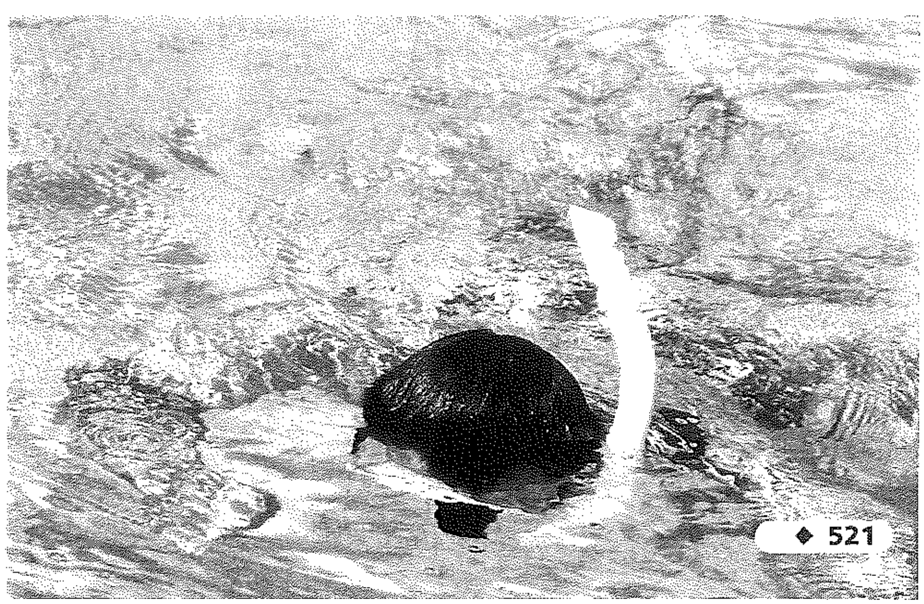
Think It Over

Developing Hypotheses How do you think the angle at which the ball hits the wall is related to the angle at which the ball bounces back? Test your hypothesis.

You slip into the water in your snorkel gear. With your mask on, you can see clearly across the pool. As you start to swim, your flippers disturb the water, sending ripples moving outward in all directions. As each ripple hits the wall, it bounces off the wall and travels back toward you.

When water waves hit the side of a swimming pool, they bounce back because they cannot pass through the solid wall. Other kinds of waves may interact in a similar way when they hit the surface of a new medium. This type of interaction is called reflection.

Making waves in a pool ▶



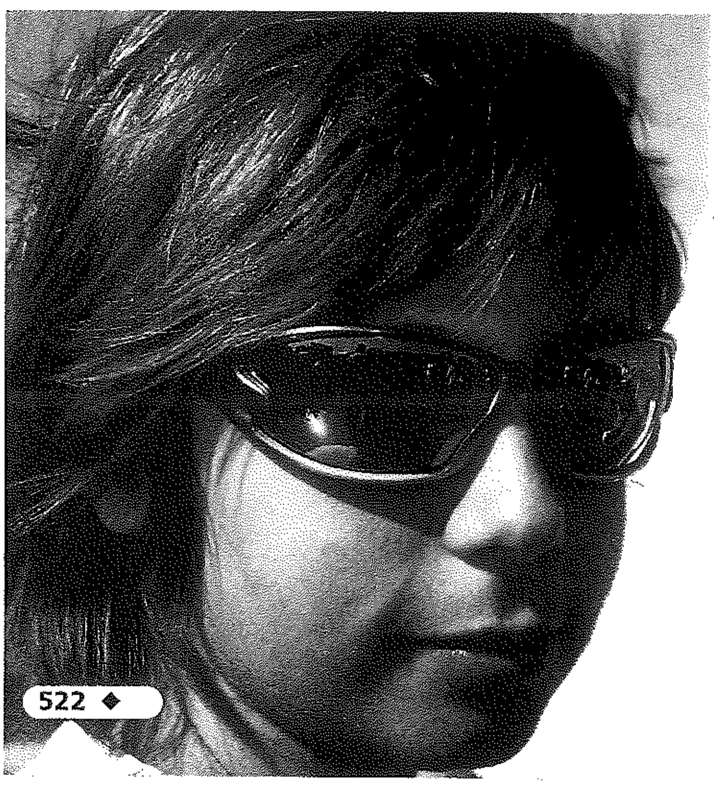
Reflection

When an object or a wave hits a surface through which it cannot pass, it bounces back. This interaction with a surface is called **reflection.** There are many examples of reflection in your everyday life. When you did the Discover Activity, you saw that the ball hit the wall and bounced back, or was reflected. When you looked in your mirror this morning, you used light that was reflected to see yourself. If you have ever shouted in an empty gym, the echo you heard was caused by sound waves that reflected off the gym walls.

All waves obey the law of reflection. To help you understand this law, look at Figure 7. In the photo, you see light reflected off the surface of the sunglasses. The diagram shows how the light waves travel to make the reflection. The arrow labeled *Incoming wave* represents a wave moving toward the surface at an angle. The arrow labeled *Reflected wave* represents the wave that bounces off the surface at an angle. The dashed line labeled *Normal* is drawn perpendicular to the surface at the point where the incoming wave strikes the surface. The angle of incidence is the angle between the incoming wave and the normal. The angle of reflection is the angle between the reflected wave and the normal line. The **law of reflection** states that the angle of incidence equals the angle of reflection.

Reading Checkpoint **What is reflection?**

FIGURE 7
Law of Reflection
The angle of incidence equals the angle of reflection. All waves obey this law, including the light waves reflected from these sunglasses.
Predicting *What happens to the angle of reflection if the angle of incidence increases?*



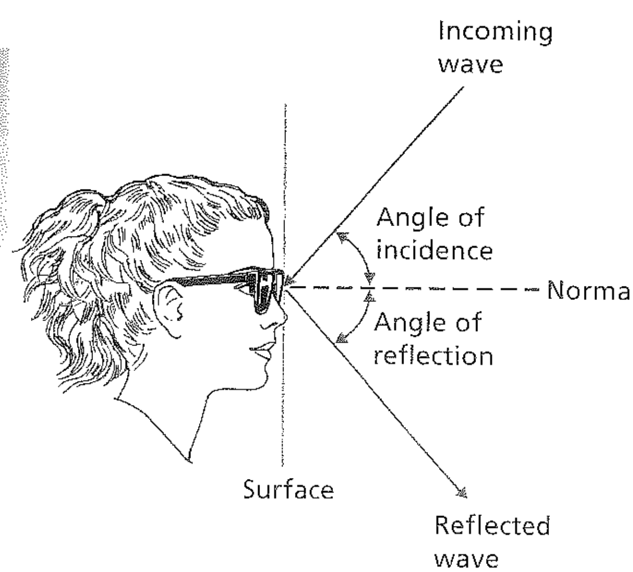
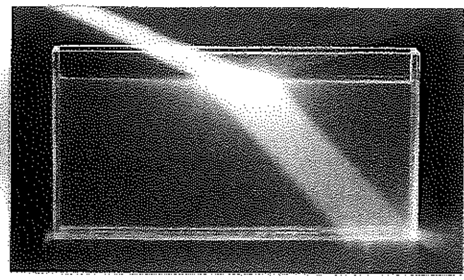
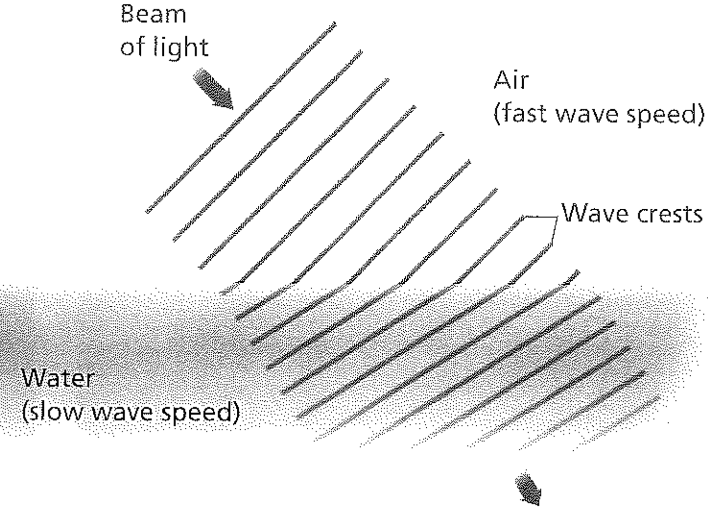


FIGURE 8
Refraction of Light Waves
Light bends when it enters water at an angle because one side of each wave slows down before the other side does.





Refraction

Have you ever been riding a skateboard and gone off the sidewalk onto grass? If so, you know it's hard to keep moving in a straight line. The front wheel on the side moving onto the grass slows down. The front wheel still on the sidewalk continues to move fast. The difference in the speeds of the two front wheels causes the skateboard to change direction.

What Causes Refraction? Like the skateboard that changes direction, changes in speed can cause waves to change direction, as shown in Figure 8. **When a wave enters a new medium at an angle, one side of the wave changes speed before the other side, causing the wave to bend.** The bending of waves due to a change in speed is called **refraction.**

When Does Refraction Occur? A wave does not always bend when it enters a new medium. Bending occurs only when the wave enters the new medium at an angle. Then one side of the wave enters the medium first. This side changes speed, but the other side still travels at its original speed. Bending occurs because the two sides of the wave travel at different speeds.

Even if you don't skateboard, you have probably seen refraction in daily life. Have you ever had trouble grabbing something underwater? Have you ever seen a rainbow? Light can bend when it passes from water into air, making an underwater object appear closer than it really is. When you reach for the object, you miss it. When white light enters water, different colors in the light bend by different amounts. The white light separates into the colors you see in a rainbow.

Reading Checkpoint **When does refraction occur?**

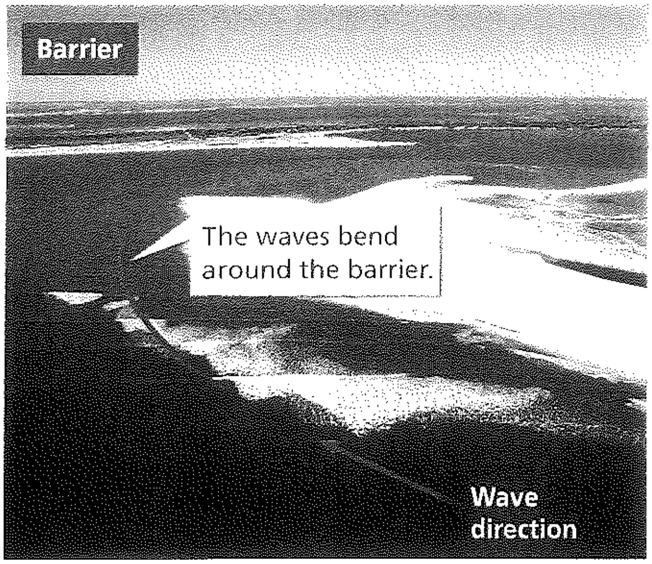
Lab zone Skills Activity

Observing

You can simulate what happens as waves move from one medium to another.

1. Roll a drinking straw from a smooth tabletop straight onto a thin piece of terry cloth or a paper towel. Describe how the straw's motion changes as it leaves the smooth surface.
2. Repeat Step 1, but roll the straw at an angle to the cloth or paper.

Describe what happens as each side of the straw hits the cloth or paper. How are your results similar to what happens when waves are refracted?



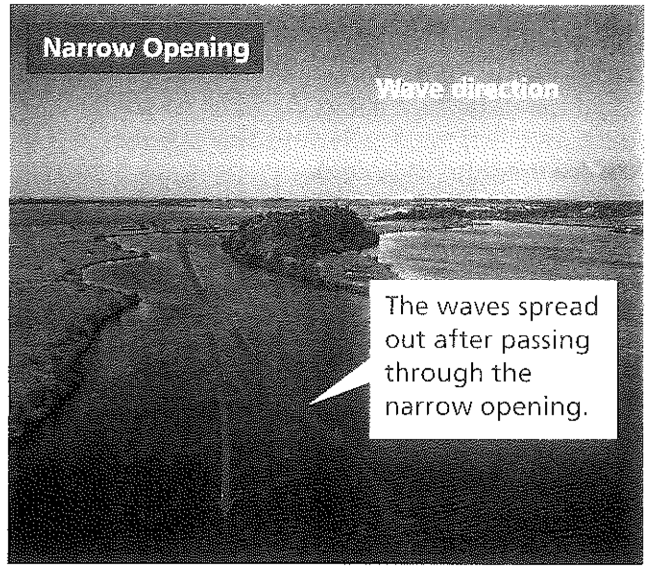


FIGURE 9
Diffraction of Water Waves
Waves diffract when they move around a barrier or pass through an opening. As a wave passes a barrier, it bends around the barrier. After a wave goes through a narrow opening, it spreads out.

Diffraction

Sometimes waves bend around a barrier or pass through a hole. **When a wave moves around a barrier or through an opening in a barrier, it bends and spreads out.** These wave interactions are called **diffraction.** Figure 9 shows how waves bend and spread by diffraction.

Interference

Have you ever seen soccer balls collide in a practice drill? The balls bounce off each other because they cannot be in the same place at the same time. Surprisingly, this is not true of waves. Unlike two balls, two waves can overlap when they meet. **Interference** is the interaction between waves that meet. **There are two types of interference: constructive and destructive.**

Constructive Interference The interference that occurs when waves combine to make a wave with a larger amplitude is called **constructive interference.** You can think of constructive interference as waves "helping each other," or adding their energies. When the crests of two waves overlap, they make a higher crest. When the troughs of two waves overlap, they make a deeper trough. In both cases, the amplitude increases.

Figure 10 shows how constructive interference can occur when two waves travel toward each other. When the crests from each wave meet, constructive interference makes a higher crest in the area of overlap. The amplitude of this crest is the sum of the amplitudes of the two original crests. After the waves pass through each other, they continue on as if they had never met.

Reading Checkpoint **What is constructive interference?**

Destructive Interference The interference that occurs when two waves combine to make a wave with a smaller amplitude is called **destructive interference.** You can think of destructive interference as waves subtracting their energies.

Destructive interference occurs when the crest of one wave overlaps the trough of another wave. If the crest has a larger amplitude than the trough, the crest "wins" and part of it remains. If the original trough had a larger amplitude, the result is a trough. If the original waves had equal amplitudes, then the crest and trough can completely cancel as shown in Figure 10.

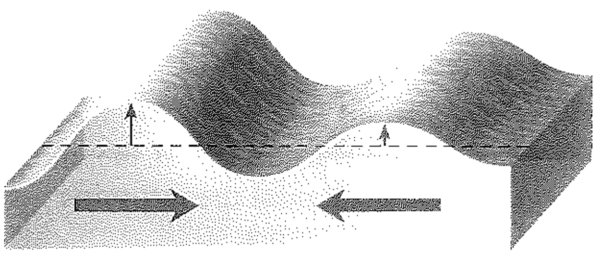
Go Online
active art

For: Wave Interference activity
Visit: PHSchool.com
Web Code: cgp-5013

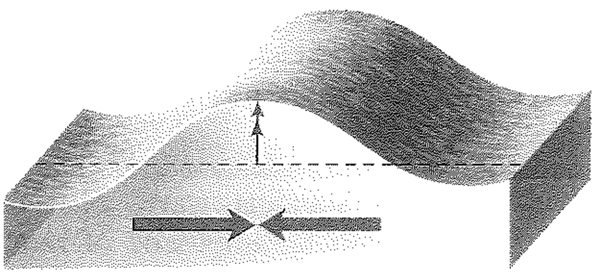
FIGURE 10
Wave Interference

Interference can be constructive or destructive.
Interpreting Diagrams *What does the black dotted line represent in the diagram below?*

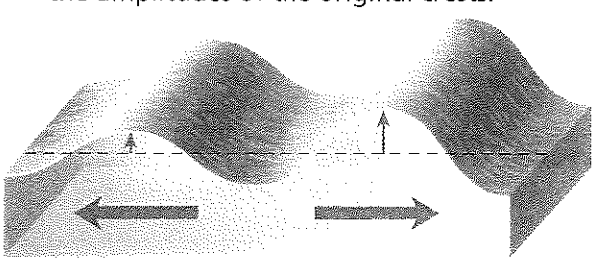
Constructive Interference



1 Two waves approach each other. The wave on the left has a higher amplitude.

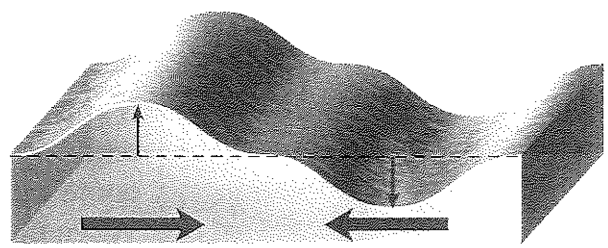


2 The crest's new amplitude is the sum of the amplitudes of the original crests.

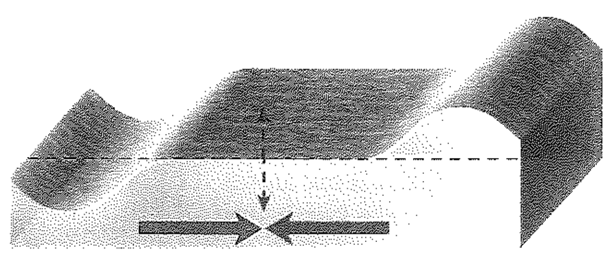


3 The waves continue as if they had not met.

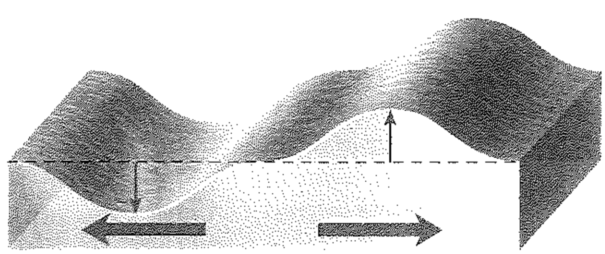
Destructive Interference



1 Two waves approach each other. The waves have equal amplitudes.

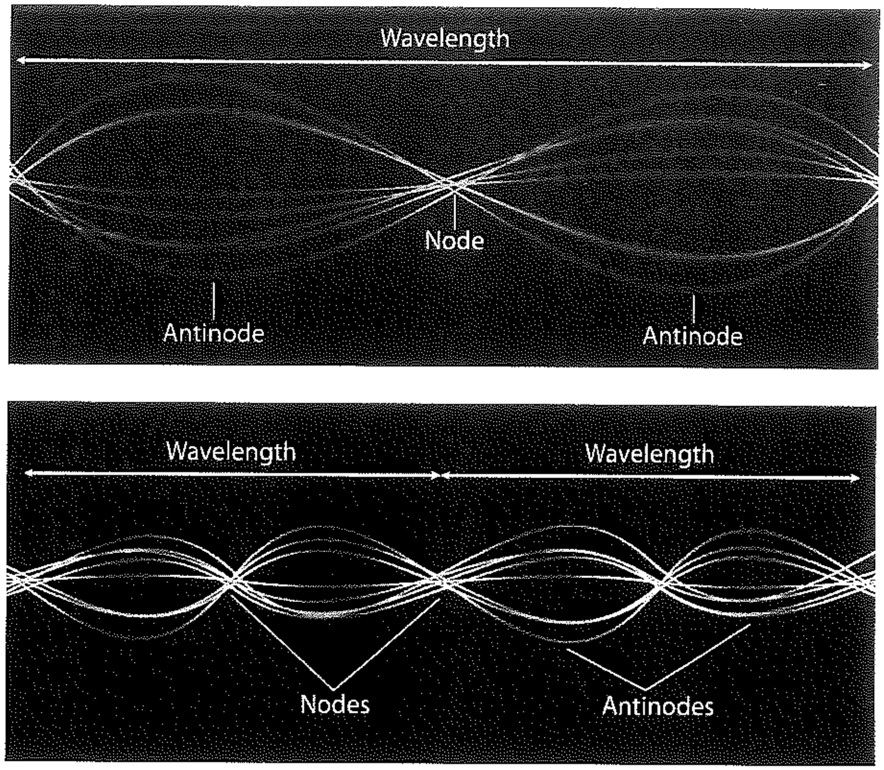


2 A crest meets a trough. In the area of overlap, the waves cancel completely.



3 The waves continue as if they had not met.

FIGURE 11
Standing Waves
These illustrations show standing waves in vibrating elastic strings.



Lab zone Try This Activity

Interfering Waves

1. Place two identical empty bottles near each other. Using a straw, blow gently across the top of one bottle until you hear a sound. Describe the sound.
2. Using two straws, blow across the tops of both bottles at the same time. Describe what you hear.
3. Add a few drops of water to one bottle. Blow across the top of each bottle and note any differences in the sound.
4. Using two straws, blow across the tops of both bottles at the same time.

Observing Describe the sound you heard in Step 4. How did it differ from the sounds you heard in the other steps?

Standing Waves

If you tie a rope to a doorknob and continuously shake the free end, waves will travel down the rope, reflect at the end, and come back. The reflected waves will meet the incoming waves. When the waves meet, interference occurs.

If the incoming wave and a reflected wave have just the right frequency, they produce a combined wave that appears to be standing still. This combined wave is called a standing wave. A **standing wave** is a wave that appears to stand in one place, even though it is really two waves interfering as they pass through each other.

Nodes and Antinodes In a standing wave, destructive interference produces points with an amplitude of zero, as shown in Figure 11. These points of zero amplitude on a standing wave are called **nodes.** The nodes are always evenly spaced along the wave. At points in the standing wave where constructive interference occurs, the amplitude is greater than zero. The points of maximum amplitude on a standing wave are called **antinodes.** These are also the points of maximum energy on the wave. The antinodes always occur halfway between two nodes.

Resonance Have you ever pushed a child on a swing? At first, it is difficult to push the swing. But once you get it going, you need only push gently to keep it going. This is because the swing has a natural frequency. Even small pushes that are in rhythm with the swing's natural frequency produce large increases in the swing's amplitude.

Most objects have at least one natural frequency of vibration. Standing waves occur in an object when it vibrates at a natural frequency. If a nearby object vibrates at the same frequency, it can cause resonance. **Resonance** is an increase in the amplitude of a vibration that occurs when external vibrations match an object's natural frequency.

Resonance can be useful. For example, musical instruments use resonance to produce stronger, clearer sounds. But sometimes resonance can be harmful. Figure 12 shows Mexico City after an earthquake in 1985. Mexico City is built on a layer of clay. The frequency of the earthquake waves matched the natural frequency of the clay layer, so resonance occurred. City buildings 8 to 18 stories high had the same natural frequency. Due to resonance, these buildings had the most damage. Both shorter and taller buildings were left standing because their natural frequencies did not match the natural frequency of the clay layer.

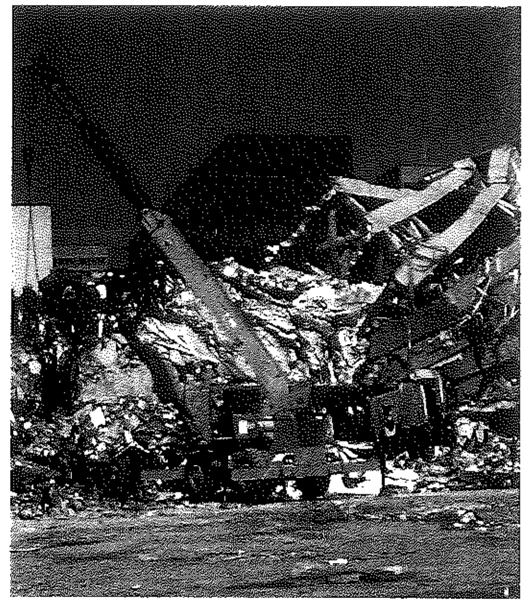


FIGURE 12
Destructive Power of Resonance
In the 1985 earthquake in Mexico City, resonance caused the greatest damage to buildings between 8 and 18 stories tall.
Inferring *Why did taller buildings survive the earthquake?*

Reading Checkpoint How can resonance be useful?

Section 3 Assessment

Target Reading Skill Asking Questions Use the answers to the questions you wrote about the headings to help you answer the questions below.

Reviewing Key Concepts

1. a. Listing What are three ways that waves change direction?
   b. Summarizing How does a wave change direction when it bounces off a surface?
   c. Relating Cause and Effect How does a change in speed cause a wave to change direction?
2. a. Identifying What are two types of interference?
   b. Interpreting Diagrams Look at Figure 10. What determines the amplitude of the wave produced by interference?
   c. Predicting Wave A has the same amplitude as wave B. What will happen when a crest of wave A meets a trough of wave B? Explain.
3. a. Defining What is a standing wave?
   b. Explaining How do nodes and antinodes form in a standing wave?

Lab zone At-Home Activity

Waves in a Sink With your parent's permission, fill the kitchen sink with water to a depth of about 10 cm. Dip your finger into the water repeatedly to make waves. Demonstrate reflection, diffraction, and interference for your family members.

Lab zone **Skills Lab**

Making Waves

Problem

How do water waves interact with each other and with solid objects in their paths?

Skills Focus

observing, making models

Materials

- water
- plastic dropper
- metric ruler
- paper towels
- modeling clay
- cork or other small floating object
- ripple tank (aluminum foil lasagna pan with mirror at the bottom)

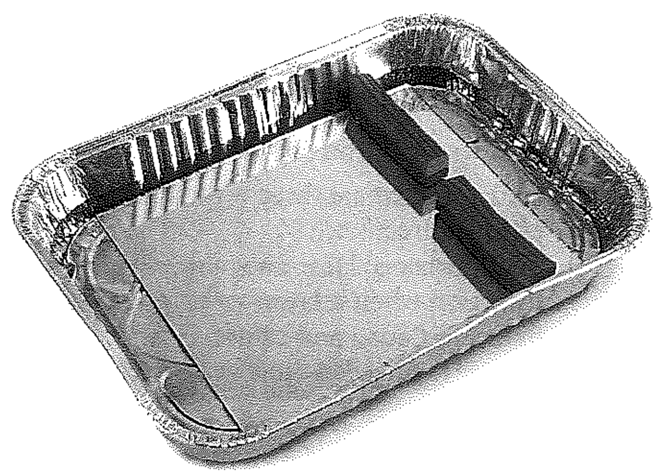
Procedure

1. Fill the pan with water to a depth of 1.5 cm. Let the water come to rest. Make a data table like the one shown in your text.
2. Fill a plastic dropper with water. Then release a drop of water from a height of about 10 cm above the center of the ripple tank. Observe the reflection of the waves that form and record your observations.
3. Predict how placing a paper towel across one end of the ripple tank will affect the reflection of the waves. Record your prediction in your notebook.
4. Drape a paper towel across one end of the ripple tank so it hangs in the water. Repeat Step 2, and record your observations of the waves.
5. Remove the paper towel and place a stick of modeling clay in the water near the center of the ripple tank.

Data Table

Type of Barrier	Observations Without Cork	Observations With Cork

6. From a height of about 10 cm, release a drop of water into the ripple tank halfway between the clay and one of the short walls. Record your observations.
7. Place the clay in a different position so that the waves strike it at an angle. Then repeat Step 6.
8. Place two sticks of clay end-to-end across the width of the tank. Adjust the clay so that there is a gap of about 2 cm between the ends of the two pieces. Repeat Step 6. Now change the angle of the barrier in the tank. Again repeat Step 6, and watch to see if the waves interact with the barrier any differently.



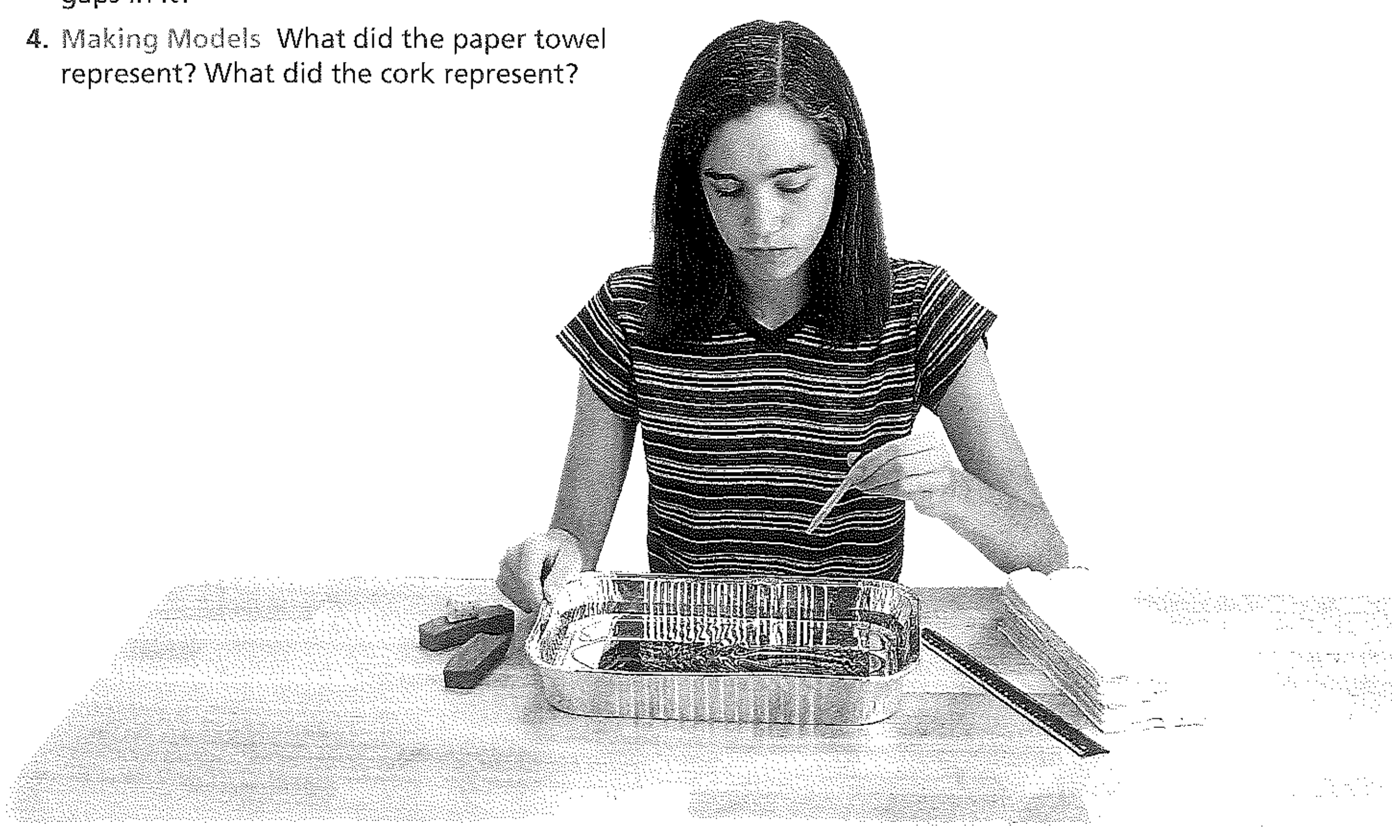
9. Cut the two pieces of clay in half. Use the pieces to make a barrier with three 2-cm gaps. Then repeat Step 6.
10. Remove all the clay and add a small floating object, such as a cork, to the water. Then repeat Steps 2–9 with the floating object. Observe and record what happens to the cork in each step.
11. Once you have finished all of the trials, clean and dry your work area.

Analyze and Conclude

1. Observing How are the waves affected by the paper towel hanging in the water?
2. Observing What happens when the waves strike a barrier head on? When they strike it at an angle?
3. Observing What happens when the waves strike a barrier with a gap in it? With three gaps in it?
4. Making Models What did the paper towel represent? What did the cork represent?
5. Applying Concepts How does the behavior of waves in your model compare to the behavior of waves in a harbor?
6. Communicating Evaluate your model. Write a paragraph about the ways your model represents a real situation. Then write a paragraph about your model's limitations.

More to Explore

Predict what would happen if you could send a steady train of uniform waves the length of the ripple tank for an extended time. Use a plastic bottle with a pinhole in the bottom to make a dropper that will help to test your prediction. Get permission from your teacher to try out your dropper device.



Section 4 Integrating Earth Science

Seismic Waves

Reading Preview

Key Concepts

- What are the types of seismic waves?
- How does a seismograph work?

Key Terms

- seismic wave
- P wave
- S wave
- surface wave
- tsunami
- seismograph

Target Reading Skill

Building Vocabulary Using a word in a sentence helps you think about how to best explain the word. As you read, carefully note the definition of each Key Term. Also note other details in the paragraph that contains the definition. Use all this information to write a sentence using the Key Term.

Lab zone Discover Activity

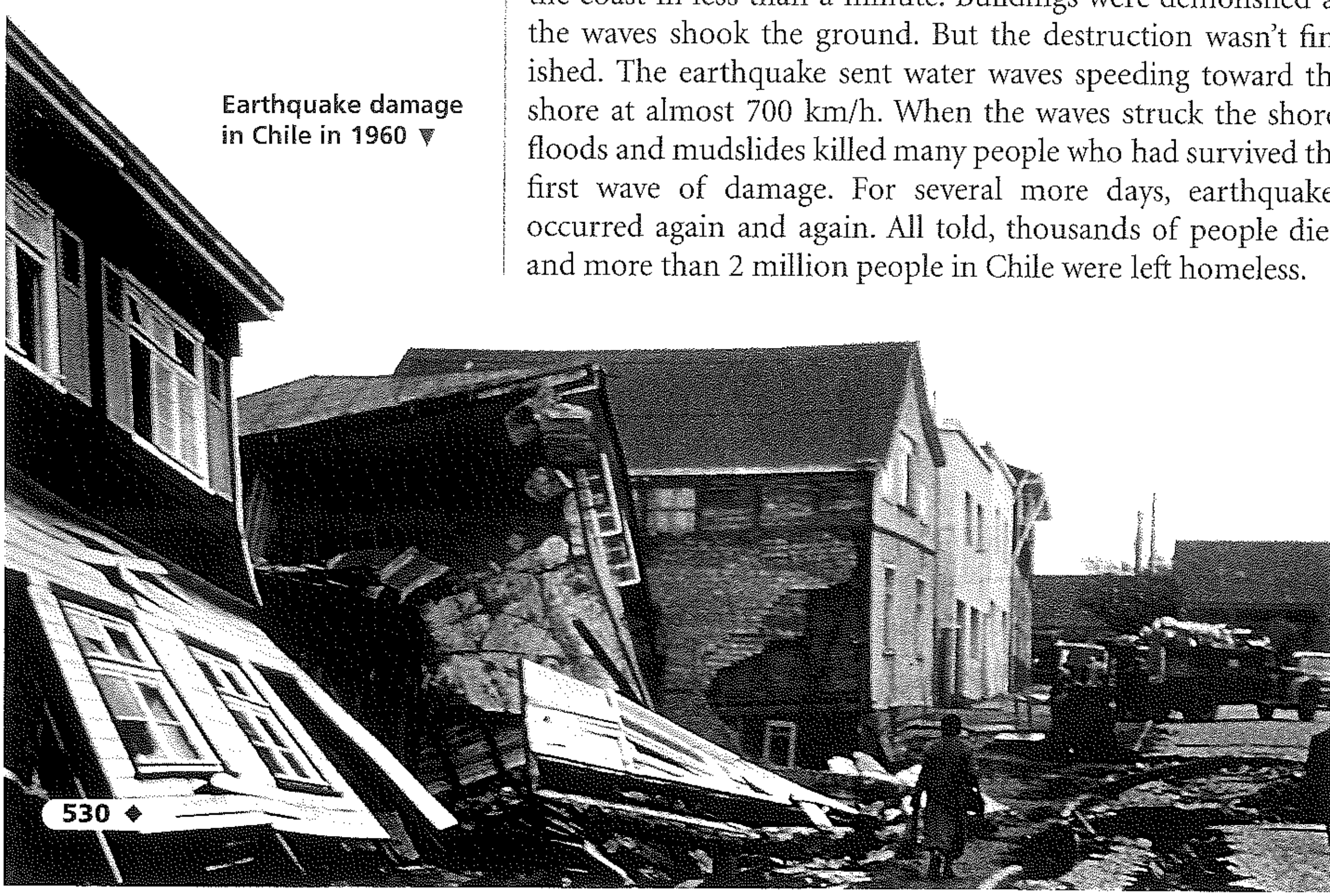
Can You Find the Sand?

1. Fill a plastic film canister with sand and replace the lid.
2. Place the canister on a table with four identical but empty canisters. Mix them around so that a classmate does not know which canister is which.
3. With your fist, pound on the table a few times. Ask your classmate which canister contains the sand.
4. Then stick each canister to the table with some modeling clay. Pound on the table again. Can your classmate tell which canister contains sand?

Think It Over

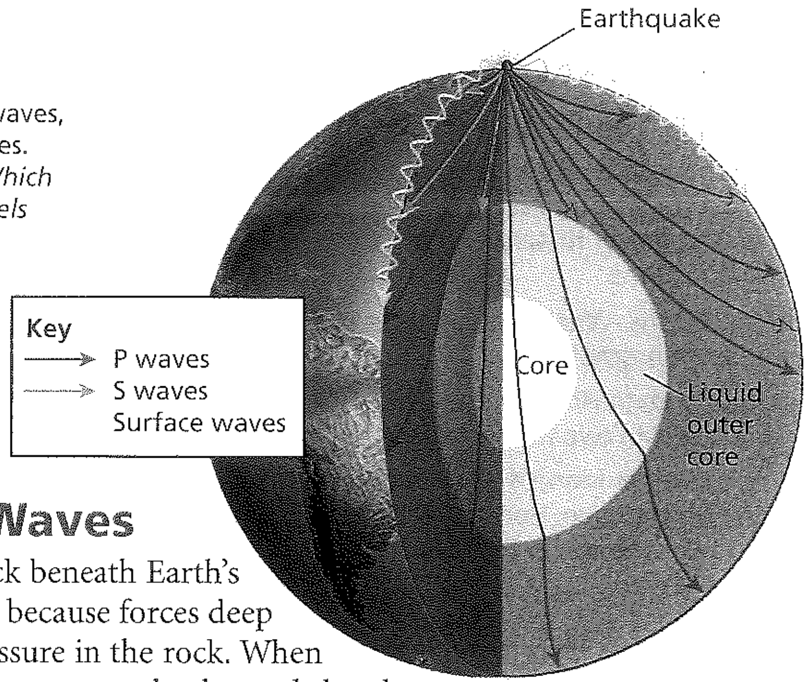
Inferring Pounding on a table makes waves. Why might the canister with sand respond differently from the empty canisters?

On May 22, 1960, a massive earthquake occurred under the Pacific Ocean about 120 km west of Chile. Traveling underground faster than the speed of sound, earthquake waves hit the coast in less than a minute. Buildings were demolished as the waves shook the ground. But the destruction wasn't finished. The earthquake sent water waves speeding toward the shore at almost 700 km/h. When the waves struck the shore, floods and mudslides killed many people who had survived the first wave of damage. For several more days, earthquakes occurred again and again. All told, thousands of people died and more than 2 million people in Chile were left homeless.



Earthquake damage in Chile in 1960 ▼

FIGURE 13
Seismic Waves
Seismic waves include P waves, S waves, and surface waves.
Interpreting Diagrams *Which kind of seismic wave travels through Earth's core?*



Types of Seismic Waves

An earthquake occurs when rock beneath Earth's surface moves. This rock moves because forces deep inside Earth create stress or pressure in the rock. When the pressure in the rock builds up enough, the rock breaks or changes shape, releasing energy in the form of waves. The waves produced by earthquakes are called **seismic waves.** (The word seismic comes from the Greek word *seismos*, which means "earthquake.")

Seismic waves ripple out in all directions from the point where the earthquake occurred. As the waves move, they carry energy through Earth. The waves can travel from one side of Earth to the other. **Seismic waves include P waves, S waves, and surface waves.** Figure 13 shows how each kind of wave travels through Earth.

P Waves Some seismic waves are longitudinal waves. Longitudinal seismic waves are known as **P waves,** or primary waves. They are called primary waves because they move faster than other seismic waves and so arrive at distant points before other seismic waves. P waves are made up of compressions and rarefactions of rock inside Earth. These waves compress and expand the ground like a spring toy as they move through it.

S Waves Other seismic waves are transverse waves with crests and troughs. Transverse seismic waves are known as **S waves,** or secondary waves. S waves shake the ground up and down and side to side as they move through it. They cannot travel through liquids. Because part of Earth's core is liquid, S waves do not travel directly through Earth like P waves. Therefore, S waves cannot be detected on the side of Earth opposite an earthquake. Scientists on the side of Earth opposite the earthquake detect mainly P waves.

Go Online
SCI LINKS NSTA
For: Links on seismic waves
Visit: www.SciLinks.org
Web Code: scn-1514

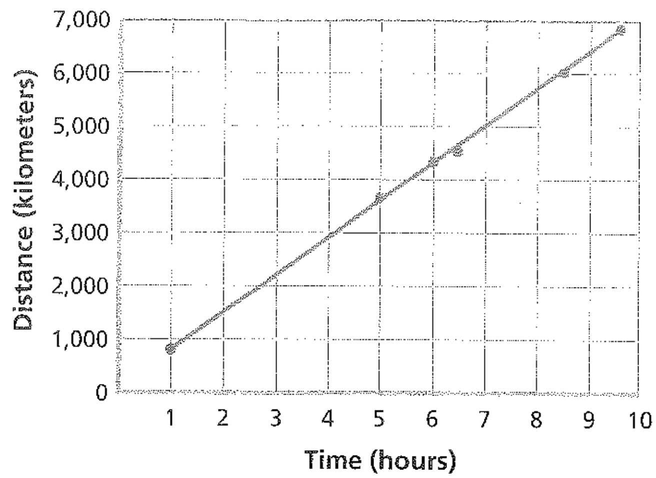
Math Analyzing Data

Motion of a Tsunami

This graph shows the rate at which a tsunami moves across the Pacific Ocean. Use the data plotted on the graph to answer the following questions.

1. Reading Graphs What two variables are plotted on the graph?
2. Interpreting Data How far does the tsunami travel in two hours? In four hours?
3. Predicting Easter Island is 3,700 kilometers from the earthquake. How many hours would it take the tsunami to reach Easter Island?

Speed of a Tsunami

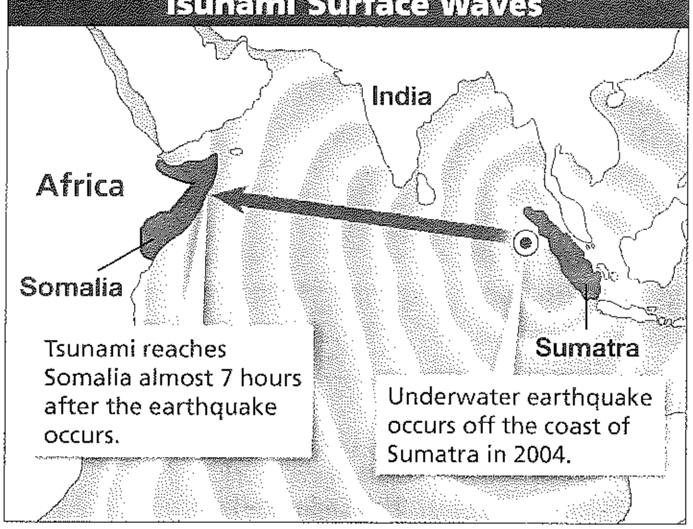


Surface Waves When P waves and S waves reach Earth's surface, they can create surface waves. A **surface wave** is a combination of a longitudinal wave and a transverse wave that travels along the surface of a medium. Surface waves produced by earthquakes move more slowly than P waves and S waves. However, they can cause the most severe ground movements. They combine up-and-down and side-to-side motions, making the ground roll like ocean waves.

Earthquakes that occur underwater, like the one off the coast of Sumatra, Indonesia, in 2004, can produce huge surface waves on the ocean called **tsunamis** (tsoo NAH meez). Tsunamis come in all sizes, from 2 centimeters to 30 meters tall. They can travel thousands of kilometers across the ocean. In the deep ocean, the larger waves are only about 1 meter high. But as they near land, tsunamis slow down in the shallow water. The waves in the back catch up with those in the front and pile on top. Tsunamis caused by the 2004 earthquake near Sumatra traveled as far as 7,000 km across the Indian Ocean to Somalia. Tragically, the tsunamis killed more than 230,000 people worldwide and caused more than $100 billion in home and property damage.

FIGURE 14
This map shows the progress of the 2004 tsunami caused by an earthquake near Indonesia.
Classifying *What type of wave interference—constructive or destructive—causes tsunamis?*

Tsunami Surface Waves



Reading Checkpoint **How are tsunamis produced?**

Detecting Seismic Waves

To detect and measure earthquake waves, scientists use instruments called **seismographs** (SYZ muh grafs). **A seismograph records the ground movements caused by seismic waves as they move through Earth.**

The frame of the seismograph is attached to the ground, so the frame shakes when seismic waves arrive. Seismographs used to have pens attached to the frame that made wiggly lines on a roll of paper as the ground shook. Now scientists use electronic seismographs to record data about Earth's motion.

Because P waves travel through Earth faster than S waves, P waves arrive at seismographs before S waves. By measuring the time between the arrival of the P waves and the arrival of the S waves, scientists can tell how far away the earthquake was. By comparing readings from at least three seismographs located at different places on Earth, scientists can tell where the earthquake occurred.

To find oil, water, and other valuable resources, geologists set off explosives at Earth's surface. Seismic waves from the explosions reflect from structures under the ground. Geologists then use seismograph data to locate the underground resources.

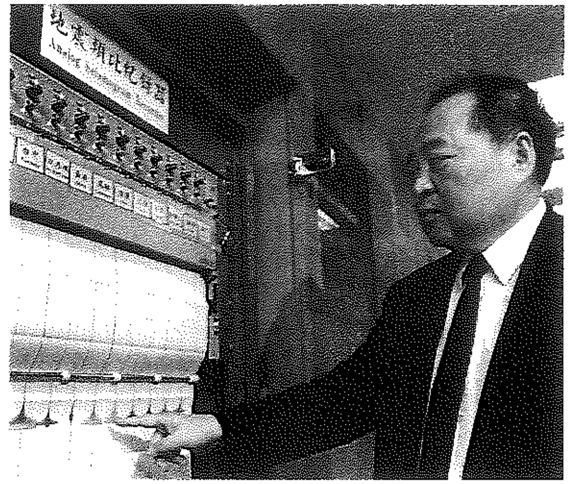


FIGURE 15
Seismologist Studying Data
A scientist studies the arrival time of seismic waves on the printout from a seismograph.

Section 4 Assessment

Target Reading Skill Building Vocabulary Use your sentences about seismic waves to help you answer the questions below.

Reviewing Key Concepts

1. a. Identifying What are three types of seismic waves?
   b. Classifying Which seismic waves are transverse waves? Which are longitudinal waves?
   c. Comparing and Contrasting Why do seismic waves that travel along Earth's surface cause more damage than other seismic waves?
2. a. Defining What is a seismograph?
   b. Explaining How does a seismograph work?
   c. Interpreting Data S waves arrive in Los Angeles 3 minutes after P waves. In Dallas, S waves arrive 1 minute after P waves. Which city is closer to the earthquake? Explain your answer.

Lab zone At-Home Activity

Sounds Solid Explore how waves travel through different solids. Have a family member or friend tap one end of a table with a spoon. Now put your ear to the table and listen again. What difference do you notice? Repeat the tapping on various surfaces around your home. What observations have you made?

Chapter 15 Study Guide

The BIG Idea **Transfer of Energy** A source of energy produces a mechanical wave when it causes a medium to vibrate back-and-forth or up-and-down.

1 What Are Waves?

Key Concepts

- Mechanical waves are produced when a source of energy causes a medium to vibrate.
- Mechanical waves are classified by how they move. There are two types of mechanical waves: transverse waves and longitudinal waves.

Key Terms

wave
energy
medium
mechanical wave
vibration
transverse wave
crest
trough
longitudinal wave
compression
rarefaction

2 Properties of Waves

Key Concepts

- The basic properties of waves are amplitude, wavelength, frequency, and speed.
- The speed, wavelength, and frequency of a wave are related to one another by the formula:

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

Key Terms

amplitude
wavelength
frequency
hertz (Hz)

3 Interactions of Waves

Key Concepts

- When an object or a wave hits a surface through which it cannot pass, it bounces back.
- When a wave enters a new medium at an angle, one side of the wave changes speed before the other side, causing the wave to bend.
- When a wave moves around a barrier or through an opening in a barrier, it bends and spreads out.
- There are two types of interference: constructive and destructive.
- If the incoming wave and a reflected wave have just the right frequency, they produce a combined wave that appears to be standing still.

Key Terms

reflection
law of reflection
refraction
diffraction
interference
constructive interference
destructive interference
standing wave
node
antinode
resonance

4 Seismic Waves

Key Concepts

- Seismic waves include P waves, S waves, and surface waves.
- A seismograph records the ground movements caused by seismic waves as they move through Earth.

Key Terms

seismic wave
P wave
S wave
surface wave
tsunami
seismograph

Review and Assessment

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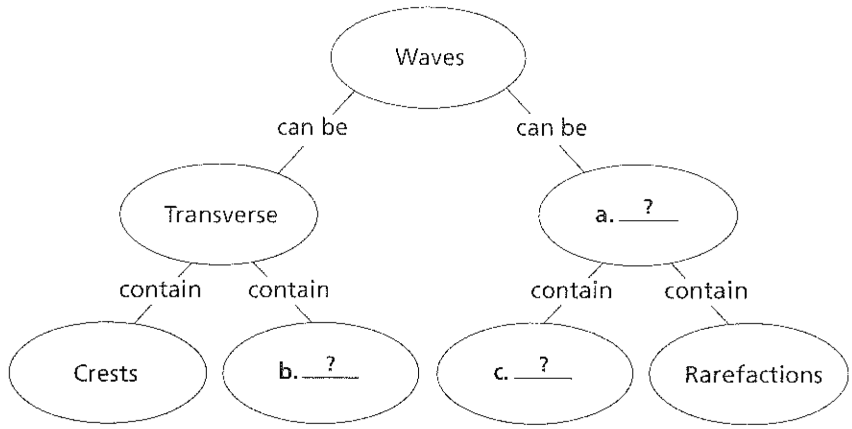
Organizing Information

Concept Mapping Copy the concept map about waves onto a sheet of paper. Then complete it and add a title. (For more on Concept Mapping, see the Skills Handbook.)



Reviewing Key Terms

Choose the letter of the best answer.

1. A wave transfers
   a. energy. b. particles.
   c. water. d. air.
2. A wave that moves the medium in the same direction that the wave travels is a
   a. transverse wave. b. longitudinal wave.
   c. standing wave. d. mechanical wave.
3. The distance between one crest and the next crest is the wave's
   a. amplitude. b. wavelength.
   c. frequency. d. speed.
4. The number of complete waves that pass a point in a certain amount of time is a wave's
   a. amplitude. b. frequency.
   c. wavelength. d. speed.
5. The bending of a wave due to a change in its speed is
   a. interference. b. reflection.
   c. diffraction. d. refraction.
6. The interaction between waves that meet is
   a. reflection. b. diffraction.
   c. refraction. d. interference.
7. A point of zero amplitude on a standing wave is called a
   a. crest. b. node.
   c. trough. d. antinode.
8. Seismic waves that do not travel through liquids are
   a. P waves. b. surface waves.
   c. S waves. d. tsunamis.

Writing in Science

Research Report Write an article for a boating magazine about tsunamis. Include details about what causes them and why they are dangerous. Explain what is being done to help reduce damage from tsunamis.

Review and Assessment

Checking Concepts

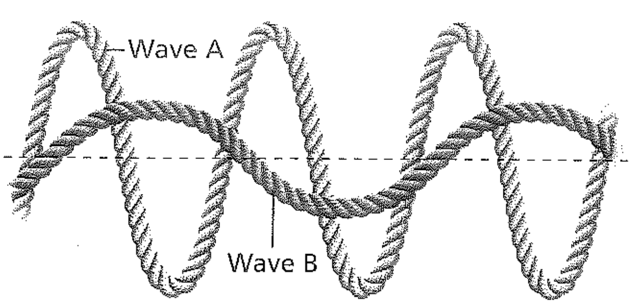
9. Explain the difference between transverse and longitudinal waves. Use diagrams to illustrate your explanation.
10. How can you measure the amplitude of a transverse wave?
11. Describe how to measure the speed of a wave.
12. What is the angle of incidence if a reflected wave bounces off a mirror with an angle of reflection equal to 55°?
13. Describe the two types of diffraction.
14. Explain why S waves cannot be detected everywhere on Earth after an earthquake.

Math Practice

15. Angles Label a 90° angle on a transverse wave.
16. Calculating Speed A wave in a spring has a wavelength of 0.1 m and a frequency of 20 Hz. What is the wave's speed?
17. Calculating Wavelength A sound wave has a frequency of 660 Hz and its speed is 330 m/s. What is its wavelength?

Thinking Critically

18. Applying Concepts Suppose ripples move from one side of a lake to the other. Does the water move across the lake? Explain.
19. Comparing and Contrasting The waves shown below travel at the same speed.
    a. Which wave has the higher frequency?
    b. Which has the longer wavelength?
    c. Which has the greater amplitude?

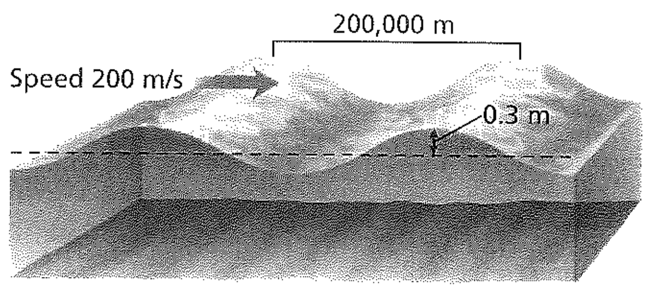


20. Predicting One wave has an amplitude of 2 m, and a second wave has an amplitude of 1 m. At a given time, crests from each wave meet. Draw a diagram and describe the result.
21. Making Models If you push a shopping cart that has a stiff or damaged wheel, it is difficult to steer the cart in a straight line. Explain how this is similar to refraction of a wave as it enters a new medium.

Applying Skills

Use the illustration below to answer Questions 22–25.

The wave in the illustration is a giant ocean wave produced by an underwater earthquake.



22. Classifying What kind of wave is shown in the diagram?
23. Interpreting Diagrams What is the amplitude of the wave? What is its speed?
24. Calculating Find the frequency of the wave.
25. Calculating How long would it take this wave to travel 5,000 km?

Lab zone Chapter Project

Performance Assessment Share your examples of periodic motion with your classmates. On your display, highlight the repeating patterns and the frequency of each example. Point out interesting connections. For example, track-and-field practice involves repetitions, as do other sports. Which examples involve waves moving through a medium?

Standardized Test Prep

Test-Taking Tip

Using Formulas

Some test questions require you to use a formula to answer the question. If you are given the formula, you may need to rearrange it to solve the problem. In the sample question below, you are asked to solve for frequency. Rearrange the formula by dividing both sides by wavelength:

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

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

Then solve for frequency by substituting in the known values for speed and wavelength.

Sample Question

A sound wave has a wavelength of 2.0 m. The speed of the wave is 340 m/s. What is the frequency? (*Hint:* Speed = Wavelength × Frequency)

A 170 m/s
B 680 m/s
C 170 Hz
D 680 Hz

Answer

C is correct because 170 Hz equals 340 m/s divided by 2.0 m. You can eliminate **A** and **B** because the answers have a unit for speed. **D** was incorrectly calculated using multiplication.

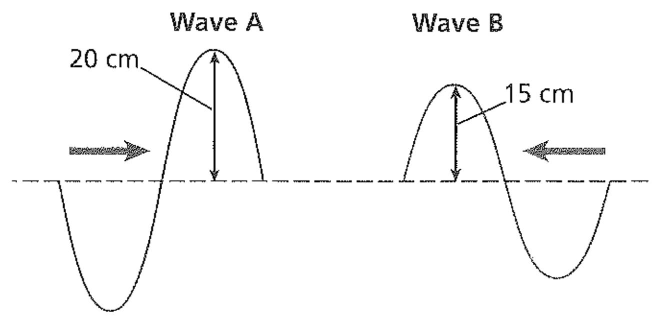
Choose the letter of the best answer.

1. The speed of a wave in a spring is 3 m/s. If the wavelength is 0.1 m, what is the frequency?
   A 30 Hz
   B 0.3 Hz
   C 30 m/s
   D 0.3 m/s

2. A wave enters a new medium. The wave
   F slows down and bends.
   G speeds up and bends.
   H may slow down or speed up.
   J must always bend.

3. During a storm, a TV reporter says that the ocean waves are 3 meters high. This reported distance equals the distance
   A from one crest to the next crest.
   B from one trough to the next trough.
   C from a crest to a trough.
   D from a crest to the level of calm water.

4. Two waves move in opposite directions as shown in the diagram below. What will be the height of the crest produced when the crests from each wave meet?
   F 20 cm
   G 35 cm
   H 15 cm
   J 5 cm



5. In an experiment, you and a friend stand at opposite ends of a football field. Your friend pops an inflated balloon while you observe. Which of the following is a testable hypothesis?
   A If sound travels much faster than light, you will hear the balloon pop before you see it pop.
   B If light travels much faster than sound, you will see the balloon pop before you hear it.
   C If sound and light travel at the same speed, you will see and hear the balloon pop at the same time.
   D all of the above

Constructed Response

6. A large rock is tossed into a pond to produce a water wave. Explain how you know that the wave transfers energy but not matter across the pond.