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?

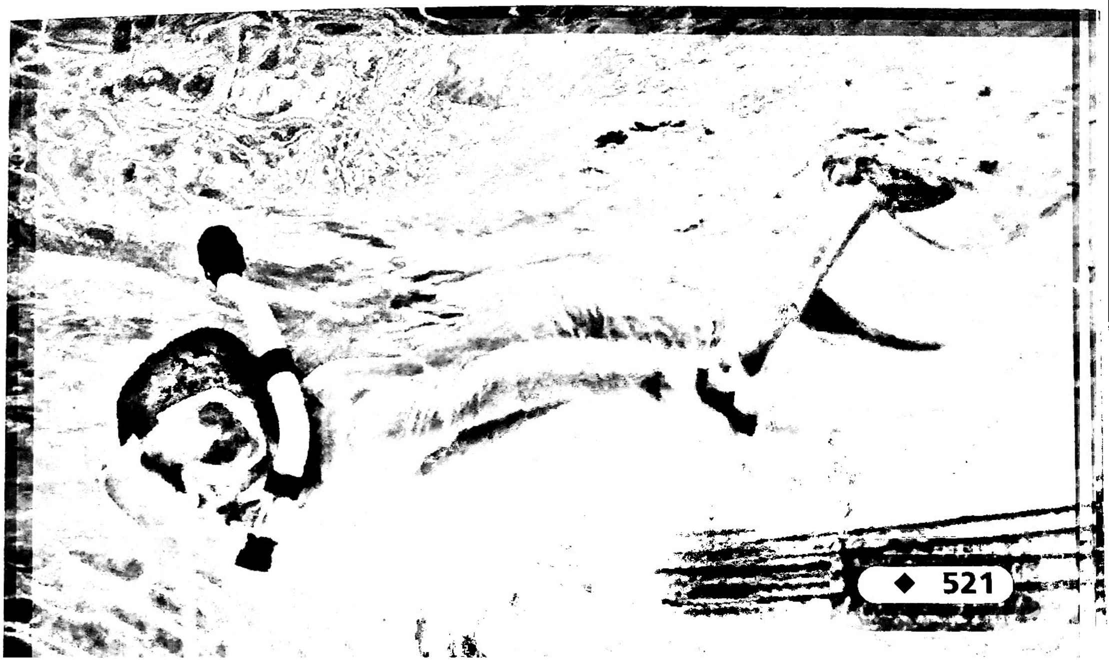
1. Choose a spot at the base of a wall. From a distance of 1 m, roll a wet ball along the floor straight at the spot you chose. Watch the angle at which the ball bounces by looking at the path of moisture on the floor.
2. Wet the ball again. From a different position, roll the ball at the same spot,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

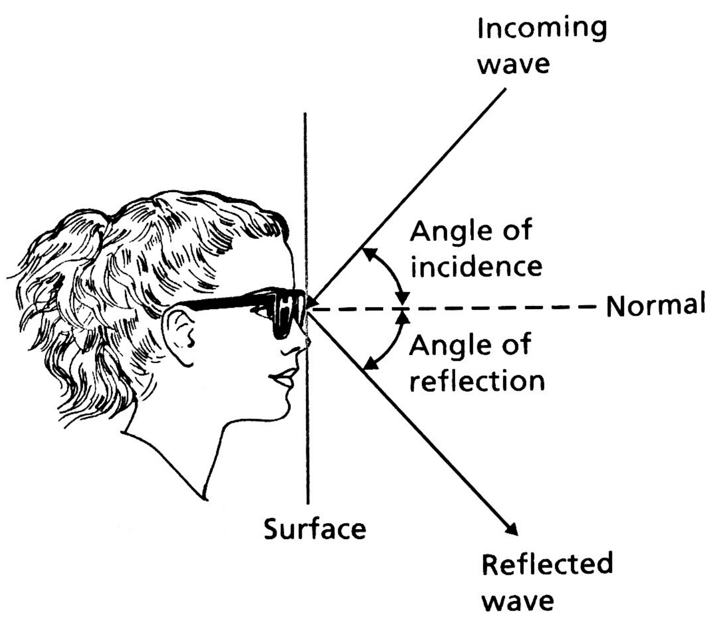
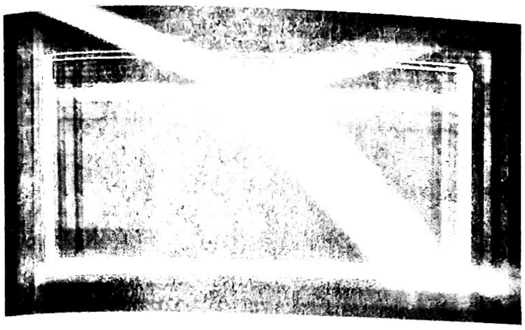
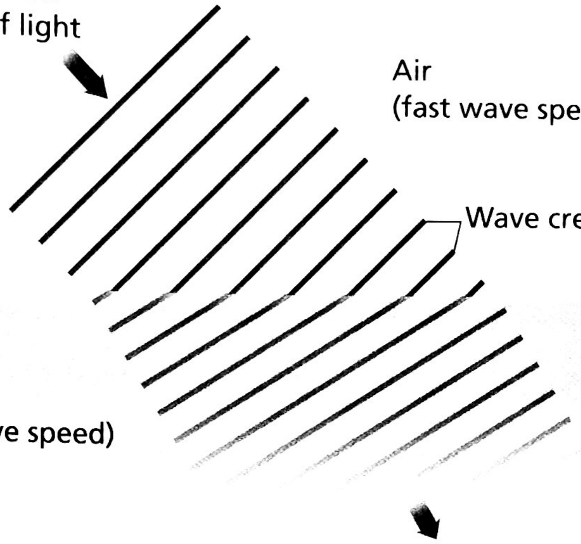


FIGURE 7
Law of Reflection
The angle of incidence equals the angle of reflection. All waves obey this law, including the light waves reflected from these sunglasses.
Predicting *What happens to the angle of reflection if the angle of incidence increases?*

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?**

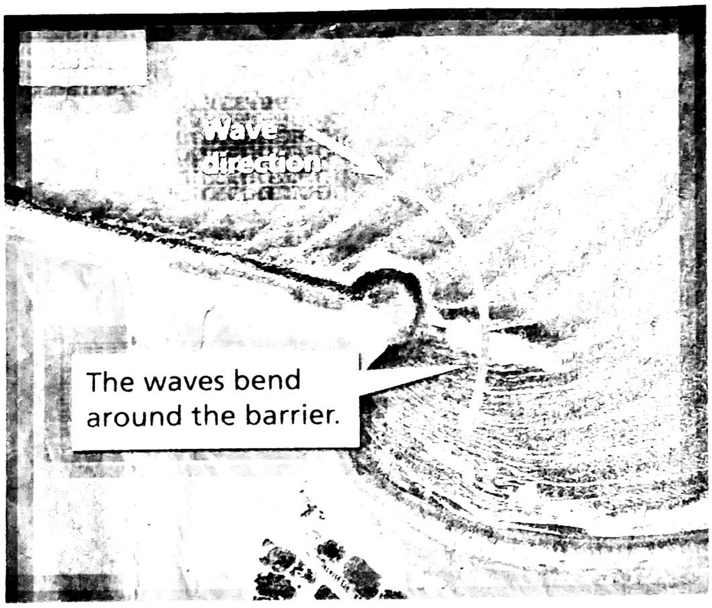
Lab zone **Skills Activity**

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?



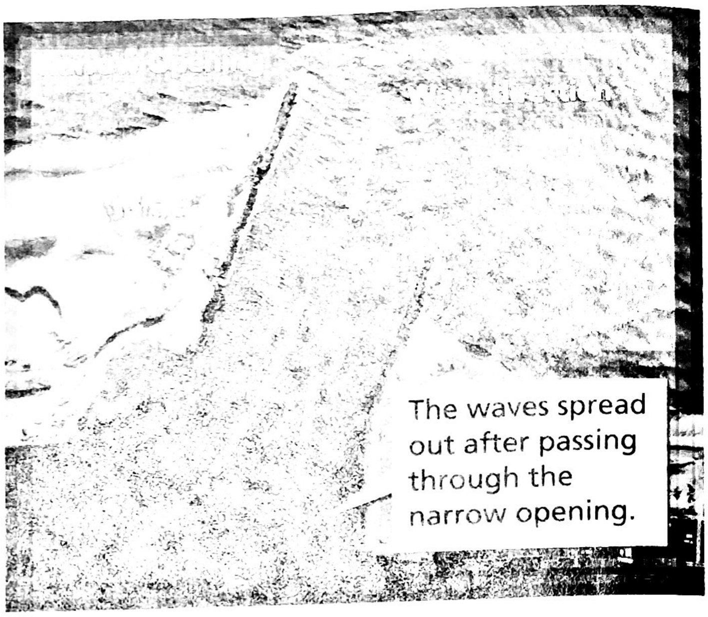


FIGURE 9
Diffraction of Water Waves
Waves diffract when they move around a barrier or pass through an opening. As a wave passes a barrier, it bends around the barrier. After a wave goes through a narrow opening, it spreads out.

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.

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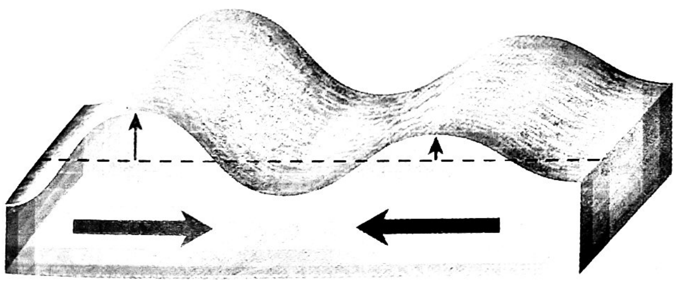
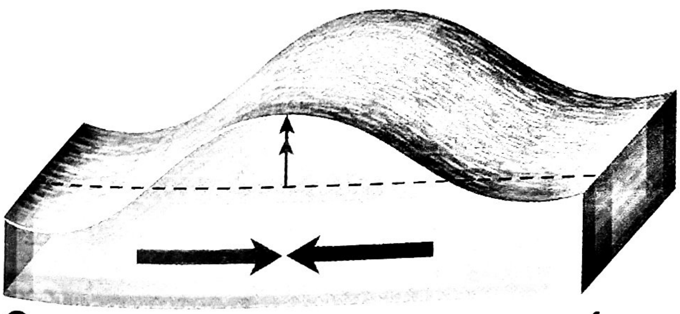
FIGURE 10
Wave Interference
Interference can be constructive or destructive.
Interpreting Diagrams *What does the black dotted line represent in the diagram below?*

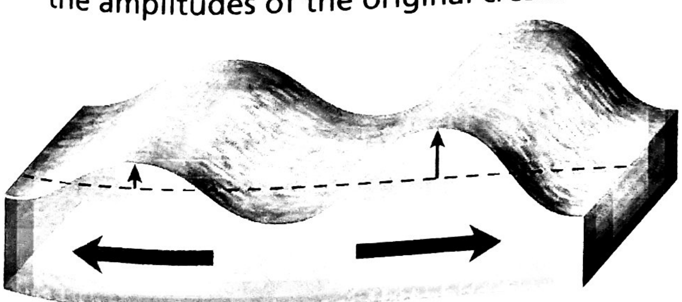
Constructive Interference



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

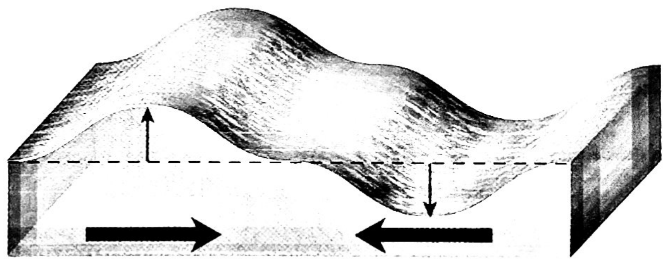


❷ The crest's new amplitude is the sum of the amplitudes of the original crests.

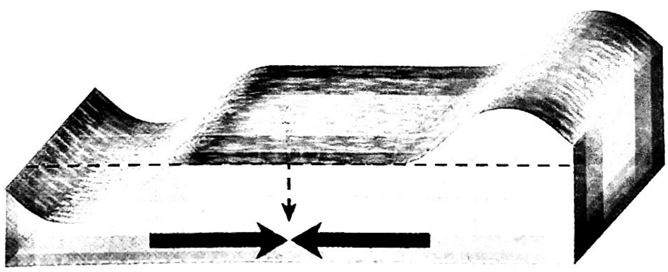


❸ The waves continue as if they had not met.

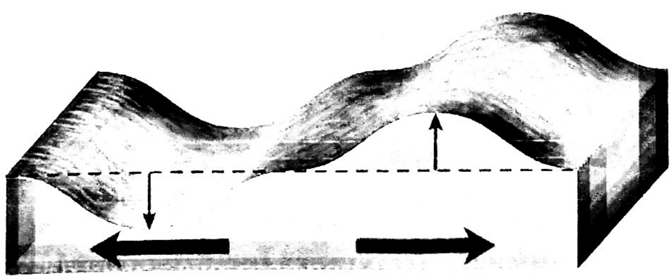
Destructive Interference



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

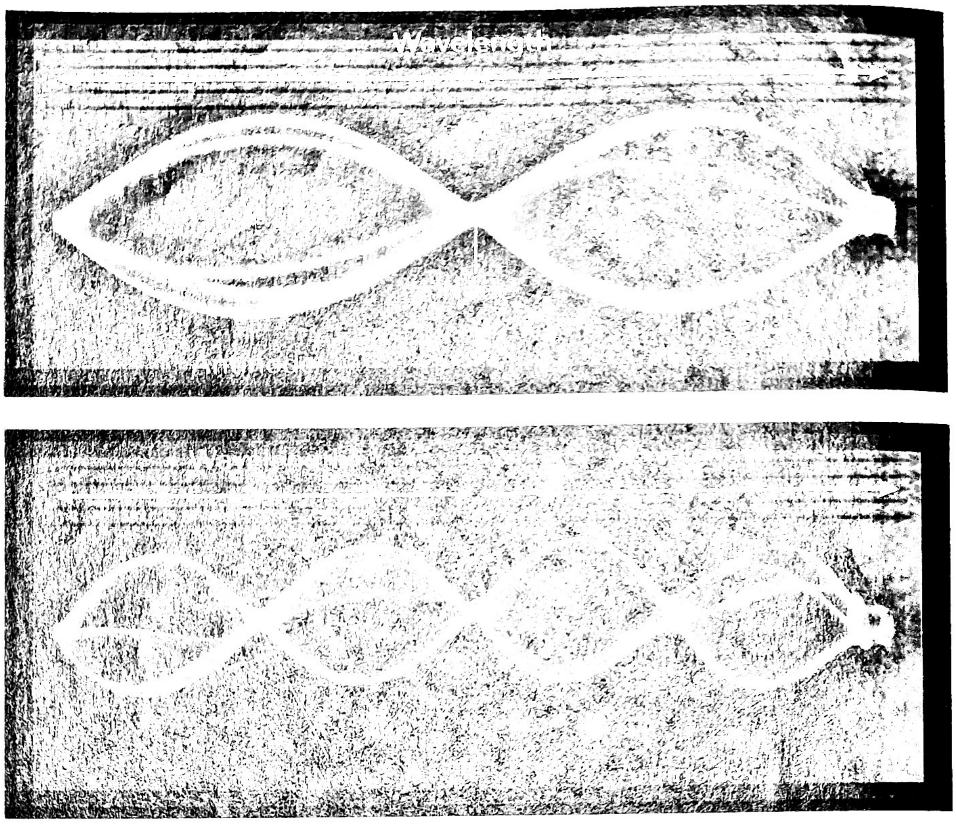


❷ A crest meets a trough. In the area of overlap, the waves cancel completely.



❸ The waves continue as if they had not met.

FIGURE 11
Standing Waves
These photos show standing waves in vibrating elastic strings. The photographer used a bright flashing light called a strobe to "stop" the motion.



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.

Reading Checkpoint **How can resonance be useful?**

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?*

Section 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.