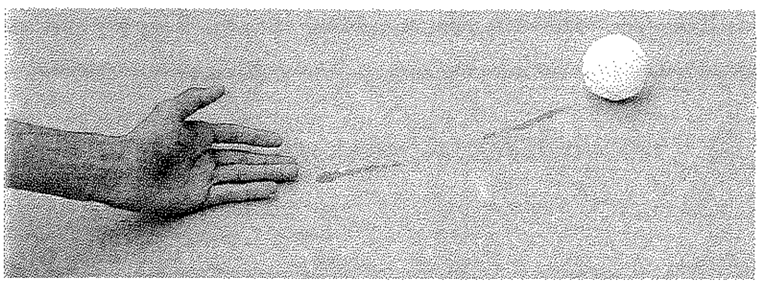
SECTION 3 Interactions of Waves

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 at an angle to the spot you chose. Watch the angle at which the ball bounces back 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? To test your hypothesis, roll the ball from several different positions toward the same spot on the wall.

GUIDE FOR READING

- How do waves bend?
- How do waves interact with each other?

Reading Tip Before you read, preview *Exploring Interactions of Waves* on pages 486–487. Make a list of any unfamiliar words you find there. As you read, write a definition for each word on your list.

It is a hot, sunny day. You are the first person to enter the calm water of the swimming pool. To test the temperature of the water, you dip one foot in first. Your foot causes a series of ripples to travel across the water to the far wall of the pool. As each ripple hits the wall, it bounces off the wall and travels back toward you.

Reflection

When water waves hit the side of a swimming pool, they bounce back. **When an object or wave hits a surface through which it cannot pass, it bounces back.** This is called **reflection.**

To show reflection of a wave, draw a line in the direction of the motion of the wave. Now imagine a line perpendicular to the wall or surface. The **angle of incidence** is the angle between the incoming wave and the imaginary perpendicular line. The **angle of reflection** is the angle between the reflected wave and the imaginary line. The law of reflection states that the angle of reflection equals the angle of incidence. All waves obey the law of reflection.

There are many examples of reflection in your everyday life. A ball that hits a wall bounces back, or is reflected. When you look in a mirror, you use reflected light to see yourself. An echo is an example of reflected sound.

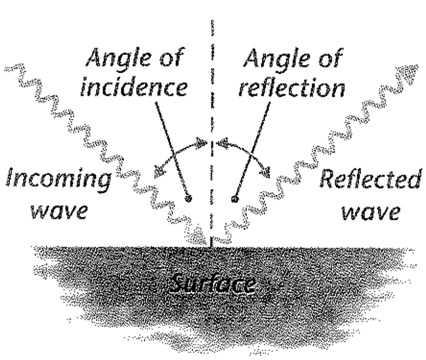


Figure 9 The angle of reflection is equal to the angle of incidence.

Refraction

Have you ever pushed a shopping cart that had a stiff wheel? If so, you know how difficult it is to control the direction of the cart. This is because the stiff wheel can't turn as fast as the other wheels. As you push the cart, it tends to veer to the side of the sticky wheel and so changes direction. Waves sometimes change direction when they enter a new medium. If a wave enters the new medium at an angle, one side changes speed before the other side. **When a wave moves from one medium into another medium at an angle, it changes speed as it enters the second medium, which causes it to bend.** The bending of waves due to a change in speed is called **refraction.**

Though all waves change speed when they enter a new medium, they don't always bend. Bending occurs when one side of the wave enters the new medium before the other side of the wave. The side of the wave that enters the new medium first changes speed first. The other side is still traveling at its original speed. The bending occurs because the two sides of the wave are traveling at different speeds.

☑ *Checkpoint* *What is refraction?*

Sharpen your Skills

Observing ACTIVITY

Here is how 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?

Diffraction

Sometimes waves can bend around an obstacle in their path. For example, waves can pass through a narrow entrance to a harbor and then spread out inside the harbor. Figure 10 shows water waves diffracting as they enter a harbor.

When a wave passes a barrier or moves through a hole in a barrier, it bends and spreads out. The bending of waves

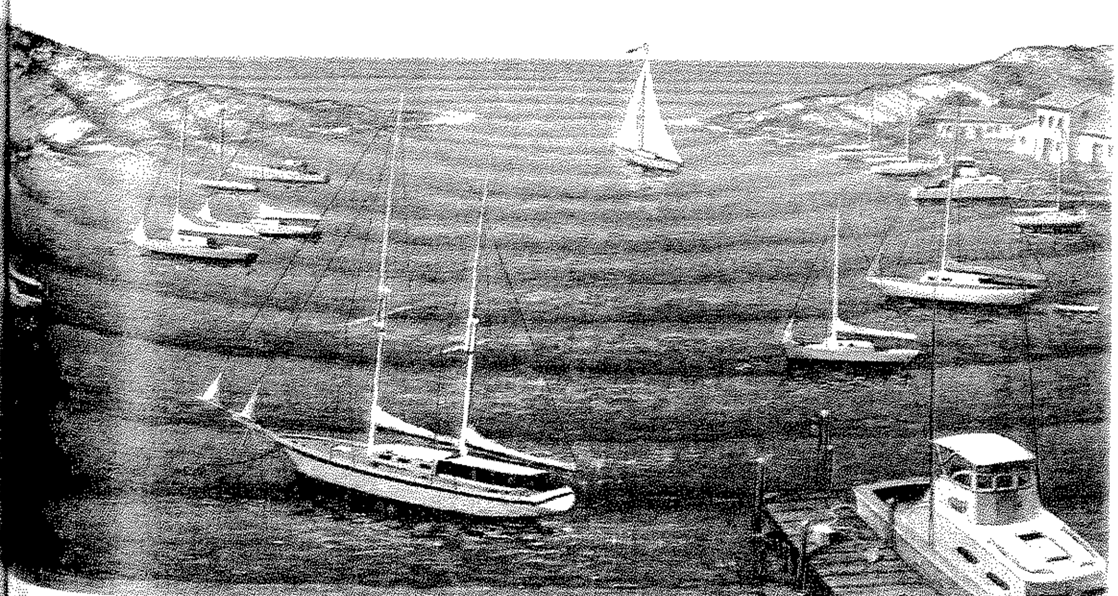


Figure 10 Waves from the ocean enter the harbor and spread out. This is an example of diffraction. *Predicting How do you think the waves in the harbor would change if the opening were wider?*

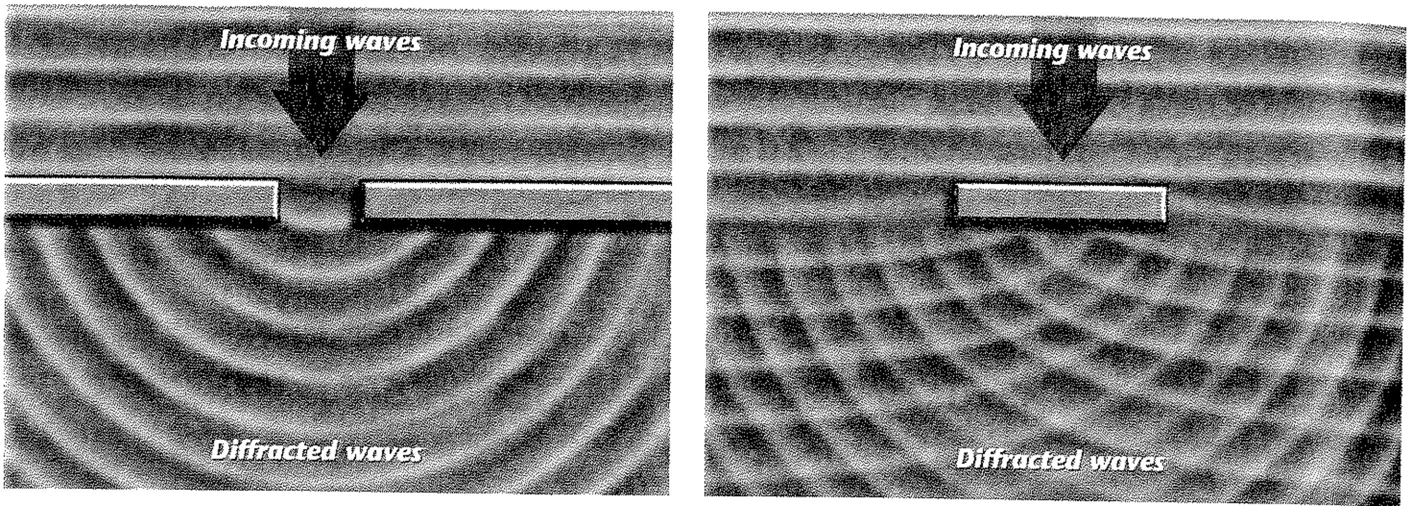


Figure 11 The diagram shows how waves diffract. A wave can go through a hole in a barrier and spread out (left). Or it can bend around a barrier (right).

around the edge of a barrier is known as **diffraction.** Figure 11 shows a water wave passing through a hole in a barrier and another bending around a barrier. In each case, you see the wave diffracting on the other side of the barrier.

☑ ***Checkpoint*** *What is diffraction?*

Interference

Suppose that you and a friend are each holding one end of a rope. If you both flick the ends at the same time, you send two waves toward each other. What will happen when those two waves meet?

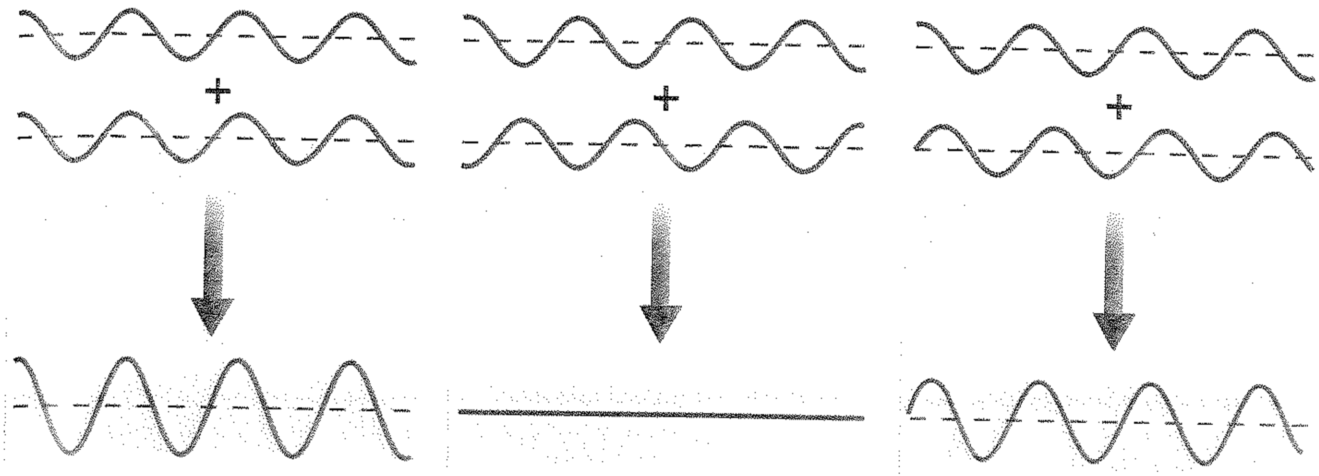
When two or more waves meet, they have an effect on each other. This interaction is called **interference.** There are two types of interference: constructive and destructive.

Constructive Interference **Constructive interference** occurs whenever two waves combine to make a wave with a larger amplitude. You can think of constructive interference as waves "helping each other" to give a stronger result, or adding energy.

Figure 12 shows two identical waves (same amplitude, same wavelength) traveling in the same direction at the same time. If the two waves travel along the same path at the same time, they will behave as one. What will the combined wave look like? The crests of the first wave will occur at the same place as the crests of the second wave. The energy from the two waves will combine. Thus the amplitude of the new wave will be twice the amplitude of either of the original waves.

If the waves have the same wavelength but different amplitudes, the crests will still occur at the same place and add together. The resulting amplitude will be the sum of the two original amplitudes. Similarly, the troughs will occur together, making a deeper trough than either wave alone.

Figure 12 The diagrams show how identical waves can combine.



A. When the crests align, the waves add together and produce a wave with twice the original amplitude.

B. When the crests of one wave align with the troughs of another, they cancel each other out.

C. If one wave travels a little behind the other, they combine both constructively and destructively at different places.

Destructive Interference When the amplitudes of two waves combine with each other producing a smaller amplitude, the result is called **destructive interference.** What happens if the crests don't meet at the same place? In this case, one wave comes after the other. Figure 12B shows what happens when the crests of the first wave occur at the same place as the troughs of the second wave. The amplitude of the first wave cancels out the amplitude of the second wave. This type of interference produces a wave with an amplitude of zero. The original waves seem to be destroyed. If the two waves have different amplitudes, they will not cancel each other out but will combine to produce a wave with a smaller amplitude.

Two identical waves can travel along the same path, one a little behind the other. When this happens, the waves combine constructively in some places and destructively in others.

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 collide with the incoming waves. When the waves meet, interference occurs. After they pass each other, they carry on as if the interference had never occurred.

If the incoming wave and the reflected wave combine at the right places, the combined wave appears to be standing still. 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. If you make a standing wave on a rope, the wave looks as though it is standing still. But in fact, waves are traveling along the rope in both directions.

TRY THIS

Standing Waves

ACTIVITY

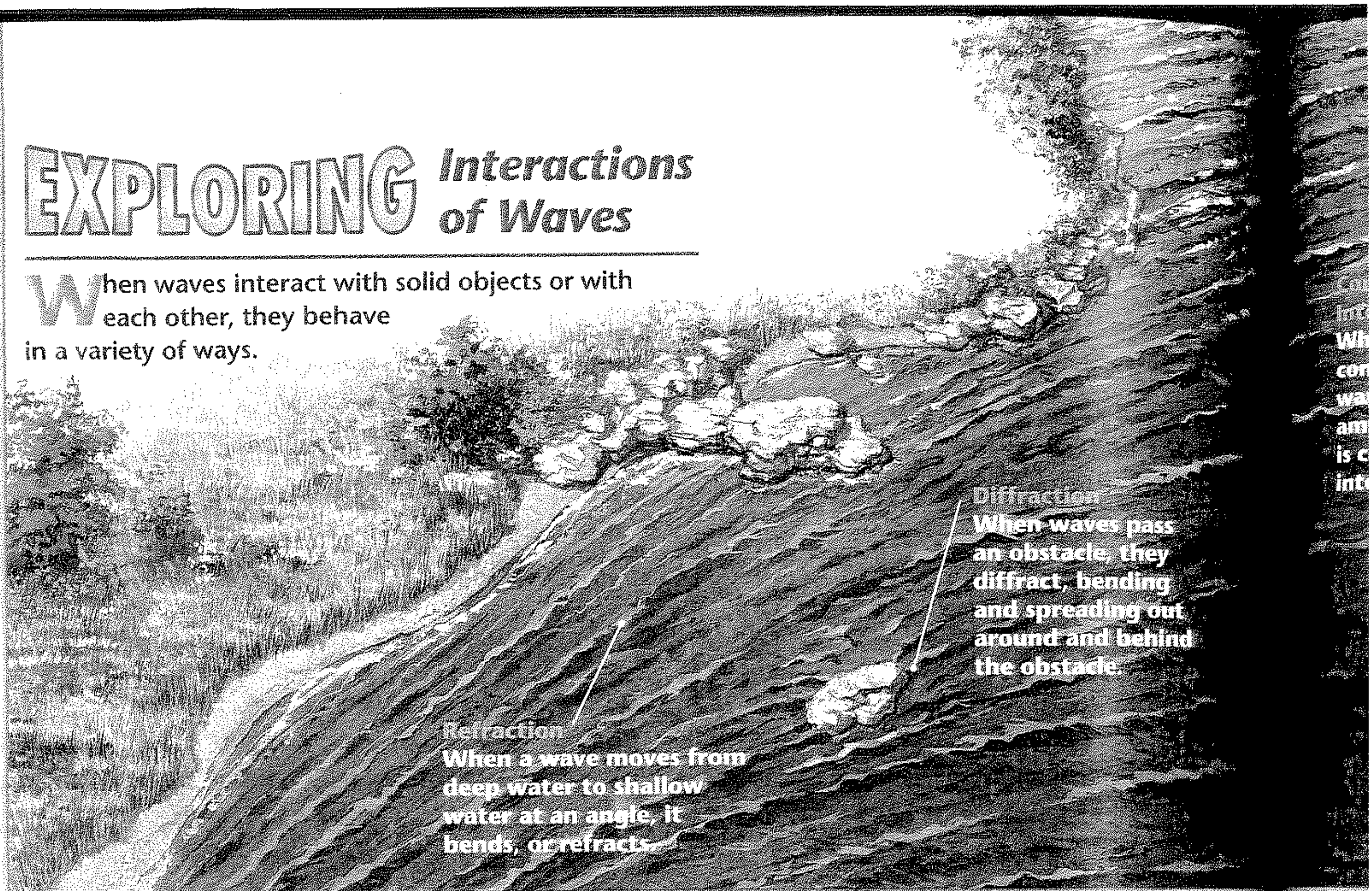
Here's how you can make a standing wave.

1. Tie a piece of elastic cord about 3 m long to a fixed, solid object. Hold the cord securely and pull it tight.
2. Slowly move the end of the cord up and down until you produce a standing wave.
3. Now move the cord up and down twice as fast to double the frequency. What happens?

Predicting What do you think will happen if you triple the original frequency? Try it. Be careful to keep a good grip on the cord.

EXPLORING *Interactions of Waves*

When waves interact with solid objects or with each other, they behave in a variety of ways.

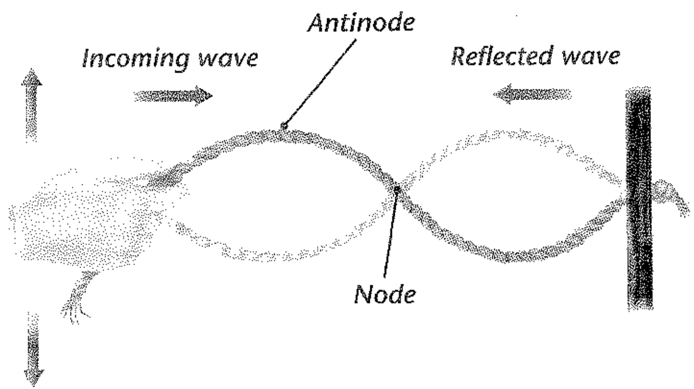


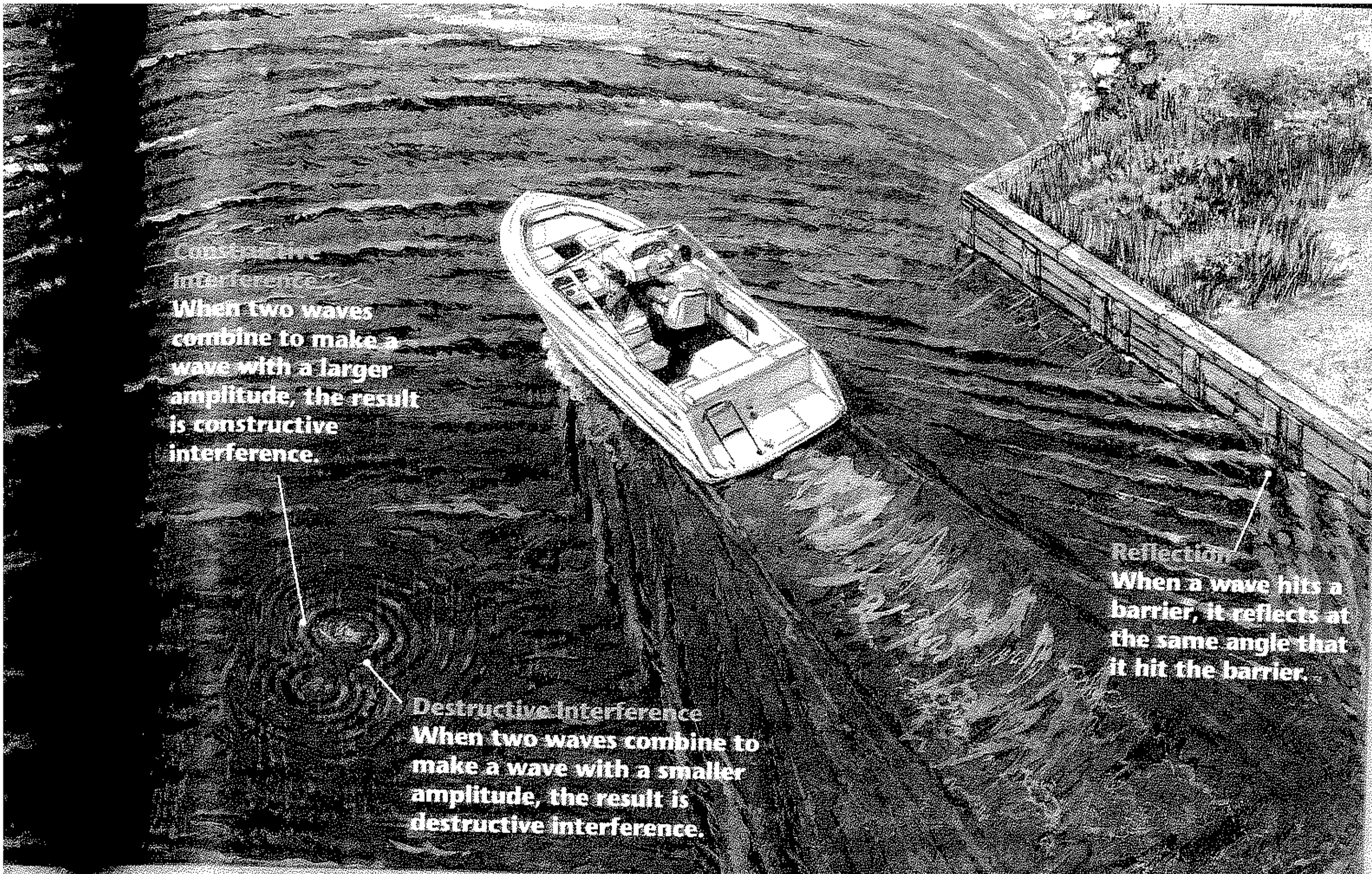
Nodes and Antinodes At certain points, destructive interference causes the two waves to combine to produce an amplitude of zero, as in Figure 13. These points are called **nodes.** The nodes always occur at the same place on the rope. The diagram also shows how the amplitudes of the two waves combine to produce amplitudes greater than zero. The crests and troughs of the standing wave are called **antinodes.** These are the points of maximum energy.

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. When an object is vibrating at a certain frequency, it takes very little energy to maintain or increase the amplitude of the wave.

Most objects have a natural frequency of vibration. Their particles vibrate naturally at a certain frequency. **Resonance** occurs when vibrations traveling through an object match the object's natural frequency. If vibrations of the same frequency are added, the amplitude of the object's vibrations increases.

Figure 13 A standing wave is set up when the reflected wave interacts with the incoming wave. The nodes are the points of zero amplitude. The antinodes are the points of maximum amplitude.





An object that is vibrating at its natural frequency absorbs energy from objects that vibrate at the same frequency. Resonance occurs in music and adds a distinct quality to the sound.

If an object is not very flexible, resonance can cause it to shatter. For this reason, marching troops are told to break step as they cross a bridge. If they all march across the bridge in perfect step, it is possible that the pounding could match the natural frequency of the bridge. The increased vibration could cause the bridge to collapse.

Section 3 Review

1. What is the law of reflection?
2. What causes refraction?
3. Describe the difference between constructive and destructive interference.
4. What causes a standing wave?
5. **Thinking Critically Predicting** Two water waves have the same wavelength. The crests of one occur at the same place as the crests of the second. If one wave has twice the amplitude of the other, will the waves interfere constructively or destructively? Explain.

Science at Home

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 in the water repeatedly to make waves. Demonstrate reflection and interference to your family members. Try to think of ways to demonstrate refraction and diffraction as well.