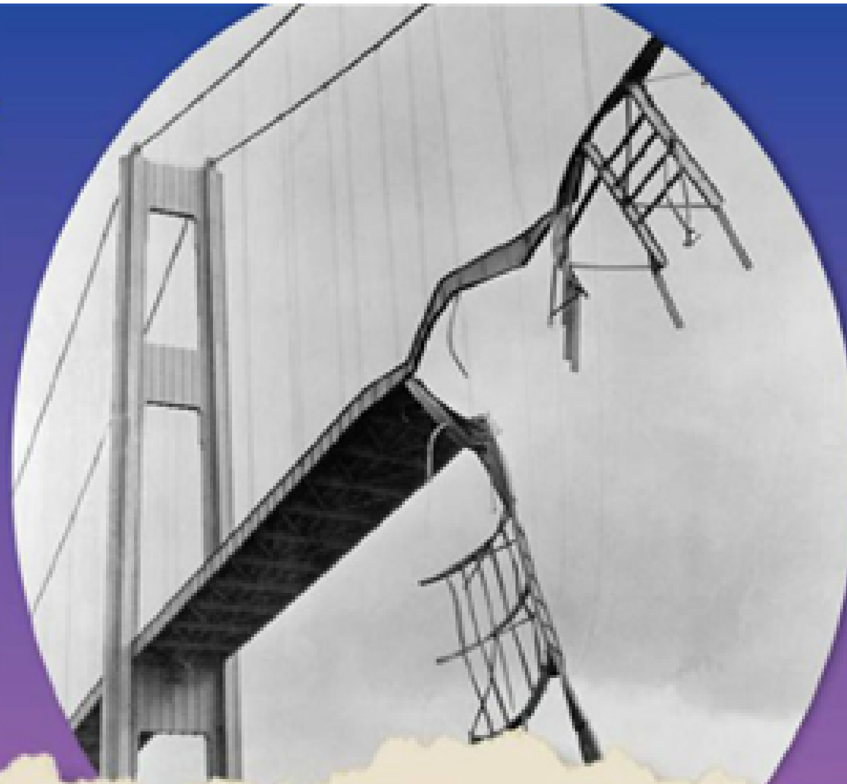
The Fall of Galloping Gertie

"My breath was coming in gasps; my knees were raw and bleeding, my hands bruised and swollen.... Safely back at the toll plaza, I saw the bridge in its final collapse and saw my car plunge into the Narrows."

This dramatic piece of writing is a witness's real-life account of the collapse of the Tacoma Narrows Bridge in Tacoma, Washington, on November 7, 1940.

Prior to its collapse, the suspension bridge was known for its swaying and rolling in the wind. This motion happened so regularly that the bridge was nicknamed "Galloping Gertie." Only four months after its construction, the bridge collapsed into the waters of Puget Sound during a windstorm. Although a disaster, Galloping Gertie's collapse became a valuable teaching tool for engineers.



Lab zone Do the Inquiry Warm-Up *How Does a Ball Bounce?*

Communicate Discuss the following questions with a partner. Write your answers below.

1. Why is "Galloping Gertie" an appropriate nickname for the bridge?

the up and down motion of the bridge looked like a galloping horse

2. If you were an engineer studying this bridge collapse, what is one thing you would research?

test the structure of the bridge, compare to other bridge in the area

What Changes the Direction of a Wave?

If you toss a ball against a wall, the ball bounces back in a new direction. Like a ball, waves can also change direction. **Waves change direction by reflection, refraction, and diffraction.**

Reflection When a wave hits a surface, any part of the wave that cannot pass through the surface bounces back. This interaction with a surface is called reflection. Reflection happens often in your everyday life. When you looked in your mirror this morning you used reflected light to see yourself. The echo you hear when you shout in an empty gym is also a reflection.

In **Figure 1** you can see how light waves are reflected. All reflected waves obey the law of reflection.

FIGURE 1

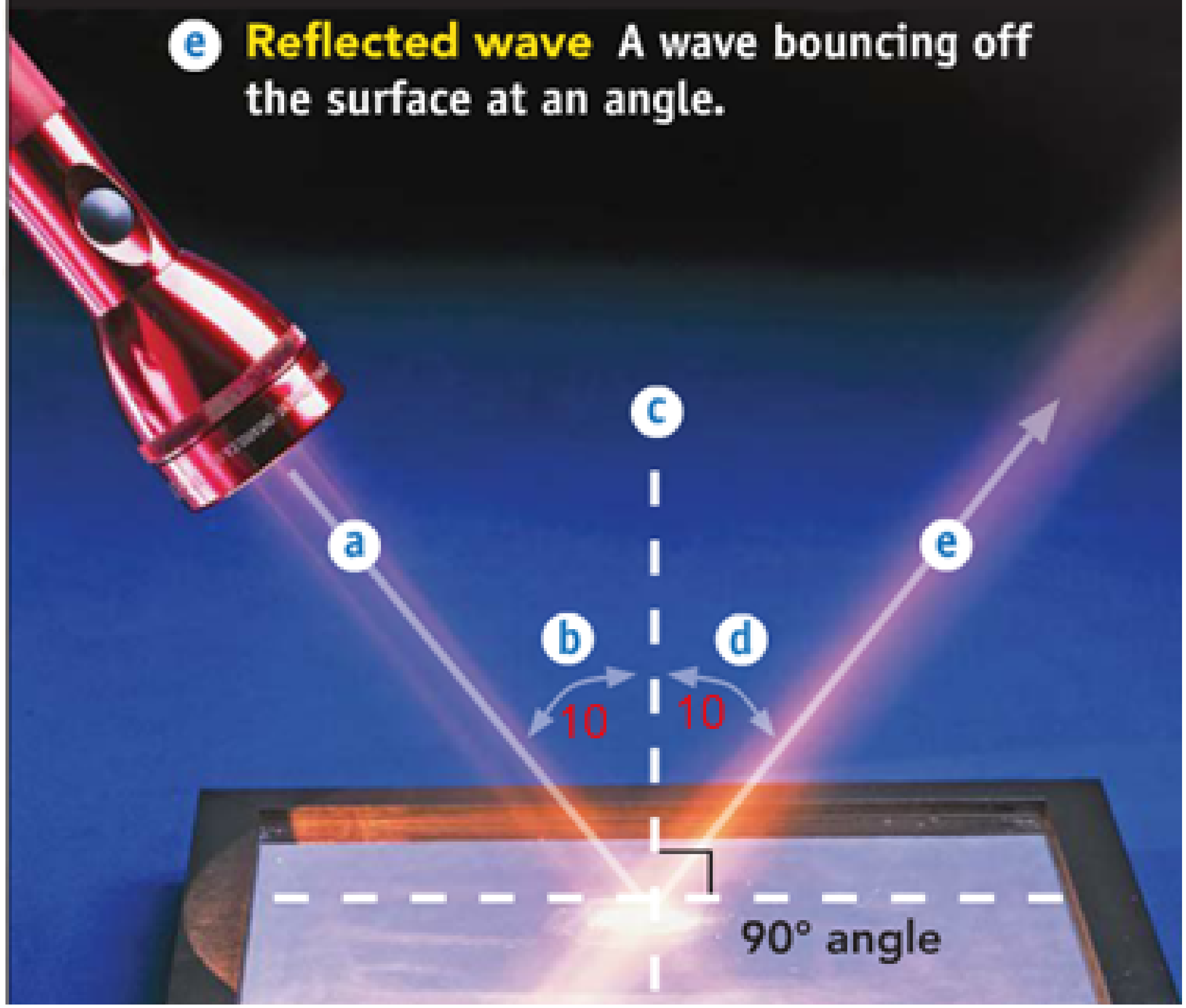
The Law of Reflection

The law of reflection states that the angle of incidence equals the angle of reflection.

✏ **Explain** Read the sequence of steps, matching each step to its letter in the photo. If the angle of incidence is 45°, explain what the angle of reflection would be.

45

- **a** **Incoming wave** A wave moving toward the surface at an angle.
- **b** **Angle of incidence** The angle between the incoming wave and the normal.
- **c** **Normal** A line perpendicular to the surface at the point where reflection occurs.
- **d** **Angle of reflection** The angle between the reflected wave and the normal.
- **e** **Reflected wave** A wave bouncing off the surface at an angle.



Refraction Have you ever ridden 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.

Like a skateboard that changes direction, changes in speed can cause waves to change direction. Look at **Figure 2.** When a wave enters a new medium at an angle, one side of the wave changes speed before the other side. This causes the wave to bend. Bending occurs because different parts of the wave travel at different speeds. Refraction is the bending of waves due to a change in speed.

Waves do not always bend when entering a new medium. No bending occurs if a wave enters a new medium at a right angle. Bending does not occur if the speed of the wave in the new medium is the same as the speed of the wave in the old medium.

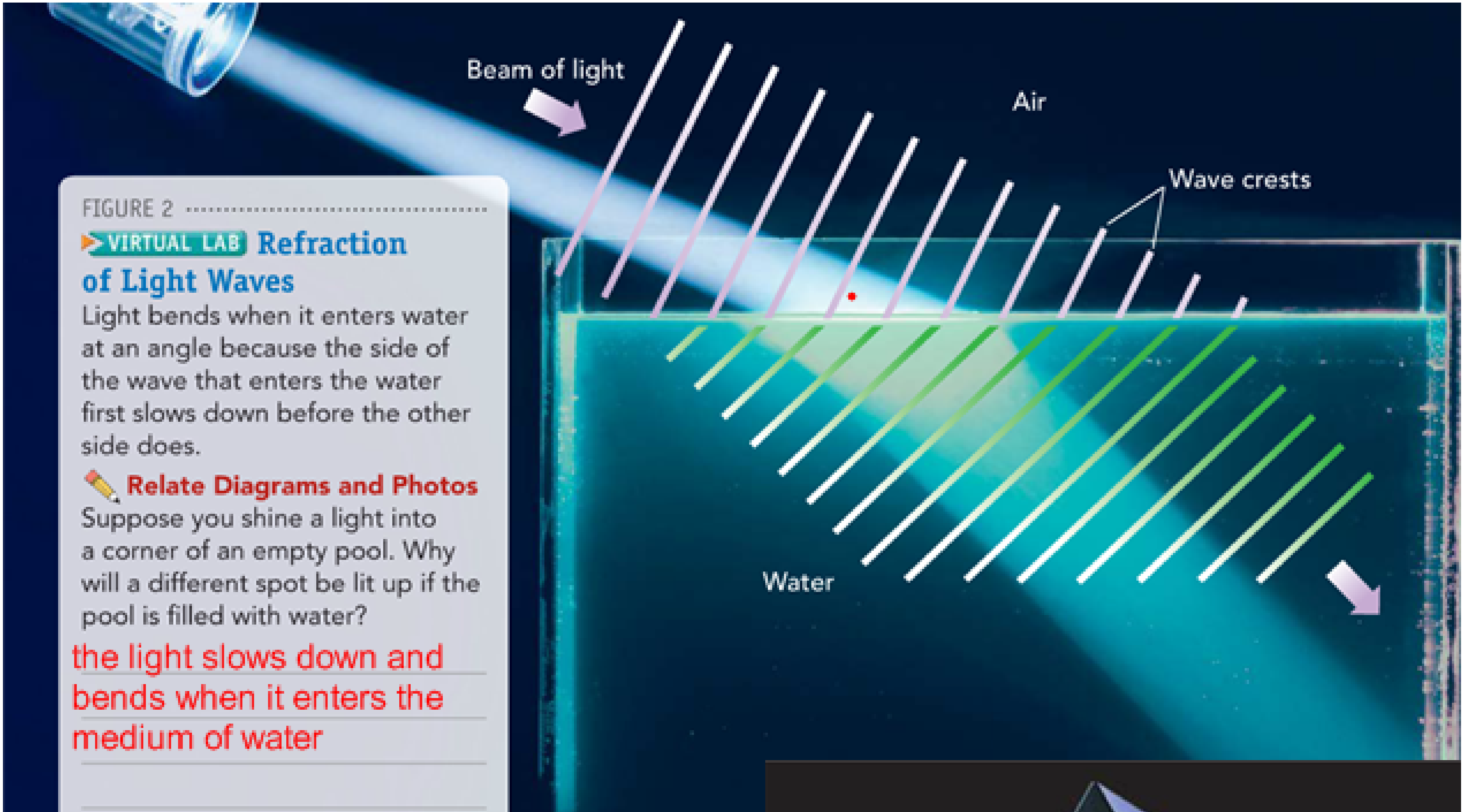


FIGURE 2

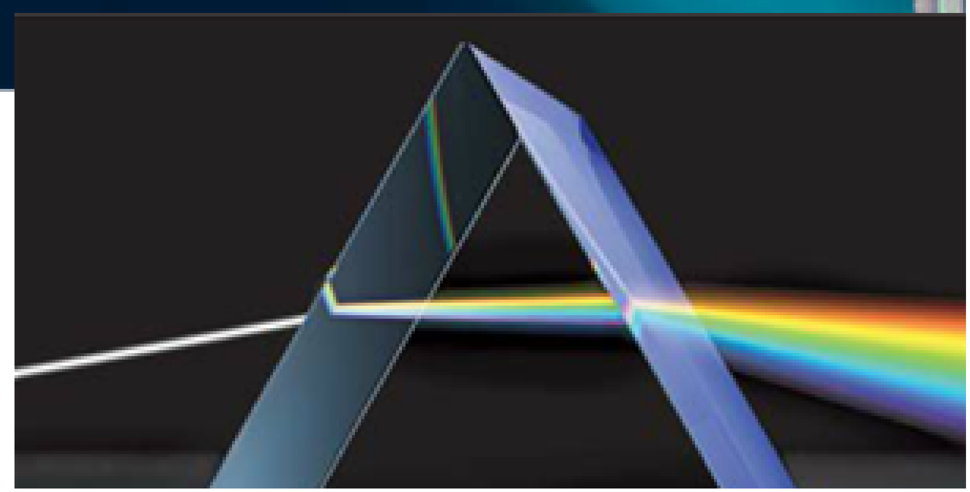
VIRTUAL LAB **Refraction of Light Waves**

Light bends when it enters water at an angle because the side of the wave that enters the water first slows down before the other side does.

Relate Diagrams and Photos

Suppose you shine a light into a corner of an empty pool. Why will a different spot be lit up if the pool is filled with water?

the light slows down and bends when it enters the medium of water

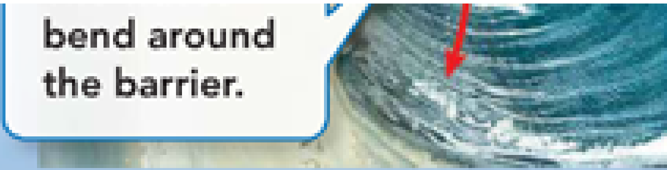


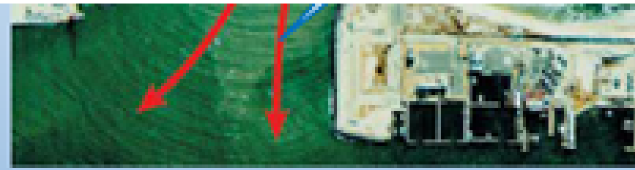
Diffraction Waves sometimes bend around barriers or pass through openings. When a wave moves around a barrier or through an opening in a barrier, it bends and spreads out. These wave interactions are called diffraction. Two examples of diffraction are shown in **Figure 3.**

FIGURE 3

The Diffraction of Water Waves

Water waves diffract when they encounter canals or shorelines.





apply it!

Use the three pictures on the right to answer the questions.

1 Observe Under each picture, write how the waves are changing direction.

2 Summarize In what way are reflection, refraction, and diffraction similar?

all 3 waves change direction

refraction

reflection

diffraction

zone Making Waves.

Assess Your Understanding

1a. **Define** What is diffraction?

when a wave bends and spreads out

b. **Classify** A wave bends after entering a new medium. What type of interaction is this?

refraction

got it?

○ **I get it!** Now I know that a wave's direction can be changed by

reflection
refraction
diffraction

○ I need extra help with

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What Are the Two Types of Wave Interference?

Have you ever seen soccer balls collide? 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.**

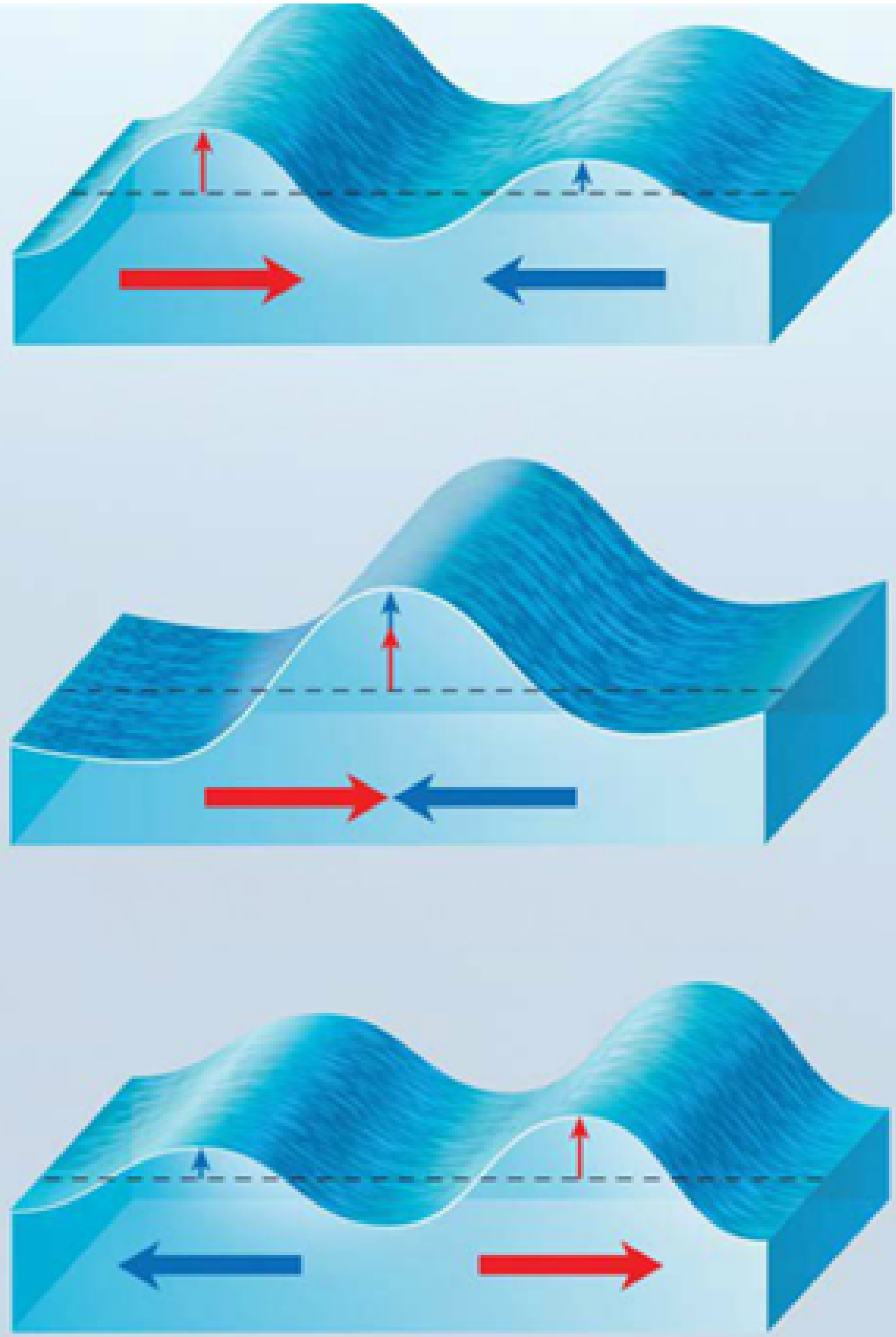
Constructive Interference Interference in which waves combine to form a wave with a larger amplitude than any individual wave's amplitude is called constructive interference. You can think of constructive interference as waves "helping each other," or adding their energies. For example, in **Figure 4,** when the crests of two waves overlap, they make a higher crest. If two troughs overlap, they make a deeper trough. In both cases, the amplitude of the combined crests or troughs increases.

of the bird's feathers creates the interference. The bright colors are only seen at specific angles of reflection.

FIGURE 4

Constructive Interference

Infer **Explain what the black dotted line represents. Then tell what happens to the direction of each wave when the waves meet.**



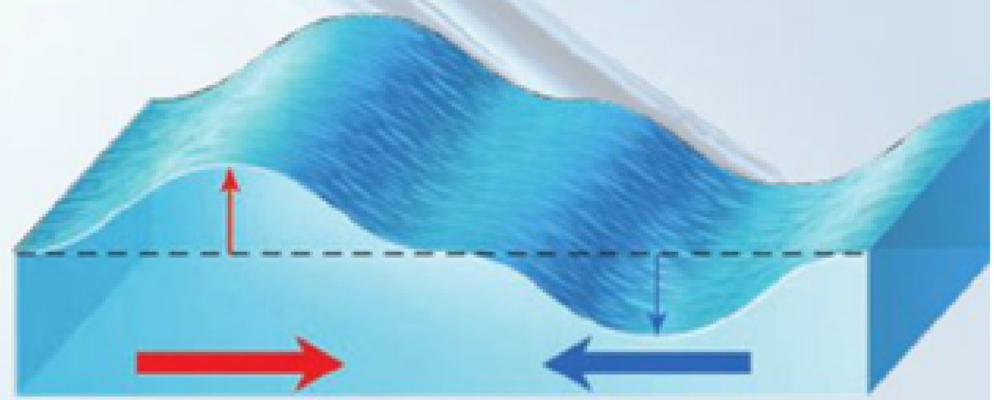
1. Two waves approach each other. The wave on the left has a greater amplitude.

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

3. The waves continue on as if they had not met.

Destructive Interference Interference in which two waves combine to form a wave with a smaller amplitude than either original wave had is called destructive interference. Destructive interference can occur when the crest of one wave overlaps the trough of another wave. If the crest has a larger amplitude than the trough of the other wave, the crest "wins" and part of it remains. If the original trough had a larger amplitude than the crest of the other wave, the result is a trough. If a crest and trough have equal amplitudes, they will completely cancel as shown in **Figure 5.** Destructive interference is used in noise-canceling headphones to block out distracting noises in a listener's surroundings.

1



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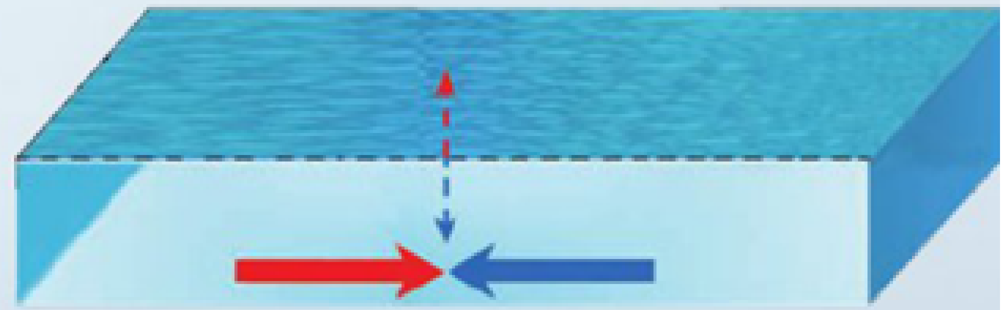

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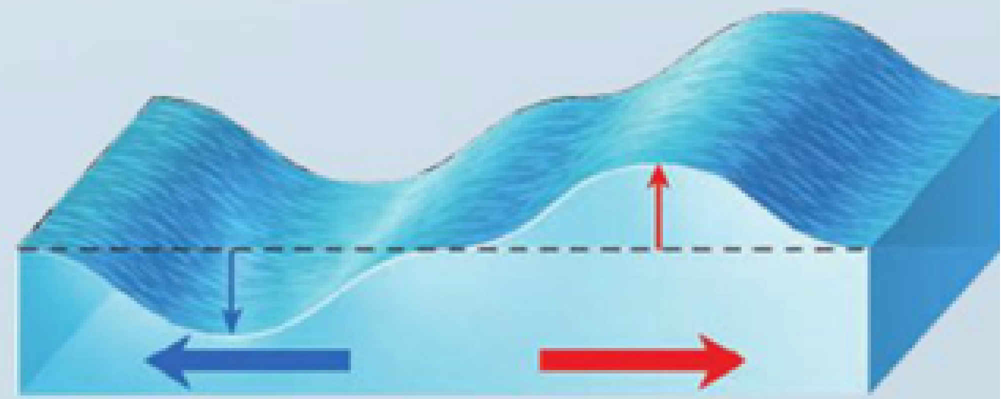

Assess Your Understanding

got it?

○ **I get it!** Now I know that the two types of wave interference are ______________________________

____

○ I need extra help with ______________________________

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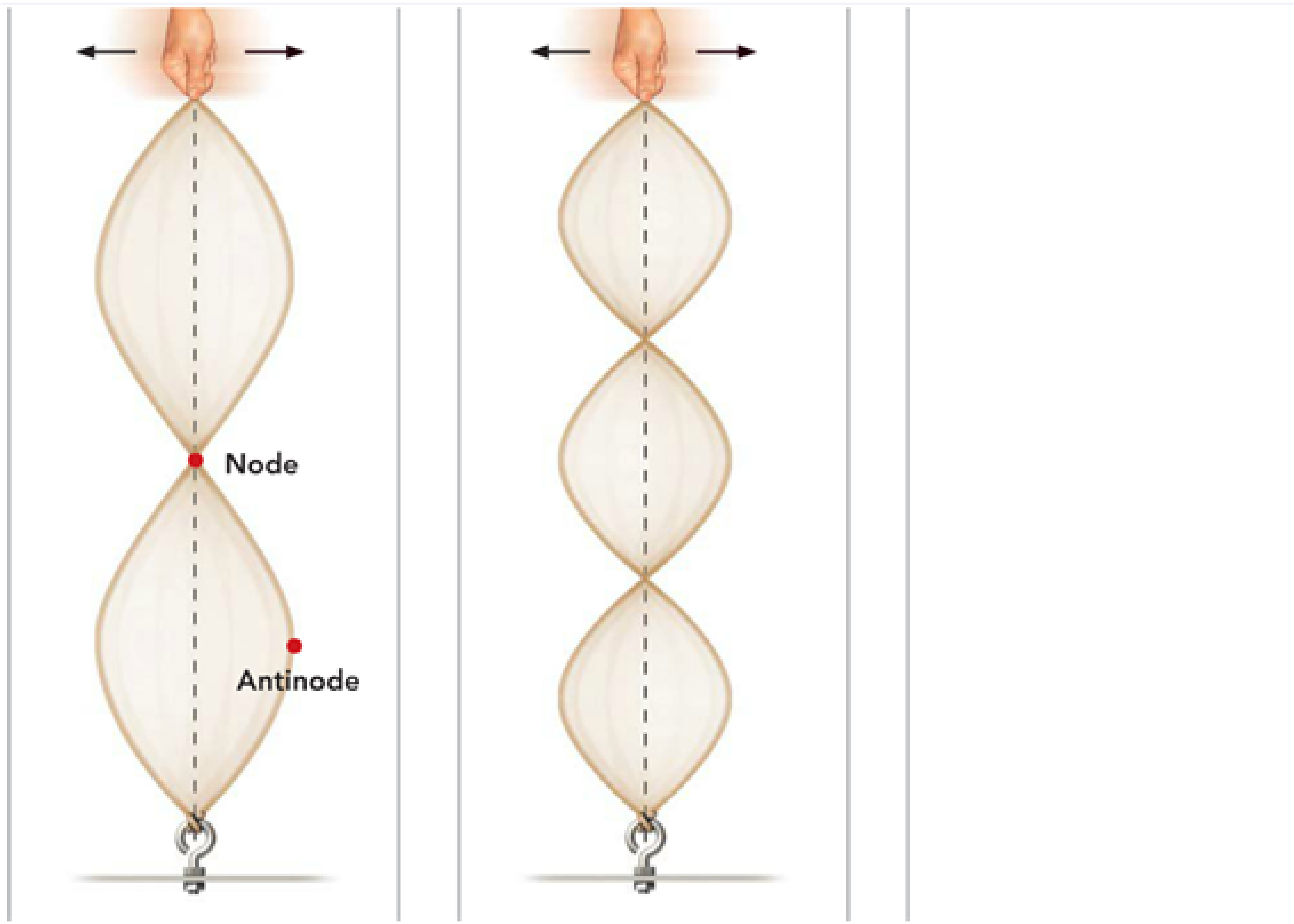
How Do Standing Waves Form?

If you tie a rope to a doorknob and 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 and interference occurs. **If the incoming wave and reflected wave have just the right frequency, they combine to form a wave that appears to stand still. This wave is called a standing wave.** A standing wave is a wave that appears to stand in one place, even though it is two waves interfering as they pass through each other.

Nodes and Antinodes In a standing wave, destructive interference produces points with zero amplitude, called nodes, as shown in **Figure 6.** 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. Points of maximum amplitude on a standing wave are called antinodes. The antinodes always occur halfway between two nodes.



1. **Identify** In the second box, label the nodes and antinodes.

2. CHALLENGE In the third box, draw the next standing wave in the series, and label its nodes and antinodes.

Resonance Have you ever pushed a child on a swing? At first the swing is difficult to push. But once it is going, you need only a gentle push 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.

The Tacoma Narrows Bridge, or "Galloping Gertie," may have collapsed because of resonance. Storm winds are said to have resonated with the natural frequency of the bridge. This caused the amplitude of the bridge's sway to increase until the bridge collapsed. You can see the result of the collapse in **Figure 7.**

FIGURE 7

The Power of Resonance

Winds blew as fast as 67 km/h during the storm in which the Tacoma Narrows Bridge collapsed.

Redesign **What might engineers do differently when designing a new bridge for this location?**

zone

Assess Your Understanding

2a. **Describe** What causes resonance to occur?

b. **Relate Cause and Effect** What causes nodes to form in a standing wave?

got it?

- O I get it! Now I know that standing waves form when
- O I need extra help with

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