Section 17.3

1 FOCUS

Objectives

17.3.1 **Describe** how reflection, refraction, diffraction, and interference affect waves.

17.3.2 **State a rule** that explains refraction of a wave as it passes from one medium to another.

17.3.3 **Identify** factors that affect the amount of refraction, diffraction, or interference.

17.3.4 **Distinguish** between constructive and destructive interference and **explain** how standing waves form.

Reading Focus

Build Vocabulary L2

Concept Map Have students build a concept map using the terms in this section. Students should write Behavior of Waves in an oval at the top and connect it with linking words to ovals containing vocabulary terms.

Reading Strategy L2

a. A wave reflected at a fixed boundary is inverted but has the same speed and frequency. **b.** Refraction occurs because one side of a wave front moves more slowly than the other side. **c.** The larger the wavelength, the more a wave diffracts. **d.** It can be constructive or destructive. **e.** It forms only for multiples of one-half wavelength.

2 INSTRUCT

Reflection

Teacher Demo

Water-Wave Reflections L2

Purpose Students will observe surface wave reflections.

Materials clear bowl, water, overhead projector

Procedure Fill the bowl with water and place it on the overhead projector. Make gentle waves with a finger.

Expected Outcome Surface waves can be observed reflecting off the side of the bowl. **Visual**

17.3 Behavior of Waves

Reading Focus

Key Concepts

- How does reflection change a wave?
- What causes the refraction of a wave when it enters a new medium?
- What factors affect the amount of diffraction of a wave?
- What are two types of interference?
- What wavelengths will produce a standing wave?

Vocabulary

- reflection
- refraction
- diffraction
- interference
- constructive interference
- destructive interference
- standing wave
- node
- antinode

Reading Strategy

Identifying Main Ideas Copy and expand the table below. As you read, write the main idea of each topic.

Topic	Main Idea
Reflection	a. ___?___
Refraction	b. ___?___
Diffraction	c. ___?___
Interference	d. ___?___
Standing waves	e. ___?___

Have you ever noticed bright lines like those shown in Figure 8 dancing on the bottom of a pool? These lines are produced when light shines through waves on the surface of the water. The lines don't seem to have a pattern because there are so many waves interacting. Imagine following just one of these waves. What will happen when it strikes the side of the pool? When it encounters another wave or an obstacle like a person? As the waves crisscross back and forth, many interactions can occur, including reflection, refraction, diffraction, and interference.

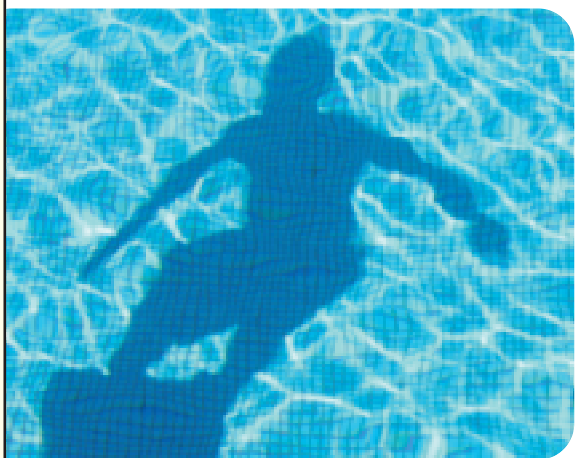

Figure 8 The ripples visible on the bottom of the pool are caused by light shining through surface waves.

Reflection

The next time you are in a pool, try to observe ripples as they hit the side of the pool. **Reflection** occurs when a wave bounces off a surface that it cannot pass through. The reflection of a wave is like the reflection of a ball thrown at a wall. The ball cannot go through the wall, so it bounces back.

If you send a transverse wave down a rope attached to a wall, the wave reflects when it hits the wall. **Reflection does not change the speed or frequency of a wave, but the wave can be flipped upside down.** If reflection occurs at a fixed boundary, then the reflected wave will be upside down compared to the original wave.

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Section Resources

Print

- ***Reading and Study Workbook With Math Support***, Section 17.3
- ***Transparencies***, Section 17.3

Technology

- ***Interactive Textbook***, Section 17.3
- ***Presentation Pro CD-ROM***, Section 17.3
- ***Go Online***, NSTA SciLinks, Diffraction and interference

Refraction

Refraction is the bending of a wave as it enters a new medium at an angle. Imagine pushing a lawnmower from grass onto gravel, as shown in Figure 9. The direction of the lawnmower changes because one wheel enters the gravel before the other one does. The wheel on the gravel slows down, but the other wheel is still moving at a faster speed on the grass. The speed difference between the two wheels causes the lawnmower to change direction. Refraction changes the direction of a wave in much the same way. **When a wave enters a medium at an angle, refraction occurs because one side of the wave moves more slowly than the other side.**

Figure 10 shows the refraction of an ocean wave as it flows into a shallow area. The shallower water can be considered a new medium. The lines on the photograph show the changing direction of the wave. These lines, called wave fronts, are parallel to the crests of the wave.

Notice that the wave fronts approach the shore at an angle. The left side of each wave enters shallower water before the right side does. As the left side of the wave slows down, the wave bends toward the left.

If a wave front is parallel to the shoreline, the wave enters the shallower water all at once. The wave will slow down but it will not change direction. Refraction of the wave occurs only when the two sides of a wave travel at different speeds.

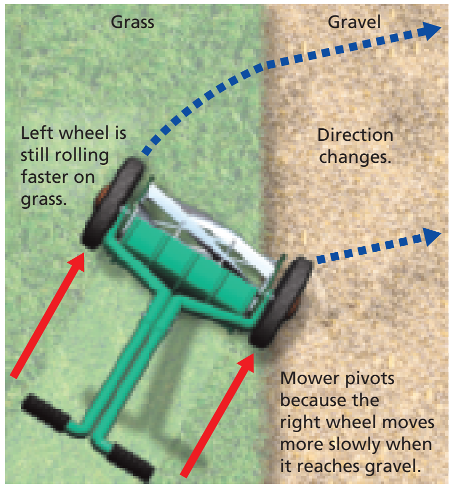

Figure 9 A lawnmower turns when it is pushed at an angle from the grass onto the gravel. **Relating Cause and Effect** ***Explain why the lawnmower straightens out after both wheels are on the gravel.***

Reading Checkpoint *What is refraction?*

Figure 10 As an ocean wave approaches the shore at an angle, the wave bends, or refracts, because one side of each wave front slows down before the other side does.

Customize for English Language Learners

Increase Word Exposure
This section contains several new and potentially confusing vocabulary word pairs, such as *reflection* and *refraction* or *constructive* and *destructive.* While students read the section in class, post the vocabulary terms on the board or wall. Carefully define each word when it first appears. Then, ask for student help in distinguishing between the similar-sounding words.

Build Reading Literacy L1

Active Comprehension Refer to page **498D** in this chapter, which provides the guidelines for active comprehension.

Read the introductory paragraph on p. 508. Ask, **What more would you like to know about how waves interact?** or **What about wave behavior interests you?** You will need to make connections for the students between waves and their lives. For example, students may have observed ripples in a drink sitting on top of a loudspeaker. Write down several of the students' responses. Have students read the section. While reading, have them consider the questions that they had about the material. Have students discuss the section content, making sure that each question raised at the beginning is answered or that students know where to look for the answer.
Verbal

Refraction

Address Misconceptions L2

Some students may think that a wave always changes direction as it passes through a boundary. Refraction is always accompanied by a change in wavelength and speed. However, the direction of a wave does not always change. For example, although water waves approaching a beach perpendicular to the beach do not change direction, they do slow down as the wave fronts get closer together.
Verbal, Visual

Build Science Skills L2

Posing Questions Have students look at Figure 10. Ask, **How could you test the assertion that water waves move more slowly in more shallow water?** *(Possible answer: Set up a wave tank and measure wave speed at different depths, making sure to hold all other variables constant.)*
Logical

Answer to . . .

Figure 9 *Once both wheels are on the gravel, they move at the same speed, so the lawnmower no longer changes direction.*

Reading Checkpoint *Refraction is the bending of a wave as it enters a new medium at an angle.*

Diffraction

Use Visuals

L1

Figure 11 Emphasize to students that both pictures are showing the same phenomena, diffraction. Point out the similarities between the two images. Ask, **What would the diffraction pattern look like if one of the barriers were removed in Figure 11A?** *(The waves would still spread out behind the other barrier. This would look like half of the diffraction pattern in Figure 11B.)*
Visual, Logical

Interference

Address Misconceptions

L2

Students sometimes make an analogy between pulses and particles traveling toward each other and assume that when two pulses meet in the center of a long spring, they bounce or reflect as if they were solid objects. Use a long, soft spring and a jump rope to demonstrate two differently sized and shaped pulses approaching each other so that students can see that they pass through each other.
Verbal

Go Online NSTA SCILINKS

Download a worksheet on diffraction and interference for students to complete, and find additional teacher support from NSTA SciLinks.

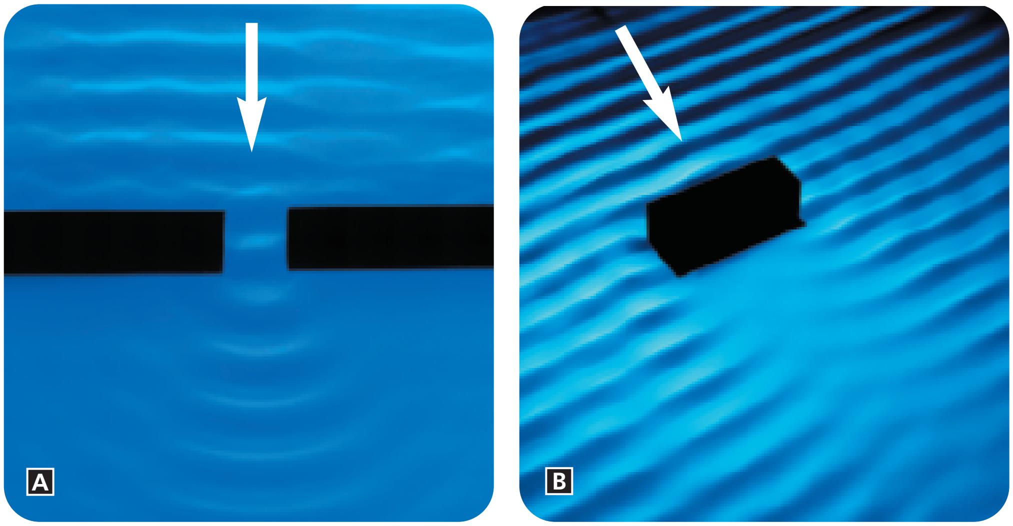

Figure 11 **A** Mechanical waves, like the water waves shown here, diffract as they move past an obstacle or through an opening. **A** This wave diffracts, or spreads out, after it passes through a narrow opening. **B** Diffraction also occurs when a wave encounters an obstacle.

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For: Links on diffraction and interference
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Diffraction

Diffraction (dih FRAK shun) is the bending of a wave as it moves around an obstacle or passes through a narrow opening. Figure 11A shows how water waves spread out as they pass through a narrow opening. The pattern produced is very similar to the circular ripples you see when a pebble is tossed into a pond. Diffraction also occurs when waves bend around an obstacle, as shown in Figure 11B.

A wave diffracts more if its wavelength is large compared to the size of an opening or obstacle. If the wavelength is small compared to the opening or obstacle, the wave bends very little. The larger the wavelength is compared to the size to the opening or obstacle, the more the wave diffracts.

Reading Checkpoint *What is diffraction?*

Interference

If two balls collide, they cannot continue on their original paths as if they had never met. But waves can occupy the same region of space and then continue on. **Interference** occurs when two or more waves overlap and combine together. **Two types of interference are constructive interference and destructive interference.** The displacements of waves combine to increase amplitude in constructive interference and to decrease amplitude in destructive interference.

Facts and Figures

The First Known Seismoscope Earthquakes travel through Earth as longitudinal waves, transverse waves, and surface waves. Surface waves are the most destructive and are the waves that people feel during an earthquake. The world's first earthquake wave detector was invented in 132 A.D. by Zhang Heng, a scientist in the Han Dynasty in China. It was sensitive enough to detect small surface waves. The device had eight dragons arranged in a circle. Each dragon's mouth held a brass ball. When an earthquake wave passed, a brass ball would fall, indicating the direction of the wave. One day a ball fell, indicating that an earthquake had occurred, although no one had felt an earthquake. A few days later, couriers arrived, reporting an earthquake in Lung-Hsi, about 640 km away.

Constructive Interference Imagine a child being pushed on a swing by her mother. If the mother times her pushes correctly, she will push on the swing just as the child starts to move forward. Then the mother's effort is maximized and the child gets a boost to go higher. In the same way, the amplitudes of two waves can add together. **Constructive interference** occurs when two or more waves combine to produce a wave with a larger displacement.

What happens if you and a friend send waves with equal frequencies toward each other on a jump rope? Figure 12A shows how constructive interference produces a wave with an increased amplitude. The crests of waves 1 and 2 combine to make a higher crest in wave 3. At the point where two troughs meet, wave 3 has a lower trough.

Destructive Interference What happens if the mother has bad timing while pushing on the swing? Instead of working to boost her daughter upward, some of her effort is wasted, and the girl will not swing as high. In much the same way, destructive interference can reduce the amplitude of a wave. **Destructive interference** occurs when two or more waves combine to produce a wave with a smaller displacements.

In Figure 12B, two waves with the same frequency meet, but this time the crest of wave 1 meets the trough of wave 2. The resulting wave 3 has a crest at this point, but it is lower than the crest of wave 1. Destructive interference produces a wave with a reduced amplitude.

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active art

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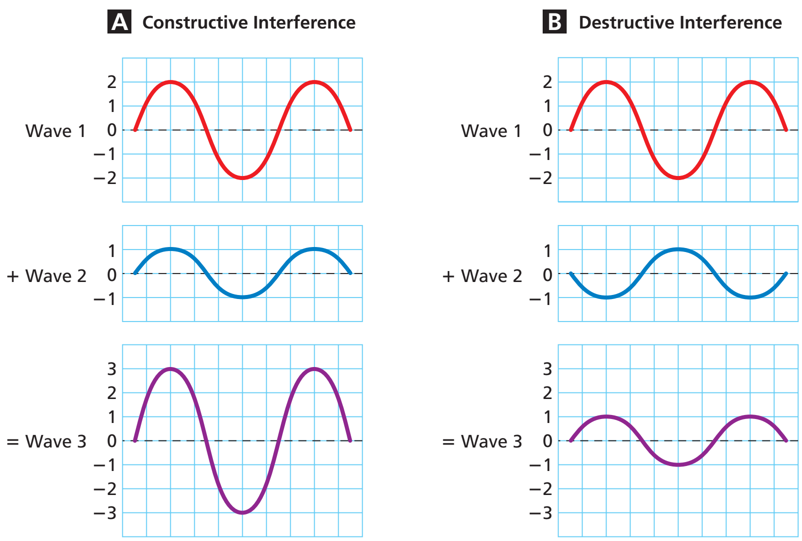

Figure 12 Two waves with equal frequencies travel in opposite directions. The motions are graphed here to make it easier to see how the waves combine. **A** When a crest meets a crest, the result is a wave with an increased amplitude. **B** When a crest meets a trough, the result is a wave with a reduced amplitude. **Making Generalizations** ***How is the amplitude of wave 3 related to the amplitudes of waves 1 and 2?***

Use Visuals

L1

Figure 12 Have students examine the figure carefully. Note that the two waves are moving in opposite directions. In Figure 12A, the crests line up with crests and the troughs line up with troughs. In Figure 12B, the crests line up with troughs and the troughs with crests. Ask, **In Figure 12A, what would wave 3 look like if wave 1 and wave 2 had the same amplitude?** *(The amplitude of wave 3 would be twice that of wave 1 or 2.)* **In Figure 12B, what would wave 3 look like if wave 1 and wave 2 had the same amplitude?** *(Wave 3 would have zero amplitude.)* Point out to students that even in the case of two waves with the same amplitude, the waves do not entirely cancel. After they pass through each other, they continue on in their original form.
Visual, Logical

Build Science Skills

L2

Using Tables and Graphs Give students dimensions for the horizontal axis of the grid in Figure 12, such as each increment equals 10 cm. Ask students to determine the wavelength of waves 1 and 2 in Figures 12A and 12B. *(The wavelength of each of the waves equals 60 cm.)* Ask, **Do waves 1 and 2 in Figure 12B have the same wavelength?** *(Yes)* **If each graph grid represents a time period of 10 seconds, what is the period and frequency of wave 1 in Figure 12A?** *(Period = 6 s; frequency = 1/6 Hz)*

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Students can interact with simulations of constructive and destructive interference online.

Answer to . . .

Figure 12 *The amplitude of wave 3 equals the sum of the amplitudes of waves 1 and 2 for constructive interference. For destructive interference, it's the difference of the amplitudes.*

Reading Checkpoint *Diffraction is the bending of a wave when it encounters an obstacle or a narrow opening.*

Section 17.3 (continued)

Standing Waves

Teacher Demo

Standing Waves

L2

Purpose Students will observe different standing waves.

Materials long, soft, heavy rope, such as a jump rope

Class Time 10 minutes

Procedure Tie one end of the rope to a chair or other firm support. Hold the other end of the rope so that it is suspended in air. Start with the rope hanging in an arc. Make standing waves by shaking the rope at different frequencies. Ask students to estimate the wavelength as you increase the frequency and produce more nodes. *(As the frequency increases, the wavelength decreases.)*

Expected Outcome The length of the rope must be an integral number of half wavelengths for a standing wave to occur. **Kinesthetic, Visual**

3 ASSESS

Evaluate Understanding

L2

Have students write three review questions for this section.

Reteach

L1

Use Figures 9–13 as examples that illustrate the key concepts of the section.

Writing in Science

Students will need to first decide how the time between photographs compares with the period of the wave. If the five photographs occur during one half period of the wave, the sequence will show the person starting at a maximum crest and moving downward to a minimum trough. No circular motion should result because the lateral motions caused by the two waves should cancel.

Interactive Textbook If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 17.3.

Answer to . . .

Figure 13 *The upper photograph has waves with a longer wavelength.*

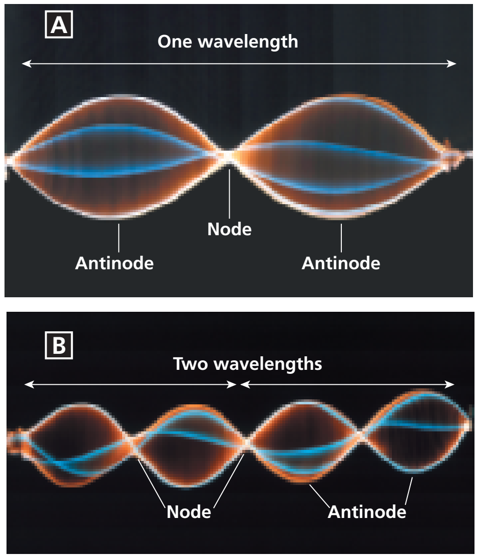


Figure 13 These photos show standing waves for two different frequencies. **A** One wavelength equals the length of the cord. **B** Two wavelengths equal the length of the cord. **Interpreting Photos** ***In which photo do the waves have a longer wavelength?***

Standing Waves

If you tie one end of a rope to a chair and shake the other end, waves travel up the rope, reflect off the chair, and travel back down the rope. Interference occurs as the incoming waves pass through the reflected waves. At certain frequencies, interference between a wave and its reflection can produce a standing wave. A **standing wave** is a wave that appears to stay in one place—it does not seem to move through the medium.

You can observe a standing wave if you pluck a guitar string or any elastic cord. Only certain points on the wave, called nodes, are stationary. A **node** is a point on a standing wave that has no displacement from the rest position. At the nodes, there is complete destructive interference between the incoming and reflected waves. An **antinode** is a point where a crest or trough occurs midway between two nodes.

Why does a standing wave happen only at particular frequencies? **A standing wave forms only if half a wavelength or a multiple of half a wavelength fits exactly into the length of a vibrating cord.** In Figure 13A, the wavelength equals the length of the cord. In Figure 13B, the wavelength is halved. You can adjust the wavelength by changing the frequency of the waves. Once you find a frequency that produces a standing wave, doubling or tripling the frequency will also produce a standing wave.

Section 17.3 Assessment

Reviewing Concepts

1. How is a wave changed by reflection?
2. What causes refraction when a wave enters a medium at an angle?
3. What determines how much a wave diffracts when it encounters an opening or an obstacle?
4. List the types of interference.
5. At what wavelengths can a standing wave form in an elastic cord?

Critical Thinking

6. **Comparing and Contrasting** How does the frequency of a reflected wave compare to the frequency of the incoming wave?
7. **Comparing and Contrasting** How are diffraction and refraction similar? How are they different?
8. **Applying Concepts** What is the amplitude of the wave that results when two identical waves interfere constructively?

Writing in Science

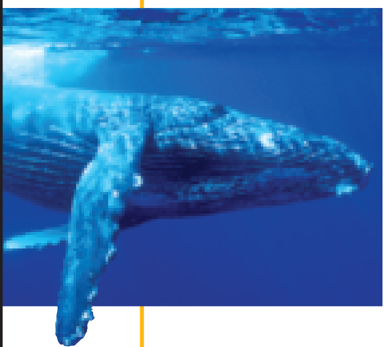
Explain a Sequence Imagine you are floating in a wave pool. The crest of one wave hits you from the left just as the crest of another hits you from the right. The two waves are otherwise identical. A friend takes a series of five photos starting when the crests hit you. Write a paragraph describing the photos.

Section 17.3 Assessment

1. The reflected wave is upside down compared to the original wave.
2. Refraction occurs because the entire wave does not enter the new medium at the same time. One side of a wave front entering the new medium undergoes a speed change before the rest of the wave front does, resulting in the change in direction.
3. The larger the wavelength of a wave compared to the size of the obstacle or opening, the more the wave diffracts.
4. Destructive, constructive
5. A standing wave forms only if half a wavelength or a multiple of half a wavelength fits exactly into the length of the vibrating object.
6. The frequencies are equal. Reflection does not change the frequency of a wave.
7. Diffraction and refraction both involve the bending of waves. Refraction occurs when a wave enters a new medium at an angle, while diffraction occurs when a wave encounters an obstacle or a narrow opening.
8. The amplitude of the resulting wave is double the amplitude of the two interfering waves.

issues in SCIENCE

Are Regulations Needed to Protect Whales from Noise Pollution?



Researchers have known for decades that humpback whales sing complicated songs. Their songs can be as long as 30 minutes, and a whale may repeat the song for two or more hours. Songs can be heard at distances of hundreds of kilometers. There is evidence that whales use variations in the songs to tell other whales about the location of food and predators. Only the male humpbacks sing, which has led some researchers to think that songs are also used to attract a mate.

The whale songs may be threatened by noise pollution. In the past 50 years, ocean noise has increased due to human activity. Goods are transported across the ocean in larger ships than ever before. Large ships use bigger engines. They produce low-frequency noise by stirring up air bubbles with their propellers. Unfortunately, whales also use low-frequency sound in their songs, perhaps because these sounds carry farther than high-frequency sounds in the ocean. Propeller noise from large ships is loud enough to interfere with whale songs at a distance of 20 kilometers.

The Viewpoints

Regulations Are Needed to Reduce Noise Pollution From Large Ships

Whales use their songs in ways that affect their survival—eating, mating, and avoiding predators. Studies often focus on the effects of noise from a single ship, but in routes taken by ocean freighters, noise from many ships combines to produce a higher volume. Ocean freighters often travel near whale migration routes, so even noise that affects whales at a distance of 20 kilometers may have an impact on whale survival. If regulations are delayed until research can prove that noise pollution affects whales, it may be too late to help the whales. Many kinds of whales are on the endangered species list, so it is important to err on the side of safety.

Regulations Are Not Needed to Reduce Noise Pollution From Large Ships

Whale songs can be lengthy and are often repeated, so the effect of noise from ships is limited because ships quickly move out of an area. One study showed that whales changed the rhythm and tempo of their songs in response to noise from large ships, but there was no evidence that the communication was less effective. Also, it is expensive to modify ship propellers to reduce low-frequency noise. If less-developed countries cannot afford to modify ships, regulations will not be effective in reducing ocean noise levels.

Research and Decide

1. **Defining the Issue** In your own words, describe the major issue that needs to be resolved about ocean noise pollution.
2. **Analyzing the Viewpoints** List three arguments for those who think regulations should require large ships to reduce noise pollution. List three arguments for those who think regulations are not necessary.
3. **Forming Your Opinion** Explain which argument you find most convincing.

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Answers

1. The issue is: Should regulations be passed to limit noise from large ships?

2. For Regulation: Whales depend on communication for breeding and locating food resources. Noise that affects whales at a short distance may still have an impact on behavior. Because many species are endangered, it is wise to err on the safe side of the issue. Against Regulation: Whale songs can be lengthy and are often repeated, so there are several opportunities for a message to get through. Whales may modify songs in response to noise pollution, but there's no evidence it makes communication less effective. Reducing noise of large ships may not be feasible in less developed countries, which makes regulations ineffective.

3. Students should support their decision by referring to the arguments in Question 2.

issues in SCIENCE

Are Regulations Needed to Protect Whales from Noise Pollution? L2

Background

In the United States, whales fall under the Marine Mammal Protection Act of 1972 (MMPA). This act makes it illegal for any person residing in the United States to kill, hunt, injure, or harass any species of marine mammal. The act includes noise pollution. Ocean noise may result from military testing, sonar, assembling and dismantling of drilling rigs, seismic testing, marine commerce, and proposed experiments using 195-dB pulses to measure the temper-ature in the North Atlantic. Low-frequency sonar produces 235-dB pulses. Oil tankers continuously produce low-frequency sounds of 177 dB at 500 Hz in all the shipping lanes of the world. Seismic oil-exploration pulses are 210 dB. For comparison, the call of a gray whale is 185 dB.

Since light does not penetrate very far in ocean water, whales use sound to find their way around, locate food, and understand their environment. Sound travels five times faster in water than in air and is transmitted more efficiently. Some sounds can travel for hundreds of kilometers.

Whales are thought to hear in the range of 40 Hz to 150 kHz, depending on the species. However, the upper and lower limits are inferred for many whales. Research into large whale hearing is limited by the large size and behaviors of these animals.

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Have students further research the issues related to this topic.

Mechanical Waves and Sound 513