SECTION 2

Making Waves

Section Overview

To help understand basic wave properties, students produce a "stadium wave" in which successive rows of students stand up with their hands up and then sit down to develop a wave-like effect in the classroom. They record the direction the wave moved, the direction they moved, and why the wave moved forward without them. They then consider any variables that could be changed in their "class wave." In *Part B* of the *Investigate*, they send pulses on a coiled spring and describe the movement of a piece of tape or yarn placed in the middle of the spring. The angle between an arrow showing the motion of the wave and an arrow showing the motion of the tape or yarn is subsequently recorded, establishing the concept of a transverse wave. Students measure the speed of the pulse for different wave amplitudes. They create standing waves on the helical spring and determine the relationship among the wave's speed, frequency, and wavelength. They make both transverse and compressional (longitudinal) waves on the helical spring and contrast the motion of the two kinds of waves. Finally, students build a model to help relate basic wave properties to observations of wave motion.

Background Information

Sound is produced and travels in waves to our ears. A wave is a disturbance that travels through a medium such as air or water. Waves are a collective effect. The neighboring parts of the wave medium—the matter the wave moves through—interact and propagate a disturbance from one place to another. For waves on a coiled spring, each part of the spring influences the neighboring parts through the force of the stretched spring. A disturbance in one part of the spring creates forces on neighboring parts, and the disturbance moves. For a spring, the disturbance is a stretching of the spring from its equilibrium position, which is a straight spring.

In *Section 2*, students disturb this equilibrium by whipping one end of the coiled spring back and forth to make a pulse, as shown in a drawing in *Part B* of the *Student Edition*. In the pulse, the spring's coils are stretched. The neighboring parts of the spring pull these coils back toward their equilibrium position. Of course, these coils also exert a force on the neighboring parts of the spring (Newton's third law) and tend to pull them away from their equilibrium position. That is how the pulse moves.

Periodic waves of the right frequency can set up stable patterns called standing waves. For standing wave patterns, the whole spring goes through the equilibrium position twice in each wave cycle. Notice that the spring does not have to be motionless when it is in the equilibrium position. Observe the diagram of the standing wave following *Question 11* in the *Student Edition*. As previously suggested, the spring is moving at this time. Therefore, all of the energy in the spring is in the form of kinetic energy as the spring moves through the equilibrium position.

The most important wave properties are amplitude, frequency, wavelength, and speed. The first example discussed in *A Physicist's Response* is how a tsunami grows. For this case, amplitude depends on wave speed. When a tsunami wave approaches land, the wave speed decreases and the amplitude increases. This is what lead to the devastating effects that occurred in the Indian Ocean in December 2004. For a more detailed discussion of a tsunami wave, refer to G. A. DiLisi and R. A. Rarick, "Modeling the 2004 Indian Ocean Tsunami for Introductory Physics Students," The Physics Teacher 44, 585-588 (2006).

When two waves pass through each other, the two amplitudes simply add at every point. This is the principle of superposition. To measure the wavelength (the distance between adjacent crests), a snapshot of the wave with a meter stick right above the crests can be taken. To measure the frequency of the waves by timing one complete cycle, a movie of the motion could be made with a clock in the frame of the camera. The period of a wave is simply the inverse of its frequency. Notice how the units invert as well. One hertz is a cycle per second. It is the inverse of the period of a wave, which is measured in seconds (cycles are a dimensionless counting unit).

When watching water waves wash over a rock, a particular crest for a time of one wave period moves one wavelength. The frequency gives the number of wave periods in one second. Thus, the speed v is simply the wavelength λ times the frequency f, $v = \lambda f$. A wave moves through a medium. The spring is the medium for waves in the coiled spring, water is the medium for water waves, and air is the medium for sound waves. But there are waves that do not require a medium. These are electromagnetic waves that can travel through a vacuum (for example, light coming from the Sun to Earth).

Electromagnetic waves move freely through space, which is an excellent vacuum. The Sun gives off light and radio waves, which are different forms of electromagnetic waves. Various distant objects in the universe give off every kind of electromagnetic radiation, and all these waves travel through the emptiness of space to reach Earth.

In a standing wave pattern, the spring vibrates but no waves seem to move along its length. Standing waves occur only at certain frequencies, which correspond to simple patterns of motion. In the lowest frequency standing wave on a spring, the spring bends in the middle, with the ends, fixed in place. If the frequency is doubled, there is a node, a point of no motion, in the middle of the spring (refer to drawings toward the end of *Part B* in the *Investigate*). In a standing wave, a small amount of oscillation with just the right frequency can excite a huge oscillation in the vibrating system, a phenomenon called resonance. Moving the frequency away from a resonant frequency produces disorganized motion with a very small amplitude. Students will observe this effect when shaking their coiled springs. If they shake at a frequency corresponding to a standing wave pattern, the coiled spring will undergo large amplitude oscillations. If they shake the spring at some other frequency, the oscillations will be disorganized and of small amplitude.

NOTES

Crucial Physics

- Waves are disturbances that travel through a medium. (An exception: electromagnetic waves can travel through a vacuum.)
- Waves are characterized by wave **speed** (how fast the disturbance travels). The wave speed depends on the characteristics of the medium.
- **Periodic** (repetitive waves) are characterized by the wave **period** T (time between recurring features of the wave), the wave **frequency** f (the number of oscillations per second), and the **wavelength** λ (distance between recurring features of the wave). $T = 1/f$
- The wavelength λ, the frequency f, and the wave speed v are related by $v = f\lambda$.
- **Transverse** waves have the wave disturbance perpendicular to the direction in which the wave is traveling. **Longitudinal** waves have the wave disturbance in the same direction in which the wave is traveling.
- The **amplitude** of a wave is the largest displacement of the medium from its equilibrium position.
- **Standing waves** are wave patterns that do not move through the medium. A **node** is a spot in a standing wave pattern at which the medium is completely stationary. An **antinode** is a spot in a standing wave pattern at which the medium has its largest displacement.
- For a standing wave on a string (or a coiled spring) with both ends fixed, the wavelength λ is related to the length L of the vibrating medium by

$$L = n\lambda/2, \quad n = 1, 2, 3, \ldots$$

The number n is the number of antinodes in the standing wave pattern.

- Waves transfer **energy** from one location to another. The larger the amplitude of a wave, the more energy the wave carries.

Learning Outcomes	Location in the Section	Evidence of Understanding
Observe the motion of a pulse.	***Investigate*** Part B: Steps 2, 3	Students are able to observe wave motion in a coiled spring.
Calculate the speed of a wave pulse.	***Investigate*** Part B: Steps 6, 7 Part C	Students start a pulse on a spring and measure the time it takes to travel the length of the spring.
Observe standing waves.	***Investigate*** Part B: Steps 10-13	Students rapidly whip one end of the coiled spring until they create a standing wave.
Investigate the relationship among wave speed, wavelength, and frequency.	***Investigate*** Part B: Steps 10-13 ***Physics Talk*** ***Physics to Go*** Question 2	Students change wave frequency to study the relationship. Read how the three variables are related. Student answers match those in *Physics to Go*.
Make a model of wave motion.	***Investigate*** Part D: Steps 1-4	Students draw periodic transverse waves on pieces of adding-machine tape.
Distinguish between transverse and longitudinal waves.	***Investigate*** Part B: Step 3 and Part C: Step 1	Students generate both transverse and longitudinal waves and record in their logs how the spring coils move in the two cases.

Section 2 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Styrene-foam cup, 12 ounces	4 per group	
Helical coil	1 per group	
Stopwatch	1 per group	
Ruler, metric, in./cm	1 per group	
Adding-machine tape, roll	1 per group	
Tape, masking		6 per class
Card, unlined index, 3" x 5" pkg 100		4 per class
Large area clear of obstructions*	1 per group	

*Additional items needed not supplied

Time Requirement

- Allow two class periods or 90 minutes for the students to complete the *Investigate* part of this section.

Teacher Preparation

- You will have to take special care to ensure that your students do not tangle the coiled springs. One procedure that works is to place the responsibility for keeping the coiled spring untangled on one student in the group.
- Remind students not to release the ends of the coiled spring when they finish using it. Rather, have them walk toward the other end of the spring with the spring still in hand to release the tension and then place the coil back in its container.
- If measuring tapes are available, use them to measure the length of the stretched spring rather than meter sticks.
- If material is a problem, you may choose to have some groups do the coiled spring first while others do the helical spring, and later reverse groups.
- A careful count of stopwatches before and after the *Investigate* is important.
- For *Part C* you may suggest students keep the spring elevated above the floor while propagating longitudinal waves. The friction of the moving coils on the floor is greater for the longitudinal wave than the transverse waves, causing it to die out more quickly.
- For *Part D*, prepare the index cards with the slits prior to the *Investigate*.

Safety Requirements

- Students must wear safety goggles during this *Investigate*.
- Warn students that once they stretch the helical spring they must be very careful not to suddenly release the end of the spring when it is under tension. The spring will recoil rapidly and can cause injury to an unprepared holder of the other end.
- If students are generating a standing wave with the helical spring when holding the spring in the air, be aware that a large amplitude standing wave may build quickly. Ensure that no students are standing alongside the spring, and that both students have a firm grip on the spring ends.

Materials and Equipment

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Styrene-foam cup, 12 ounces	4 per group	
Helical coil		1 per class
Stopwatch		1 per class
Ruler, metric, in./cm	1 per group	
Adding-machine tape, roll	1 per group	
Tape, masking		6 per class
Card, unlined index, 3" x 5" pkg 100		4 per class
Large area clear of obstructions*		1 per class

*Additional items needed not supplied

Time Requirement

- Allow one class period or 45 minutes for you to complete *Parts B* and *C* of the *Investigate* (students will have completed *Part A* the previous day), and students will complete *Part D*.

Teacher Preparation

- If measuring tapes are available, use them to measure the length of the stretched spring rather than meter sticks.
- For *Part C* keep the spring elevated above the floor while propagating longitudinal waves. The friction of the moving coils on the floor is greater for the longitudinal wave than the transverse waves, causing it to die out more quickly.
- For *Part D*, prepare the index cards with the slits prior to the *Investigate*.
- Have a student volunteer available to assist in the demonstration holding one end of the springs.
- Make a Blackline Master of the chart following *Step 13.a)* of the *Investigate*.
- Have the materials for students to complete *Part D* of the *Investigate* ready to hand out, one setup per group. Index cards should have the slit pre-cut to ready for immediate use.

Safety Requirements

- Everyone near the springs must wear safety goggles during this *Investigate*.
- Warn the student volunteer holding the other end of the spring that once the helical spring is stretched, they must be very careful not to suddenly release the end of the spring when it is under tension. The spring will recoil rapidly and can cause injury to an unprepared holder of the other end.
- When generating a standing wave with the helical spring with the spring in the air, be aware that a large amplitude standing wave may build quickly. Ensure that no students are alongside the spring, and that those generating the wave have a firm grip on the spring ends.

NOTES

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Making scientific measurements Using equipment properly	***Investigate*** Part B: Step 1	**Augmentation** • Students with gross motor and attention issues may struggle to stretch a coiled spring and accurately measure the distance between the springs. Instruct students to place a tape mark on the floor, measure 4 meters in a straight line, and then mark the other end with a piece of tape. Then students can stretch the coiled spring between these two marks to begin the *Investigate*. • Model the proper technique for holding on to and creating pulses in the coiled spring.
Following a series of directions	***Investigate*** Parts B and C	**Augmentation** • Students with sequential learning, reading, and attention issues may struggle to follow this list of instructions. Break the *Investigate* into smaller chunks. For example, instruct students to complete, *Part B*, *Steps 1-2*, and then summarize the results, or have a brief discussion as a class. Next, instruct students to complete *Steps 3-5* and check in and then *Steps 6-7*, and so on. • Provide time limits for each small chunk of tasks. Some students may not need to check in with the whole group and should continue to work at their own pace. • Set up structured group routines with clear roles for each student (coiled spring holders, measurers, recorders, task manager, and so on.) **Accommodation** • Provide a lab handout that has the lab broken into smaller chunks with blank spaces for each student observation or response.
Describing the motion of a coiled spring	***Investigate*** Parts B and C	**Augmentation** • Students may struggle to draw a sketch of a three-dimensional object. Model how to quickly make a sketch of a coiled spring. Instruct students to use a similar sketch each time they are asked to record the motion related to the coiled spring. **Accommodation** • Students who have more serious fine-motor issues may struggle to reproduce a coiled spring sketch, even with a model. Provide a sheet of coiled spring sketches on which students could add arrows to represent the motion they observe in this investigation.
Synthesizing information to understand essential concepts	***Investigate*** Part B, Step 15	**Augmentation** • Many students struggle to synthesize information from a series of observations into meaningful units of understanding. Students have completed many tasks to reach this point and are now being asked to summarize their observations. Ask students to summarize independently for 5 minutes, discuss their ideas with a partner for 5 minutes, and then report their conclusions to the class. • Remind students to refer back to their observations to complete the statements.
Comparing and contrasting wave properties related to sound and light	***Chapter 5***	**Augmentation** • Throughout this chapter, students will complete investigations related to sound and light. A graphic organizer such as the "Sound waves vs. light waves Graphic Organizer" will help students synthesize and summarize their learning to compare and contrast the properties of sound and light. Amplitude is defined and then described relative to sound and light early in the *Physics Talk*. This is an example of information that could be recorded on the graphic organizer. Without an organized way to summarize this text, students may gloss over important points. • This graphic organizer could also be used as a review at the end of the chapter.
Applying an inverse relationship mathematically	***Chapter 5***	**Augmentation** • Students struggle to use the frequency and period equations, especially if they have to find the inverse of a fraction. Many students recognize this relationship as a reciprocal. Provide direct instruction to teach this concept and allow opportunities for practice.

Strategies for Students with Limited English-Language Proficiency

Point out new vocabulary words in context and practice using the words as much as possible throughout the section. As you work through the section, have students write the terms in their *Active Physics* log book and add the definitions in their own words. Encourage students to accompany the definitions with labeled diagrams and illustrations.

amplitude	wavelength
interference	antinode
longitudinal (compressional) wave	average
medium	concentric circles
node	constructive interference
oscillation	crest
period	destructive interference
periodic wave	displacement
principle of superposition	frequency
pulse	hertz
reflect	in phase
standing wave	transverse wave
trough	wave

There are new vocabulary terms in this section. A solid grasp of the vocabulary is essential for students to fully understand waves. One way to practice using the words is for students to work in teams to write meaningful sentences about the content in this section. The goal is to use as many words as possible correctly. The terms should be written in complete sentences. Most of the sentences should be simple, but encourage students to include some compound sentences to demonstrate their understanding of bits of related information or opposite information. For example:

- A crest is the highest point of a wave, and a trough is the lowest point.

The rubric for grading these sentences should include four elements: correct science, correct usage of vocabulary, correct sentence structure and grammar, and quantity of work.

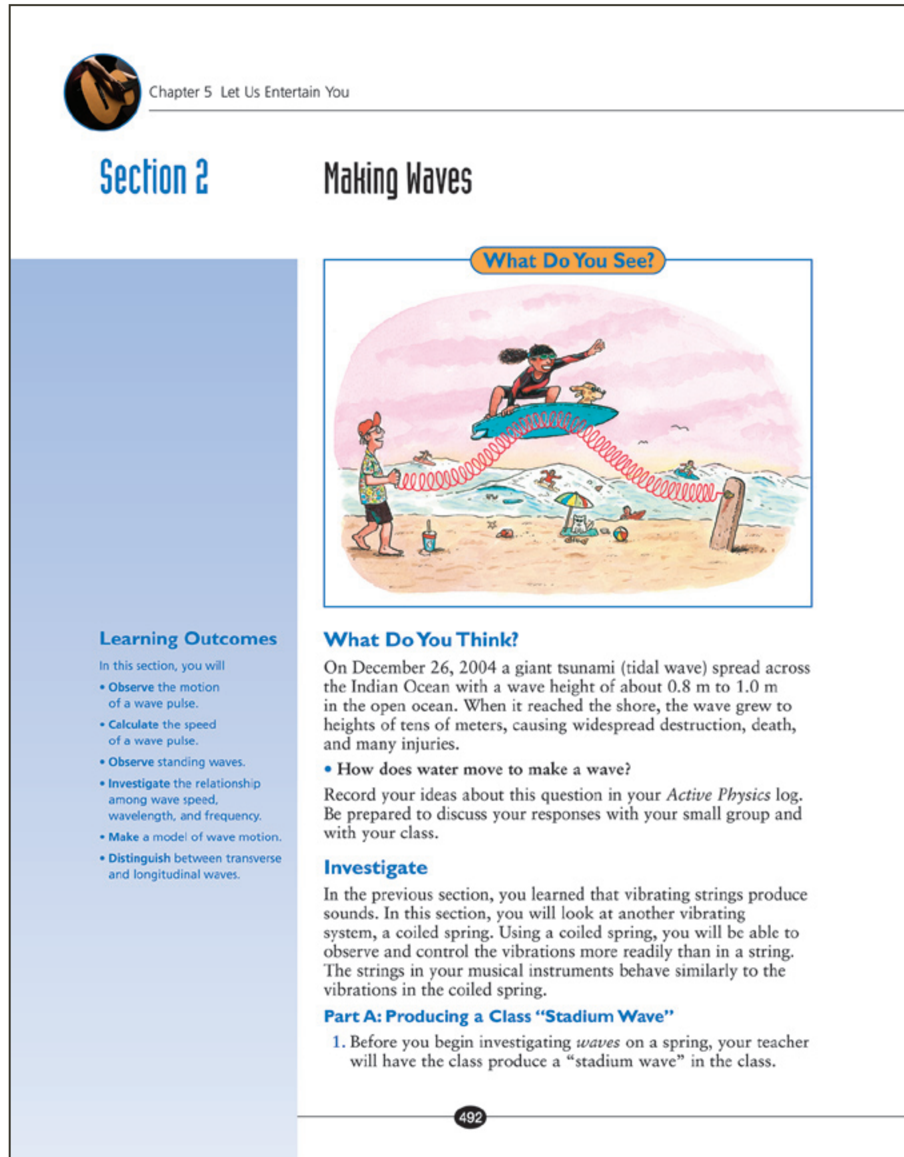
Rapid feedback about students' sentences is essential, because the sentences and errors will be fresh in the students' minds. A quick and powerful method for providing this feedback is to prepare a list of examples of incorrect sentences from the work collected. Divide examples into the following categories: incorrect science, incorrect usage of vocabulary, incorrect sentence structure, and incorrect grammar. Choose several examples from the collected work to use in each category and edit the sentences until they contain only one or two obvious errors, or limit the choices to these kinds of sentences. At the beginning of class on the day following the sentence-writing activity, provide each student with a page containing a double-spaced, typed list of the incorrect sentences, with headings for the categories. Allow students 10 minutes to silently make corrections to the sentences. Then, place a copy of the list on the overhead projector and collect students' ideas on how to repair the sentences, guiding them toward correct science and English usage.

SECTION 2

Teaching Suggestions and Sample Answers

What Do You See?

The main purpose of the *What Do You See?* illustration is to give students ideas of what they will be learning later in this section. The illustration can be interpreted on many levels. Students might comment on the wave made by the coiled spring, the person pulling it, the surfer riding on the spring or another aspect of the illustration. The various interpretations that are made should help you begin an interesting and focused discussion. Consider writing students' ideas on the board, so that they can return to their initial impressions to develop a more wholesome understanding of *Making Waves*.


Chapter 5 Let Us Entertain You

Section 2 Making Waves

What Do You See?

Learning Outcomes

In this section, you will

- **Observe** the motion of a wave pulse.
- **Calculate** the speed of a wave pulse.
- **Observe** standing waves.
- **Investigate** the relationship among wave speed, wavelength, and frequency.
- **Make** a model of wave motion.
- **Distinguish** between transverse and longitudinal waves.

What Do You Think?

On December 26, 2004 a giant tsunami (tidal wave) spread across the Indian Ocean with a wave height of about 0.8 m to 1.0 m in the open ocean. When it reached the shore, the wave grew to heights of tens of meters, causing widespread destruction, death, and many injuries.

- How does water move to make a wave?

Record your ideas about this question in your *Active Physics* log. Be prepared to discuss your responses with your small group and with your class.

Investigate

In the previous section, you learned that vibrating strings produce sounds. In this section, you will look at another vibrating system, a coiled spring. Using a coiled spring, you will be able to observe and control the vibrations more readily than in a string. The strings in your musical instruments behave similarly to the vibrations in the coiled spring.

Part A: Producing a Class "Stadium Wave"

1. Before you begin investigating *waves* on a spring, your teacher will have the class produce a "stadium wave" in the class.

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Students' Prior Conceptions

In addition to students using metal coils and strings to create sound and to examine the nature of compression (longitudinal) and transverse waves, encourage students to seek out interactive media, either with the use of the computer and the Internet or other video presentations. This will provide opportunities to test their nascent ideas about how waves move in different ways and with different speeds to create patterns of waves, transmit energy and create sounds and light.

1. **As waves move, matter, such as molecules of air or other vibrating matter, moves along with the waves.** The specific instructions that have students attach a piece of colored yarn to visualize the different motions of the transfer of energy along longitudinal and transverse waves lead students to doubt this prior conception. It also accommodates the concept in their minds that energy travels along the medium, from molecule to molecule, and that the medium moves differently for transverse and for longitudinal waves. Molecules move perpendicularly to the transfer of energy in transverse waves and vibrate parallel to the transfer of energy in longitudinal waves.

What Do You Think?

These are specific questions that will have varied student responses. You should encourage them to discuss their answers and the tsunami that spread across the Indian Ocean to stimulate students' curiosity. You will find students more receptive with a context that is relevant to them and draws their attention. Tell them to keep revisiting their responses to determine the accuracy in light of the content they will be learning.

What Do You Think?

A Physicist's Response

When water makes a wave, the molecules in the water are disturbed from their position of rest by some force such as the earthquake that started the tsunami. Water molecules are loosely bound to one another, and when one is pulled upward, it exerts a force on its neighbors, pulling them upward as well, starting a wave crest. After the water molecules have reached their peak, the force of gravity pulls them back down toward their position of rest. The inertia of the molecules causes them to overshoot their position at rest, creating the trough. Eventually the upward force of the neighboring molecules and the water below overcomes the inertia, reversing the direction and repeating the process that raised the crest.

A tsunami begins when an earthquake shifts the ocean bottom and creates a small step in the height of the water surface. This step is usually only a few tens of centimeters high. The small disturbance in the surface spreads out in circular waves from the point above the earthquake, but the amplitude remains small as long as the water depth does not change. However, when the wave reaches more shallow water, the wave speed drops, and the back of the wave overruns the front, increasing the amplitude, just as if the waves were piling up on top of each other. This is exactly the same effect, but on a much larger scale, that creates breaking waves at ocean beaches. It is the large amplitude wave that causes devastation as it hits the shore. The breaking of the waves is an example of the violation of the principle of superposition. Technically, the breaking of the waves is a nonlinear effect. (Simple superposition applies only when the waves are linear and the amplitudes are not too large.)

CHAPTER 5

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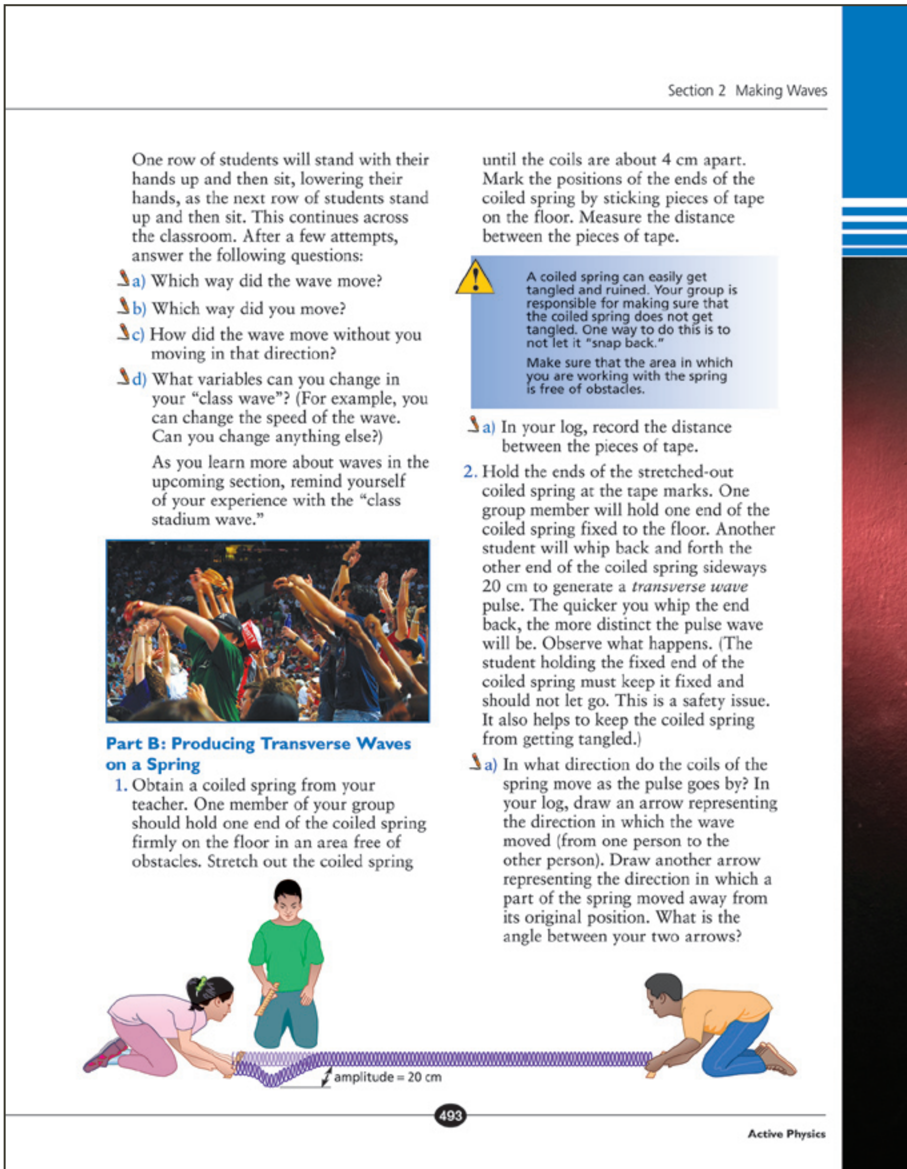


One row of students will stand with their hands up and then sit, lowering their hands, as the next row of students stand up and then sit. This continues across the classroom. After a few attempts, answer the following questions:

a) Which way did the wave move?

b) Which way did you move?

c) How did the wave move without you moving in that direction?

d) What variables can you change in your "class wave"? (For example, you can change the speed of the wave. Can you change anything else?)

As you learn more about waves in the upcoming section, remind yourself of your experience with the "class stadium wave."

Part B: Producing Transverse Waves on a Spring

1. Obtain a coiled spring from your teacher. One member of your group should hold one end of the coiled spring firmly on the floor in an area free of obstacles. Stretch out the coiled spring until the coils are about 4 cm apart. Mark the positions of the ends of the coiled spring by sticking pieces of tape on the floor. Measure the distance between the pieces of tape.

A coiled spring can easily get tangled and ruined. Your group is responsible for making sure that the coiled spring does not get tangled. One way to do this is to not let it "snap back."

Make sure that the area in which you are working with the spring is free of obstacles.

a) In your log, record the distance between the pieces of tape.

2. Hold the ends of the stretched-out coiled spring at the tape marks. One group member will hold one end of the coiled spring fixed to the floor. Another student will whip back and forth the other end of the coiled spring sideways 20 cm to generate a *transverse wave* pulse. The quicker you whip the end back, the more distinct the pulse wave will be. Observe what happens. (The student holding the fixed end of the coiled spring must keep it fixed and should not let go. This is a safety issue. It also helps to keep the coiled spring from getting tangled.)

a) In what direction do the coils of the spring move as the pulse goes by? In your log, draw an arrow representing the direction in which the wave moved (from one person to the other person). Draw another arrow representing the direction in which a part of the spring moved away from its original position. What is the angle between your two arrows?

Investigate

Part A: Producing a Class "Stadium Wave"

1.a)

The wave moved across the class.

1.b)

The students moved up and down.

1.c)

The wave moves because adjacent particles (the students) move up and down, causing the wave to move across.

1.d)

The wave speed, amplitude (the students could jump rather than just stand up), and direction could easily be changed.

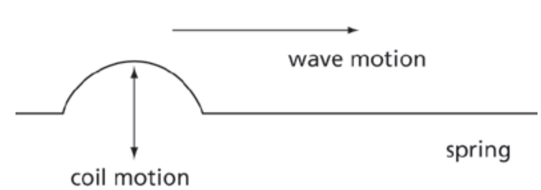
Part B: Producing Transverse Waves on a Spring

1.a)

The distances will vary. Suggested distance is around 8 m.

2.a)

The coils move sideways as the wave moves along the spring. Students' diagrams should show the spring with the wave moving from one end to the other while the coils of the spring move perpendicularly to the spring. The angle between the motion of the spring coils, and direction the wave travels is 90°. Students' diagrams should looks like the one below.



2.b)

The coils of the spring move at right angles to the motion of the pulse. If students carefully observe the motion of the piece of tape as a wave pulse passes by, they will see that the motion of the tape is "sideways" (technically, it is transverse). Students' diagrams for this section should be the same as for *Step 2.a)*.

2.c)

Answers will vary. Transverse is a good name for the pulse because it moves at right angles to the direction that the coils in the spring move.

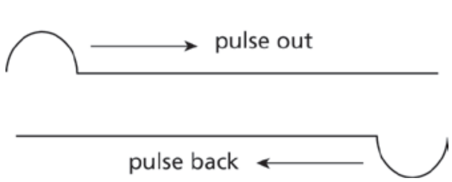
2.d)

The original amplitude was the sideways distance the students whipped the spring to generate the wave. This distance was 20 cm.

2.e)

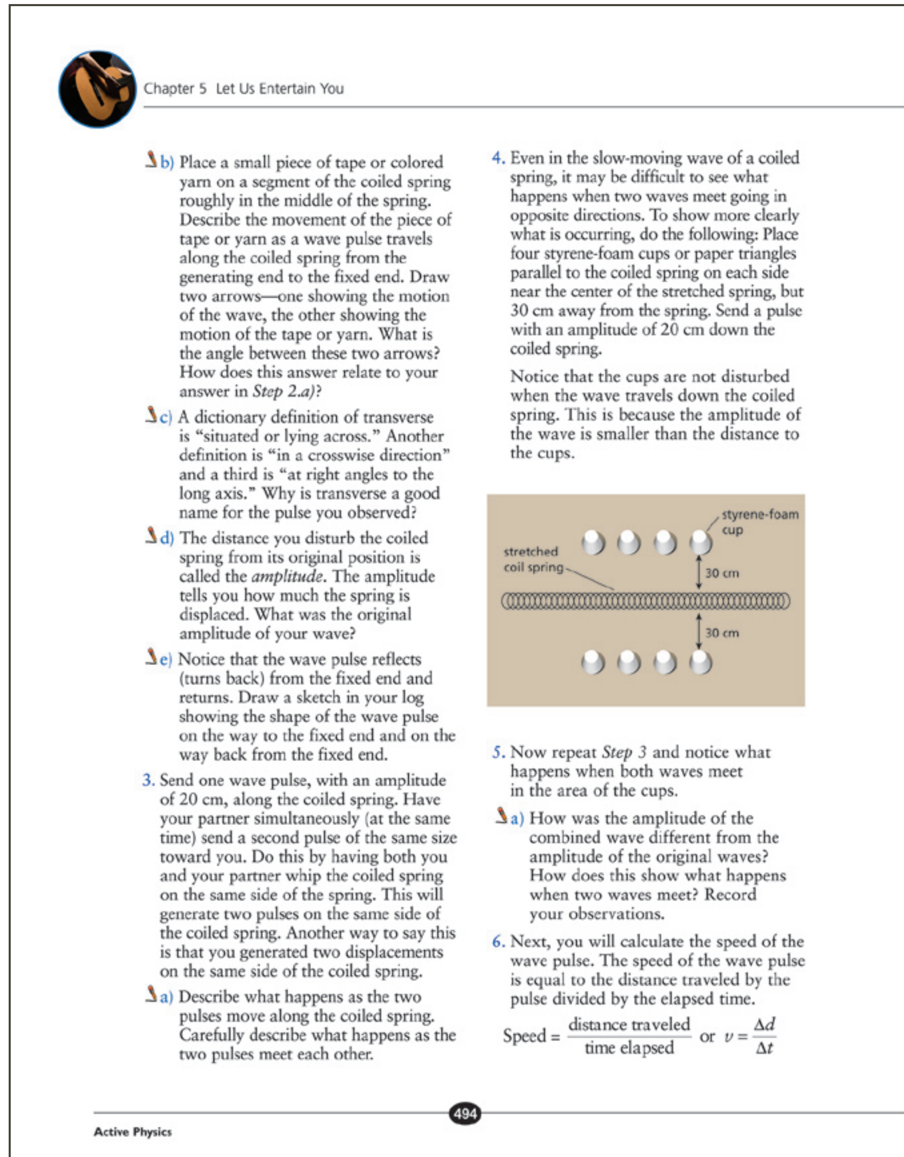
The pulse will change orientation when it reflects from the fixed end of the coiled spring.

That is, if the pulse was to the left as it approached the fixed end, it will be to the right after reflection. The diagram should appear like the one shown below:



3.a)

When the pulses overlap, the deflection of a coiled spring is the sum of the deflections due to the individual pulses.



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b) Place a small piece of tape or colored yarn on a segment of the coiled spring roughly in the middle of the spring. Describe the movement of the piece of tape or yarn as a wave pulse travels along the coiled spring from the generating end to the fixed end. Draw two arrows—one showing the motion of the wave, the other showing the motion of the tape or yarn. What is the angle between these two arrows? How does this answer relate to your answer in *Step 2.a)*?

c) A dictionary definition of transverse is "situated or lying across." Another definition is "in a crosswise direction" and a third is "at right angles to the long axis." Why is transverse a good name for the pulse you observed?

d) The distance you disturb the coiled spring from its original position is called the *amplitude*. The amplitude tells you how much the spring is displaced. What was the original amplitude of your wave?

e) Notice that the wave pulse reflects (turns back) from the fixed end and returns. Draw a sketch in your log showing the shape of the wave pulse on the way to the fixed end and on the way back from the fixed end.

3. Send one wave pulse, with an amplitude of 20 cm, along the coiled spring. Have your partner simultaneously (at the same time) send a second pulse of the same size toward you. Do this by having both you and your partner whip the coiled spring on the same side of the spring. This will generate two pulses on the same side of the coiled spring. Another way to say this is that you generated two displacements on the same side of the coiled spring.

a) Describe what happens as the two pulses move along the coiled spring. Carefully describe what happens as the two pulses meet each other.

4. Even in the slow-moving wave of a coiled spring, it may be difficult to see what happens when two waves meet going in opposite directions. To show more clearly what is occurring, do the following: Place four styrene-foam cups or paper triangles parallel to the coiled spring on each side near the center of the stretched spring, but 30 cm away from the spring. Send a pulse with an amplitude of 20 cm down the coiled spring.

Notice that the cups are not disturbed when the wave travels down the coiled spring. This is because the amplitude of the wave is smaller than the distance to the cups.

5. Now repeat *Step 3* and notice what happens when both waves meet in the area of the cups.

a) How was the amplitude of the combined wave different from the amplitude of the original waves? How does this show what happens when two waves meet? Record your observations.

6. Next, you will calculate the speed of the wave pulse. The speed of the wave pulse is equal to the distance traveled by the pulse divided by the elapsed time.

$$\text{Speed} = \frac{\text{distance traveled}}{\text{time elapsed}} \quad \text{or} \quad v = \frac{\Delta d}{\Delta t}$$

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4.

Students follow up with the investigation.

5.a)

Students should see that the two 20-cm waves pulses on the same side of the spring add together to form a 40-cm pulse where they meet. This pulse will be large enough to hit one or more of the cups, showing the increased amplitude.

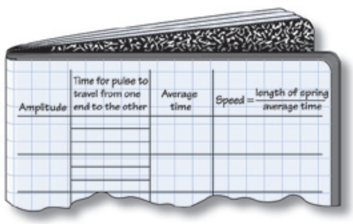
Section 2 Making Waves

You have measured the length between the pieces of tape in *Step 1*. Now, you can measure the elapsed time.

Start a pulse on the spring and measure the time it takes the pulse to travel the length of the spring. Take three measurements and then calculate the average. Keep your amplitude the same for each trial and record its value.

a) Record your data in a table like the one shown.

b) Calculate the average speed of the wave pulse. Record the speed in your data table in your log.



7. Measure the time it takes for wave pulses with two other amplitudes to travel the length of the spring. Make one pulse with an amplitude larger and one smaller than the value used in *Step 6*.

a) Take three measurements in each case and calculate their average.

b) Record the results in the table in your log.

c) Calculate the average pulse speeds and record them in your data table.

d) Does the speed of the pulse depend on the amplitude? You may find that there is some difference when you compare pulse speed with amplitude. You must decide if the difference is large or small. Compare your results with those found by other groups of students.

8. Carefully bring the ends of your coiled spring back together so that the spring does not get tangled, and return it to your teacher.

9. Obtain another, more tightly coiled spring from your teacher. Stretch the coiled spring on the floor so that the coils are about 1 cm apart. Be careful to hold the end of this spring very tightly on the floor so that it does not slip from your grip. This is a safety issue. Send a pulse down the spring, as before, by using a quick back and forth "whip" motion.

a) Does this pulse seem to go faster or slower than the one on the less tightly coiled spring? Record your observations in your log.

b) Calculate the average speed of the wave pulse in the spring. Show your calculations in your log.

c) Record any difference you noticed in the wave speed of the tightly coiled spring compared to the coiled spring you used in the previous steps of the *Investigate*.

10. Now use this tightly coiled spring to make periodic (repetitive) waves. Make certain that the person on the other end of the spring is still holding that end tightly on the floor. Keeping the ends of the spring the same distance apart as before, whip one end of the coiled spring back and forth three times along the floor. The result you observe is called a *periodic wave*.

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Active Physics

6.a)

Students' data for the speed of the coiled spring's waves will depend on the spring's material (metal or plastic) and on how the spring is stretched. Shown below is the sample data for a standing wave. Here, the wavelength is twice the length of the coiled spring.

The length of the spring = 2.4 m and time for the pulse to travel from one end to the other = 0.6 s

6.b)

Sample data for speed is shown below:

Wave speed =
$2.4\ \text{m}/0.6\ \text{s} = 4.0\ \text{m/s}$.

7.a)

Answers will vary. Students will record length and times for the pulses to travel along the spring.

7.b)

Students record the data in their log.

7.c)

Student data should be similar to that in *Steps 6.a)* and *6.b)*.

7.d)

The speed should be independent of the pulse size (amplitude). However, because there is some uncertainty in the measurements of the speeds (you might have students measure the speed two or three times for the same amplitude), students may see some variation in speed with amplitude. You should encourage them to ask whether the differences seen with different amplitudes are significant compared to the differences seen with repeated measurements with the same amplitude.

8.

Students should bring the coiled spring back to you.

9.a)

The pulse on the more tightly coiled spring should appear to travel much faster due to the increased tension between the coils in this spring.

9.b)

Students' calculations should appear similar to that of *Steps 6.a)* and *b)*, but the wave speed calculated should be significantly higher.

9.c)

Students will record that the wave traveled faster in the more tightly coiled spring.

CHAPTER 5

10.a)

The motion will probably be disorganized and appear as a series of pulses.

10.b)

Now the motion is organized. The spring looks like a sine wave.

11.a)

Students will measure the wavelength of the wave produced. Depending upon the frequency of the wave being generated, the number of wavelengths on the spring will vary, and the length of the wave will vary accordingly.

11.b)

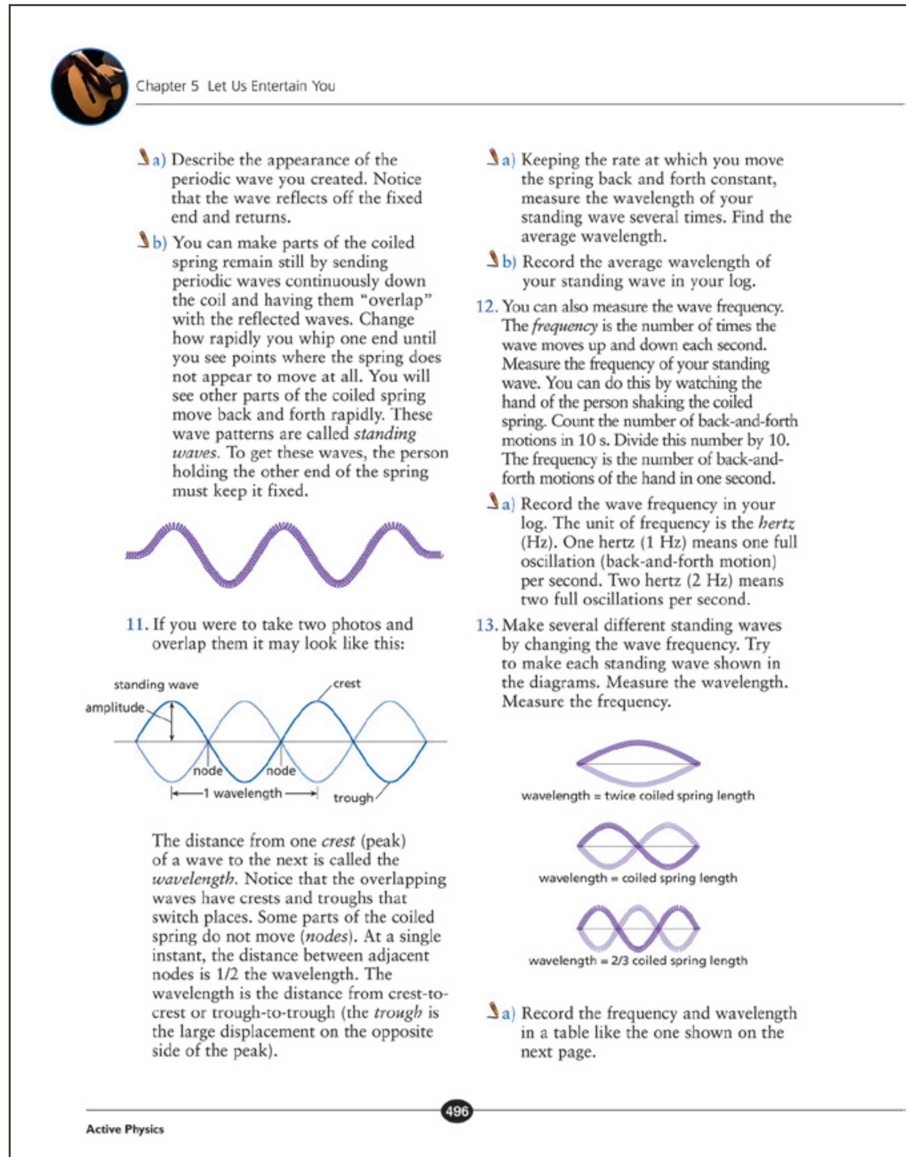
Students should record the average wavelength.

12.a)

Students will count the number of waves in 10 s and then divide the wave number by 10 s to get the frequency in waves per second or hertz. Alternatively, they may use a stopwatch to time how long it takes to generate 10 complete cycles.

13.a)

Students record their data in a table.



Chapter 5 Let Us Entertain You

a) Describe the appearance of the periodic wave you created. Notice that the wave reflects off the fixed end and returns.

b) You can make parts of the coiled spring remain still by sending periodic waves continuously down the coil and having them "overlap" with the reflected waves. Change how rapidly you whip one end until you see points where the spring does not appear to move at all. You will see other parts of the coiled spring move back and forth rapidly. These wave patterns are called *standing waves.* To get these waves, the person holding the other end of the spring must keep it fixed.

11. If you were to take two photos and overlap them it may look like this:

The distance from one *crest* (peak) of a wave to the next is called the *wavelength.* Notice that the overlapping waves have crests and troughs that switch places. Some parts of the coiled spring do not move (*nodes*). At a single instant, the distance between adjacent nodes is 1/2 the wavelength. The wavelength is the distance from crest-to-crest or trough-to-trough (the *trough* is the large displacement on the opposite side of the peak).

a) Keeping the rate at which you move the spring back and forth constant, measure the wavelength of your standing wave several times. Find the average wavelength.

b) Record the average wavelength of your standing wave in your log.

12. You can also measure the wave frequency. The *frequency* is the number of times the wave moves up and down each second. Measure the frequency of your standing wave. You can do this by watching the hand of the person shaking the coiled spring. Count the number of back-and-forth motions in 10 s. Divide this number by 10. The frequency is the number of back-and-forth motions of the hand in one second.

a) Record the wave frequency in your log. The unit of frequency is the *hertz* (Hz). One hertz (1 Hz) means one full oscillation (back-and-forth motion) per second. Two hertz (2 Hz) means two full oscillations per second.

13. Make several different standing waves by changing the wave frequency. Try to make each standing wave shown in the diagrams. Measure the wavelength. Measure the frequency.

a) Record the frequency and wavelength in a table like the one shown on the next page.

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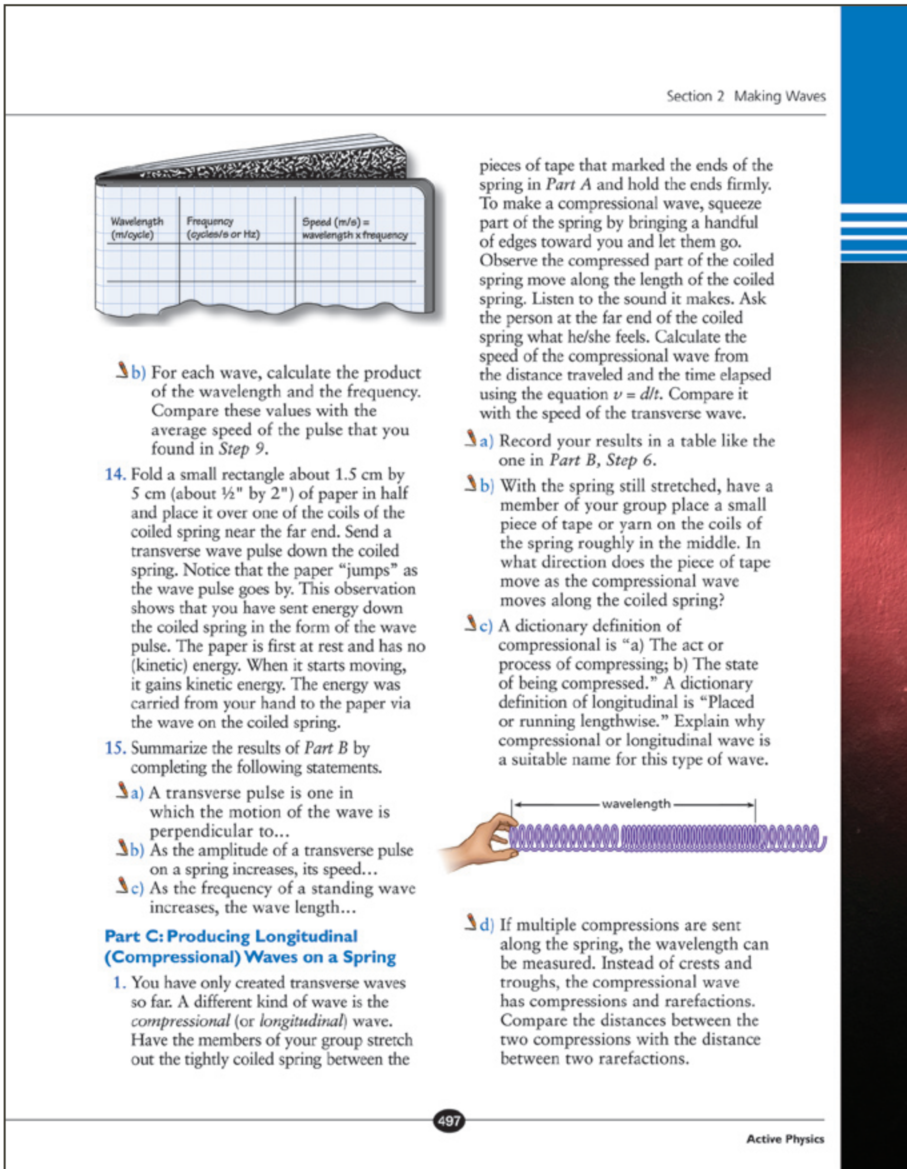

Section 2 Making Waves

Wavelength (m/cycle)	Frequency (cycles/s or Hz)	Speed (m/s) = wavelength x frequency

b) For each wave, calculate the product of the wavelength and the frequency. Compare these values with the average speed of the pulse that you found in *Step 9*.

14. Fold a small rectangle about 1.5 cm by 5 cm (about ½" by 2") of paper in half and place it over one of the coils of the coiled spring near the far end. Send a transverse wave pulse down the coiled spring. Notice that the paper "jumps" as the wave pulse goes by. This observation shows that you have sent energy down the coiled spring in the form of the wave pulse. The paper is first at rest and has no (kinetic) energy. When it starts moving, it gains kinetic energy. The energy was carried from your hand to the paper via the wave on the coiled spring.

15. Summarize the results of *Part B* by completing the following statements.

a) A transverse pulse is one in which the motion of the wave is perpendicular to…

b) As the amplitude of a transverse pulse on a spring increases, its speed…

c) As the frequency of a standing wave increases, the wave length…

Part C: Producing Longitudinal (Compressional) Waves on a Spring

1. You have only created transverse waves so far. A different kind of wave is the *compressional* (or *longitudinal*) wave. Have the members of your group stretch out the tightly coiled spring between the pieces of tape that marked the ends of the spring in *Part A* and hold the ends firmly. To make a compressional wave, squeeze part of the spring by bringing a handful of edges toward you and let them go. Observe the compressed part of the coiled spring move along the length of the coiled spring. Listen to the sound it makes. Ask the person at the far end of the coiled spring what he/she feels. Calculate the speed of the compressional wave from the distance traveled and the time elapsed using the equation $v = d/t$. Compare it with the speed of the transverse wave.

a) Record your results in a table like the one in *Part B, Step 6*.

b) With the spring still stretched, have a member of your group place a small piece of tape or yarn on the coils of the spring roughly in the middle. In what direction does the piece of tape move as the compressional wave moves along the coiled spring?

c) A dictionary definition of compressional is "a) The act or process of compressing; b) The state of being compressed." A dictionary definition of longitudinal is "Placed or running lengthwise." Explain why compressional or longitudinal wave is a suitable name for this type of wave.

d) If multiple compressions are sent along the spring, the wavelength can be measured. Instead of crests and troughs, the compressional wave has compressions and rarefactions. Compare the distances between the two compressions with the distance between two rarefactions.

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13.b)

Students should find that the product of the wave's frequency and wavelength is approximately constant. These values should be very close to the value of the wave speed for the coiled spring found in *Step 9*.

14.

This investigation demonstrates that when a wave travels in a medium, only energy is transmitted. No particles move from one end to the other.

15.

Students summarize their results.

15.a)

A transverse pulse is one in which the motion of the wave is perpendicular to the motion of the particles of the medium.

15.b)

As the amplitude of a transverse pulse on a spring increases, its speed remains the same.

15.c)

As the frequency of a standing wave increases, the wavelength decreases, and the wave velocity remains the same.

Part C: Producing Longitudinal (Compressional) Waves on a Spring

1.a)

Students calculate the wave speed from their recorded length and time for the pulse to travel the length of the coiled spring as was done in Steps *6.a)* and *6.b)* and record their results in a table.

1.b)

Students should observe that the tape moves back and forth in the direction of travel of the wave.

1.c)

Compressional is a good term for the wave since the coils are compressed together before the wave is released, and then the compression travels along the spring. Longitudinal is also a good name, since the wave runs along lengthwise in the direction of the spring.

1.d)

The compressions are analogous to the crests of a wave, while the rarefactions compare to the troughs. Just as the distance from crest to crest is equal to the distance from trough to trough, the distance from compression to compression is equal to the distance from rarefaction to rarefaction.

CHAPTER 5

Part D: Using a Wave Viewer

1.

Students construct a wave viewer. It is best to have the cards prepared beforehand for students.

2.

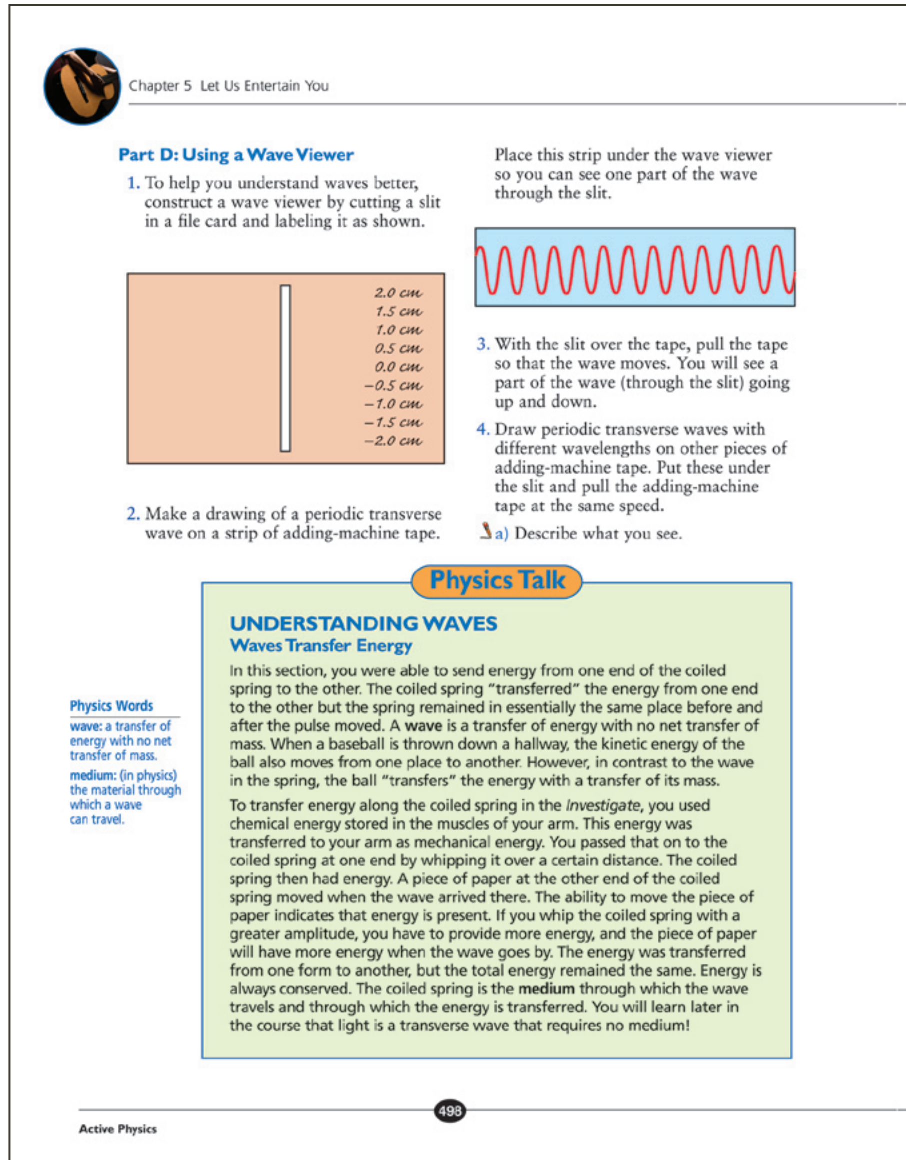
Students make a drawing of a periodic transverse wave.

3.

Students should only pay attention to the part of the wave they can see through the slit.

4.a)

Students should see the up and down motion moving faster for the waves of shorter wavelength (higher frequency), and slower for waves of longer wavelength (lower frequency).


Chapter 5 Let Us Entertain You

Part D: Using a Wave Viewer

1. To help you understand waves better, construct a wave viewer by cutting a slit in a file card and labeling it as shown.

2. Make a drawing of a periodic transverse wave on a strip of adding-machine tape.

Place this strip under the wave viewer so you can see one part of the wave through the slit.

3. With the slit over the tape, pull the tape so that the wave moves. You will see a part of the wave (through the slit) going up and down.

4. Draw periodic transverse waves with different wavelengths on other pieces of adding-machine tape. Put these under the slit and pull the adding-machine tape at the same speed.

a) Describe what you see.

Physics Talk

UNDERSTANDING WAVES

Waves Transfer Energy

In this section, you were able to send energy from one end of the coiled spring to the other. The coiled spring "transferred" the energy from one end to the other but the spring remained in essentially the same place before and after the pulse moved. A **wave** is a transfer of energy with no net transfer of mass. When a baseball is thrown down a hallway, the kinetic energy of the ball also moves from one place to another. However, in contrast to the wave in the spring, the ball "transfers" the energy with a transfer of its mass.

To transfer energy along the coiled spring in the *Investigate*, you used chemical energy stored in the muscles of your arm. This energy was transferred to your arm as mechanical energy. You passed that on to the coiled spring at one end by whipping it over a certain distance. The coiled spring then had energy. A piece of paper at the other end of the coiled spring moved when the wave arrived there. The ability to move the piece of paper indicates that energy is present. If you whip the coiled spring with a greater amplitude, you have to provide more energy, and the piece of paper will have more energy when the wave goes by. The energy was transferred from one form to another, but the total energy remained the same. Energy is always conserved. The coiled spring is the **medium** through which the wave travels and through which the energy is transferred. You will learn later in the course that light is a transverse wave that requires no medium!

Physics Words

wave: a transfer of energy with no net transfer of mass.

medium: (in physics) the material through which a wave can travel.

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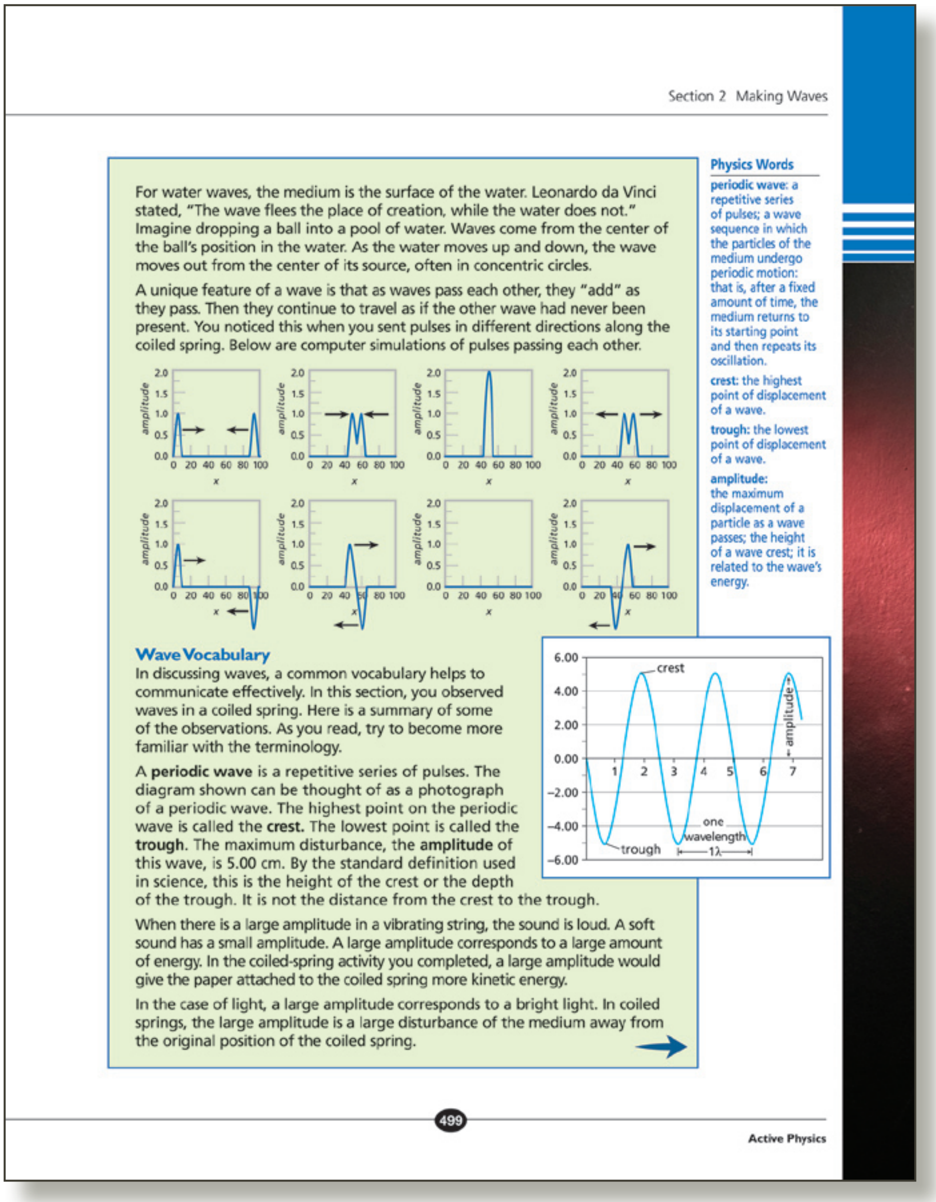
Active Physics

Physics Talk

Students learn about waves and how waves transfer energy. A good way of summarizing information in the *Physics Talk* is to have students write down the main concepts in their *Active Physics* logs. Leonardo da Vinci's quote provides an opportunity to ask students how the statement applies to water waves. Students should focus on the *Physics Words* as they read the *Physics Talk*. Refer to important vocabulary words frequently while discussing waves to build students' familiarity with new terminology. Ask them to sketch the diagram of a wave that shows its wavelength and amplitude. Make sure that students are able to distinguish between a trough and a crest. Steer your discussion from standing and transverse waves to sound waves by asking students to describe sound waves and how sound waves travel when someone speaks.

As students learn how to calculate speed, point out the units for frequency, wavelength, and speed. Ask them to change the values of variables in the speed equation given in *Sample Problem 2* to help them understand how speed varies with a change in frequency or a change in wavelength. Encourage students to come up to the board and solve problems. This will provide an opportunity for a whole-class interaction.



For water waves, the medium is the surface of the water. Leonardo da Vinci stated, "The wave flees the place of creation, while the water does not." Imagine dropping a ball into a pool of water. Waves come from the center of the ball's position in the water. As the water moves up and down, the wave moves out from the center of its source, often in concentric circles.

A unique feature of a wave is that as waves pass each other, they "add" as they pass. Then they continue to travel as if the other wave had never been present. You noticed this when you sent pulses in different directions along the coiled spring. Below are computer simulations of pulses passing each other.

Physics Words

periodic wave: a repetitive series of pulses; a wave sequence in which the particles of the medium undergo periodic motion: that is, after a fixed amount of time, the medium returns to its starting point and then repeats its oscillation.

crest: the highest point of displacement of a wave.

trough: the lowest point of displacement of a wave.

amplitude: the maximum displacement of a particle as a wave passes; the height of a wave crest; it is related to the wave's energy.

Wave Vocabulary

In discussing waves, a common vocabulary helps to communicate effectively. In this section, you observed waves in a coiled spring. Here is a summary of some of the observations. As you read, try to become more familiar with the terminology.

A **periodic wave** is a repetitive series of pulses. The diagram shown can be thought of as a photograph of a periodic wave. The highest point on the periodic wave is called the **crest.** The lowest point is called the **trough**. The maximum disturbance, the **amplitude** of this wave, is 5.00 cm. By the standard definition used in science, this is the height of the crest or the depth of the trough. It is not the distance from the crest to the trough.

When there is a large amplitude in a vibrating string, the sound is loud. A soft sound has a small amplitude. A large amplitude corresponds to a large amount of energy. In the coiled-spring activity you completed, a large amplitude would give the paper attached to the coiled spring more kinetic energy.

In the case of light, a large amplitude corresponds to a bright light. In coiled springs, the large amplitude is a large disturbance of the medium away from the original position of the coiled spring.

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5-2c Blackline Master

CHAPTER 5

Chapter 5 Let Us Entertain You

Physics Words

wavelength: the distance between two identical points in consecutive cycles of a wave.

frequency: the number of waves produced per unit time; the frequency is the reciprocal of the amount of time it takes for a single wavelength to pass a point.

period: the time required to complete one cycle of a wave.

transverse wave: a wave in which the motion of the medium is perpendicular to the motion of the wave.

longitudinal (compressional) wave: a wave in which the motion of the medium is parallel to the direction of the motion of the wave.

standing wave: a wave pattern that remains in a constant position (also called a stationary wave pattern).

The **wavelength** (λ) of a periodic wave is the distance between two consecutive crests or between two consecutive troughs. (The Greek letter λ, *lambda*, is the symbol for wavelength.) In the diagram, the wavelength (λ) is 2.5 cm.

The **frequency** (f) of a periodic wave is the number of vibrations occurring per unit of time. A frequency of 10 waves per second may also be referred to as 10 vibrations per second, 10 cycles per second, 10 s^{-1}, or 10 Hz (hertz). Generally, humans can hear frequencies ranging from very low (20 Hz) to very high (20,000 Hz). You cannot tell the frequency by examining the wave in the diagram. The "snapshot" of the wave is at an instant of time. To find the frequency, you have to know how many crests pass by a point in a given time.

The **period** (T) of a wave is the time it takes to complete one cycle of the wave. It is the time required for a full cycle (crest-trough-crest) to pass a given point.

If three waves pass a point every second, the frequency is three waves per second. The period would be the time for one wave to pass the point, which equals ⅓ s. If 10 waves pass a point every second, the frequency is 10 waves per second. The period would be the time for one wave to pass the point, which equals $\frac{1}{10}$ s. Mathematically, this relationship can be represented as

$$\text{period} = \frac{1}{\text{frequency}} \quad \text{or} \quad T = \frac{1}{f}$$

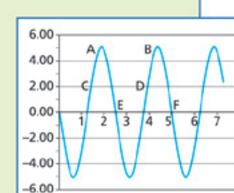
$$\text{frequency} = \frac{1}{\text{period}} \quad \text{or} \quad f = \frac{1}{T}$$

The period and the frequency are inversely related to one another.

Different points in a periodic wave are said to be "in phase" if they have the same displacement and are moving in the same direction. All crests of the wave shown below are "in phase."

In the wave shown, the following pairs of points are in phase:

- A and B
- C and D
- E and F



A **transverse wave** is a wave in which the direction the medium moves is perpendicular to the direction of the wave. A **compressional (longitudinal)** wave is a wave in which the direction the medium moves is parallel to the direction the wave moves.

In the *Investigate*, you first sent a pulse down the coiled spring. You noticed that the pulse reflected off the end and returned back to the beginning. When you sent a periodic wave down the coiled spring, those waves also reflected off the end and returned back along the coiled spring. It is the combination of the wave moving up the coiled spring and the reflected wave moving back down the coiled spring that produces the **standing waves** you observed.

A **node** is a spot on a standing wave where the medium is motionless. At a node, the medium does not move while other places of the standing wave move up and down. The locations of these nodes do not change as the wave medium vibrates in a standing wave pattern. An **antinode** is a spot on a standing wave where the displacement is the largest. The locations of these antinodes do not change as the wave medium vibrates in a standing-wave pattern.

Physics Words

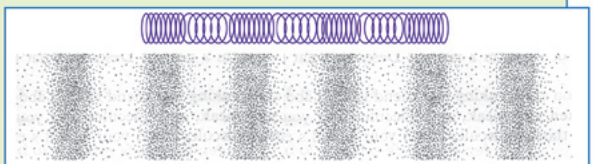
node: a point on a standing wave where the medium is motionless.

antinode: a point on a standing wave where the displacement is the largest.

Sound Is a Compressional Wave

Compressional waves on a coiled spring are similar to sound waves in air. Just as you compressed a part of the coiled spring, when someone speaks, some of the air molecules get compressed. Just as the tightly coiled wave moved along the spring, these compressions move through the air. Just as the spring returned to its original uncompressed state after the wave passed, the air molecules move back and forth, (returning to their original location) after the sound wave has passed. Just as the part of the spring closest to you did not move along the spring, the air molecules do not move across the room. The sound waves move across the room. These sound waves eventually impact the air next to your ear and cause your eardrum to vibrate. These vibrations are then electrically coded and sent to your brain where you recognize the voice and can make sense of the language.

Calculating the Speed of Waves Using Distance and Time



The molecules in the air bunch up in a similar fashion as coils of the spring bunch up in a compressional wave on a coiled spring.

You can find the speed of a wave by measuring the distance the crest moves during a certain time interval.

$$\text{Speed} = \frac{\text{distance traveled}}{\text{time elapsed}}$$

In mathematical language

$$v = \frac{\Delta d}{\Delta t}$$

where v = speed,

Δd = distance traveled, and

Δt = time elapsed.

CHAPTER 5

Checking Up

1.

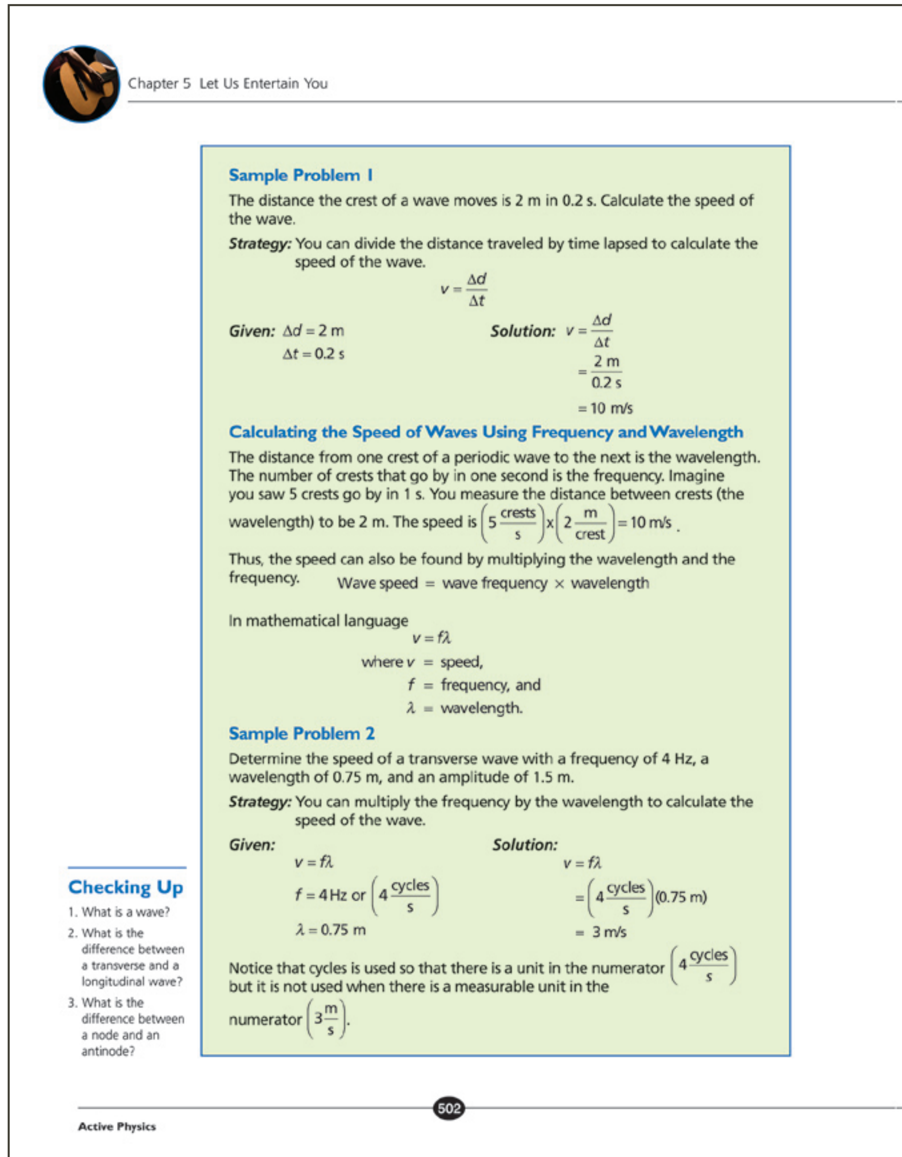
A wave is a transfer of energy through a medium that takes place without the transfer of mass.

2.

In a transverse wave, the direction in which the medium moves is perpendicular to the direction of the wave. In a longitudinal wave, the direction in which the medium moves is parallel to the direction of the wave.

3.

A node is a point on a stationary wave where there is no transfer of energy and the medium is motionless, while an antinode is a point where the displacement of the medium is the largest.



Chapter 5 Let Us Entertain You

Sample Problem 1

The distance the crest of a wave moves is 2 m in 0.2 s. Calculate the speed of the wave.

Strategy: You can divide the distance traveled by time lapsed to calculate the speed of the wave.

$$v = \frac{\Delta d}{\Delta t}$$

Given: $\Delta d = 2\text{ m}$, $\Delta t = 0.2\text{ s}$

Solution:

$$v = \frac{\Delta d}{\Delta t} = \frac{2\text{ m}}{0.2\text{ s}} = 10\text{ m/s}$$

Calculating the Speed of Waves Using Frequency and Wavelength

The distance from one crest of a periodic wave to the next is the wavelength. The number of crests that go by in one second is the frequency. Imagine you saw 5 crests go by in 1 s. You measure the distance between crests (the wavelength) to be 2 m. The speed is $\left(5\frac{\text{crests}}{\text{s}}\right)\times\left(2\frac{\text{m}}{\text{crest}}\right) = 10\text{ m/s}$.

Thus, the speed can also be found by multiplying the wavelength and the frequency.

Wave speed = wave frequency × wavelength

In mathematical language

$$v = f\lambda$$

where v = speed,
f = frequency, and
λ = wavelength.

Sample Problem 2

Determine the speed of a transverse wave with a frequency of 4 Hz, a wavelength of 0.75 m, and an amplitude of 1.5 m.

Strategy: You can multiply the frequency by the wavelength to calculate the speed of the wave.

Given:

$v = f\lambda$

$f = 4\text{ Hz or }\left(4\frac{\text{cycles}}{\text{s}}\right)$

$\lambda = 0.75\text{ m}$

Solution:

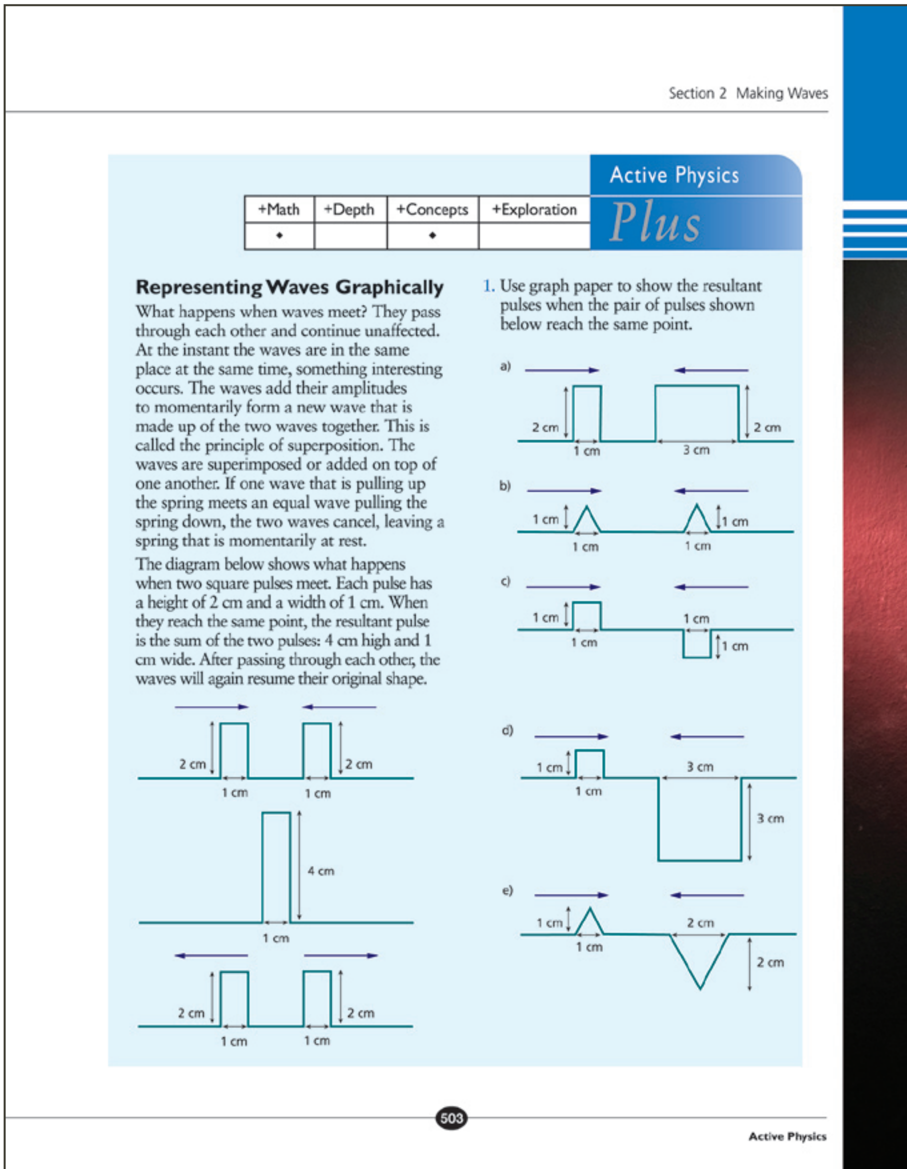
$$v = f\lambda = \left(4\frac{\text{cycles}}{\text{s}}\right)(0.75\text{ m}) = 3\text{ m/s}$$

Notice that cycles is used so that there is a unit in the numerator $\left(4\frac{\text{cycles}}{\text{s}}\right)$ but it is not used when there is a measurable unit in the numerator $\left(3\frac{\text{m}}{\text{s}}\right)$.

Checking Up

1. What is a wave?
2. What is the difference between a transverse and a longitudinal wave?
3. What is the difference between a node and an antinode?

Active Physics 502


Section 2 Making Waves

Active Physics *Plus*

+Math	+Depth	+Concepts	+Exploration
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Representing Waves Graphically

What happens when waves meet? They pass through each other and continue unaffected. At the instant the waves are in the same place at the same time, something interesting occurs. The waves add their amplitudes to momentarily form a new wave that is made up of the two waves together. This is called the principle of superposition. The waves are superimposed or added on top of one another. If one wave that is pulling up the spring meets an equal wave pulling the spring down, the two waves cancel, leaving a spring that is momentarily at rest.

The diagram below shows what happens when two square pulses meet. Each pulse has a height of 2 cm and a width of 1 cm. When they reach the same point, the resultant pulse is the sum of the two pulses: 4 cm high and 1 cm wide. After passing through each other, the waves will again resume their original shape.

1. Use graph paper to show the resultant pulses when the pair of pulses shown below reach the same point.

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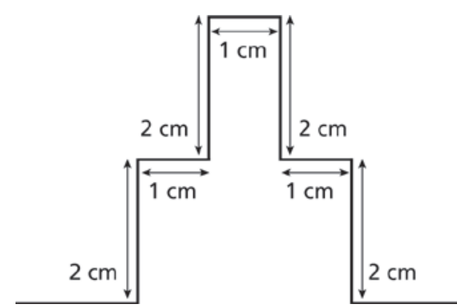
Active Physics

Active Physics Plus

Students draw diagrams to demonstrate what happens to waves of different amplitudes when they meet at the same place and time. The momentary superposition or cancellation of waves is reconstructed below.

a)



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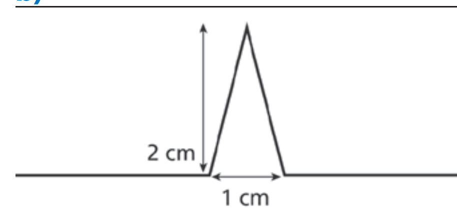

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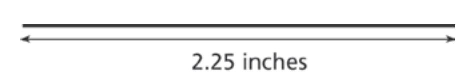

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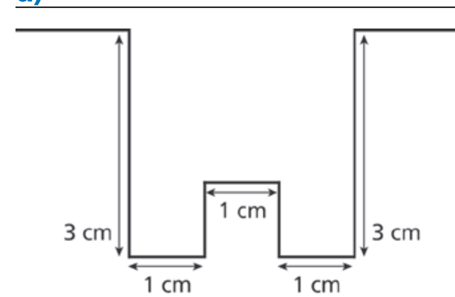

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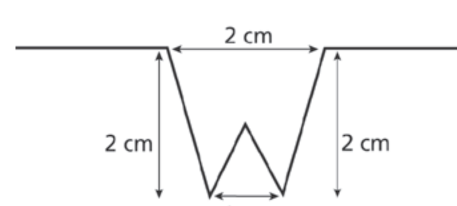
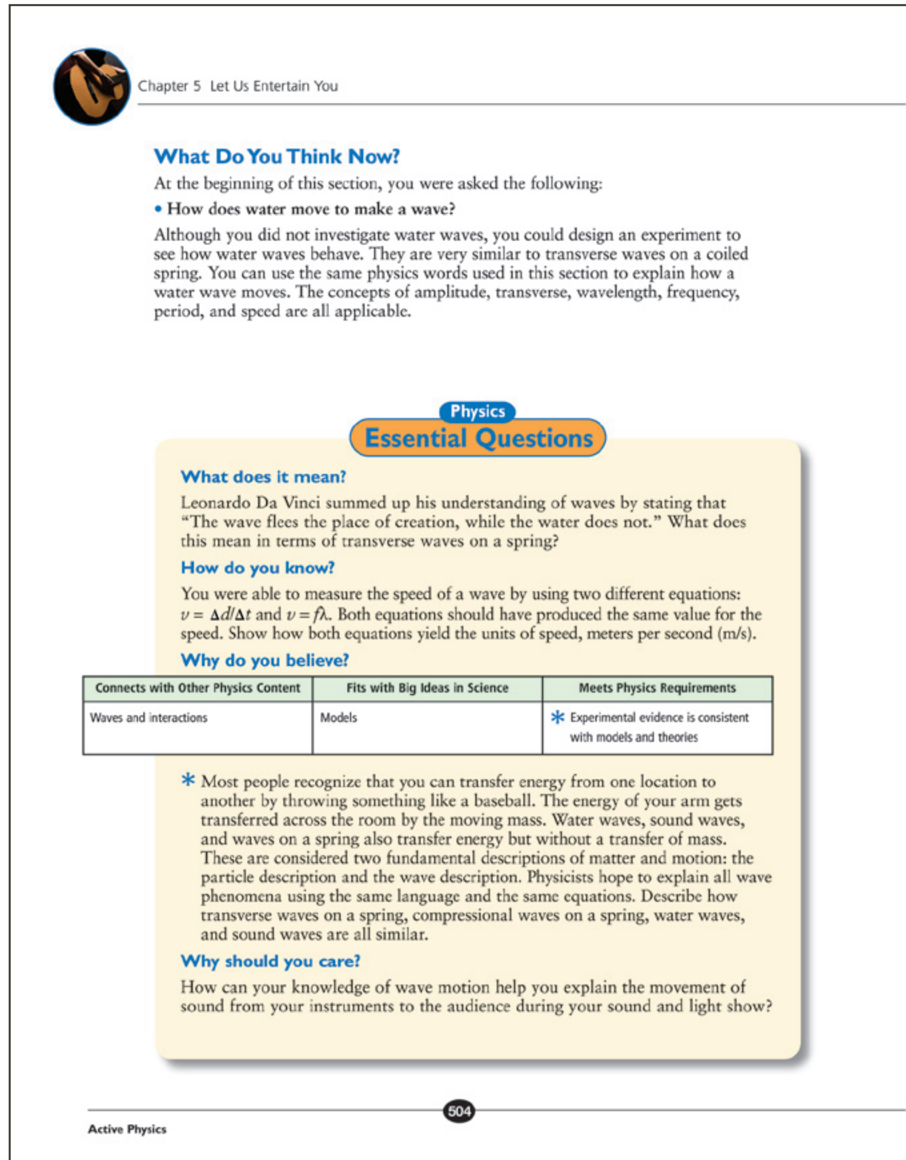


CHAPTER 5

What Do You Think Now?

The question in *What Do You Think Now?* does not only require an answer for a wave, but it also opens up the opportunity for discussing real-life phenomena that are life-changing events, like the tsunami. Share *A Physicist's Response* with your students and discuss how amplitude, wavelength, and frequency of a wave can be explained. Encourage students to revise their description of a wave and incorporate additional features. Have them review their answers in terms of all they have learned about waves so far.



Chapter 5 Let Us Entertain You

What Do You Think Now?

At the beginning of this section, you were asked the following:

- **How does water move to make a wave?**

Although you did not investigate water waves, you could design an experiment to see how water waves behave. They are very similar to transverse waves on a coiled spring. You can use the same physics words used in this section to explain how a water wave moves. The concepts of amplitude, transverse, wavelength, frequency, period, and speed are all applicable.

Physics **Essential Questions**

What does it mean?

Leonardo Da Vinci summed up his understanding of waves by stating that "The wave flees the place of creation, while the water does not." What does this mean in terms of transverse waves on a spring?

How do you know?

You were able to measure the speed of a wave by using two different equations: $v = \Delta d/\Delta t$ and $v = f\lambda$. Both equations should have produced the same value for the speed. Show how both equations yield the units of speed, meters per second (m/s).

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Waves and interactions	Models	* Experimental evidence is consistent with models and theories

* Most people recognize that you can transfer energy from one location to another by throwing something like a baseball. The energy of your arm gets transferred across the room by the moving mass. Water waves, sound waves, and waves on a spring also transfer energy but without a transfer of mass. These are considered two fundamental descriptions of matter and motion: the particle description and the wave description. Physicists hope to explain all wave phenomena using the same language and the same equations. Describe how transverse waves on a spring, compressional waves on a spring, water waves, and sound waves are all similar.

Why should you care?

How can your knowledge of wave motion help you explain the movement of sound from your instruments to the audience during your sound and light show?

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Active Physics

Physics Essential Questions

What does it mean?

In a spring, the wave moves along the spring, but each part of the spring returns to its original location.

How do you know?

Both equations are written as follows:

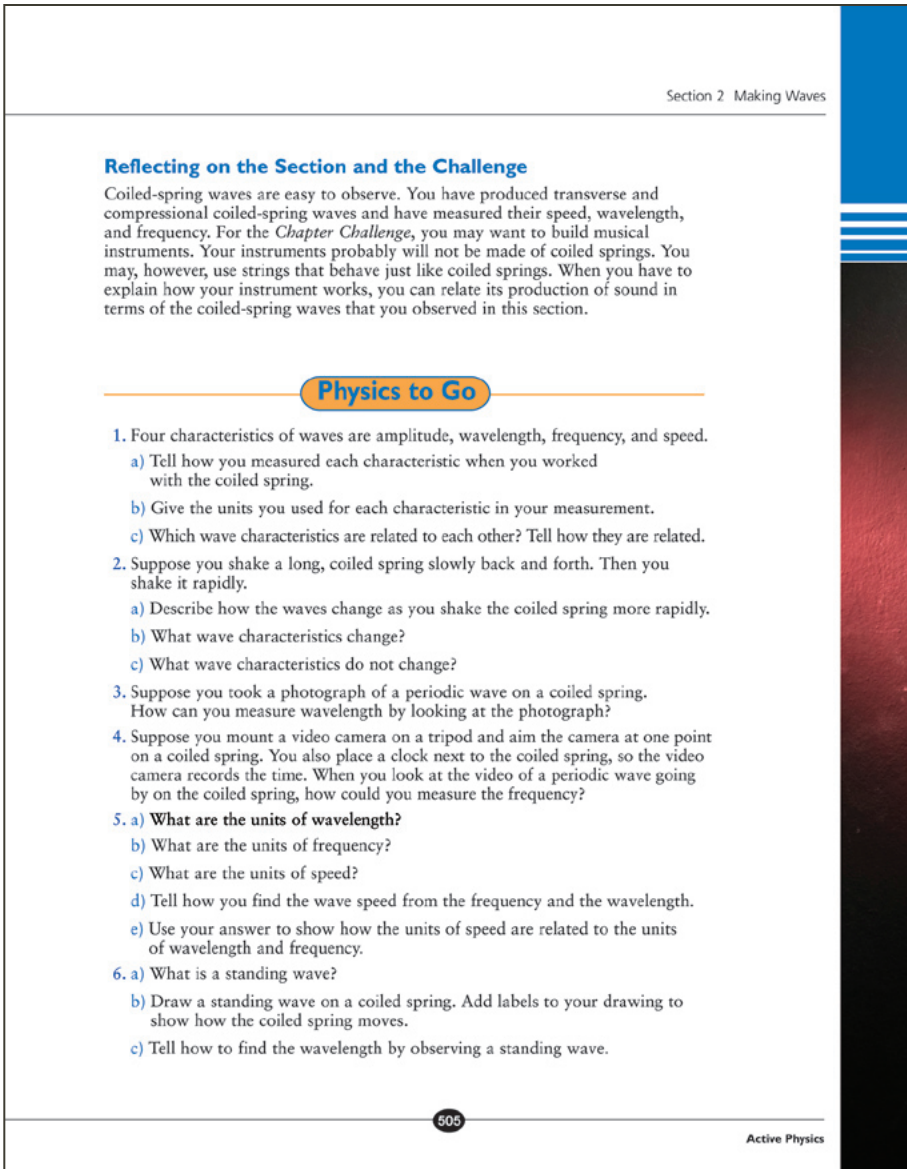
$v = d/t$ = meters/second and
$v = fx$ = (cycles/second)(meters) = meters/second

Why do you believe?

In all of these media, the wave motion is perpendicular to the disturbance. For example, the water moves up and down while the wave moves outward.

Why should you care?

The vibration of the strings produces a sound wave. The sound wave then travels through space as a longitudinal wave.



Reflecting on the Section and the Challenge

Coiled-spring waves are easy to observe. You have produced transverse and compressional coiled-spring waves and have measured their speed, wavelength, and frequency. For the *Chapter Challenge*, you may want to build musical instruments. Your instruments probably will not be made of coiled springs. You may, however, use strings that behave just like coiled springs. When you have to explain how your instrument works, you can relate its production of sound in terms of the coiled-spring waves that you observed in this section.

Physics to Go

1. Four characteristics of waves are amplitude, wavelength, frequency, and speed.
   a) Tell how you measured each characteristic when you worked with the coiled spring.
   b) Give the units you used for each characteristic in your measurement.
   c) Which wave characteristics are related to each other? Tell how they are related.
2. Suppose you shake a long, coiled spring slowly back and forth. Then you shake it rapidly.
   a) Describe how the waves change as you shake the coiled spring more rapidly.
   b) What wave characteristics change?
   c) What wave characteristics do not change?
3. Suppose you took a photograph of a periodic wave on a coiled spring. How can you measure wavelength by looking at the photograph?
4. Suppose you mount a video camera on a tripod and aim the camera at one point on a coiled spring. You also place a clock next to the coiled spring, so the video camera records the time. When you look at the video of a periodic wave going by on the coiled spring, how could you measure the frequency?
5. a) What are the units of wavelength?
   b) What are the units of frequency?
   c) What are the units of speed?
   d) Tell how you find the wave speed from the frequency and the wavelength.
   e) Use your answer to show how the units of speed are related to the units of wavelength and frequency.
6. a) What is a standing wave?
   b) Draw a standing wave on a coiled spring. Add labels to your drawing to show how the coiled spring moves.
   c) Tell how to find the wavelength by observing a standing wave.

Reflecting on the Section and the Challenge

While students reflect on the *Chapter Challenge* and all that they have investigated and read in *Section 2*, point out to them that the instruments they are thinking of building will function well if they apply their understanding of waves to produce the sound effects. For instance, strings producing shorter wavelength sounds will have a higher frequency than those sounds produced by strings vibrating at longer wavelengths. Consider asking them the difference between a compressional wave and a transverse wave, and whether they can explain how sound travels.

CHAPTER 5

Physics to Go

1.a)

For amplitude, students measure the distance of a point on the spring from its rest (equilibrium) position. For wavelength, students make a standing wave, measure the distance between the points of the spring that do not move (the nodes), and find that twice this distance is the wavelength. For frequency, students measure how many times they shook the spring in ten seconds and divide by ten. For speed, students make a pulse, measure distance traveled and time elapsed, and divide distance traveled by the time elapsed.

1.b)

The unit used for amplitude and wavelength is meter; for frequency, 1/s or hertz; for speed, m/s.

1.c)

Speed, frequency and wavelength are related to each other. Speed is the frequency multiplied by the wavelength.

2.a)

Shaking the spring more rapidly produces crests that become closer and closer together. Shaking the spring more rapidly to produce standing waves will result in waves of shorter wavelength.

2.b)

The wavelength and frequency change.

2.c)

The speed does not change.

3.

Use a meter stick to measure the distance between one crest and the next in the image of a periodic wave in the photograph.

4.

You can measure frequency by measuring the time for a point on the spring to go through one complete cycle. You might have to measure for ten cycles and divide the time by ten to get better accuracy.

5.a)

Units of wavelength can be any unit of length, including meters, centimeters, kilometers, feet, and so on.

5.b)

The units of frequency are cycles per second or hertz.

5.c)

The units of speed are m/s, cm/s, or ft/s.

5.d)

speed = wavelength × frequency

5.e)

speed in m/s =

m (unit of wavelength) ×

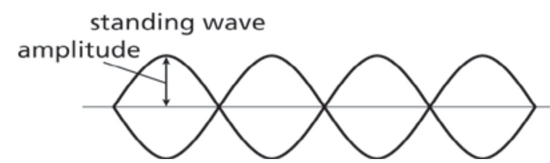
s^{-1}(unit of frequency)

6.a)

A standing wave is a repeating back-and-forth motion that forms a stationary pattern.

6.b)

The drawing should appear like the one below.



6.c)

To find the wavelength, measure the distance from crest-to-crest or from trough-to-trough.

NOTES

NOTES

7.a)

In a compressional wave, the back-and-forth motion is in the direction of the disturbance. In a transverse wave, the back-and-forth motion is perpendicular to the direction of the disturbance.

7.b)

In transverse waves, the spring moves back-and-forth perpendicular to its length. In compressional (longitudinal) waves, the spring moves back-and-forth along its length.

7.c)

The second periodic wave was generated by reflecting the vibration from the fixed end of the spring held in the student's hand, which was not shaking the spring.

8.a)

You shook the spring at a higher frequency.

8.b)

You shook the spring at a lower frequency.

9.a)

For a string with both ends fixed, the number of loops (antinodes) n, the length of the string L, and the wavelength λ are related by the following equation:

$$n\lambda = 2L \quad \text{or} \quad \frac{2L}{n} = \lambda$$

Using $\frac{2L}{n} = \lambda$,

For $n = 1$, $\lambda = 2L = 10.0$ m
For $n = 2$, $\lambda = 2L/2 = 5.0$ m
For $n = 3$, $\lambda = 2L/3 = 3.33$ m
For $n = 4$, $\lambda = 2L/4 = 2.5$ m
For $n = 5$, $\lambda = 2L/5 = 2.0$ m

7. a) Explain the difference between transverse waves and compressional (longitudinal) waves.
   b) Coiled-spring waves can be either transverse or compressional. Describe how the coiled spring moves in each case.
   c) Standing waves require two periodic waves traveling in opposite directions. In the *Investigate*, one student was sending waves down the coiled spring. How was the other wave generated?
8. a) When you made standing waves, how did you shake the coiled spring (change the frequency) to make the wavelength shorter?
   b) When you made standing waves, how did you shake the coiled spring (change the frequency) to make the wavelength longer?
9. A coiled spring is stretched out to 5.0 m in length between you and your partner. By shaking the coiled spring at different frequencies, you are able to produce standing waves with one antinode, two antinodes, three antinodes, four antinodes, and even five antinodes.
   a) What are the wavelengths of each of the wave patterns you have produced?
   b) How are the frequencies of the wave patterns related to each other?
10. A tightrope walker stands in the middle of a high wire that is stretched 10 m between the two platforms at the ends of the wire. The tightrope walker bounces up and down, creating a standing wave with a single antinode and a period of 2.0 s.
    a) What is the wavelength of the wire wave being produced?
    b) What is the frequency of this wave?
    c) What is the speed of the wave?
11. A transverse pulse with an amplitude of 3 cm is sent to the right along a coiled spring. A second transverse pulse with an amplitude of 2 cm is sent to the left along the same coiled spring and on the same side as the first pulse.
    a) What will be the amplitude of the pulse at the moment the centers of each pulse meet?
    b) How would your answer change if the pulses were on opposite sides of the coiled spring?
12. During the coiled-spring investigation, your partner generates a wave pulse that takes 2.64 s to go to the far end of the coiled spring and back to your partner. The coiled spring stretches 4.5 m along the floor. What is the speed of the wave pulse on the coiled spring?

9.b)

Because the speed of the waves stays the same, students should use the equation frequency = speed/wavelength. If the frequency for one loop is f, the speed for $n = 2$ is $2f$, for $n = 3$ is $3f$, and so on.

10.a)

The standing wave has one loop (antinode), so the wavelength $= 2L = 20$ m.

10.b)

The frequency = 1/period =

$0.5\ \text{sec}^{-1} = 0.5$ Hz.

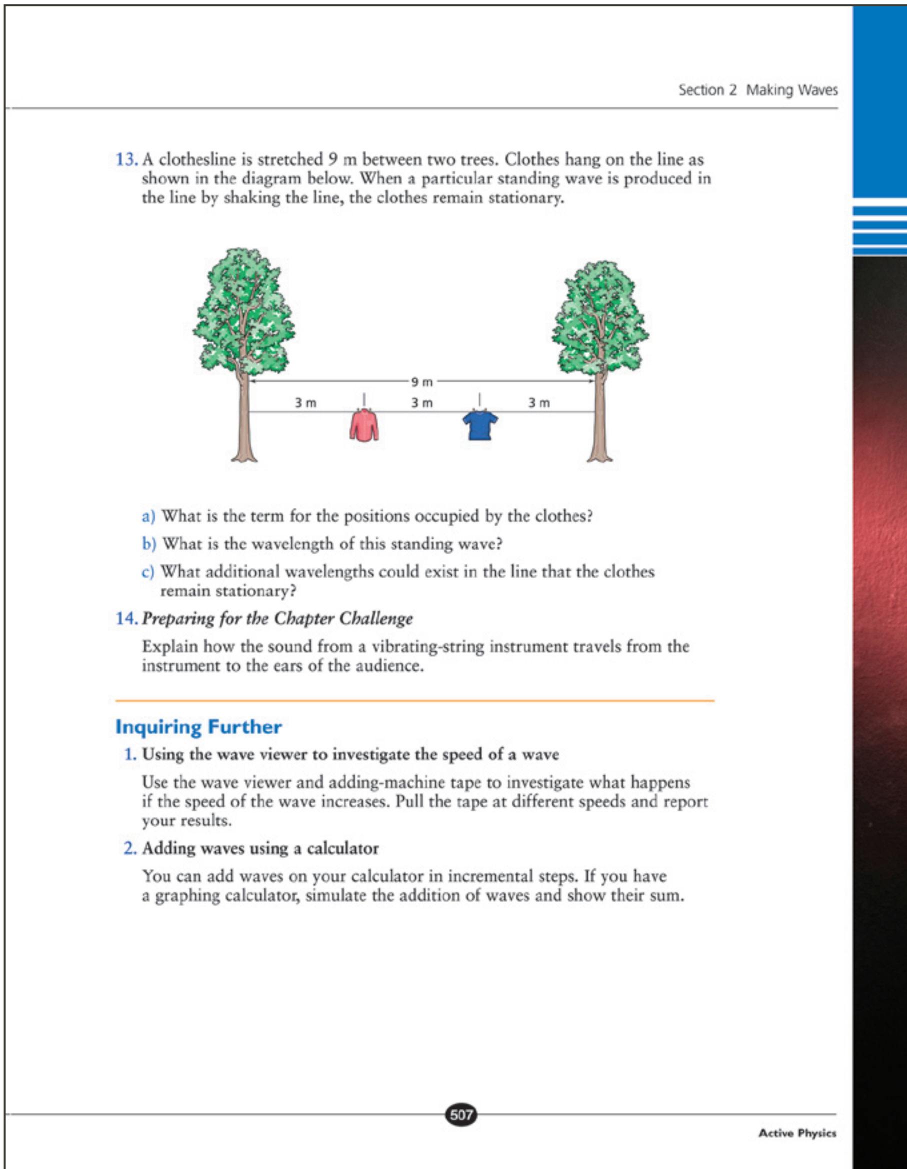
10.c)

The wave speed,

$v = f\lambda = \left(0.5\ \frac{1}{s}\right)(20\ \text{m}) = 10$ m/s.

11.a)

The amplitude will be 5 cm—the pulses add up on the same side.


Section 2 Making Waves

13. A clothesline is stretched 9 m between two trees. Clothes hang on the line as shown in the diagram below. When a particular standing wave is produced in the line by shaking the line, the clothes remain stationary.

a) What is the term for the positions occupied by the clothes?

b) What is the wavelength of this standing wave?

c) What additional wavelengths could exist in the line that the clothes remain stationary?

14. *Preparing for the Chapter Challenge*

Explain how the sound from a vibrating-string instrument travels from the instrument to the ears of the audience.

Inquiring Further

1. Using the wave viewer to investigate the speed of a wave

Use the wave viewer and adding-machine tape to investigate what happens if the speed of the wave increases. Pull the tape at different speeds and report your results.

2. Adding waves using a calculator

You can add waves on your calculator in incremental steps. If you have a graphing calculator, simulate the addition of waves and show their sum.

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11.b)

The amplitude will be 1 cm—the pulses would subtract if they were on opposite sides.

12.

You can solve this problem using the basic kinematics equation:

$v = \Delta d / \Delta t = 9 \text{ m} / 2.64 \text{ s} = 3.4 \text{ m/s}$

Note that the total distance traveled is 9 m, twice the length of the stretched spring.

13.a)

The clothes are located at the nodes.

13.b)

$\lambda = 6$ m.

13.c)

Wavelengths in which nodes will occur at the same locations will allow the clothes to remain stationary. These would include (but not limited to):
$\lambda = 0.75$ m, 1 m, 2 m and 3 m.

14.

Preparing for the Chapter Challenge

The sound waves from the vibrating string instrument vibrate the air molecules back and forth and eventually the vibrations then travel close to the air molecules next to the ear and the eardrums. The eardrums vibrate, sending electrically coded messages to the brain, where the brain recognizes the voice and makes sense of the sound waves received.

Inquiring Further

1. Using the wave viewer to investigate the speed of a wave

Students will see that as the tape is pulled past the viewer faster, the point visible in the viewer moves up and down faster. This corresponds to a greater wave frequency, since the wavelength on the tape has not changed.

2. Adding waves using a calculator

Waves on the graphing calculator can be simulated by typing in sine and cosine functions to shown addition and subtraction of waves. For example, type in $Y_1 = 4 \sin(x - \pi/2)$ and $Y_2 = 4 \sin(x + \pi/2)$ in the Y = register to show the two waves with opposite amplitudes. To see the result of the two waves canceling, type in $Y_3 = Y_1 + Y_2$, where Y_3 will show a straight line due to the cancellation.

CHAPTER 5

SECTION 2 QUIZ

5-2d **Blackline Master**

1. Two students, 8 m apart, are holding a stretched, coiled spring between them. One student sends a pulse down the string, and they observe it takes 4 s for the pulse to go from one end of the spring to the other, and then back to its starting point. What is the speed of the pulse on the spring?

   a) 0.5 m/s. b) 2 m/s.

   c) 4 m/s. d) 8 m/s.

2. If the students in Question 1 doubled the size of the pulse that traveled down the spring, the speed of the wave on the spring would be

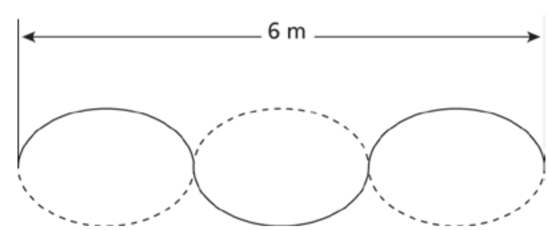
   a) 1 m/s. b) 4 m/s.

   c) 8 m/s. d) 16 m/s.

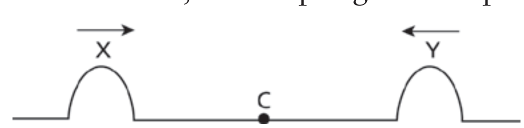
3. Two students, 6 m apart, are holding a stretched, coiled spring between them and the standing wave shown in the diagram below. The wavelength of the standing wave produced is

   a) 2 m. b) 4 m.

   c) 6 m. d) 12 m.

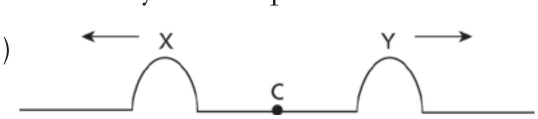


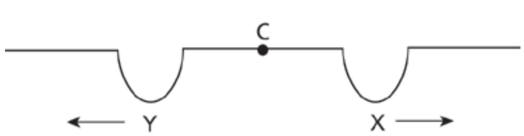
4. Two pulses traveling down a stretched, coiled spring meet at point C.

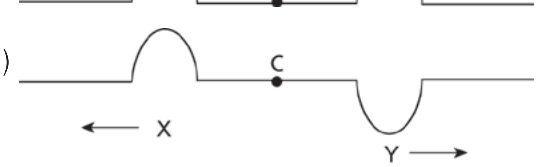


   Which diagram below correctly shows the pulses after they meet at point C?

   a)


   b)


   c)


   d)


5. Two students using a coiled, stretched spring produce 5 waves each second. What is the period of these waves?

   a) 0.5 s. b) 5 s.

   c) 0.05 s. d) 0.2

SECTION 2 QUIZ ANSWERS

1. c) The speed of the wave can be found using the equation $v = d/t$. The distance traveled is twice the spring length. Because the pulse goes to one end and back, the speed is 16 m/4 s = 4 m/s. The other answers would be due to using the formula incorrectly and using the distance traveled as 8 m rather than 16 m.

2. b) Students should have observed from the *Investigate* that the speed of the wave pulse is approximately independent of its size.

3. b) The wavelength of the standing wave would consist of the distance from crest-to-crest, which would be 2/3 of the total distance, or 4 m. Students would choose *c*) if they thought that the wavelength was equal to the distance between the two ends, while those who thought the wavelength would be only one loop would choose *a*).

4. a) The two pulses meet and pass through each other, and then continue on their path. Choice *b*) shows the pulses meeting and reflecting off each other, while *c*) shows them inverting and after passing through, neither of which occur.

5. d) The wave period is 1/frequency and the frequency is the number of waves per second, or 5 hertz. The period then is 1/(5 Hz) = 0.2 s. Choice *a*) is a common student mistake thinking that 1/5 equals 0.5. The other answers are distracters with no logical basis.

CHAPTER 5