Throughout the guide, teaching tips are in red.

Activity Description & Estimated Class Time

These activities are designed for four 50-minute class periods. Part 1, *Waves and Energy*, explores examples of energy transmission through waves. Students discuss how energy moves from place to place in these examples, then simulate transverse and longitudinal waves with a spring. Afterward, they begin exploring concepts of frequency and amplitude using the spring. In part 2, *Transverse Waves*, students analyze properties of transverse waves during two 50-minute periods. Students manipulate a computer wave simulation to develop and demonstrate understanding of cycle, period, frequency, wavelength, and amplitude. As a math extension, students find a proportional relationship between a wave's period and its frequency. In part 3, *Types of Waves*, students connect what they have learned to sound, light, and earthquakes during one 50-minute period.

Objectives

Students will demonstrate knowledge and understanding of the following ideas and content:

- waves transmit energy
- frequency of waves
- wavelength
- amplitude of waves

Students demonstrate this knowledge and understanding by responding to challenges to change frequency, wavelength, and amplitude in a computer simulation, and to change these factors in a wave that they make with a spring. They also apply these ideas to examples in earthquakes, light, and sound.

Correlations to NC Science Standards

6.P.1.1 *Compare the properties of waves to the wavelike property of energy in earthquakes, light and sound.*

Correlations to Selected Common Core State Standards for Mathematics

Ratios and Proportional Relationships 6.RP: Understand ratio concepts and use ratio reasoning to solve problems.

3. Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations.

    b. Solve unit rate problems including those involving unit pricing and constant speed. For example, if it took 7 hours to mow 4 lawns, then at that rate, how many lawns could be mowed in 35 hours? At what rate were lawns being mowed?

    d. Use ratio reasoning to convert measurement units; manipulate and transform units appropriately when multiplying or dividing quantities.

Brief Science Background

Many forms of energy travel as waves through space and through materials. Forms of energy that travel as waves include sound, light, radiant heat, radio, and earthquakes. Generally, some form of energy starts a wave going, and when the wave reaches its destination, it adds some energy to the place it arrives. Sometimes, a wave can start out as one form of energy and become a different form of energy when it arrives. For example, a light wave travels from its source to a solar collector, where it becomes electricity.

As a wave travels, it cycles between a high (peak) and low (trough) value. The distance from peaks and troughs to the zero line is called amplitude. The wave completes a cycle in a specific amount of time, called the period, and the cycles occur at a set rate. The rate of cycling is called frequency. When waves move through a medium at a constant speed and cycle at a constant rate, the distance between peaks (or troughs) is constant. That distance is called wavelength.

Waves come in several forms. Some move side-to-side or up and down as they travel. For example, some earthquake waves travel horizontally but the earth they travel through moves up and down. These are called transverse waves. Other waves alternately compress and spread out the material they travel through. For example, as a sound wave travels through air, it alternately compresses the air in one place and spreads it out in another. These are called longitudinal waves. Still other waves, such as water waves, combine different kinds of motion, causing the earth they move through to shift in a variety of patterns.

Part 1 — Waves and Energy –50 minutes

Materials

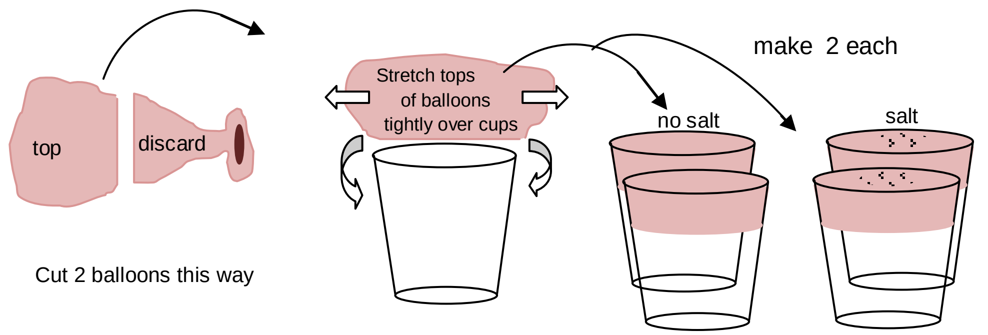
Materials for the whole class or the teacher

- four tall 9-oz cups
- four balloons to stretch over the cups
- five restaurant salt packets
- two photovoltaic cell-motor-light setups
- one plain white sheet of copier paper, cut in half across its width (supplied by teacher)
- two 5 x 8 inch plastic trays
- water (supplied by teacher)
- two ping-pong balls
- two 1-oz cup lids
- two copies of BLM 2 *Directions for Wave Stations* in Black Line Masters
- copies of *Student Exploration Sheets*, BLM 3, 1 full sheet per student
- spring toys, 1 per pair of students
- science notebook for each student (to be supplied by the teacher)
- two clamp lights with 75-watt bulbs and extension cords

Preparation

Set up six stations as follows:

1. Two stations with cups and balloons Stretch balloon tops over four tall 9-oz cups, as shown below. Open one salt packet and put a pinch of salt on top of the balloon on one cup, then do the same with another cup. Leave the other two cups without salt. Place a pair of cups, one with salt and one without, at each of the two stations. Leave a copy of balloon cup directions from BLM 1 at both stations.



2. Two stations with water in trays - Put about 3/4 inch of water in two 5 x 8 plastic trays. Set up two stations with a tray, a cup lid, and a ping-pong ball at each. Leave a copy of water tray directions from BLM 1 at both stations.

3. Two stations with a light, solar cell, and motor - Be sure the motor runs when the light is on. Leave the light off after you check. Leave a sheet of paper and a copy of clamp light and solar cell directions from BLM 1 at both stations.

Procedure

Stations

1. Divide the class into 6 groups of roughly equal size. Leave one copy of BLM 2 Student Worksheets for each student who will visit each station.

2. Explain that there are six stations around the room, but only three different types of station. Each group will go to a station, follow the directions there, record what they find out on their worksheets, and move to a station that is different from the one they just visited. They are to go to all 3 different types of station. Tell the class that at each station, you will allow 1 minute to do the activity, call time, then 4 minutes to write, and then call time to move to the next station.

3. Ask each team to go to a station.

4. *Demonstrate only if necessary*. Be ready to:

- Hold the cup with no salt about 8-10 inches away from the cup with the salt grains on it. Then pinch the balloon on the cup you are holding, pull it back, and release it with a snap such that the salt on the other cup moves.
- Put a cup lid in one end of the water tray, and drop the ping-pong ball in the water at the opposite end.
- Switch on the light over a solar cell and motor; then switch it back off.

Part 1 cont.

5. After all students have filled out their record sheets, ask them to return to their seats.

6. Hold a whole-class discussion. Ask students to describe what they saw, including a cause and an effect. *For example, snapping a balloon on one cup made salt grains move on the other cup; light made the motor turn; the ball dropping in water made the plastic lid move.*

7. Continue the discussion by reminding the class that any change or movement requires energy. Starting with the ping-pong ball and water tray, ask students to describe what changed or moved and what kind of energy caused it. Ask the following questions to get students' ideas. Don't explain anything until you get all responses. Ask:

   - What was the source of the energy?
   - How did the energy travel from place to place?
   - What medium did the energy go through as it traveled?

Answer Key

Rather than go over these answers with students, try to facilitate the discussion to tie their responses to these ideas.

Water tray: a student put energy into the ping-pong ball by lifting it up against gravity. That energy became kinetic energy when the ball fell. The kinetic energy moved the water where the ball landed. That movement traveled as a wave across the tray. When the wave reached the other end, it moved the cup lid. The wave moved through water.

Balloon cups: stretching the balloon on the plain cup put mechanical energy into the balloon. When the balloon was released with a snap, the mechanical energy vibrated the air surrounding the cup and became sound energy. The sound traveled to the other cup as a wave that traveled through the air and hit the balloon on the other cup. That balloon responded to the sound wave by vibrating and moving the salt.

Light, solar cell, and motor: electrical energy came into the light bulb through wires from generators at a power station. The light bulb gave off light energy that traveled as a wave. When the light wave struck the solar cell, it produced enough electricity to turn the motor. The energy traveled through the air.

Wrap-up

Summarize the main ideas as follows:

- Energy caused things to move.
- Some of the energy in these examples moved as waves. **In some cases, students have to take your word for this. For example, with the light/solar cell, their experience does not support this claim. They saw energy but not waves.**
- Waves can move through different substances, such as air and water.

Part 1 cont.

Wave Simulations Using a Spring

Use tabletops if they are five feet long or more. If these are not available, this activity can be done on an uncarpeted floor. Ask students to work in pairs and give a spring toy to each pair.

1. In each pair, have one of the students hold one end of the spring and the other student hold the opposite end. Then ask them to work together to stretch the spring until it is 5-8 feet long. Next, challenge them to find different ways to send energy from one end of the spring to the other without lifting either end from the surface. They can move the ends of the spring in any way except lifting it from the surface.

   Notebook Prompt: Describe the ways you sent energy through the spring. Use a labeled drawing that fills a page. Give evidence to support your claim that energy traveled from one end of the spring to the other.

   Discuss ways that students described energy moving along the spring.

2. Still working in pairs, ask students to make an S-like wave and describe two things about it:

   - the motion of their hand (including the direction) in making the wave;
   - the motion of the wave moving on the spring (including the direction).

   Tell students that this is called a <u>transverse wave</u>. It is the way water waves and light move.

3. Ask students to make the other kind of wave and to describe the same two things:

   - the motion of their hand (including the direction) in making the wave;
   - the motion of the wave moving on the spring (including the direction).

   Tell students that this is called a <u>longitudinal wave</u>. It is the way sound waves travel from the source of a sound to a person's ears.

   Notebook Prompt: Define both types of wave in your own words.

Part 2 — Transverse Waves – two 50-minute class periods

Materials

Materials for the whole class or the teacher

- access to computers, 1 per pair of students
- Smartboard™ or computer projector
- one copy each for projection: BLM 3 Challenges (2 pages); BLM 4 Things You Can Do With the Wave Simulator; BLM 5 Wave Simulations; and BLM 6 Wave Timer.
- Wave Components descriptions (BLM 8), either one copy for projection or as one copy per pair of students
- *Transverse Waves Exploration* student worksheets (BLM 7a,7b); one set per student
- science notebook for each student (to be supplied by the teacher)

Part 2 cont.

Materials for groups of 2 students

- a computer connected to the internet
- Wave Components descriptions, if this will not be projected for the whole class to see (see Materials for the whole class, above)
- science notebook for each student (to be supplied by the teacher)

Preparation

1) Schedule access to the computer lab.

2) Post the web site http://ciblearning.org/lesson-materials. Ask students to click on "Grade 6 Materials," then "Wave On a String Animation." Enter the user name cibl6 and password learn12* to allow students to use the wave simulation.

Procedure

With all students in pairs at computer terminals, ask them to go to the web site you posted. Have students enter the login and password.

1) Project BLM 3 Challenge 1. Ask everyone to try out features of the simulation. Challenge them to find and list 13 things that they can change or do with the simulation. Let them know that everyone will share what they find out after 5 minutes. When 5 minutes have elapsed, list the things students tell you they discovered. Afterwards, show the complete list found in BLM 4:

- change the frequency setting
- change the amplitude setting
- move the vertical ruler
- move the horizontal ruler
- move the reference line
- pause (stop the moving wave)
- play (make the wave move)
- step along the path the wave makes
- move the timer
- start and stop the timer
- step-time wave motion
- reset the wave motion
- reset the timer

Allow a few minutes for students to learn how to do things on the list that they did not discover themselves. Let students who figured out things teach those who did not. Do not be concerned if students do not figure out how to step-time wave motion. They will get directions for this later on.

2) Ask students to manipulate the simulator to make a wave that looks like a wave they made with the spring. Ask which type it is **transverse**. Ask the class

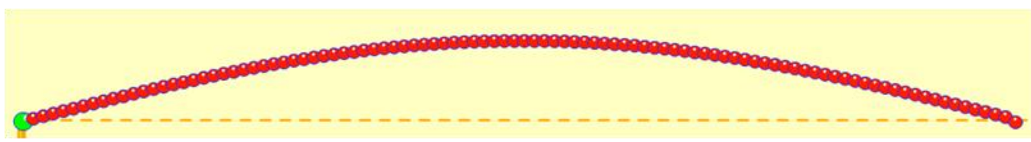
Part 2 cont.

to share things they notice about the computer-generated wave. **Students might notice:**

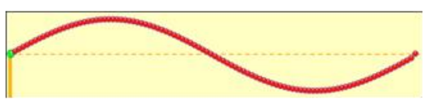
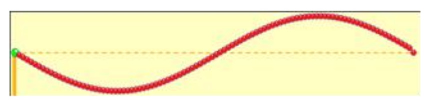
- **it seems to travel from left to right**
- **it goes up and down with a dotted line in the middle**
- **it can go faster or slower**
- **it can be taller or shorter**
- **it makes a pattern in which the wave shape repeats**

3) Project BLM 3 Challenge 2. Ask students to use their simulators to make a wave in which both ends touch the dotted yellow line and no ball is completely below the line. The amplitude setting must be between 20-100. Remind them to use the pause and step functions to put both ends of the wave on the line. Do not otherwise direct them. Ask them to pause the wave once they have it. Circulate to check. To show them what it should look like, project Figure 1 from BLM 5:

Ask students to call out or report first the amplitude and then the frequency reading **look for frequency settings around 5** that accomplish this. Waves should look like the diagram above. Ask students if they notice any pattern in the readings **frequency settings are all similar but amplitude settings can be anything above 20**.



4) Project BLM 3 Challenge 3. Ask students to set the amplitude between 20 and 100 and then make the waves shown:

 and 

Students will need to use the pause and step functions to put both ends of the wave on the yellow dotted line. Ask students to call out or report their amplitude and frequency readings **look for frequency settings around 10**. Ask students to find the shape of the wave from Challenge 2 (step 3 above) within the new wave they just generated in this step (Challenge 3). **The shape from Challenge 2 is the first half of the Challenge 3 wave shown in the left-hand figure above, and it is also the second half of the Challenge 3 wave shown in the right-hand figure above**. Ask: "What is the relationship between the frequency setting of the first (Challenge 2) wave and this new (Challenge 3) wave? **The new wave has a frequency setting that is twice that of the old wave.**

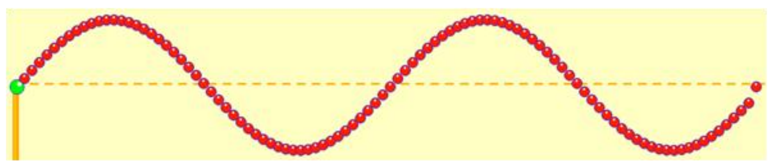
5) Ask students to describe what they notice about this wave. **They might say some of the following:**

- **It has one dip and one high spot.**
- **It touches the dotted line in three places.**
- **The bottom is the same as the top, only upside down and moved to the right.**

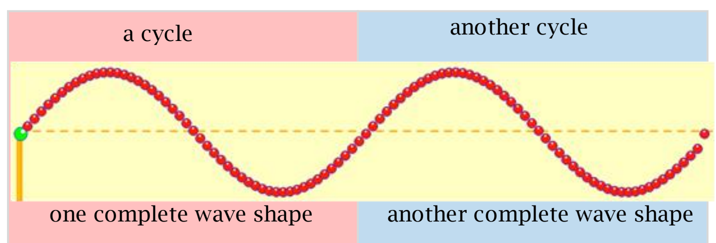
Part 2 cont.

6) Introduce the terms *crest* and *trough*. Tell students that the crest is the high point of a wave. A trough is a low point of a wave. Point these out on the screen.

7) Ask the class for ideas about how the waves generated by the computer change as the frequency setting is increased but the amplitude is kept the same. (They've just seen that increasing the frequency caused more wave parts to be shown on the screen.) Project BLM 3 Challenge 4 and ask students to draw their predictions. Then let them change the frequency to 20, run and pause. The wave should look like BLM 5 Figure 2:



8) Ask students what they notice about this wave. Accept all responses. If students do not notice that the wave form repeats twice, point it out. You can highlight half of this wave as in Figure 3:



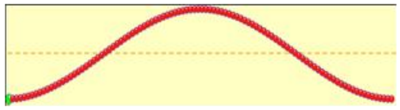
9) Introduce the term *cycle*. A wave cycle is one complete wave shape. There are two complete cycles in figure 3. Ask students to respond to the notebook prompt below and allow them to use the wave simulator to check and revise definitions as needed. Point out that this example of a cycle starts on the dotted yellow line, but a cycle can start anywhere on a wave.

Notebook Prompt: Without using the words "complete wave shape," write your own definition of a wave cycle so that someone else could identify a cycle when they see one.

10) Project BLM 5 Figure 1 again. Ask students what part, or fraction, of a cycle this figure represents **1/2 cycle**. Also project Figure 4. Ask students if these waves represent one full cycle, and why they do or do not. **Both of them do represent full cycles because they each end at the same place where they began, in relation to the yellow-dotted center line, and they also form only one wave shape.**

Part 2 cont.

Figure 4:



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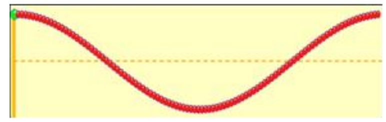
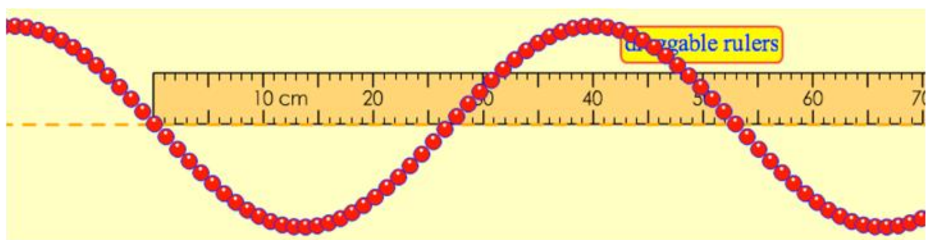


11) As a check, ask students to set their frequency controls to 30, 40, and 50, and at each setting ask them to report how many crests and how many troughs are showing **3, 4, and 5 crests and troughs, respectively**. Then ask them how many cycles are showing at each frequency setting **3, 4, and 5 cycles**.

12) Project BLM 3 Challenge 5. Ask students for their ideas about how they could measure the length of one whole cycle. In particular, ask them where they think the measurement should start and end. They might suggest starting from the dotted reference line, or measuring from crest to crest as shown below, but other ways also work. After individual students or pairs of students have chosen a way to measure one cycle and recorded their measurements, ask them to measure again using a different starting point. Ask if they got the same result. **The two measurements should be identical.**



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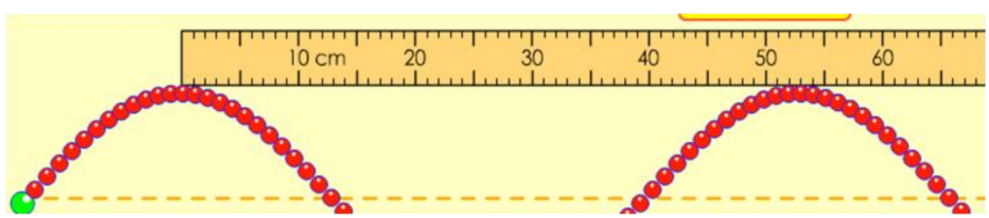


For a frequency setting of 20, look for measurements near 53 cm.

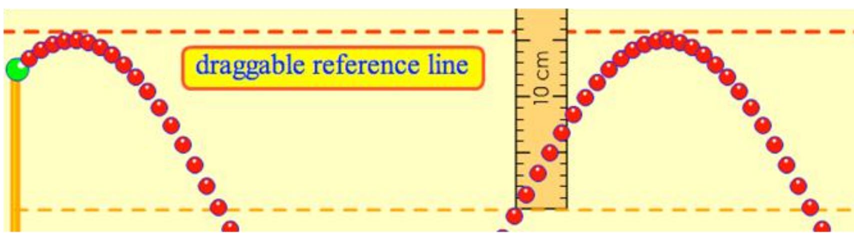
Part 2 cont.

13) Introduce the term wavelength: the length of a wave's complete shape, for example:

- from crest to adjacent crest or trough to adjacent trough
- from where it crosses the yellow-dotted center line heading downward, to where it crosses the center line going downward again

Interesting wave fact: the waves produced by microwave ovens are about one foot long.

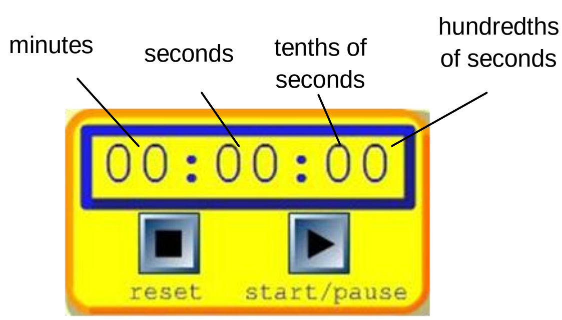
14) Project BLM 3 Challenge 6. Ask students to set the amplitude to 80, run a wave and pause it. Then ask them to use the draggable vertical ruler to measure the height in centimeters from the dotted center line to a crest. Discuss reasons for using these measurement points. Point out the draggable reference line as a tool. There are many ways to do this. Most students can find their own way or learn from others. A student might measure the height of crests by setting the reference line to touch the tops of the highest balls and setting the vertical ruler to measure the distance between the dotted center line and the reference line, as pictured below. Look for measurements just under 16 cm.



15) Introduce the term *amplitude*. Explain that amplitude is the distance from the center point of a wave to the highest *or* lowest point of a wave. It is NOT measured from lowest to highest points.

16) Point out that so far, the class has measured lengths and heights of waves. It is also important to know how fast a transverse wave moves up and down (or side to side). Ask students what additional tool or tools they would need to measure how quickly a wave rises and falls. **You need a timer to measure how fast something happens.**

17) Project BLM 3 Challenge 7. Ask students to time one cycle of a wave. Use BLM 6 to explain how to use the timer in the wave simulator.



Part 2 cont.

18) Give these instructions:

- set the frequency to 30
- use the step function and any location you choose to set the wave in a position where you can know when you have finished a whole cycle
- when you are ready to measure, reset the timer to 0
- use the step button to step through exactly one cycle of a wave
- record the time it took for a whole cycle in your notebook

Look for times around 0.91 seconds.

19) Introduce the term *period*. Students have just now measured the period of a wave: the time it takes for a wave's shape to repeat, for example, from a crest to the next crest. Also introduce the related term *frequency*. Frequency is the number of cycles of a wave that occur in a given amount of time. It is also the number of periods in a second. Frequency is often given as the number of cycles per second.

Interesting fact: FM radio towers send out waves that have a period of about one 100 millionth of a second. That's a pretty short time. By the time a second has gone by, that wave has made 100 million cycles.

20) Project BLM 8 Wave Components list and leave it up. Give out BLM 7 Transverse Wave Exploration student worksheets. Students should complete these worksheets individually but work in pairs at computers to collect the data needed. Ask them to complete only through Step 5, stop, and minimize the simulation window. Step 6 of the worksheet asks students to predict what doubling the frequency will do to the time of the period. Make sure students record their predictions on their worksheets before they use the simulation to test their predictions and record their results.

Wave Exploration Answer Key:

1) A little more than 22 cm

2) 9.5 cm for both crest and trough

3) Amplitude could be anything, but the frequency should be around 53. Frequency controls the wavelength, or distance between crests. Changing amplitude does not affect distance between crests.

4) Amplitude around 77. Only the amplitude control matters. Changing frequency does not alter the distance from the zero line to a crest or trough.

5) 1.11 seconds. There are many ways to do this. Some students time the movement of the green ball as it starts and returns to the same place on the center line in a full cycle. Some students set the vertical ruler at a crest and time until another crest reaches the ruler. Any point that can be precisely located as a wave moves through it will work.

6) Doubling the frequency should cut the time of a cycle in half. If a setting of 25 yields 1.11 seconds, a setting of 50 should yield 0.55 seconds.

Part 2 cont.

MATH EXTENSION: The period of a wave is the time it takes to go through a complete cycle. The frequency is the number of times a wave goes through a complete cycle in one second, so it is also the number of periods in a second. Give each student a copy of **BLM 9** and challenge everyone to fill in the missing periods and frequencies in the table.

Period (in decimal fraction of a second)	Period (fraction of a second)	Frequency
0.5 second	½ second	2 cycles per second
0.33 second	1/3 second	3 cycles per second
0.25 second	1/4 second	4 cycles per second
0.67 second	2/3 second	1 and ½ cycles per second
0.2 second	1/5 second	**5 cycles per second**
0.125 second	**1/8 second**	8 cycles per second
0.1 second	1/10 second	**10 cycles per second**
0.01 second	**1/100 second**	100 cycles per second
2.0 second	**2 seconds**	½ cycle per second
0.8 second	**4/5 second**	1 and ¼ cycles per second
0.6 second	3/5 second	**1 and 2/3 cycles per second**

Part 3 — Types of Waves –50 minutes

Materials

Materials for the whole class or the teacher

- Spring toys, 1 per pair of students
- wave simulation projection (Smartboard™ or computer projector)

Materials for groups of 2 or 3 students

- 1 spring toy and a flat surface, either a 5’ table or uncarpeted floor space
- science notebook for each student (to be supplied by the teacher)

Preparation

1. Check to see that wave animations requiring Quicktime function. Try the animation at http://www.physics.nyu.edu/~ts2/Animation/Trans_Long_Periodic_Waves.html. **If it does not work on your PC, download Quicktime for the PC** at http://support.apple.com/downloads/QuickTime_7_5_5_for_Windows. If you are using a Mac, you have Quicktime.

2. Arrange space for students to make waves with the springs.

Procedure

Longitudinal waves - 15 minutes

1) Give a spring to each pair of students, and ask them to use it to make a transverse wave. Then ask them to:

- increase the wave's frequency and describe what they did to increase it,
- give evidence that the frequency increased (how it looked different from when its frequency was slower),
- increase the amplitude and describe what they did to increase it,
- give evidence that the amplitude increased (how it looked different from when its amplitude was smaller).

2) Ask teams to make a longitudinal wave with the spring . Then ask them to:

- increase the frequency of the longitudinal wave and describe what they did to increase it,
- give evidence that the frequency increased.

3) Show http://www.physics.nyu.edu/~ts2/Animation/Trans_Long_Periodic_Waves.html on a Smartboard™ or computer projector. This page includes 3 types of waves. DO NOT run the top example labeled "transverse wave." Run the bottom two simulations only—"longitudinal wave" and "periodic transverse wave." After students watch, ask them to make an "alike and different" chart for the two types of waves with at least three similarities and three differences.

4) Discuss the students' lists. **Possible answers include:**

Similar:

- **Both waves have a regular repeating pattern. The longitudinal wave has denser and more spread out areas that regularly repeat (a frequency). The transverse wave has ups and downs that repeat (a frequency).**
- **Both waves move along the spring.**
- **Both waves start with movement at one end.**

Different:

- **The red balls in the longitudinal wave move forward and back, but in the transverse wave the balls move side to side or up and down.**
- **The transverse wave takes up more space above and below the line while the longitudinal wave moves straight down the spring. Does that mean the longitudinal wave doesn't have an amplitude? Or might the longitudinal wave have a different kind of amplitude?**
- **The balls in the longitudinal wave are sometimes spaced close together and sometimes farther apart, but those in the transverse wave seem to stay spaced more the same distance apart.**

Part 3 cont.

5) Pose the following question: If both kinds of waves have similar parts and properties, what do you think a crest or a trough might look like on a longitudinal wave? How might you measure a wavelength on a longitudinal wave?

Introduce the terms *compression* and *rarefaction* (see Detailed Background Information). As longitudinal waves pass through a medium, the waves press the medium together in some places, or compress it. In other places, the waves separate particles of the medium, or rarefy it. With longitudinal waves, compressed and rarified areas of the medium alternate along the path of the wave.

With longitudinal waves, a complete wave (or cycle) is one compression and one rarefaction. A wavelength is the distance between one compression and the next compression (or between one rarefaction and the next rarefaction). A crest in a transverse wave corresponds to the place in a longitudinal wave where the medium is most compressed. A trough in a transverse wave corresponds to the place in a longitudinal wave where the medium is most rarefied. A longitudinal wave's amplitude is a measure of how tightly the compressions are packed together and how spread out the rarefactions are.

Interesting wave fact: the lowest pitch a human can hear is a sound wave with a wave length of about 7.3 yards, about the length of a classroom.

6) Explain that sound energy travels in longitudinal waves. Demonstrate with sound cups by having a student place a finger lightly on the balloon of one cup while, a few inches away, you snap the balloon of the other cup. Ask the student what they feel. Explain that the vibrations they feel are the compressions in the air striking the balloon they are touching.

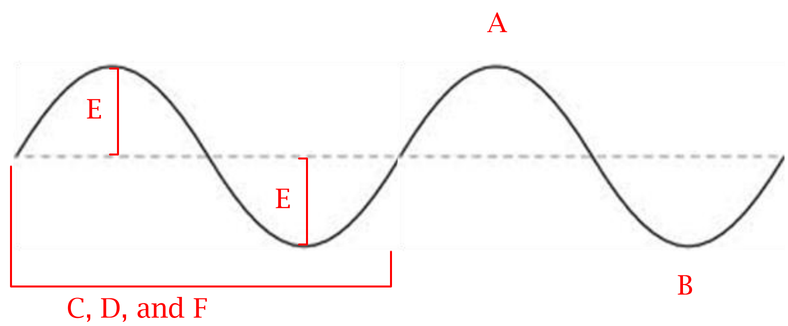
Part 3 cont.

Wrap-Up

1) Give each student a copy of BLM 10. Ask students to define each term and label, as best they can, where each term occurs on the wave diagram. Let them know they can add lines to the diagram if they need to. Students will not be able to label frequency (G), but you do not need to tell them this.

Answer Key:

A. Crest
B. Trough
C. Wavelength
D. Cycle
E. Amplitude
F. Period
G. Frequency



Student definitions should be as in step 2 below, but in their own words.

2) Go over the answers after they are done. Use BLM 8 to review these terms:

- crest and trough: crest is the highest point of the wave; trough is the lowest point
- Wavelength is the distance over which a wave's shape repeats, for example, from crest to the adjacent crest or from trough to adjacent trough.
- A cycle is one complete shape of the wave, for example, from crest to crest or trough to trough.
- Amplitude is the distance from the center point of the wave (also called the rest point) to the highest or lowest point.
- The period is the time it takes for a wave's shape to repeat, for example, from crest to adjacent crest or trough to adjacent trough.
- The frequency is the number of cycles of a wave that occur in a given amount of time. Frequency is often stated as the number of cycles per second.

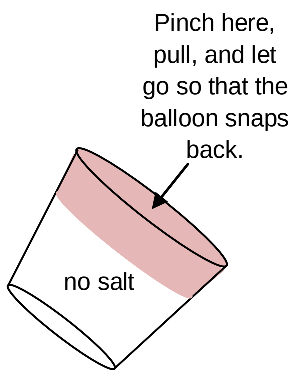
3) Ask students to imagine that each one of them is in charge of a group of 8 people. Explain that their task is to plan how these 8 people would move to demonstrate a transverse wave to the class. Give the students 5 minutes to work alone on their plans. Then divide the class into groups of 8 and give them 5 minutes to prepare their demonstrations.

4) Let each group present its wave. After all groups have done so, ask a group to demonstrate their wave again. At some point during the demonstration, call out "freeze!" With the wave frozen, ask other students in the class to identify a trough, a crest, and where a cycle starts and ends on the wave.

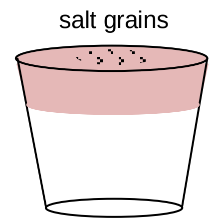
5) Challenge the groups to demonstrate a longitudinal wave. Give the groups five minutes to prepare, and then have them present their waves.

BLM 1: Station Directions

Cut these out and place at the appropriate stations.



Lift the cup without salt a few inches above the table and hold it 8-10 inches from the cup that has salt on it. Pinch the center of the balloon on the lifted cup and stretch the balloon away from the cup. Let go with a snap. Watch the salt grains on the other cup.

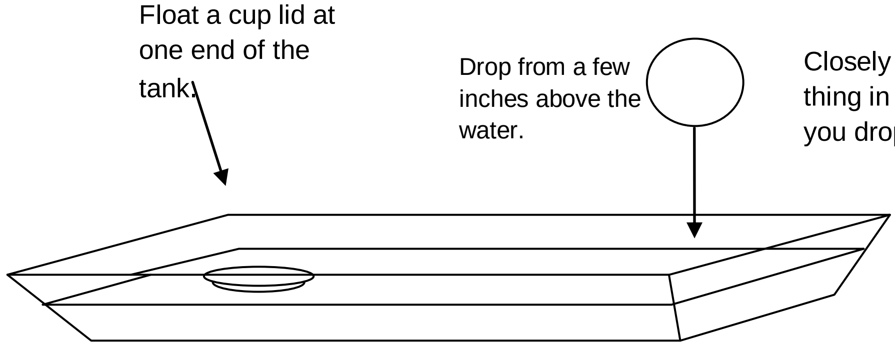


Drop a ping-pong ball at the opposite end of the tank.

Float a cup lid at one end of the tank.

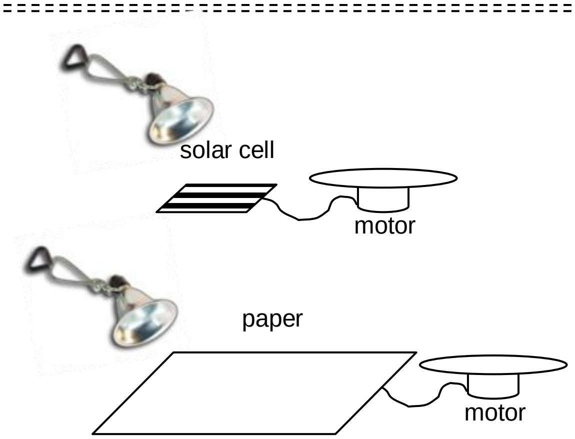
Drop from a few inches above the water.

Closely watch everything in the tank when you drop the ball.



Start with the clamp light off and the motor still. Turn the light on. Watch what happens when the light is turned on, and again when it is turned off.

With the clamp light off and the motor still, put a piece of paper over the solar cell and then turn on the light. Watch what happens. Then, with the light still on, remove the paper covering the solar cell. Observe what happens.



BLM 2: Student Exploration Sheets

Make 1 copy of the page for every 2 students. Cut to make 1 cutout per student who will visit each station.

Name____________________________________

Check the station you are observing: balloon cup □ water tank □ light and motor □

Describe what you observed. Include both a cause and an effect.

Name____________________________________

Check the station you are observing: balloon cup □ water tank □ light and motor □

Describe what you observed. Include both a cause and an effect.

Name____________________________________

Check the station you are observing: balloon cup □ water tank □ light and motor □

Describe what you observed. Include both a cause and an effect.

BLM 3 *1 of 2 pages*

Challenges (show one at a time)

Challenge 1 - Try out features of the simulation. Find and list 13 things that you can change or do with the simulation. Everyone will share what they find out after 5 minutes.

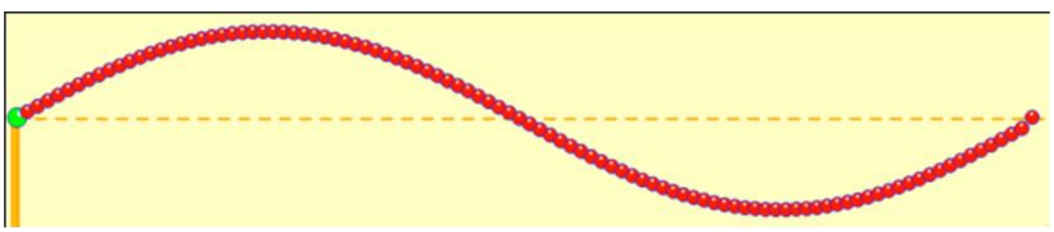
Challenge 2 - Use the wave simulator to make a wave in which:

- **both ends touch the dotted yellow line**
- **no ball is completely below the line**
- **the amplitude setting is between 20 and 100**

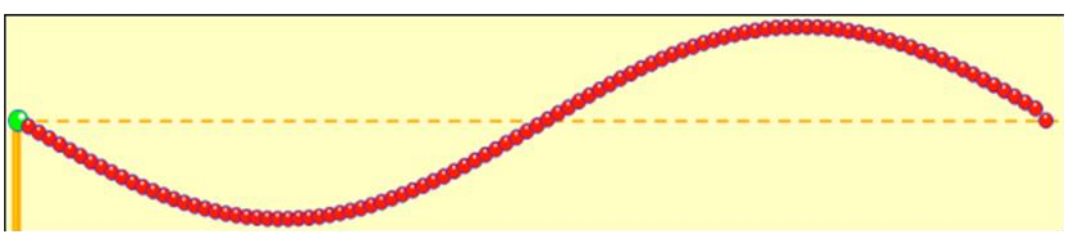
TIP: Use the step function to get the green ball on the far left of the dotted yellow line and a red ball on the far right of the dotted yellow line.

Challenge 3

1. **Make a wave that looks like this:**



2. **Record your amplitude and frequency settings**
3. **Make a wave that looks like this:**



4. **Record your amplitude and frequency settings**

BLM 3, ***2 of 2 pages***

Challenges (show one at a time)

Challenge 4

1. Without using the computer to look at a wave, draw a wave that would be made by setting the frequency to 20.

2. After you have drawn your prediction, set the frequency at 20, run and pause. Compare the wave to your prediction.

Challenge 5 – Using a frequency setting of 20, measure the length of one whole cycle.

Challenge 6

1. Set the amplitude to 80, run a wave, and pause it.

2. Measure the height in centimeters of a crest, measuring from the dotted center line.

Challenge 7 - Time one cycle of a wave.

1. Set the frequency to 30.

2. Use the step function and any marker you choose to stop the wave in a position where you can know when you finish a whole cycle

3. When you are ready to measure, reset the timer to 0

4. Use the step function to step through one cycle

5. Record the time it took for a whole cycle in your notebook.

BLM 4

Things You Can Do With the Wave Simulator

- change the frequency setting
- change the amplitude setting
- move the vertical ruler
- move the horizontal ruler
- move the draggable reference line
- pause (stop the moving wave)
- play (make the wave move)
- step along the path the wave makes
- move the timer
- start and stop the timer
- time between steps
- reset the wave motion
- reset the timer

BLM 5: Wave Simulations

Figure 1

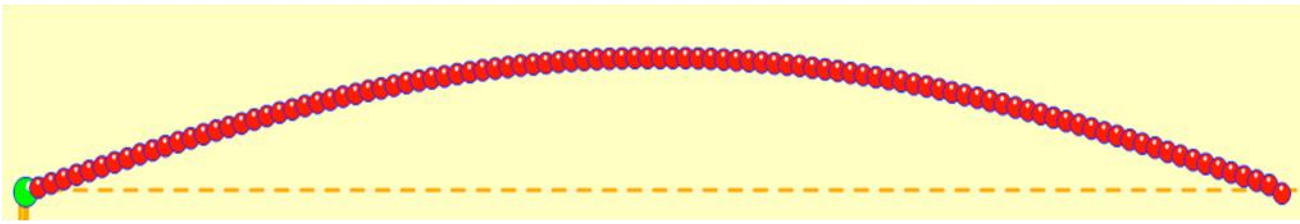


Figure 2

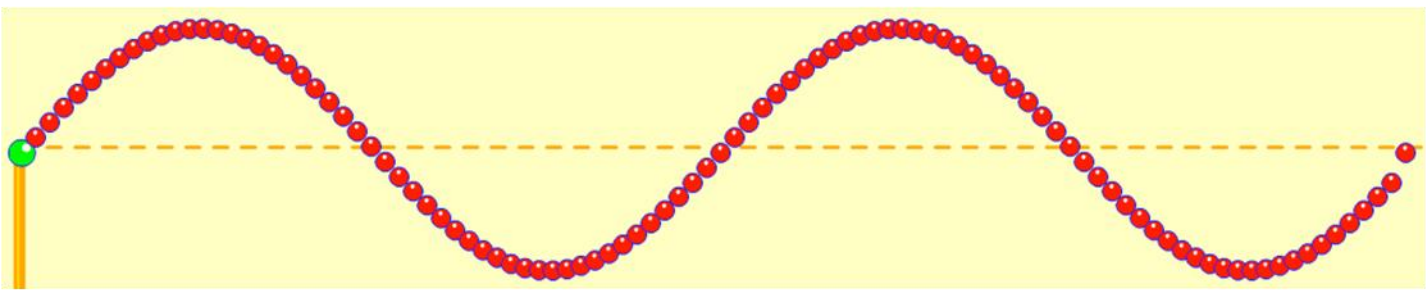


Figure 3

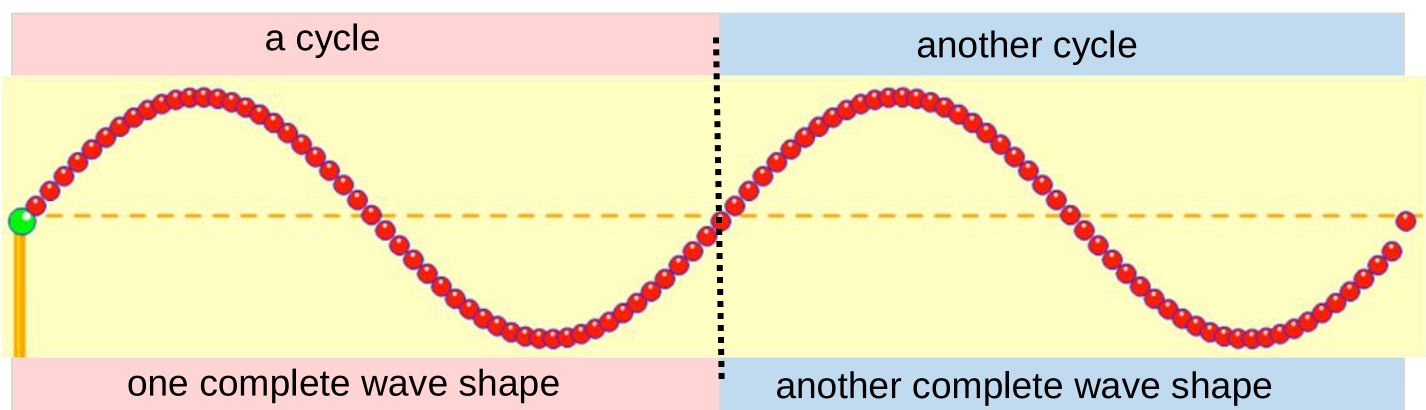
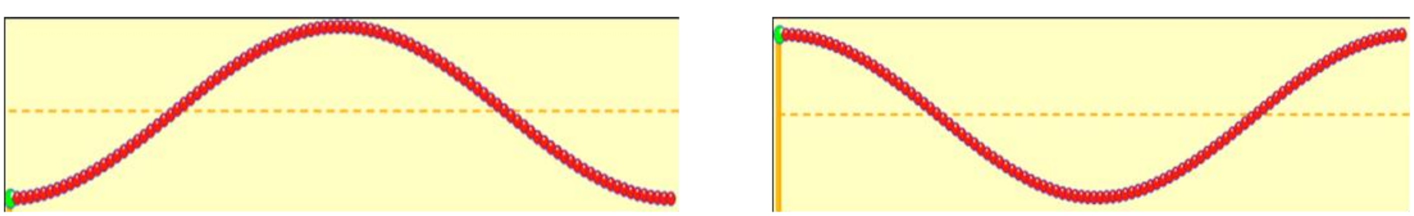
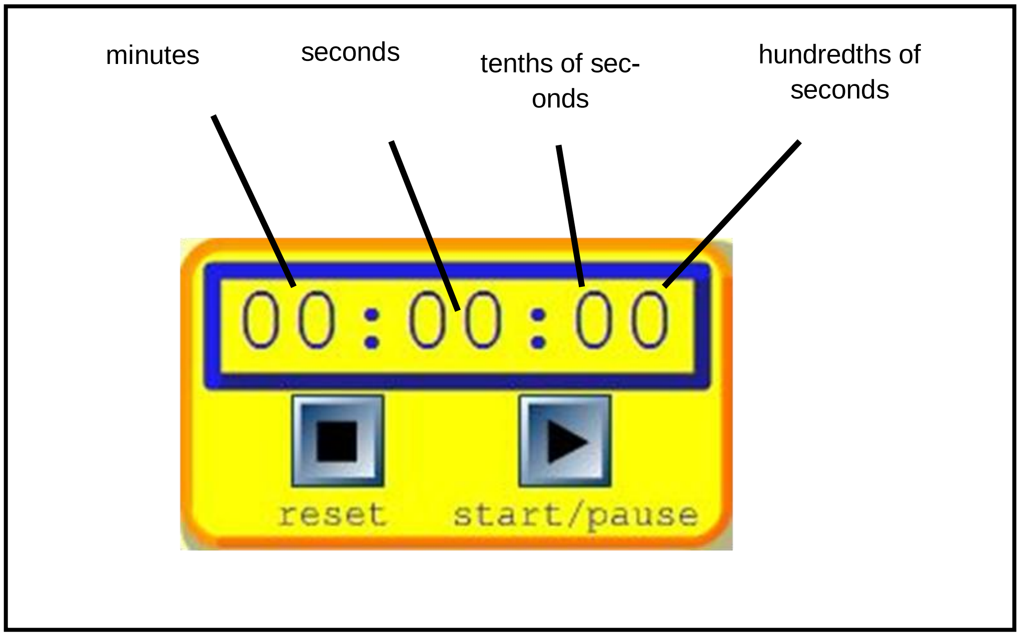


Figure 4



BLM 6: Wave Timer



BLM 7: Transverse Wave Exploration

Name ___________________________________

1. Set the frequency and amplitude controls at 48 and begin running the wave. Use the pause button to stop the wave. Measure a wavelength. The wavelength measurement is____________________________________.
2. With the wave stopped and the frequency and amplitude still set at 48, measure the amplitude of the wave. The amplitude measurement is_____________________.

3. Make a wave that has a length of 20 cm. Record the control settings that achieved this length.

   Amplitude __________Frequency ____________

   Which of the two controls made the most difference in length?_______________________________________

   What difference did the other one make?____

   What do you think might explain this? ____

   ____

4. Adjust the controls to make a wave measuring 15 cm in wave height..

   Amplitude setting______________ Frequency setting ______________________

   Which control makes the most difference in wave height?____

   What difference does the other one make? ____

   What do you think might explain this? ____

   ____

5. Set the frequency to 25 and use the timer to find how long one complete cycle takes. Record the time (to the nearest .01 sec.): __________seconds.

   Describe how you knew when the wave looked exactly like it did when you started: ___________________

   ____

   With the frequency set to 25, measure the length of a cycle in centimeters. Length of cycle:_________cm.

6. Minimize the window on the screen. Predict the time the wave will take to go through a cycle with the frequency set to 50. Your prediction: _________Describe how you went about predicting this.

   ____

   ____

   Open the window and test your prediction. Compare your prediction to what actually occurred:

   ____

   ____

7. How does the frequency control relate to actual frequency? ____

____

BLM 8

Wave Components

Crest: the crest is the highest point of the wave. The trough is the lowest point of the wave.

Wavelength: wavelength is the distance over which a wave's shape repeats, for example, from crest to the adjacent crest or from trough to adjacent trough.

Amplitude: amplitude is the distance from the center point of the wave (also called rest point) to the highest or lowest point. It is how high and how low a transverse wave goes.

Cycle: a cycle is one complete shape of a wave. For example, a cycle may be measured from crest to crest or trough to trough.

Period: the period is the time it takes for a wave's shape to repeat, for example, from crest to adjacent crest or trough to adjacent trough.

Frequency: the frequency is the number of cycles of a wave that occur in a given amount of time. Frequency is often stated as the number of cycles per second.

BLM 9

Name________________________________

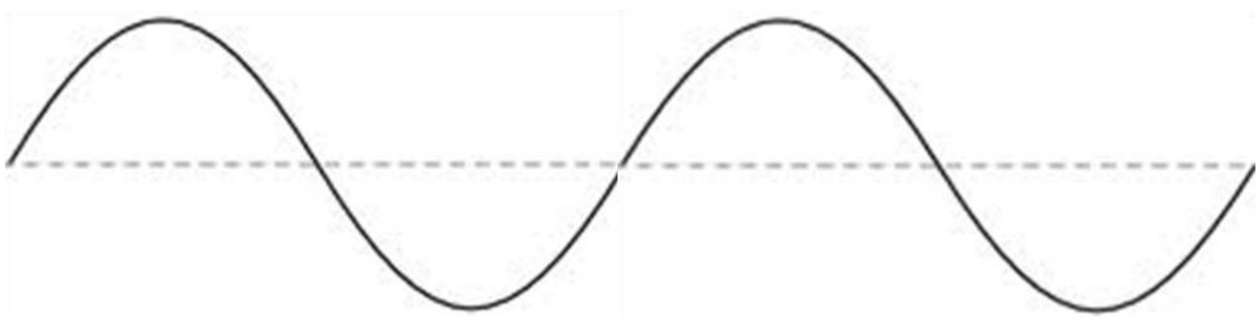
Fill in the blank squares with the correct number.

Period (in decimal fraction of a second)	Period (fraction of a second)	Frequency
0.5 second	½ second	2 cycles per second
0.33 second	1/3 second	3 cycles per second
0.25 second	1/4 second	4 cycles per second
0.67 second	2/3 second	1 and ½ cycles per second
0.2 second	1/5 second	
		8 cycles per second
0.1 second	1/10 second	
		100 cycles per second
		½ cycle per second
		1 and ¼ cycles per second
0.6 second	3/5 second	

BLM 10

Name______________________________

Define each term below and label all the ones that you can on the wave diagram. You may add lines to the diagram if you need to.



A. Crest______________________________

B. Trough______________________________

C. Wavelength______________________________

D. Cycle______________________________

E. Amplitude______________________________

F. Period______________________________

G. Frequency______________________________

Appendix

Common Student Preconceptions About This Topic

Children generally do not think of light, radio waves, sound, or earthquakes as waves in the same category as waves on water. These phenomena appear to be very different. Their wave nature is invisible. It is difficult to directly experience these forms of energy as waves in the way we experience waves rolling on the ocean. As a result, most people, including children, take scientists' word for it that these forms of energy travel in similar ways.

Detailed Background Information

In physics, a wave is defined as a repeating disturbance that carries energy as it moves through a medium from one place to another. While we can see ocean waves and feel the kinetic energy they carry, the waves we most commonly experience are light and sound waves, which we can neither see nor feel in the same way as ocean waves. Nevertheless, in the 19^{th} century several physicists conducted ingenious experiments that led to the widely accepted wave theories of light, sound, and several other forms of energy.

Light waves are examples of transverse waves, which resemble the S-shapes a child's spring toy (*e.g.*, a Slinky™) can make when lying on a flat surface. These are similar to the way ocean waves move with their characteristic high parts (peaks) and low parts (troughs). Transverse waves can vary in their amplitude and wavelength.

Amplitude is the height of the peaks from a horizontal line that splits the waves into equal top and bottom halves. It is also the depth of the troughs from that same line. The amplitude of a wave is related to the amount of energy it transports. High amplitude waves carry more energy than low amplitude waves. High-amplitude sound waves sound loud, and low amplitude sound waves sound quiet.

Wavelength: The distance between two adjacent peaks or two adjacent troughs. In other words, it is the horizontal distance traveled by one complete wave. A complete wave consists of one whole peak and one whole trough; it can also be thought of as an S lying on its side (rotated 90°). The shorter the wavelength, the more energy the wave carries.

The period is the amount of time it takes for one complete wave form. For example, the time that elapses from the moment when one crest passes a point until the next crest passes the same point. Periods are measured in seconds. The shorter the period, the more energy the wave carries.

Frequency is the number of complete waves that occur in a certain amount of time. Frequencies are generally stated in cycles per second, with one cycle being the same as one complete wave. Physicists use the term *hertz*

Appendix cont.

(named for the German Physicist Heinrich Hertz) instead of cycles per second to describe a wave's frequency. One hertz is equal to one cycle per second. A hertz is abbreviated as *Hz*. This abbreviation is often preceded by another, such as *k*, meaning kilohertz (one thousand hertz, or kHz) or *M*, meaning megahertz (one million hertz, or MHz). The higher the frequency, the more energy the wave carries.

Radio waves are a subset of a broader category known as electromagnetic waves, which also includes microwaves, infrared light, visible light, ultraviolet light, X-rays, and gamma rays. Of these transverse waves, radio waves have the lowest frequencies – as low as 3 kHz (3000 cycles per second), although the frequencies used by commercial radio stations range from 535-1700 kHz for AM stations, and 88-108 MHz for FM stations. Radio waves also have the longest wavelengths – up to 100 km (about 64 miles), but commercial radio waves range from 560 meters (AM) to 2.8 meters (FM). Besides radio stations, many common consumer devices use radio waves, including cell and cordless phones, garage door openers, and GPS units.

Starting with radio waves and followed by microwaves, infrared light (also known as radiant heat), and the rest of the electromagnetic waves listed in the order above, wavelengths decrease as the list proceeds. Microwave ovens, for example, typically produce wavelengths of about 10-30 centimeters. Light that is visible to humans travels in waves of lengths from about 700 nanometers (700 billionths of a meter) for red, to 400 nanometers for violet. Medical X-rays machines produce waves that are about 10,000 times shorter than those of violet light.

Gamma rays, which are another form of radioactive waves that travel to Earth through outer space, have even shorter wavelengths, and they also have the highest frequencies of the electromagnetic waves. In fact, for all of these waves, there is an inverse relationship between wavelength and frequency. Radio waves, having the longest lengths, have the lowest frequency range, from 3,000 Hz up to about 1 billion Hz. The waves produced by microwave ovens have frequencies of about 1-3 billion Hz, while the frequencies of visible light range from about 250 trillion Hz (for red) to 850 trillion Hz (for violet). Medical X-rays cycle at the unimaginable rate of 1 quintillion (1,000,000,000,000,000,000) Hz.

Although their wavelengths and frequencies differ, all types of electromagnetic waves have one thing in common: they all travel at the same speed of 299.8 million meters per second, also known as the speed of light.

Sound waves move in a very different way than light and the other electromagnetic waves. While electromagnetic waves are all examples of transverse ways, sound waves are examples of longitudinal waves. Keeping in mind that a wave is a repeating disturbance within a medium, which carries energy as it moves from one place to another, a transverse wave displaces particles of the medium in directions that are perpendicular to the direction the wave is traveling. An ocean wave models this idea very well:

the wave moves horizontally toward the shore, but the water (the medium) moves vertically as peaks and troughs form.

In longitudinal waves, however, the particles of the medium move back and forth in the same direction as the wave itself, that is, parallel to the wave's movement. In longitudinal waves, the particles are alternately pushed together, or compressed, and then bounce back to their original, uncompressed positions. Physicists refer to the compressed regions as *compressions* and the uncompressed regions as *rarefactions*. If we could actually see the particles, the wave would look like alternating bands of lighter (rarefied) and darker (compressed) areas moving in a straight line, as if they were traveling through a pipe. Excellent animations of both longitudinal and transverse waves can be found at http://www.acs.psu.edu/drussell/Demos/waves/wavemotion.html.

In a longitudinal wave, just as in a transverse wave, the wavelength is the distance spanning one complete wave. Therefore, a longitudinal wavelength is the distance from the start of one compression to the start of the next compression (or the start of one rarefaction to the start of the next rarefaction). Likewise, the period of a longitudinal wave is how long it takes for one complete wave, that is, one compression plus one rarefaction, to pass a given point. The frequency is the number of complete waves that pass a given point in one second, just as in transverse waves. In sound waves, the pitch of the sound is determined by its frequency, with lower pitches having lower frequencies and higher pitches having higher frequencies.

The amplitude of a longitudinal wave is a measure of how closely packed together the compressions are, or how spread out the rarefactions are. It takes more energy to pack particles of the medium together in a longitudinal wave, just as it takes more energy to move particles vertically in a transverse wave. Louder sounds have higher amplitudes, and vice versa.

While both transverse and longitudinal waves transport energy from one place to another, they do not move particles of the medium from one place to another. If they did, sound waves, for example, would push particles of air ahead of them and we would feel a breeze at our ears every time we hear a sound, or wind gusts if the sound was very loud. Instead, the disturbance that moves through the air is only temporary, and the displaced particles return to their original positions once the wave passes. The animations seen at the website above show this very clearly.

Waves travel through a variety of media. Light waves from the sun travel through the vacuum of space, and then through air once they reach the atmosphere. They can also travel through water, but not through solid materials. Radio waves can travel through the air and then through solid materials to reach our radios (receivers), where the energy they carry is converted to the sound energy we hear as music and speech from the radio speakers. Sound waves can travel through liquids, which is how dolphins and whales communicate, and gases (such as air), but they can't travel in a vacuum. While in orbit, NASA's Space Shuttles travel at speeds of about 17,500 miles

Appendix cont.

per hour, but they do so in silence.

The waves of kinetic energy that occur in an earthquake travel through the solid materials comprising the earth's surface. The very first waves that occur are longitudinal waves, known as the P-waves, or primary waves. These radiate out from the location where a pair of tectonic plates move relative to each other, either colliding or pulling apart. These longitudinal waves are followed within seconds by the secondary waves, known as S-waves, which are transverse waves. The last, slowest moving waves are the most destructive, because they produce both the side-to-side motions of a longitudinal wave and the up-and-down motions of a transverse wave. These waves are known as Rayleigh waves. An animation of Rayleigh waves can also be found at http://www.acs.psu.edu/drussell/Demos/waves/wavemotion.html. All three types of earthquake waves have higher amplitudes in major earthquakes than in minor earthquakes.

The waves of tsunamis are examples of water waves having very high amplitudes, and thus carrying a lot of damaging energy. In order to keep things simpler, throughout this set of lessons we use water waves as an example of transverse waves. However, water waves are actually a combination of transverse and longitudinal waves, as shown in another animation at the website above. This animation, like those of the other wave types, also clearly demonstrates the fact that the particles of the medium (water) do not travel with the waves. If they did, there would be no water left in the middle of our oceans!