Activity 1

Making Waves

What Do You Think?

On December 26, 2004, one of the largest tsunamis (tidal waves) hit many countries in the Indian Ocean in Southeast Asia, causing massive damage. Some of the waves reached almost 35 meters (100 feet) in height.

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

Record your ideas about these questions in your *Active Physics* log. Be prepared to discuss your responses with your small group and with your class.
For You To Do

1. In an area free of obstacles, stretch out a Slinky® so the turns are a few centimeters apart. Mark the positions of the end of the Slinky by sticking pieces of tape on the floor. Measure the distance between the pieces of tape.
   a) Record the distance between the pieces of tape in your log.

2. With the Slinky stretched out to the tape, grab the spring near one end, as shown in the drawing, and pull sideways 20 cm and back. To move it correctly, move your wrist as if snapping a whip. Observe what happens. You have made a transverse pulse.
   a) In what direction does the spring move as the pulse goes by?
   b) A dictionary definition of transverse is: “Situated or lying across.” Why is transverse a good name for the wave you observed?

   c) Measure and record the amplitude of the wave. The distance you disturbed the spring is called the amplitude. The amplitude tells how much the spring is displaced.

3. After you have experimented with making pulses, measure the speed of the pulse. You will need to measure the time it takes the pulse to go the length of the spring. Take several measurements and then average the values.
   a) Record your data in the second and third rows of a table like the one on the following page.
Let Us Entertain You

<table>
<thead>
<tr>
<th>Amplitude</th>
<th>Time for pulse to travel from one end to the other</th>
<th>Average time</th>
<th>Speed = length of spring average time</th>
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4. Measure the speed of the pulses for two other amplitudes, one larger and one smaller than the value used in **Step 3**.
   a) Record the results in the table in your log.
   b) How does the speed of the pulse depend on the amplitude?

5. Now make waves! Swing one end back and forth over and over again along the floor. The result is called a periodic wave.
   a) Describe the appearance of the periodic wave you created.

6. To make these waves look very simple, change the way you swing the end until you see large waves that do not move along the spring. You will also see points where the spring does not move at all. These waves are called standing waves.

7. The distance from one crest (peak) of a wave to the next is called the wavelength. Notice that you can find the wavelength by looking at the points where the spring does not move. The wavelength is twice the distance between these points. Measure the wavelength of your standing wave.
   a) Record the wavelength of your standing wave in your log.

8. 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. (Hint: Watch the hands of the person shaking the spring. Time a certain number of back-and-forth motions. The frequency is the number of back-and-forth motions of the hand in one second.)
9. Make several different standing waves by changing the wave frequency. Try to make each standing wave shown in the drawings (at right). Measure the wavelength. Measure the frequency.

a) Record both in a table like the one below.

<table>
<thead>
<tr>
<th>Wavelength (m/cycle)</th>
<th>Frequency (cycles/s or Hz)</th>
<th>Speed (m/s) wavelength × frequency</th>
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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 Steps 3 and 4 above.

10. All the waves you have made so far are transverse waves. A different kind of wave is the compressional (or longitudinal) wave. Have the members of your group stretch out the Slinky between the pieces of tape and hold the ends firmly. To make a compressional wave, squeeze part of the spring and let it go. Measure the speed of the compressional wave and compare it with the speed of the transverse wave.

a) Record your results in a table partly like the one after Step 3.
b) In what direction does the Slinky move as the wave goes by?
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.

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

12. Make a drawing of a 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.

13. 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.

14. Draw 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.
FOR YOU TO READ

Wave Vocabulary

In this activity, you were able to send energy from one end of the Slinky to the other. You used chemical energy in your muscles to create mechanical energy in your arms that you then imparted to the Slinky. The Slinky had energy. A card at the other end of the Slinky would have moved once the wave arrived there. The ability to move the card is an indication that energy is present. The total energy is transferred but it is always conserved.

Of course, you could have used that same mechanical energy in your arm to throw a ball across the room. That would also have transferred the energy from one side of the room to the other. It would have also moved the card.

There is a difference between the Slinky transferring the energy as a wave and the ball transferring the energy. The Slinky wave transferred the energy, but the Slinky basically stayed in the same place. If the part of the Slinky close to one end were painted red, the red part of the Slinky would not move across the room. The Slinky wave moves, but the parts of the Slinky remain in the same place as the wave passes by. A wave can be defined as a transfer of energy with no net transfer of mass.

Leonardo da Vinci stated that “the wave flees the place of creation, while the water does not.” The water moves up and down, but the wave moves out from its center.

In discussing waves, a common vocabulary helps to communicate effectively. You observed waves in the lab activity. We will summarize some of the observations here and you can become more familiar with the terminology.

A periodic wave is a repetitive series of pulses. In the periodic wave shown in the diagram above, the highest point is called the crest. The lowest point is called the trough. The maximum disturbance, the amplitude, is 5.00 cm. Notice that this is the height of the crest or the height of the trough. It is not the distance from the crest to the trough.
The **wavelength** of a periodic wave is the distance between two consecutive points in phase. The distance between two crests is one wavelength or \( \lambda \). (The Greek letter lambda is used to signify wavelength.) The wavelength of the wave in the diagram is 2.5 cm.

The amplitude of a periodic wave is the maximum disturbance. A large amplitude corresponds to a large energy. In sound, the large amplitude is a loud sound. In light, the large amplitude is a bright light. In Slinkies, the large amplitude is a large disturbance.

The wavelength of the wave in the diagram is 2.5 cm. It is the distance between two crests or the distance between two troughs.

The **frequency** is the number of vibrations occurring per unit time. A frequency of 10 waves per second may also be referred to as 10 vibrations per second, 10 cycles per second, 10 per second, 10 s\(^{-1}\), 10 Hz (hertz). The human ear can hear very low sounds (20 Hz) or very high sounds (20,000 Hz). You can’t 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. It is the time required for one crest to pass a given point. The period and the frequency are related to one another. 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 \( \frac{1}{3} \) second. Mathematically, this relationship can be represented as:

\[
T = \frac{1}{f} \quad \text{or} \quad f = \frac{1}{T}
\]

Points in a periodic wave can 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 **node** is a spot on a standing wave where the medium is motionless. There are places along the medium that do not move as the standing wave moves up and down. The locations of these nodes do not change as the standing wave vibrates. A **transverse wave** is a wave in which the motion of the medium is perpendicular to the motion of the wave. A **longitudinal wave** is a wave in which the motion of the medium is parallel to the direction of the motion of the wave.
PHYSICS TALK

Calculating the Speed of Waves

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

\[
\text{speed} = \frac{\text{change in distance}}{\text{change in time}}
\]

In mathematical language:

\[
v = \frac{\Delta d}{\Delta t}
\]

where

\[
v = \text{speed} \quad d = \text{distance} \quad t = \text{time}
\]

Suppose the distance the crest moves is 2 m in 0.2 s. The speed can be calculated as follows:

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

The distance from one crest of a wave to the next is the wavelength. The number of crests that go by in one second is the frequency. Imagine you saw five crests go by in one second. You measure the wavelength to be 2 m. The frequency is 5 crests/second, so the speed is \((5 \times 2) = 10 \text{ m/s}\). Thus, the speed can also be found by multiplying the wavelength and the frequency.

\[
\text{speed} = \text{frequency} \times \text{wavelength}
\]

In mathematical language:

\[
v = f\lambda
\]

where

\[
v = \text{speed} \quad f = \text{frequency} \quad \lambda = \text{wavelength}
\]
Standing waves happen anywhere that the length of the Slinky and the wavelength have a particular mathematical relationship. The length of the Slinky must equal \( \frac{1}{2} \) wavelength, 1 wavelength, \( \frac{3}{2} \) wavelengths, 2 wavelengths, etc.

Mathematically, this can be stated as:

\[
L = \frac{n\lambda}{2}
\]

where \( L \) is the length of the Slinky,
\( \lambda \) is the wavelength
\( n \) is a number (1, 2, 3…)

**Sample Problem 1**

You and your partner sit on the floor and stretch out a Slinky to a length of 3.5 m. You shake the Slinky so that it forms one loop between the two of you. Your partner times 10 vibrations and finds that it takes 24.0 s for the Slinky to make these vibrations.

a) How much of a wave have you generated and what is the wavelength of this wave?

**Strategy:** Draw a sketch of the wave you have made and you will notice that it looks like one-half of a total wave. It is! This is the maximum wavelength that you can produce on this length of Slinky. You can use the equation that shows the relationship between the length of the Slinky and the wavelength.

**Givens:**

\[
L = 3.5 \text{ m}
\]

\[
n = 1
\]
**Solution:**

\[ L = \frac{n\lambda}{2} \]

Rearrange the equation to solve for \( \lambda \).

\[ \lambda = \frac{2L}{n} = \frac{2(3.5 \text{ m})}{1} = 7.0 \text{ m} \]

b) What is the period of vibration of the wave?

**Strategy:** The period is the amount of time for one vibration. You have the amount of time for 10 vibrations.

**Solution:**

\[ T = \frac{\text{time for 10 vibrations}}{10} = \frac{24.0 \text{ s}}{10} = 2.4 \text{ s} \]

c) Calculate the wave frequency.

**Strategy:** The frequency represents the number of vibrations per second. It is the reciprocal of the period.

**Given:**

\[ T = 2.4 \text{ s} \]

**Solution:**

\[ f = \frac{\text{number of vibrations}}{\text{time}} \text{ or } f = \frac{1}{T} \]

\[ = \frac{1}{2.4 \text{ s}} \]

\[ = 0.42 \text{ vibrations per second} \]

\[ = 0.42 \text{ s}^{-1} \text{ or } 0.42 \text{ Hz} \]
d) Determine the speed of the wave you have generated on the Slinky.

**Strategy:** The speed of the wave may be found by multiplying the frequency times the wavelength.

**Givens:**
\[ f = 0.42 \text{ Hz} \]
\[ \lambda = 7.0 \text{ m} \]

**Solution:**
\[ v = f\lambda \]
\[ = 0.42 \text{ Hz} \times 7.0 \text{ m} \]
\[ = 29 \text{ m/s} \]

Remember that Hz may also be written as 1/s so the unit of speed is m/s.

**Sample Problem 2**

You stretch out a Slinky to a length of 4.0 m, and your partner generates a pulse that takes 1.2 s to go from one end of the Slinky to the other. What is the speed of the wave on the Slinky?

**Strategy:** Use your kinematics equation to determine the speed.

**Givens:**
\[ d = 4.0 \text{ m} \]
\[ t = 1.2 \text{ s} \]

**Solution:**
\[ v = \frac{d}{t} \]
\[ = \frac{4.0 \text{ m}}{1.2 \text{ s}} \]
\[ = 3.3 \text{ m/s} \]
Reflecting on the Activity and the Challenge

Slinky waves are easy to observe. You have created transverse and compressional Slinky waves and have measured their speed, wavelength, and frequency. For the Chapter Challenge, you may want to create musical instruments. You will receive more guidance in doing this in the next activities. Your instruments will probably not be made of Slinkies. You may, however, use strings that behave just like Slinkies. When you have to explain how your instrument works, you can relate its production of sound in terms of the Slinky waves that you observed in this activity.

Physics To Go

1. a) Four characteristics of waves are amplitude, wavelength, frequency, and speed. For each characteristic, tell how you measured it when you worked with the Slinky.
   b) For each characteristic, give the units you used in your measurement.
   c) Which wave characteristics are related to each other? Tell how they are related.

2. a) Suppose you shake a long Slinky slowly back and forth. Then you shake it rapidly. Describe how the waves change when you shake the Slinky more rapidly.
   b) What wave properties change?
   c) What wave properties do not change?

3. Suppose you took a photograph of a wave on a Slinky. 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 Slinky. You also place a clock next to the Slinky, so the video camera records the time. When you look at the video of a wave going by on the Slinky, 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) Using your answer to Part (d), 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.
    c) Add labels to your drawing to show how the Slinky moves.
    d) Tell how to find the wavelength by observing a standing wave.

7. a) Explain the difference between transverse waves and compressional waves.
    b) Slinky waves can be either transverse or compressional. Describe how the Slinky moves in each case.

8. a) When you made standing waves, how did you shake the spring (change the frequency) to make the wavelength shorter?
    b) When you made standing waves, how did you shake the spring (change the frequency) to make the wavelength longer?

9. 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.

10. A Slinky is stretched out to 5.0 m in length between you and your partner. By shaking the Slinky at different frequencies, you are able to produce waves with one loop, two loops, three loops, four loops, and even five loops.
    a) What are the wavelengths of each of the wave patterns you have produced?
    b) How will the frequencies of the wave patterns be related to each other?

11. 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. He is bouncing up and down, creating a standing wave with a single loop and a period of 2.0 s.
a) What is the wavelength of the wave he is producing?
b) What is the frequency of this wave?
c) What is the speed of the wave?

12. A clothesline is stretched 9 m between two trees. Clothes are hung on the line as shown in the diagram. When a particular standing wave is created in 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 such that the clothes remain stationary?

13. During the Slinky lab, your partner generates a wave pulse that takes 2.64 s to go back and forth along the Slinky. The Slinky stretches 4.5 m along the floor. What is the speed of the wave pulse on the Slinky?

14. A drum corps can be heard practicing at a distance of 1.6 km from the field. What is the time delay between the sound the drummer hears ($d = 0$ m) and the sound heard by an individual 1.6 km away? (Assume the speed of sound in air to be 340.0 m/s.)