4.3 Explore

How Are Sound and Light Energy Transmitted?

When you throw a ball, the kinetic energy of the moving ball is transferred along with the ball. If you throw a ball at a piece of paper, the paper will move when the ball strikes it. The movement of the paper indicates that the piece of paper now has some of the kinetic energy from the ball. You experienced this same phenomenon in the previous section when you held a vibrating tuning fork close to a dangling cork. The kinetic energy of the tuning fork made the dangling cork move. But something was different in the tuning-fork example. The tuning fork never touched the cork, yet the cork still moved. Somehow, the energy from the tuning fork was transferred to the cork without touching it.

How did the energy from the vibrating tuning fork travel between the tuning fork and the cork if they never touched one another? The answer is that the sound energy from the tuning fork traveled in **waves** toward the cork. When the energy in the waves was transmitted to the cork, the cork moved. Scientists use the idea of waves to describe how sound energy travels and is transferred. They also use the idea of waves to describe how light energy travels and is transferred. This means that everything you see and hear comes to you in the form of waves. So, to include sound and light energy in your Rube Goldberg machine, you must know something about waves.

wave: a disturbance that travels through a medium from one place to another.

mechanical wave: a transfer of energy through a medium without a transfer of the medium.

medium: the material through which a mechanical wave travels.

Mechanical Waves—Off to the Races

Your group is going to hold races between a wave in a rope and a wave in a coiled spring. At the same time, you will explore factors that affect the speed of a **mechanical wave**. A mechanical wave is a transfer of energy without a transfer of material. The material a wave moves through is called a **medium**. In this case, the rope and coiled spring are the medium that your waves will travel through. As you do your exploration, pay attention to the direction each wave travels and the direction the rope and coiled spring travel. You will each have a chance to create waves.

Materials

- coiled spring
- rope that is longer than the coiled spring
- stopwatch with second hand
- small piece of paper about 1.5 cm by 5 cm (about 0.5 in. by 2 in.)

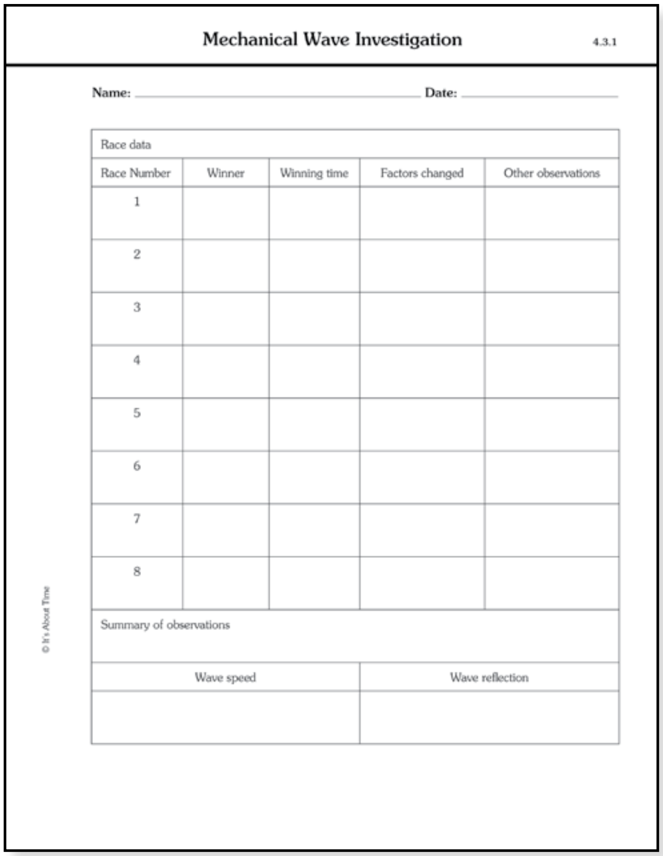
Procedure

1. Two students in your group will each hold one end of the coiled spring. Hold the spring on the ground with some tension so there is a little space between the coils. One student will generate a wave in the spring. To do this, squeeze part of the spring by bringing a handful of coil edges together and then letting them go. This type of wave is called a *longitudinal* or *compressional wave.* The other student should hold the spring fixed in place on the ground. Have each student practice making a longitudinal wave travel the length of the coiled spring until you are ready to start the first race.

2. A third and fourth student will each hold an end of the rope. They will stand next to the students holding the coiled spring, and hold the rope in a straight line on the ground. One student will generate a wave with a rapid side-to-side motion. This type of wave is called a *transverse wave.* The other student should hold the rope fixed in place on the ground. Practice making a transverse wave until you are ready to start the first race.

3. A fifth student will be the starter, and a sixth student will be the recorder. Students will get a chance to change roles so all students can generate a wave. The starter will start the race by counting down: "Ready, set, go!" At the sound of "go," each team will generate its wave, and the starter will start the stopwatch.

   The starter can call a mis-start if the waves are not produced at the same time. When the first wave reaches the students at the other end, the starter will stop the stopwatch. The recorder will record the winner of the race and record the winning time in the *Race data* table on a *Mechanical Wave Investigation* page. For the first race, nothing is recorded in the *Factors changed* column.



Mechanical Wave Investigation 4.3.1

Name: ______________________ Date: __________

Race data				
Race Number	Winner	Winning time	Factors changed	Other observations
1				
2				
3				
4				
5				
6				
7				
8				

Summary of observations	
Wave speed	Wave reflection

4. After the first trial, discuss the waves you observed and summarize your observations about the waves in the *Other observations* column.

5. Continue with more trials. In each trial, the losing team may choose one factor to change to see if the change will make their wave go faster. For example, you may want to change the amount of side-to-side motion of the rope. Record the factor in the *Factors changed* column. Record the factor before the start of the race. Make sure that the factors changed will not cause any damage to the coiled spring or to the rope.

6. After all students have had one turn in each role, both teams in each race should change a factor. Record the factors changed before each race. Then run the race and record the results.

7. Repeat *Steps 5* and *6.*

8. After your group has completed two rounds of race trials, make a list of the factors you investigated in the *Summary of observations* table. Record the effect of each factor on the speed of a wave.

9. Fold a small rectangle of paper in half and place it over one of the coils of the coiled spring near the fixed end. Also place a small piece of paper on the rope near the fixed end. Send a wave down the coiled spring and the rope. Notice what happens to the paper as the wave pulse goes by. Observe what happens to the wave when it reaches the fixed end of the coiled spring or rope. Record your observations in the *Wave reflection* box in the *Summary of observations* table on the *Mechanical Wave Investigation* page.

Stop and Think

1. In what direction did the coils of the spring move as the wave moved from one end of the coiled spring to the other?
2. A dictionary definition of compressional is “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 the type of wave you made on the coiled spring.
3. In what direction did the rope move as the wave moved from one end of the rope to the other?
4. A dictionary definition of transverse is “in a crosswise direction.” Another definition is “at right angles (perpendicular) to the long axis.” Why is transverse a good name for the wave you generated and observed on the rope?
5. Does the speed of the wave depend on how much you moved the rope sideways to generate the wave? Use evidence from your investigation to answer this question.
6. Does the speed of the wave depend on how many coils you squeezed together? Use evidence from your investigation to answer this question.
7. You observed that the paper attached close to the fixed end of the spring or rope “jumped” as the wave went by. At first, the paper was at rest and had no (kinetic) energy. When it started to move, you know that it had gained kinetic energy. Where did this energy come from?
8. What happened to the wave pulse when it reached the fixed end of the spring or rope?

Characteristics of Waves

You will learn more about sound waves and light waves later in this *Learning Set.* However, before learning about the specifics of sound waves and light waves, there are some characteristics of waves you need to know.

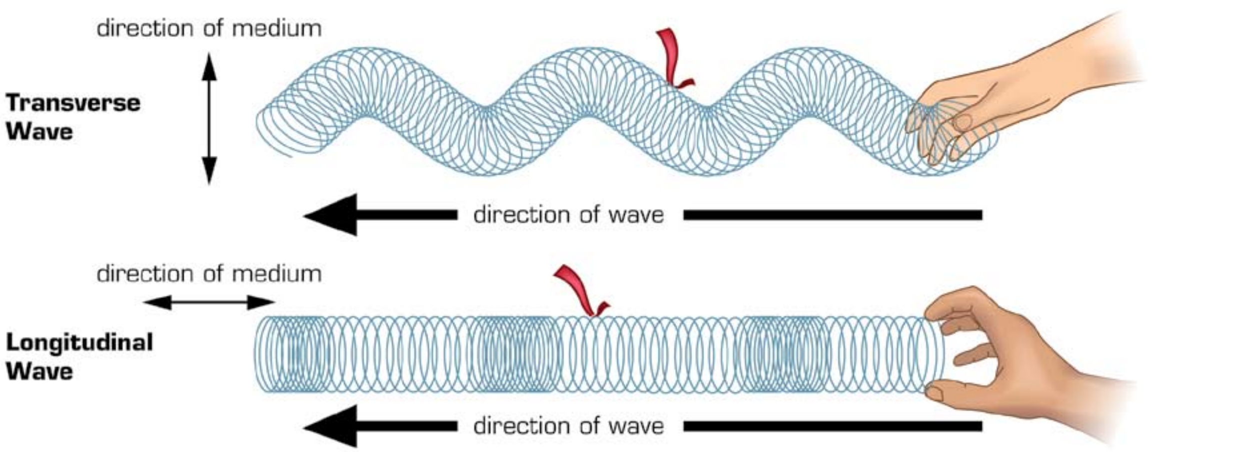
How Waves Transfer Energy

In this investigation, you observed two types of mechanical waves—**longitudinal (compressional) waves** and **transverse waves**. In longitudinal waves, the vibrations move in a direction parallel to the direction in which the wave travels. These were the type of waves you made with the coiled spring. Sound waves are longitudinal waves. The waves you made with the rope are transverse waves. You may know that the prefix "trans" means across. Transverse waves have vibrations that are across, or perpendicular to, the direction in which the wave travels. Light waves are transverse waves.

Whether a wave is a transverse wave or a longitudinal wave, it transfers energy the same way. The wave carries energy through the medium, and the energy is transferred to whatever the wave touches. You saw this when you observed the way the pieces of paper you attached to the coil and the rope moved with the wave. You saw the pieces of paper move up and down or side to side with the wave. You also saw another important property of a wave when you observed the pieces of paper. The pieces of paper returned to where they were at the start after the wave passed through.

longitudinal (compressional) wave: a wave that causes a medium to vibrate in a direction parallel to the direction in which the wave travels.

transverse wave: a wave that causes a medium to vibrate in a direction perpendicular to the direction lin which the wave travels.



In the transverse wave (top), the wave moves from side-to-side. You can see this movement if you watch the ribbon tied to the coiled wire. In the longitudinal wave (bottom), the wave moves back and forth. You can see this movement if you watch the ribbon tied to the coiled wire.

amplitude: the height of the crest in a transverse wave; a measure of how compressed the compressions are in a longitudinal wave.

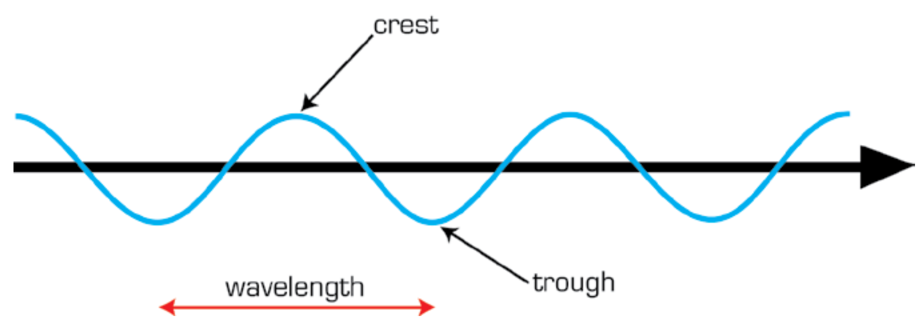
What you observed was that the wave transferred energy, but it did not transfer matter. The pieces of paper you attached to the coiled spring and the rope did not move from where you attached them. However, the wave moved from one end of the spring or rope to the other. Another example of this phenomenon is what happens when you throw a pebble into a pond. When you throw a pebble into a pond, the kinetic energy from the pebble is transferred to the water and produces a small wave. The wave moves away from the location where the pebble hit the water. After the wave passes, the water was where it was before. It is the same for sound waves and light waves. After a wave passes through a medium, the matter in the medium returns to where it was before the wave passed by.

Features of Waves

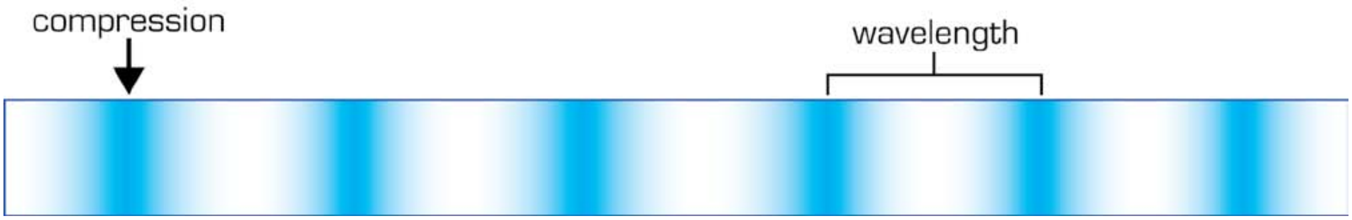
During the race, you changed several factors to see how they affected the speed of the wave. Some of the factors you may have changed were *wavelength,* wave *period* or *frequency,* and wave **amplitude**. Understanding what each of these terms means will be important when you read about sound waves in the next section.

Wavelength

When scientists study length of a wave, they begin by measuring the rest position of the medium. Think back to the waves you made with the rope. You started with the rope in a straight line; this was the rest position. The vibration caused the rope to move left of the line, then right of the line, then left again in a repeating pattern. The wave looked a bit like this:



A wave has a crest (high point) and a trough (low point). In a transverse wave, the wavelength is the distance from crest to trough.



In a longitudinal wave, a wavelength is the distance between one compression and the next compression.

The high point in a wave is called a **crest**. The low point is called a **trough**. One complete wave is the distance from crest to crest. The length of one complete wave is called the **wavelength**. You can also measure one complete wave from trough to trough, or between any two points that correspond.

In longitudinal waves, there are **compressions** in the wave instead of crests. In the coiled spring, you could see the compressions traveling the length of the spring. The distance between one compression and the next compression is the wavelength of a longitudinal wave.

Wave Period and Frequency

Imagine you are sitting at the end of a long boat dock, watching the waves in the water move toward the shore. You watch the crests as they pass you. You find that it takes two seconds for each crest to pass you. This is the **period** of the wave, the time it takes to complete one cycle of the wave—crest, trough, crest. The **frequency** of the wave is the number of cycles each second. In this case, the frequency of the wave is $\frac{1}{2}$ cycle per second. Every second, one half of the wave passes by. The period and the frequency are inversely related to one another.

Now suppose the waves slow down. You see one wave crest pass by you every five seconds. The period of the wave is now five seconds. The frequency of the wave is $\frac{1}{5}$ cycle per second. Scientists use a special name, hertz (Hz), for frequency. One hertz is one cycle per second.

Wave Amplitude

The point of greatest movement away from the rest position is called the amplitude of a wave. In a transverse wave, the amplitude is the height of a crest. In a longitudinal wave, amplitude is a measure of how compressed the compressions are. The amplitude of a wave is a measure of how much energy is used to produce the wave.

crest: the highest point of a transverse wave.

trough: the lowest point of a transverse wave.

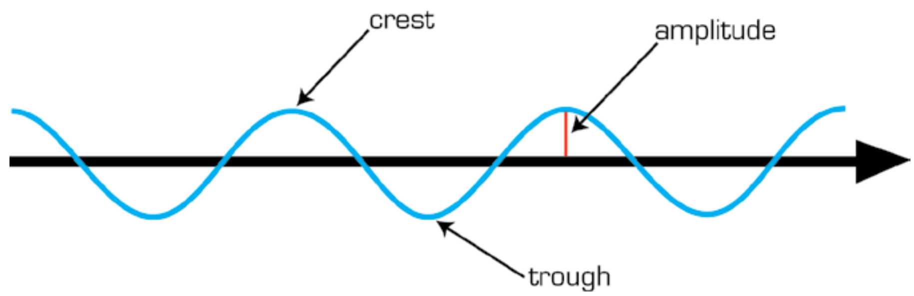
wavelength: the distance between two successive crests or troughs in a transverse wave or between two successive compressions in a longitudinal wave.

compression: region of a longitudinal wave where the particles of the medium have the highest density.

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

frequency: the number of crests or compressions in a wave that pass a point per unit time; for sound waves, measured in hertz (hz).

Perhaps you tried to make a wave go faster by shaking the rope harder or pushing and pulling harder on the spring toy. If so, you probably increased the amplitude of the wave.



In addition to crest and trough, a wave also has amplitude. In a transverse wave, amplitude is the height of a crest. In a longitudinal wave, amplitude is how compressed the compressions are.

speed of a wave: the distance a wave travels (crest, trough, crest) in a given period of time. Speed of a wave can be calculated by multiplying wavelength by frequency.

Wave Speed

Now that you know something about wavelength and wave frequency, you can think about what the **speed of a wave** might mean. The speed of a wave is measured the same way the speed of anything is measured. Speed, you know, is the time it takes to travel some distance. To calculate speed, divide the distance traveled by the time taken. The unit used for the speed of waves is the same as the speed of anything. Often, wave speeds are given in meters per second (m/s).

Now think about what the speed of a wave means in terms of wavelength and wave frequency. The distance from one crest to another of a wave is the wavelength. The time it takes for the wave to travel this distance is the period. So, to find wave speed, you can divide the wavelength by the period. Mathematically, this is the same as multiplying by the frequency. So, the speed of a wave can be calculated by multiplying wavelength and frequency.

As you may have discovered, neither frequency, wavelength, nor amplitude affected the speed of the waves you created with the ropes and coils. Waves tend to travel at one speed through a medium. If you vibrated the spring or rope faster, you made more crests or compressions per second, but the wave speed did not change. This fact will be important when you look at the relationship between the frequency and wavelength of sound waves in the next section.

Reflection of Waves

One more important characteristic of waves is **reflection**. When you throw a ball at a hard wall, the ball will bounce back. The ball **reflects** off the wall. Reflection means to turn back from a hard surface. You observed the same thing happening with the waves you created. When a wave reached the end of the coiled spring or rope, you saw that the wave was reflected back. Because waves carry energy, when a wave reflects back, the energy in the wave is also reflected. This is what happened with the waves you made in the ropes and coils. When each wave reached the fixed end of the rope or coil, the wave was reflected back, and so was the energy in the wave.

reflection: when the medium and energy in a wave is turned back from a hard surface.

reflect: to turn back from a hard surface.

Stop and Think

1. Draw a series of transverse waves. Label the wavelength, amplitude, trough, and crest of one of the waves.
2. What is the difference between wave speed and wave frequency? Use the examples of water waves in your answer.
3. What factor or factors affect the speed of a wave?

What's the Point?

Energy can be transferred by mechanical waves. When energy is transferred in this way, there is no transfer of matter. Two types of mechanical waves are longitudinal waves and transverse waves. In a longitudinal wave, the medium vibrates parallel to the direction in which the wave is traveling. In a transverse wave, the medium vibrates perpendicular to the direction in which the wave is traveling. Waves are described by the properties of wavelength, frequency, and amplitude. However, the speed of a wave does not depend on any of these factors. The speed of a wave depends on the medium through which it is traveling. Reflection is another important property of waves. Reflection is what happens when a wave meets a hard surface and bounces off of it. The reflected wave carries its energy with it as it reflects off the hard surface.