6.2 Wave Motion

A high-wire artist kicks one end of the wire before starting to cross. She sees a small transverse movement dart along the wire and reflect back from the far end. The time taken for this round trip will tell her if the tension is correct. A football coach blows a whistle, creating fluctuations in the positions of air molecules and air pressure within it that make a shrill sound. Children drop pebbles into a pond; the surface of the water oscillates up and down, and concentric ripples spread out in ever-expanding circles. Electrons shift energy levels at the surface of the Sun, sending fluctuating electric and magnetic fields through the vacuum of space. These are all examples of wave motion, or transmission.

We should be quite clear about what is being transmitted. It is a disturbance from some normal value of the medium that is transmitted, not the medium itself. For the wire, it was a small sideways displacement from the normal equilibrium position. For the sound, it was a slight forward and backward motion of air molecules about their normal average position. In the water, the disturbance was a raising and lowering of the water level from equilibrium. The activity within the sunshine is a little harder to imagine, but here the disturbance is a fluctuating electromagnetic field.

Investigation 6.2.1

Wave Transmission: Pulses on a Coiled Spring

If you hold a piece of rope in your hand and you move your hand up and down, a wave will travel along the rope away from you. Your hand is the vibrating source of energy and the rope is the material medium through which the energy is transferred. By moving your hand through one-half of a cycle, as shown in **Figure 1**, you can create a pulse.

During an investigation, it is sometimes easier to observe a single pulse in a spring than to try to study a wave consisting of a series of pulses. The knowledge gained by studying pulses on a spring can be applied to all types of waves. Thus, the concepts learned in this investigation are important to the study of waves.

INQUIRY SKILLS

● Questioning
○ Hypothesizing
● Predicting
○ Planning
● Conducting
● Recording
● Analyzing
● Evaluating
● Communicating

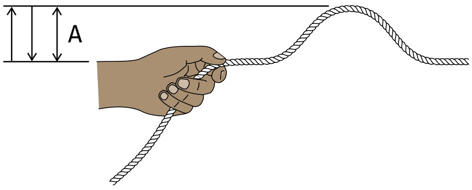

Figure 1
Producing a pulse

Questions

(i) How do pulses move along a coiled spring?
(ii) How are pulses reflected from a fixed end and a free end?

Materials

coiled spring (such as a Slinky toy)
masking tape
metre stick
piece of paper
stopwatch
string at least 4 m long

Hold the spring firmly and do not overstretch it. Observe from the side, in the case of an accidental release.

Procedure

1. Attach the masking tape to a coil near the middle of the spring. Stretch the spring along a smooth surface (such as the floor or a long table) to a length of 2.0 m. With one end of the spring held rigidly, use a rapid sideways jerk at the other end to produce a transverse pulse (**Figure 2**(**a**)). Describe the motion of the coils of the spring. (*Hint:* Watch the tape attached to the spring.)

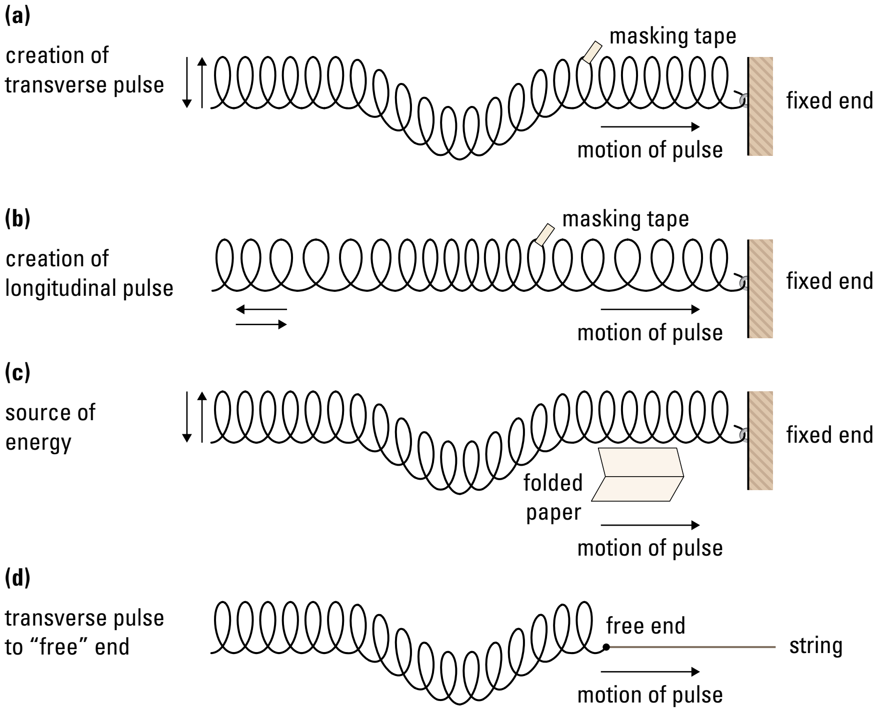

Figure 2
Procedure for Investigation 6.2.1

2. Use a rapid forward push to produce a longitudinal pulse along the spring (**Figure 2**(**b**)). Describe the motion of the coils of the spring.
3. Stand a folded piece of paper on the floor close to the end of the spring as shown in **Figure 2**(**c**). Use the energy transferred by a transverse pulse to knock the paper over. Describe where the energy came from and how it was transmitted to the paper.
4. Holding one end of the spring rigid and stretching the spring as in step 1, send a transverse pulse toward the other end. Determine whether or not the pulse that reflects off this fixed end returns on the same side of the rest axis as the original or incident pulse.
5. Tie a piece of string at least 4 m in length to one end of the spring. Using the string to stretch the spring to approximately 2.0 m, send a transverse pulse toward the string as shown in **Figure 2**(**d**). Determine whether or not the pulse that reflects off this free end of the spring returns on the same side as the incident pulse. (Note that while the free end is not truly "free" because a string is attached, it is a good approximation.)
6. Remove the string and stretch the spring to an appropriate length (e.g., 2.0 m). Measure the time taken for a transverse pulse to travel from one end of the spring to the other. Repeat the measurement several times for

accuracy while trying to keep the amplitude constant. Then find the time taken for the same type of pulse to travel from one end of the spring to the other and back again. Determine whether or not the reflected pulse takes the same time to travel the spring's length as the incident pulse.

7. Determine whether the time taken for a transverse pulse to travel from one end to the other and back again depends on the amplitude of the pulse, by sending pulses of different amplitudes and estimating the times. Repeated tests will be necessary, since the pulse moves so quickly.
8. Predict the relationship between the speed of the pulse and the stretch of the spring. Test your prediction experimentally by stretching the spring to various lengths and noting the time for a transverse pulse to travel down and back again.
9. If different types of springs are available, compare the speed of a transverse pulse along each spring.

Analysis

(a) Based on the observations in this experiment, discuss whether the following statements are true or false:
  (i) Energy may move from one end of a spring to the other.
  (ii) When energy is transferred from one end of a spring to the other, the particles of the spring are also transferred.

(b) State what happens to the speed of a pulse in a material under the following circumstances:
  (i) The condition of the material changes. For instance, stretching a spring changes its condition.
  (ii) The amplitude of the pulse increases.
  (iii) The pulse is reflected off one end of the material.

(c) A reflected pulse that is on the same side as the incident pulse is said to be in phase with the incident pulse. A reflected pulse on the opposite side of the incident pulse is out of phase with it. Is the reflected pulse in phase or out of phase for
  (i) fixed-end reflection?
  (ii) free-end reflection?

Evaluation

(d) Evaluate the prediction you made in step 8 of the procedure.

Transverse Waves

When a water wave moves across an ocean or a lake, it moves at a uniform speed. But the water itself remains in essentially the same position, merely moving up and down as the wave goes by. Similarly, when a rope is being vibrated at one end, the rope itself does not move in the direction of the wave motion; sections of the rope move back and forth or up and down as the wave travels along it.

Water waves and waves in a rope are examples of transverse waves (**Figure 3**). In a **transverse wave** the particles in the medium vibrate at right angles to the

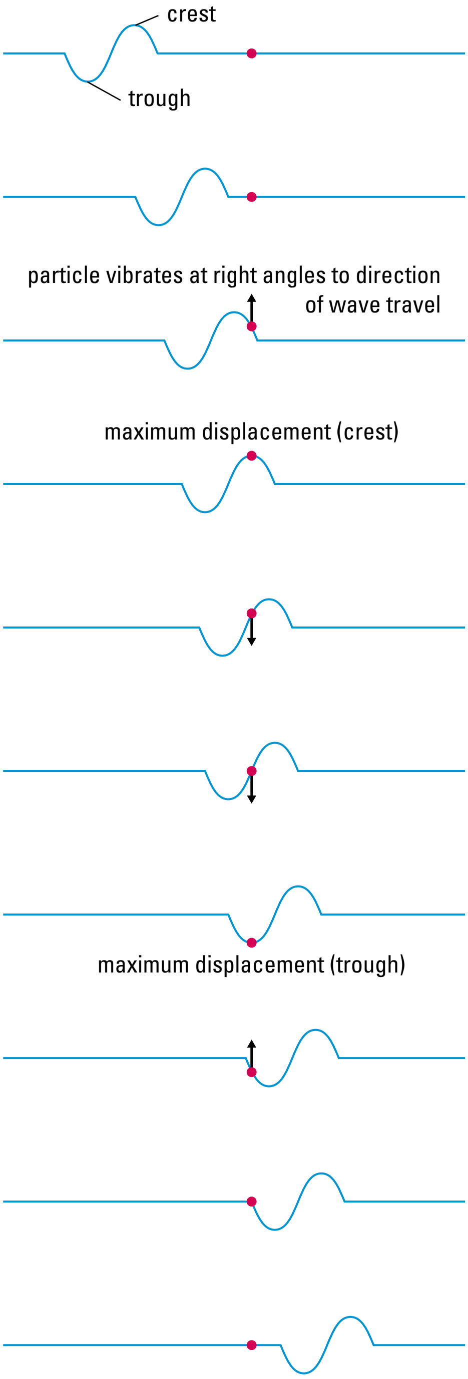

Figure 3
A crest moves through a rope from right to left.

transverse wave: particles in the medium move at right angles to the direction in which the wave travels

crest or **positive pulse:** high section of a wave

trough or **negative pulse:** low section of a wave

periodic waves: originate from periodic vibrations where the motions are continuous and are repeated in the same time intervals

pulse: wave that consists of a single disturbance

wavelength: (λ) distance between successive wave particles that are in phase

direction in which the wave travels. The high section of the wave is called a **crest** and the low section is called a **trough**. Since the crest lies above and the trough below the rest position (equilibrium), a crest can be referred to as a **positive pulse** and a trough as a **negative pulse**.

Periodic waves are waves where the motions are repeated at regular time intervals. However, a wave can also consist of a single disturbance called a **pulse**, or shock wave.

In periodic waves, the lengths of successive crests and troughs are equal. The distance from the midpoint of one crest to the midpoint of the next crest (or from the midpoint of one trough to the midpoint of the next) is called the **wavelength** and is represented by the Greek letter λ (lambda).

We have said that the amplitude of a wave is the distance from the rest position to maximum displacement. For a simple periodic wave, the amplitude is the same on either side of the rest position. As a wave travels through a medium, its amplitude usually decreases because some of its energy is being lost to friction. If no energy were required to overcome friction, there would be no decrease in amplitude and the wave would be what is called an ideal wave (**Figure 4**).

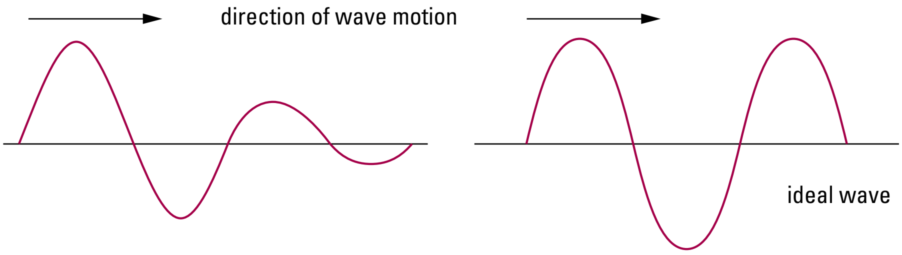

Figure 4
To make analysis easier, we will assume that the waves we are examining are ideal waves.

Longitudinal Waves

longitudinal wave: particles vibrate parallel to the direction of motion of the wave

compression: region in a longitudinal wave where the particles are closer together than normal

rarefaction: region in a longitudinal wave where the particles are farther apart than normal

In some types of waves the particles vibrate parallel to the direction of motion of the wave, and not at right angles to it. Such waves are called **longitudinal waves**. Longitudinal waves can be produced in "slinky" springs by moving one end of the spring back and forth in the direction of its length (**Figure 5**).

The most common longitudinal waves are sound waves, where the molecules, usually air, are displaced back and forth in the direction of the wave motion. In a longitudinal wave, the regions where the particles are closer together than normal are called **compressions**; the regions where they are farther apart are called **rarefactions**.

In longitudinal waves, one wavelength is the distance between the midpoints of successive compressions or rarefactions (refer to **Figure 5**). The maximum displacement of the particles from the rest position is the amplitude of the longitudinal wave. This will be discussed in more detail in Chapter 7.

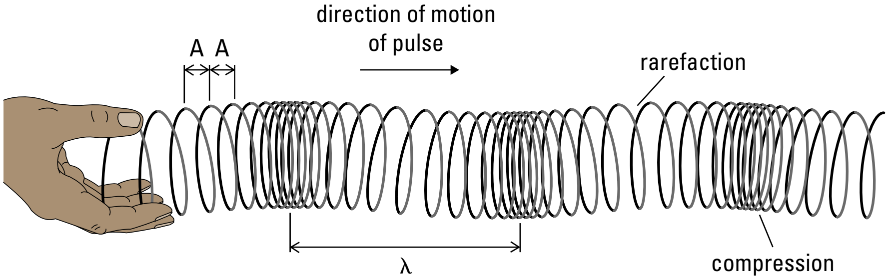

Figure 5
Longitudinal waves in a coiled spring

Sample Problem

Draw a periodic transverse wave consisting of two wavelengths with A = 1.0 cm and $\lambda = 2.0$ cm.

Solution

Draw the rest axis (PQ), then draw two lines 1.0 cm above and below PQ as shown in **Figure 6**. Label a starting point (B) and mark the points where the wave will cross the rest axis (at D, F, H, and J). Between B and D, mark the top of the crest (C) and mark all other crests and troughs in a similar fashion. Finally, draw a smooth curve joining the outlined points.

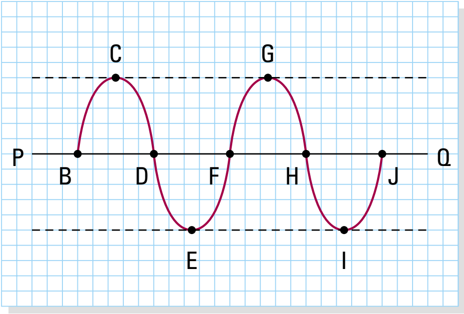

Figure 6
For Sample Problem

Practice

Understanding Concepts

1. A cross-section of a wave is shown in **Figure 7**. Name the parts of the wave indicated by the letters on the diagram.
2. Measure the amplitude and wavelength of the periodic transverse wave in **Figure 7**.
3. Measure the wavelength of the periodic longitudinal wave in **Figure 8**.
4. Draw a periodic wave consisting of two complete wavelengths, each with λ = 4.0 cm, for
   (a) a transverse wave (use A = 0.5 cm)
   (b) a longitudinal wave
5. **Figure 9** shows the profile of waves in a ripple tank.
   (a) Find the wavelength and the amplitude of the waves.
   (b) If crest A takes 2.0 s to move to where crest C is now, what is the speed of the waves?

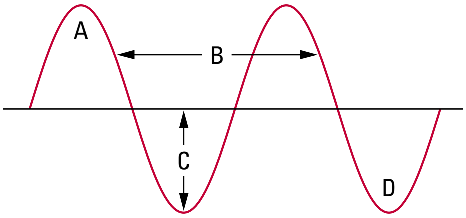

Figure 7
For questions 1 and 2

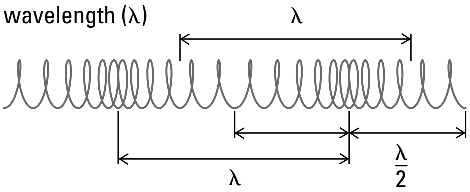

Figure 8
For question 3

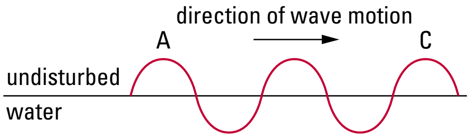

Figure 9
For question 5

SUMMARY Wave Motion

- Periodic waves originate from periodic vibrations where the motions are continuous and are repeated in the same time intervals.
- In a transverse wave, the particles of the medium move at right angles to the direction of the wave motion.
- In a longitudinal wave, the particles in the medium vibrate parallel to the direction in which the wave is moving.
- A transverse wave consists of alternate crests and troughs.
- A longitudinal wave consists of alternate compressions and rarefactions.
- One wavelength is the distance between equivalent points on successive crests or troughs in a transverse wave.
- In a longitudinal wave, one wavelength is the distance between the mid-points of successive compressions or rarefactions.
- The speed of a wave is unaffected by changes in the frequency or amplitude of the vibrating source.

Section 6.2 Questions

Understanding Concepts

1. Explain the difference between transverse and longitudinal waves.
2. Define the terms amplitude and wavelength.
3. Examine **Figure 10**.
   (a) List all pairs of points that are in phase.
   (b) Determine the wavelength, in centimetres, by measurement.
   (c) Determine the speed of the waves, if they take 0.50 s to travel from X to Y.

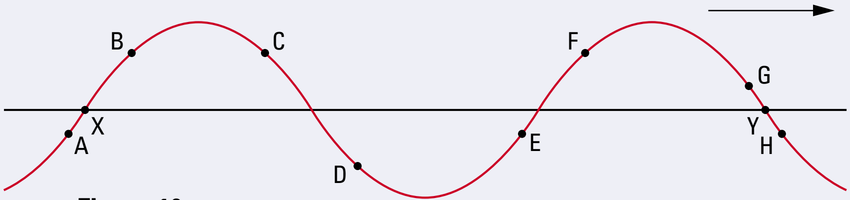

Figure 10

4. If you send a pulse down a long taut rope, its amplitude diminishes the farther it travels until eventually the pulse disappears. Explain why, using the law of conservation of energy.
5. A popular activity at a stadium sporting event is the “audience wave.” The people in one section stand up quickly, then sit down; the people in the adjacent sections follow suit in succession, resulting in a wave pattern moving around the stadium. What type of wave is this? Why?
6. Describe one or more situations in your everyday life that involve waves of some kind.

Applying Inquiry Skills

7. How could you demonstrate a pulse given six billiard balls and a flat billiard table?

Making Connections

8. In 1883, a tsunami wave hit the coast of Java and Sumatra in the Pacific Ocean. Do some research on tsunamis to answer the following questions.
   (a) What type of wave is a tsunami?
   (b) What was the amplitude or range of amplitudes of the 1883 wave when it hit the shore?
9. Lithotripsy is a common treatment for kidney stones. Do some research on lithotripsy to answer the following questions. Follow the links for Nelson Physics 11, 6.2.
   (a) What are kidney stones?
   (b) How does lithotripsy help remove kidney stones?
   (c) What is the traditional method for removing kidney stones?
   (d) Why is lithotripsy the preferred method today?

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