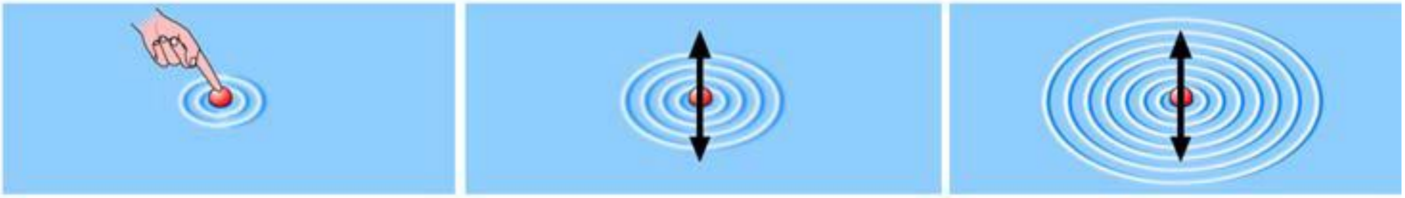
9.2 Waves

A **wave** is an oscillation that travels from one place to another. A musician's instrument creates waves that carry sound to your ears. When you throw a stone into a pond, the energy of the falling stone creates waves in the water that carry energy to the edge of the pond. In this section you will learn about waves.

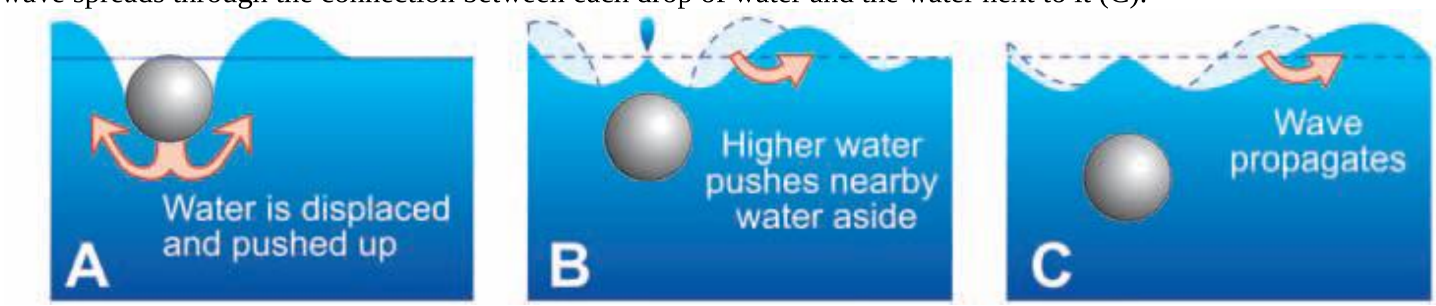
Why learn about waves?

What is a wave? If you poke a floating ball, it oscillates up and down. But, something else happens to the water as the ball oscillates. The surface of the water oscillates in response and the oscillation spreads outward from where it started. *An oscillation that travels is a wave*.



Why do waves travel?

When you drop a ball into water, some of the water is pushed aside and raised by the ball (A). The higher water pushes the water next to it (B). The water that has been pushed then pushes on the water next to *it*, and so on. The wave spreads through the connection between each drop of water and the water next to it (C).



Energy and information

Waves are a traveling form of energy because they can change motion. Waves also carry information, such as sound, pictures, or even numbers (Figure 9.9). Waves are used in many technologies because they can quickly carry information over great distances. All the information you receive in your eyes and ears comes from waves.

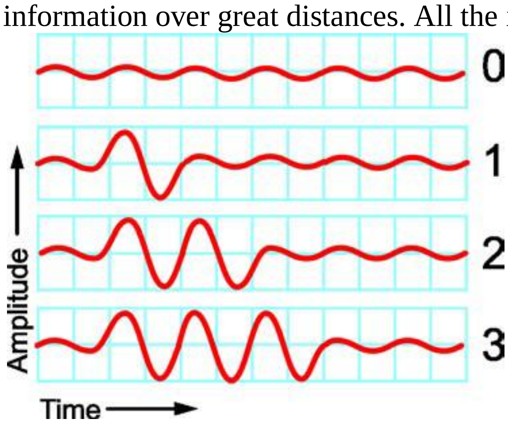


Figure 9.9: *One way to represent numbers using the waves.*

Frequency, amplitude, and wavelength

Waves are oscillators

Like all oscillations, waves have cycles, frequency, and amplitude. The frequency of a wave is a measure of how often it goes up and down at any one place (Figure 9.10). The frequency of one point on the wave is the frequency of the whole wave. Distant points on the wave oscillate up and down *with the same frequency*. A wave carries its frequency to every place it reaches. Like other frequencies, the frequency of a wave is measured in *hertz* (Hz). A wave with a frequency of one hertz (1 Hz) causes everything it touches to oscillate at one cycle per second.

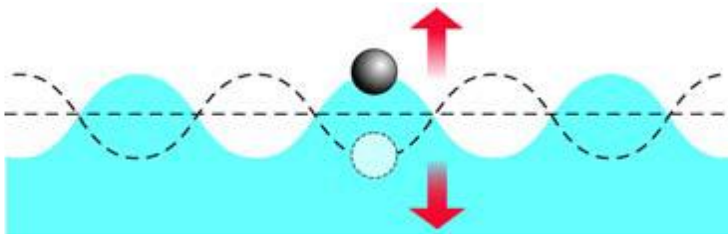


Figure 9.10: *The frequency of a wave is the rate at which every point on the wave moves up and down.*

Wavelength
You can think of a wave as a moving series of high points and low points. A *crest* is the high point of the wave, a *trough* is the low point. **Wavelength** is the distance from any point on a wave to the same point on the next cycle of the wave (Figure 9.11). The distance between one crest and the next crest is a wavelength. So is the distance between one trough and the next trough. We use the Greek letter "lambda" for wavelength. A lambda (λ) looks like an upside down "y."

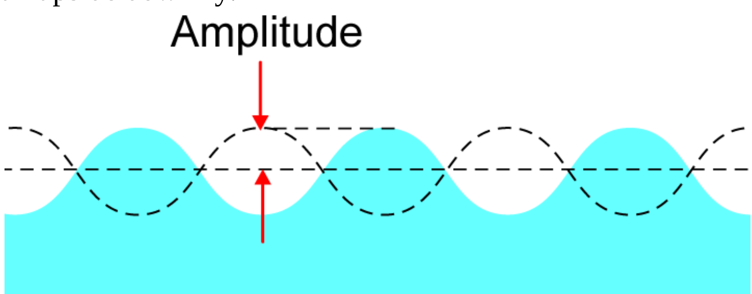


Figure 9.11: *The amplitude of a water wave is the maximum height the wave rises above the level surface.*

Amplitude
The amplitude of a wave is the maximum amount the wave causes anything to move away from equilibrium. Equilibrium is the average, or resting position (Figure 9.12). You can measure amplitude as onehalf the distance between the highest and lowest points.

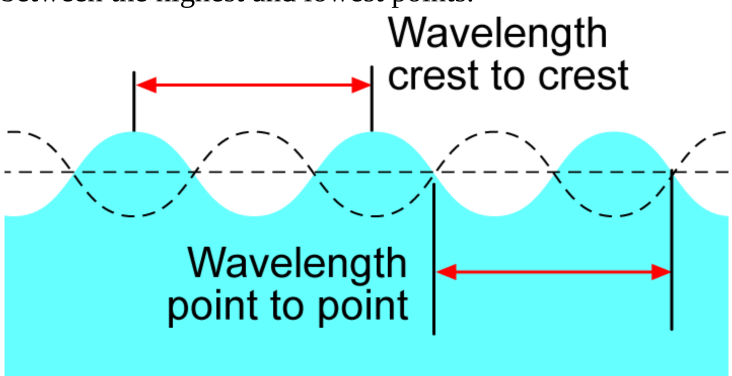


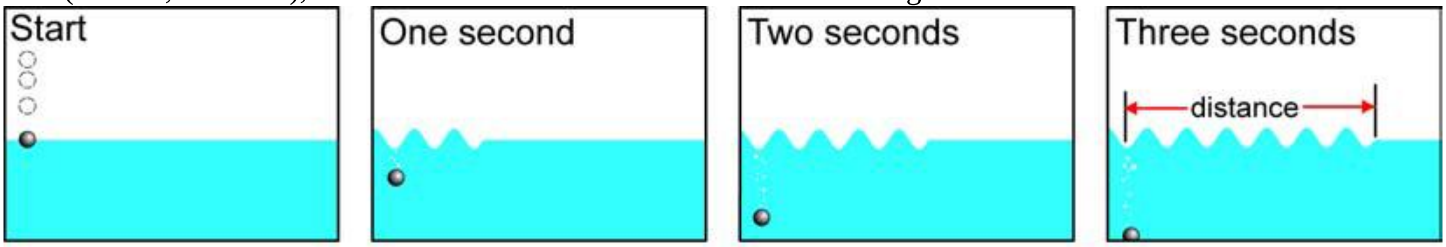
Figure 9.12: *The wavelength can be measured from crest to crest. This is the same as the distance from one point on wave to the same point on the next cycle of the wave.*

The speed of waves

What is moving?
The speed of a wave is different from the speed of a moving object, like a ball. The speed of a ball is the speed at which the ball itself moves. The speed of a wave is the speed at which the wave *spreads*. When a wave moves through water, *the water itself stays in the same average place*.

What is the speed of a wave?
The illustration below shows how to measure the speed of a wave. You start a wave in one place and measure how long it takes the wave to affect a place some distance away. The speed of the wave is how fast the wave spreads, NOT how fast the water surface moves up and down. The speed of a water wave is a few miles per hour. Light

waves are extremely fast—186,000 miles per *second* (300,000 km/s). Sound waves travel at about 660 miles per hour (about 1,000 km/h), faster than water waves and much slower than light waves.



Speed is frequency times wavelength

In one complete cycle, a wave moves forward one wavelength (Figure 9.13). The speed is the distance traveled (one wavelength) divided by the time it takes (one period). Actually, we usually calculate the speed of a wave by multiplying wavelength and frequency. This is mathematically the same since multiplying by frequency is the same as dividing by period. The result is true for all kinds of waves, including water waves, sound waves, light waves, and even earthquake waves!

$$Speed = \frac{\text{Distance traveled}}{\text{Time taken}} = \frac{\text{Wavelength}}{\text{Period}} = \left(\frac{1}{\text{Period}}\right) \times \text{Wavelength}$$

$$Speed = Frequency \times Wavelength$$

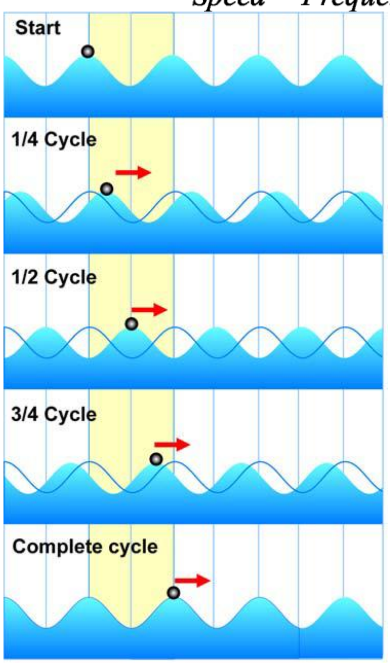


Figure 9.13: *A wave moves one wavelength in each cycle. Since a cycle takes one period, the speed of the wave is the wavelength divided by the period. Mathematically, this is the same as saying speed is frequency times wavelength.*

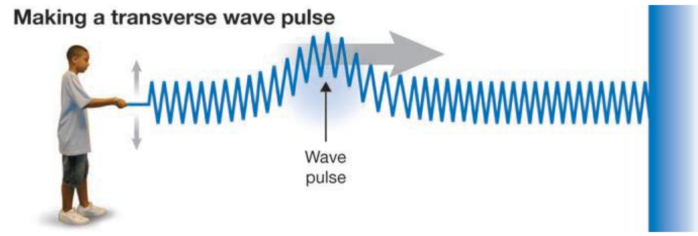
Transverse and longitudinal waves

Wave pulses

A wave *pulse* is a short 'burst' of a traveling wave. A pulse can just be a single up-down movement. The illustrations below show wave pulses in ropes and springs. It is sometimes easier to see the motion of wave pulses than it is to see long waves with many oscillations.

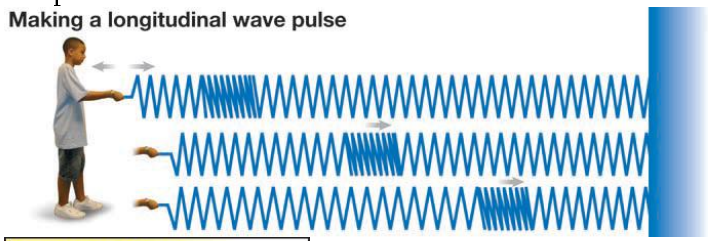
Transverse waves

There are two basic kinds of waves. The oscillations of a **transverse** wave *are not* in the direction the wave moves. For example, the wave pulse in the illustration below moves from left to right. The oscillation (caused by the girl's hand) is up and down. Water waves are also transverse waves (Figure 9.14 top).



Longitudinal waves

The oscillations of a **longitudinal** wave *are* in the same direction that the wave moves (Figure 9.14 bottom). A large spring with one end fastened to a wall is a good way to make a longitudinal wave. A sharp push-pull on the end of the spring makes a traveling wave pulse as portions of the spring compress then relax. The direction of the compressions are in the same direction that the wave moves. Sound waves are longitudinal waves.



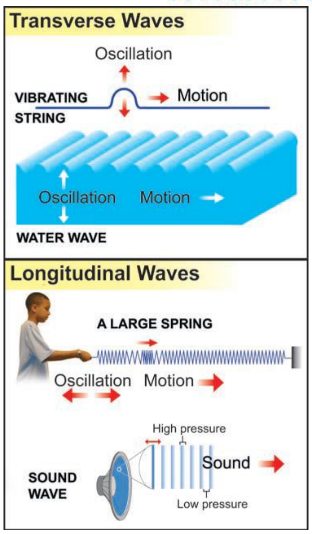


Figure 9.14: *Transverse (top) and longitudinal (bottom) waves.*

When a wave encounters objects

The four wave interactions

Have you ever heard a radio station fade out while driving into a tunnel or down into a valley? Radio signals are carried by radio waves. Like all waves, radio waves are affected by objects that get in their way. When a wave hits an object or a surface, four things can happen. The four are listed below and illustrated in Figure 9.15.

Reflection	*The wave bounces and goes in a new direction.*
Refraction	*The wave bends as it passes into and through an object.*
Diffraction	*The wave bends around an object or through holes in the object.*
Absorption	*The wave is absorbed and disappears.*

Boundaries

A *boundary* is an edge or surface where things change. The surface of a glass window is a boundary. A wave traveling in the air sees a sudden change to a new material (glass) as it crosses the boundary. Reflection, refraction, and diffraction usually occur at boundaries. Absorption also occurs at a boundary, but usually happens more within the body of a material.

Reflection

When a wave bounces off an object we call it **reflection**. A reflected wave is like the original wave but moving in a new direction. The wavelength and frequency are usually unchanged. An echo is an example of a sound wave reflecting from a distant object or wall. People who design concert halls pay careful attention to the reflection of sound from the walls and ceiling.

Refraction

Refraction occurs when a wave bends as it crosses a boundary. We say the wave is *refracted* as it passes through the boundary. Eyeglasses are a good example where refraction is used to bend light waves. People with poor eyesight have trouble focusing images. Glasses bend incoming light waves so that an image is correctly focused within the eye.

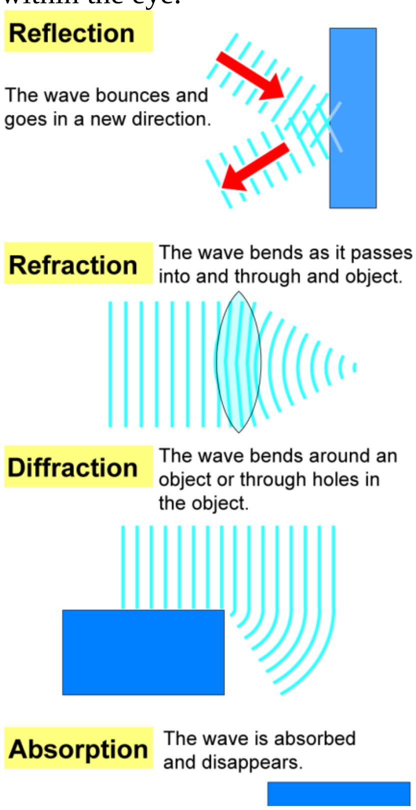
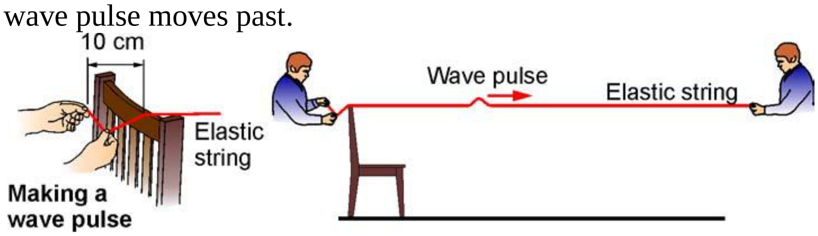


Figure 9.15: *The four basic interactions between waves and boundaries.*

Constructive and destructive interference

Wave pulses

Imagine stretching an elastic string over the back of a chair (see illustration below). To make a wave pulse, you pull down a short length of the string behind the chair and let go. This creates a wave pulse in the string that races away from the chair. The wave pulse moves *on* the string, but each section of string returns to the same place after the wave pulse moves past.



Constructive interference

Suppose you make two wave pulses on a stretched string. One comes from the left and the other comes from the right. When the waves meet, they combine to make a single large pulse. **Constructive interference** happens when waves add up to make a larger amplitude (Figure 9.16).

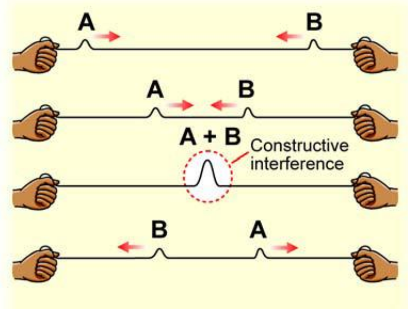


Figure 9.16: *This is an example of constructive interference.*

Destructive interference

There is another way to add two pulses. What happens when one pulse is on top of the string and the other is on the bottom? When the pulses meet in the middle, they cancel each other out (Figure 9.17). One pulse pulls the string up and the other pulls it down. The result is that the string flattens and both pulses vanish for a moment. In **destructive interference**, waves add up to make a wave with smaller or zero amplitude. After interfering, both wave pulses separate again and travel on their own. This is surprising if you think about it. For a moment, the middle of the cord is flat, but a moment later, two wave pulses come out of the flat part and race away from each other. Waves still store energy, even when they interfere. Noise cancelling headphones are based on technology that uses destructive interference.

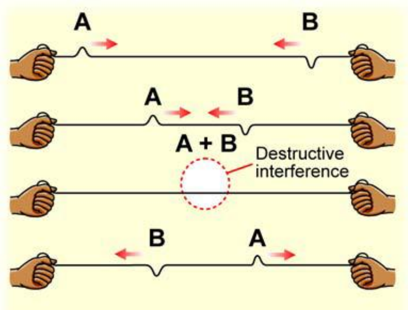


Figure 9.17: *This is an example of destructive interference.*

9.2 Section Review

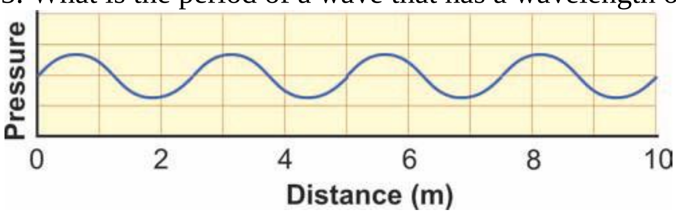
1. Which is the fastest way to send information, using sound waves, light waves, or water waves?

2. What is the difference between longitudinal and transverse waves?
a. longitudinal waves are faster
b. transverse waves are faster
c. longitudinal waves oscillate in the same direction they move
d. transverse waves oscillate in the same direction they move

3. What is the speed of a wave that has a wavelength of 0.4 meter and a frequency of 10 hertz?

4. Is a wave that travels slower than 50 m/s most likely to be a sound wave, a light wave, or a water wave?

5. What is the period of a wave that has a wavelength of 1 meter and a speed of 20 m/s?



6. The wavelength of the wave shown in the graph above is about:
a. 1.2 meters
b. 2.5 meters
c. 5.0 meters

7. One of the four wave interactions is very important to how plants use light to grow. Guess which interaction this is, and write a couple of sentences justifying your answer.

8. Two waves combine to make a wave that is larger than either wave by itself. Is this constructive or destructive interference?

9. If a wave is being absorbed, what would you expect to happen to the amplitude of the wave? Explain using the idea of energy.

VOCABULARY

wave - a traveling oscillation that has properties of frequency, wavelength, and amplitude.

wavelength - the distance from any point on a wave to the same point on the next cycle of the wave.

transverse - a wave is transverse if its oscillations *are not* in the direction it moves.

longitudinal - a wave is longitudinal if its oscillations *are* in the direction it moves.

constructive interference - when waves add up to make a larger amplitude.

destructive interference - when waves add up to make a smaller, or zero, amplitude.