6.1 Wave Properties

Warm Up

Fill a wine glass with water. Dip your finger in the water and run your wet finger around the edge of the glass until the glass starts to emit a high-pitched sound. While you are doing this, watch the surface of the water near where your finger is making the glass vibrate. Try the same activity with varying depths of water.

1. What effect does adding water to the glass have on the pitch of the sound you hear?

   ____

2. Will the glass vibrate when it is empty? Why or why not?

   ____

   ____

Good Vibrations

There are many kinds of waves in nature. You have heard of light waves, sound waves, radio waves, earthquake waves, water waves, shock waves, brain waves and the familiar wave created by a cheering crowd at a sports event. Wave motion is an important phenomenon because it is so common and it is one of the major ways in which energy can be transmitted from one place to another.

There are two basic kinds of waves. First, there is the **pulse,** which is a non-repeating wave. A single disturbance sends a pulse from the source outward, but there is no repetition of the event. For example, you may give a garden hose a quick "yank" to one side, causing a pulse to travel the length of the hose.

Second, there is the **periodic wave.** Periodic waves are probably more familiar to you. You have watched water waves moving across a pond. The waves arrive at the shore of the pond at regularly repeated time intervals. Periodic means recurring at regular intervals. Water waves are caused by a disturbance of the water somewhere in the pond.

Whether the wave is a pulse or a periodic wave, a disturbance is spread by the wave, usually through a material substance. An exception is the medium for electromagnetic radiation (light, radio, X-rays, ultraviolet, infrared, gamma radiation, etc.). The medium for electromagnetic radiation is electric and magnetic fields created by charged particles.

To have a regularly repeating wave, there must be regularly repeating vibrations. For example, the regularly repeating sound waves from a tuning fork are caused by the vibrations of the two tines of the fork disturbing the air. Vibrating electrons disturb the electric field around them to create the microwaves that cook your supper or measure the speed of your car in a radar trap.

  ISBN 978-0-9864778-3-6

Describing Waves

Wavelength (λ)

Figure 6.1.1 depicts waves emanating from a vibrating source. They could be water waves. The highest points on the waves are called **crests** and the lowest points are called **troughs**. The distance between successive crests or between successive troughs is called the **wavelength** (λ) of the wave. The symbol λ is the Greek letter lambda. The **amplitude** or height of the wave is measured from its displacement from the horizontal line in the diagram to the crest or trough. The amplitude is shown on the diagram.

Wavelengths may be measured in metres, in the case of water waves, or in nanometres (1 nm = 10^{-9}), in the case of visible light. Microwaves may be measured in centimetres, while the waves produced by AC power lines may be kilometres long. Wavelengths of audible sounds range from millimetres up to metres.

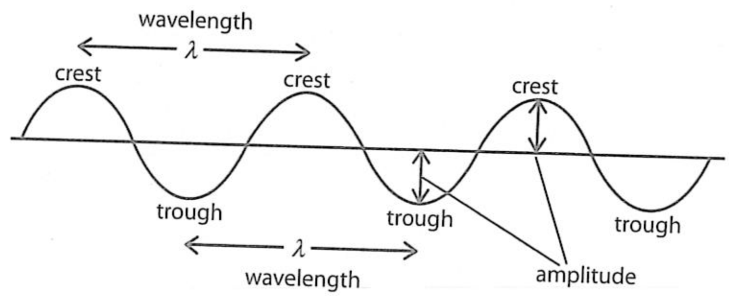

Figure 6.1.1 *Terms used for describing waves*

Frequency (f)

Another important aspect of waves is their **frequency**. The frequency of the waves tells you how often or frequently they and their source vibrate. If you are listening to a tuning fork, sound waves reach your ear with the same frequency as the vibrating fork. For example, the fork's tines vibrate back and forth 256 times in 1 s if the frequency of the fork is 256 vibrations per second. Frequency is measured in a unit called the **hertz (Hz)**. The unit is named after Heinrich Hertz (1857–1894), who was the first scientist to detect radio waves. One hertz is one vibration per second: 1 Hz = 1 s^{-1}.

A pendulum 24.8 cm long has a frequency of 1 Hz. Electrons vibrating to and fro in an alternating current circuit have a frequency of 60 Hz. Radio waves may be several kilohertz (kHz), where 1 kHz = 1 000 Hz, or they may be in the megahertz (MHz) range, where 1 MHz is equal to 1 000 000 Hz.

Period (T)

Related to the frequency of a vibration is the **period** of the vibration. The period is the time interval between vibrations. For example, if the period of a vibration is 1/2 s, then the frequency must be 2 s^{-1} or 2 Hz. Consider a pendulum with a length of 24.8 cm. It will have a frequency of 1 Hz and a period of 1 s. A pendulum 99.2 cm long will have a frequency of 1/2 Hz and a period of 2 s. A pendulum 223 cm long will have a frequency of 1/3 Hz and a period of 3 s. As you can see, frequency and period are reciprocals of each other.

$$\text{frequency} = \frac{1}{\text{period}}$$

$$f = \frac{1}{T} \text{ or } T = \frac{1}{f}$$

 ISBN 978-0-9864778-3-6

Quick Check

1. A dog's tail wags 50.0 times in 40.0 s.
   (a) What is the frequency of the tail?

   ____

   (b) What is the period of vibration of the tail?

   ____

2. A certain tuning fork makes 7680 vibrations in 30 s.
   (a) What is the frequency of the tuning fork?

   ____

   (b) What is the period of vibration of the tuning fork?

   ____

3. Tarzan is swinging back and forth on a vine. If each complete swing takes 4.0 s, what is the frequency of the swings?

   ____

Transverse and Longitudinal Waves

Figure 6.1.2 illustrates two ways to send a pulse through a long length of spring or a long Slinky. In method (a), the spring is pulled sideways, so that the disturbance is at right angles to the direction that the pulse will travel. This produces a **transverse wave.** In method (b), several turns of the spring are compressed and let go. The disturbance is in the same direction as the direction the pulse will travel. This produces a **longitudinal wave.** Transverse means *across* and longitudinal means *lengthwise*.

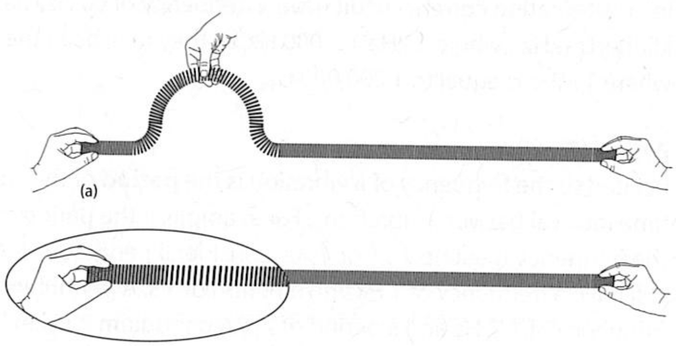

Figure 6.1.2 *(**a**) A transverse wave; (**b**) A longitudinal wave*

 ISBN 978-0-9864778-3-6

Wave Reflection and Refraction

When a wave encounters a boundary like a shoreline, wall or another medium, several things can happen. The two most common things are the wave will reflect or refract. **Reflection** occurs when a wave hits an object or another boundary and the wave is reflected back. If you attach or hold one end of a spring and send a wave down the spring, you will see it reflect off the end. Usually not all the wave is reflected back as some can be absorbed or refracted. **Refraction** is a bending of the wave and occurs when the wave hits an object at an angle or the wave enters a new medium. Refraction results from the change in the waves speed. The changing speed causes the wave to bend.

The Wave Equation

The wave shown in Figure 6.1.3 is moving through water in a wave tank. The waves in the wave tank are produced by a wave generator, which vibrates up and down with a frequency f and a period T where $T = 1/f$.

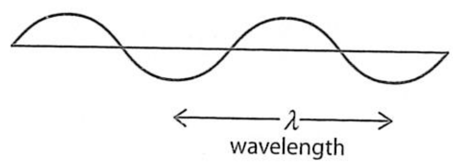

Figure 6.1.3 *A wave in a wave tank*

What is the speed of the wave? If you could see the wave tank, you could watch a wave travel its own length, or wavelength λ, and time exactly how long the wave takes to travel its own length. Since the waves are generated once every T seconds by the generator, then this T should be the period of the waves. To calculate the speed v of the waves, all you have to do is divide the wavelength by the period of the wave.

$$v = \lambda/T$$

Since $$T = 1/f \text{ or } f = 1/T$$

$$v = f\lambda$$

This relationship is a very important one, because it is true for any kind of wave. This includes sound waves, earthquake waves, waves in the strings of musical instruments or any kind of electromagnetic wave (light, infrared, radio, X-radiation, ultraviolet, gamma radiation, etc.)! In words, the wave equation says

wave speed = wavelength × frequency

Sample Problem 6.1.1 — Calculating Wave Speed

What is the speed of a sound wave if its frequency is 256 Hz and its wavelength is 1.29 m?

What to Think About	How to Do It
1. Determine what you need to find.	speed of sound
2. Select appropriate formula.	$v = \lambda f$
3. Find the speed of sound	$v = (1.29 \text{ m})(256 \text{ s}^{-1}) = 330 \text{ m/s}$

Practice Problems 6.1.1 — Calculating Wave Speed

1. If waves maintain a constant speed, what will happen to their wavelength if the frequency of the waves is
   (a) doubled?

   (b) halved?

2. What is the frequency of a sound wave if its speed is 340 m/s and its wavelength is 1.70 m?

3. Waves of frequency 2.0 Hz are generated at the end of a long steel spring. What is their wavelength if the waves travel along the spring with a speed of 3.0 m/s?

The Wave Tank as a Wave Model

The wave tank is an ingenious device that permits us to study the behaviour of waves using a water wave model. If a series of waves is generated by moving a piece of wood dowelling back and forth in a regularly repeating motion, the waves will look like the ones in Figure 6.1.4 if seen from the side. The actual water waves are transverse in nature.

If light from a point source is allowed to pass through the waves and fall on a large sheet of white paper, the light passing through the waves will form bright lines on the paper underneath the crests of the waves. In Figure 6.1.4, the point source of light is the end of the filament of a straight-filament, clear light bulb. The crests act as convex lenses and make the light from the source converge or come together. The troughs, on the other hand, act as concave lenses and make the light from the source diverge or spread out. The image you see on the white screen consists of a series of bright lines with dark spaces between successive bright lines. The bright lines represent crests and the dark areas represent troughs. The waves you see on the screen are longitudinal waves, whereas the actual water waves were transverse.

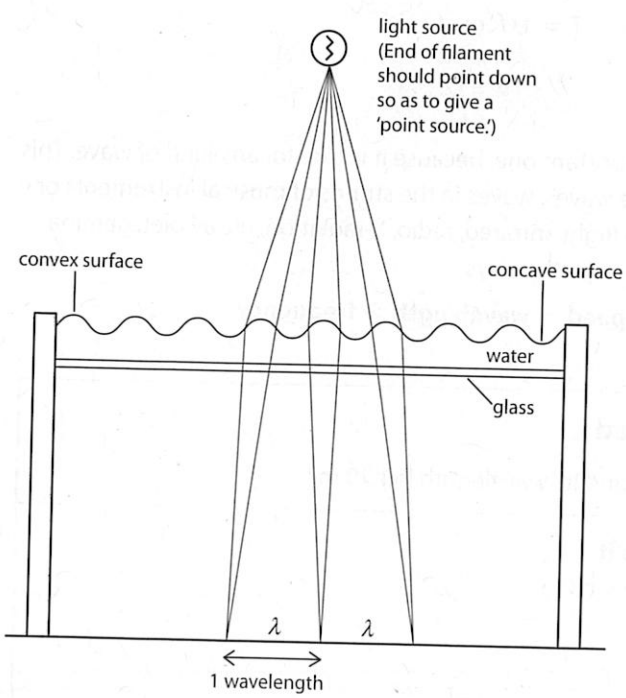

Figure 6.1.4 *Using a light source to observe water waves in a wave tank*

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