Waves

Figure 8.1: If a wet finger is pushed around the edge of a wine glass filled with water, vibrations are set up, which cause a high-pitched, pleasant sound. Notice the waves that are generated in the water by the vibrations of the glass.

8.1 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, of course, the familiar wave created by a partisan crowd at a sports event.

Wave motion is an important phenomenon because it is so commonplace, and because 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 **propagated** by the wave, usually through a material substance. The medium for electromagnetic waves (light, radio, X-rays, ultraviolet, infrared, gamma radiation, etc.) is not a material, but 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 disturbance of the air by the vibrations of the two tines of the fork. Vibrating electrons, which create disturbances in the electric field around the electrons, create the microwaves that cook your supper, or measure the speed of your car in a radar trap.

Describing Waves

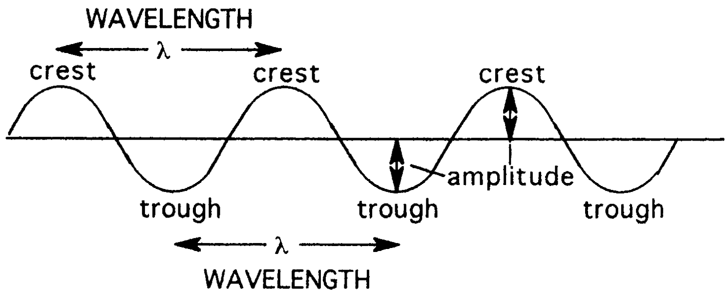

Figure 8.2

Wavelength (λ)

Figure 8.2 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 height of the wave (its displacement from the horizontal line in the diagram) is the **amplitude** of the wave. The amplitude is shown on the diagram.

Wavelengths may be measured in metres, in the case of water waves, or in nanometers (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.

Frequency (*f*)

Another important aspect of waves is the **frequency** of the waves. The frequency of the waves tells you 'how 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. The fork's tines vibrate back and forth, for example, 256 times in one second 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.

$$\mathbf{1\ Hz = 1\ s^{-1}}$$

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 1kHz = 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. If its length is 24.8 cm, it will have a frequency of 1 Hz and a period of 1 s. If its length is 99.2 cm, it 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.

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

In symbolic form, $f = \frac{1}{T}$, or $T = \frac{1}{f}$.

Transverse and Longitudinal Waves

Figure 8.3 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’.

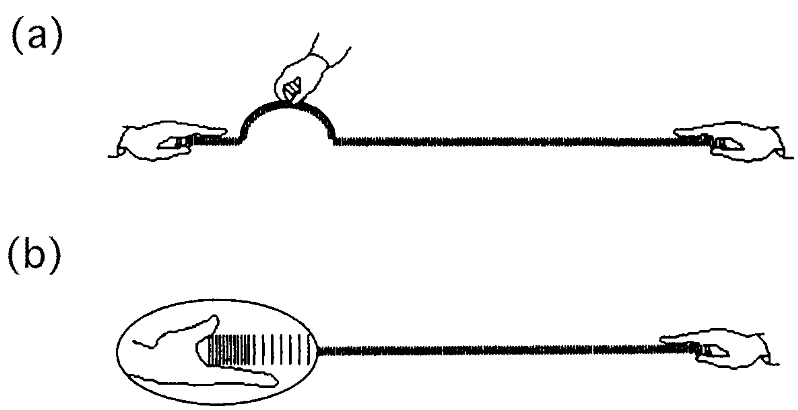

Figure 8.3

8.5 The Wave Equation

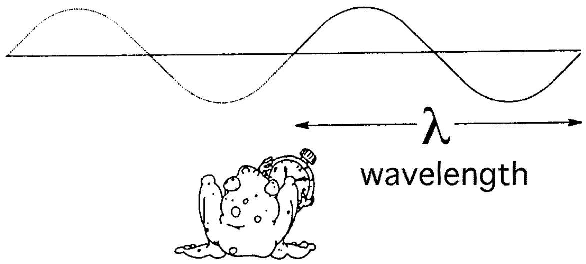

Figure 8.6

Freddie the frog (**Figure 8.6**) is sitting on the edge of a wave tank, watching the waves go by. See. He knows that the waves were produced by a wave generator, which vibrates up and down with a frequency f and a period,

$$T = 1 / f.$$

Being a dedicated physicist, Fred wants to know what the speed of the waves is. He watches a wave travel its own length (wavelength λ) and times 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 he has to do is divide the wavelength by the period of the wave! In symbolic form, $v = \lambda / T$.

Now, since $T = 1/f$, or $f = 1/T$, then

$$\boxed{v = \lambda f.}$$

This relationship is a very important one, because it is true for *any kind of waves.* 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 x frequency.

Example:

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

Solution: $v = \lambda f = (1.29\text{ m})(256\text{ s}^{-1}) = 330\text{ m/s}.$

The Speed of Sound

At a temperature of 20^{o}C, which is normal room temperature, sound will travel about 340 m/s in air, which is the same as 1220 km/h. The speed limit for vehicles on a modern highway might be 100 km/h, so the speed of sound in air is 12 times this highway speed limit!

Although the usual medium for sound is the air around us, air is not a good conductor of sound. Many materials conduct sound much better than air. The best sound conductors are made of elastic materials such as steel, glass or aluminum. Inelastic materials do not transmit sound energy as effectively.

Properties of Sound

Pitch

The **pitch** of a sound is our subjective impression of the **frequency** of the sound. The very low pitch of the piano note from the far left of the keyboard has a frequency of 27.5 Hz, while the very high pitch from the far right of the keyboard has a frequency of over 4 000 Hz!

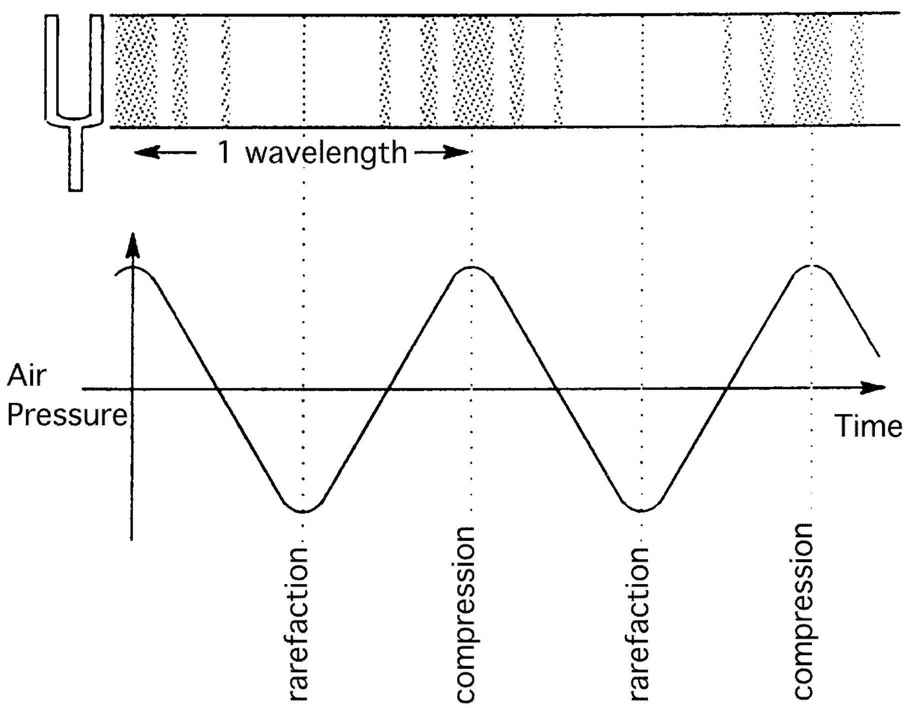

Figure 9.3

It is an interesting exercise to observe the waveforms of sounds of different pitches on the screen of an **oscilloscope**. Sound waves are **longitudinal** waves. (The air molecules vibrate to-and-fro in the direction of travel of the sound.) But the oscilloscope displays sound waves as if they were **transverse** waves. (In transverse waves, the vibration is in a direction *perpendicular* to the direction of travel of the wave. Water waves are a good example of transverse waves.)

What you see on the oscilloscope screen is actually a graph of air pressure vs time. A **compression** represents a region of unusually high air pressure, whereas a **rarefaction** is a region of low air pressure. **Figure 9.3** shows that a compression will register as a 'peak' in the pressure-time graph that you see on the oscilloscope screen. A rarefaction appears as a 'dip' in the graph.

Imagine you are listening to a high-pitched tone of frequency 3 000 Hz. This means that there are 3 000 compressions and 3 000 rarefactions arriving at your ear every second. If you were looking at this sound on the oscilloscope screen, you would see peaks for the compressions, and dips for the rarefactions. On the horizontal time scale, the peaks would be spaced 1/3 000 s apart, or 0.00033 s.

Loudness

The frequency of sound vibrations is what determines the pitch of a sound. On the oscilloscope screen, the number of waves you see on the screen in a unit of time provides an indicator of the frequency, and therefore the pitch.

You may have noticed in ***Investigation 9-3*** that if the sound was *louder,* the height of the waves was greater. In fact, the **amplitude** is a measure of the loudness of a sound. The greater the wave amplitude is, the louder the sound will be.

Light

Many useful devices have been developed because of growing knowledge of how light behaves. One can describe many of the properties of light without knowing exactly what light is, and one can invent many devices that use these properties. Cameras, eyeglasses, mirrors, microscopes, periscopes, magnifying glasses, spectroscopes and various kinds of projectors are some of the optical devices that use well-known properties of light. In this chapter, you will investigate some of the important properties of light.

10.1 The Speed of Light

The speed limit for the universe appears to be the speed of light in a vacuum, which is

$$\mathbf{2.99792458 \times 10^8\ m/s} \text{ or } \mathbf{2.99792458 \times 10^5\ km/s.}$$

In air, the speed of light is slightly less, but the difference does not appear until the fourth digit past the decimal point. For most purposes, the speed of light in a vacuum or in air can be taken to be

$$\mathbf{3.00 \times 10^8\ m/s}, \text{ or } \mathbf{3.00 \times 10^5\ km/s}.$$

Just how fast is the speed of light? If a plane travels at the speed of sound, it is considered to be moving very fast. But the speed of sound is a mere 330 m/s. To get a rough idea of how this compares with the speed of light, round it off to 3 x 10^2 m/s. The ratio of speed of light to the speed of sound is approximately

$$\frac{3 \times 10^8 \text{ m/s}}{3 \times 10^2 \text{ m/s}} = 10^6!$$

The speed of light is about one million times the speed of sound! To travel the length of a typical classroom, light would take only about 10^{-7} s, or 0.000 000 1 s. Light from the moon takes 1.3 s to reach us, and light from the sun takes about 8.3 min to travel to earth!

Reflection of Light

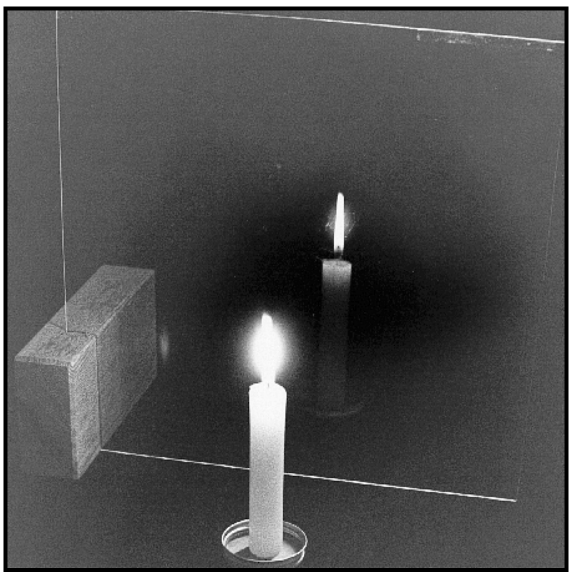

Figure 10.6

You probably take mirrors for granted, since you use them all the time, probably without thinking about what they actually do to the light that strikes them. If you look into mirrors more seriously, they will probably give you a lot to reflect on!

If you look directly into a mirror and wiggle your left ear, which ear will your image wiggle? (If you have difficulty wiggling your ear, try winking your left eye instead.)

If you look at yourself in a wall mirror, note what fraction of your body you see in the mirror. Now walk back a few metres and look into the same mirror. Do you see more of your body, less or the same fraction of your body?

You are a basketball player, 2 m tall. What is the shortest mirror you need to see your whole self in it? (This is a 3-point question!)

At night, have you ever seen your image in your living room window? Why don't you see it during the daytime?

When you look into a mirror, where exactly *is* your image? Is it on the mirror surface, in front of it or behind it? If you move closer to the mirror, what happens to your image?

In ***Investigation 10-2,*** you will experiment with mirror images, and you should be able to answer some of these questions when you are finished.

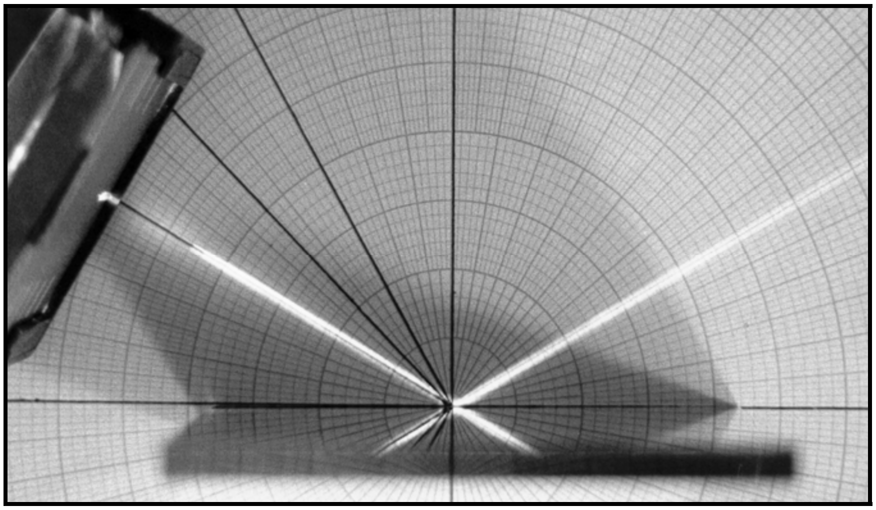

Figure 10.4

Light travels in straight lines — sometimes. See **Figures 10.4**.
The angle of incidence = the angle of reflection.

Wavelengths We Use But Cannot See

If a beam of white light is dispersed with a prism, and the spectrum viewed on screen, you will see all the colours from violet to red on the screen. In the early nineteenth century the English astronomer **William Herschel (1738-1822)** was experimenting to see which colours of light gave the greatest heating effect when allowed to shine on a blackened bulb of a thermometer. He moved the thermometer bulb through the various parts of the visible spectrum and observed increases in temperature caused by the different colours of light. He discovered to his surprise that the greatest heating effect was observed if the bulb was placed *beyond* the red end of the visible spectrum! This is how **infrared radiation** was discovered.

Infrared radiation is extremely important to us. Infrared radiation from the sun provides most of the thermal energy requirements of the planet. Scientists have developed infrared photographic techniques that permit satellite pictures of features on the earth's surface, which can be taken through clouds or fog or smoke. Objects can be photographed in the dark using infrared photography. Some auto focus cameras use infrared for focusing, which means they work in the dark. Infrared has many uses, including heat lamps, physiotherapy and medical diagnostic photography. Astronomers are now making good use of infrared images of the stars and other objects in the universe.

Infrared wavelengths cover a wide range, the shortest wavelength beginning at the red end of the visible spectrum (760 nm) and the longest wavelength being approximately 300 000 nm. Beyond the infrared lies the radio part of the spectrum.

In 1801, the German physicist, **Johann Wilhelm Ritter (1776-1810)**, was studying the effect of visible light on the chemical compound silver chloride, AgCl.

When light falls on silver chloride, the white compound decomposes and forms silver (which appears black) and chlorine, which escapes into the atmosphere. This is similar to the chemical reaction employed in photography where silver bromide is used.

Ritter knew that the effect was most noticeable at the violet end of the spectrum. He was surprised to find that if silver chloride was placed in a region beyond the violet end of the visible spectrum, the decomposition of the silver chloride was even more pronounced! Thus, **ultraviolet radiation** was discovered.

You cannot see ultraviolet, but it is wise to know about it anyway. It is ultraviolet light that gives you a suntan or sunburn. Too much exposure to the sun or to ultraviolet-rich sunlamps can be dangerous. Ultraviolet can also damage parts of your retina, thus impairing your vision.

'Black lights', sold for the purpose of making posters fluoresce, are actually sources of ultraviolet light. They also give off light in the violet part of the spectrum. Some black lights are essentially mercury vapour lamps, like fluorescent lamps used to light your classroom. Instead of having an inner coating of fluorescent chemicals, they have a violet-coloured glass tube that allows violet and ultraviolet light to pass through it.