CHAPTER 14

Wave Motion in Two Dimensions

INTRODUCTION 14.1

Waves in springs, strings, or even hoses move in only one dimension — along the material and back again. However, sound waves, water waves and light waves can move in any number of directions. This is true for the majority of waves that occur in nature. Can you think of other types of waves that are not confined to movement in one direction?

In this chapter we will look at some of the characteristics of waves that propagate in all directions.

Did you know the following facts?

- Locating earthquakes, using ultrasound on unborn babies, and bats' echolocation have something in common. Can you name it?
- The highest wave ever recorded was 34 m from crest to trough, produced during a hurricane in 1933.
- A landslide in 1958 produced a wave 24 m high in a canyon-like fiord in Alaska.
- The highest wave ever ridden was a tsunami that struck Hawaii in 1868. It was surfed in by a man named Holua, to save his own life.

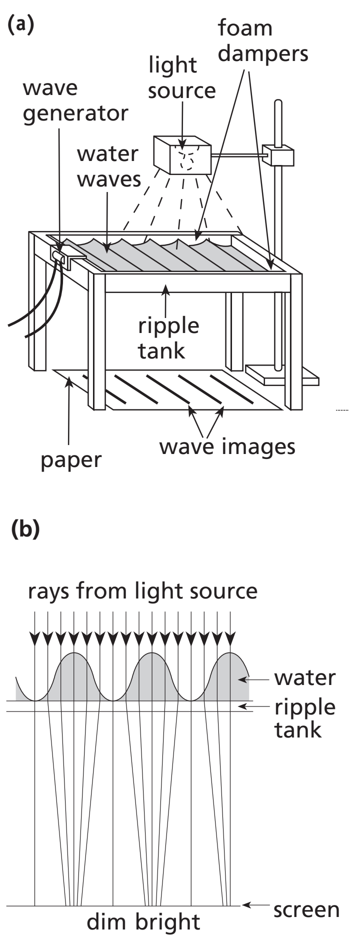


Figure 14.1
(a) A ripple tank used to study water waves. **(b)** Crests focus light to produce bright regions while troughs spread the light out to produce dark regions.

WATER WAVES — WAVEFRONTS 14.2

The problem with analysing and observing sound and light waves is that they cannot be seen. It is impossible to see and observe light waves. Why is this?

However, water waves can be generated and observed quite readily. All of us at some stage have observed or enjoyed waves at the beach. Surfers use the energy of waves to carry them forward. Many water amusement parks have wave generators to produce waves for the enjoyment of the patrons. In the laboratory, wave generators create water waves in a **ripple tank** (Figure 14.1**(a)**).

The ripple tank consists of a square tray with a glass bottom to allow a light to shine through. The sides are normally metal and are lined with foam rubber to absorb waves and thus stop reflections that may interfere with what is being observed. About 2 cm of water is placed in the tray. A light source is placed above the tray, and shines through the water and transparent bottom onto a screen placed under the tank. Waves are generated by means of an electric motor to which is attached beads to create circular waves, or a straight rod to produce straight waves. These dip into the water to create the waves as the motor turns.

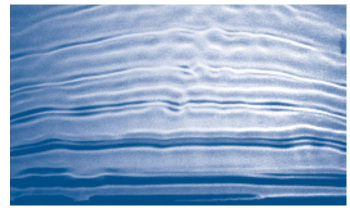
The waves produced in the ripple tank have the same characteristics as any transverse waves. They consist of crests and troughs. The crests act like converging lenses to the light from the light source and focus the light, creating bright areas on the screen. The troughs act like diverging lenses and spread the light out, producing dark areas on the screen, as shown in Figure 14.1**(b)**.

The shape of the **wavefront** depends on the shape of the '**dipper**' producing the wave. If a bead is used, circular wavefronts will be produced. If a straight bar is used, straight wavefronts will be produced as shown in the photo. The distance between crests or wavefronts is a wavelength.

The **crests** of these waves move away from the source. The direction of propagation of the wave is perpendicular to the wavefront, as shown in Figure 14.2. Points on the wavefront are moving in phase. That is, all points are moving the same way, up or down, at the same time.

For a single point source the wavefronts radiate outward, forming circular waves. Other examples of wavefronts radiating outward include those produced when bombs or firecrackers explode.

Photo 14.1
Straight waves and circular waves being generated in a ripple tank.



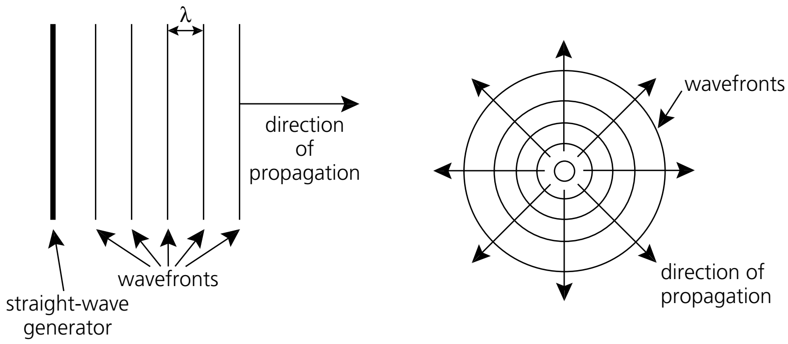


Figure 14.2
A straight-wave generator produces wavefronts that are parallel to the generator. A single dipper produces circular wavefronts that propagate radially.

It is often difficult to measure the wavelength of these waves as they are continually moving. However, by using a stroboscope the wave pattern can be observed more clearly.

SR Activity 14.1 STROBOSCOPES

A small cross is drawn on a three-bladed electric fan. When the fan is illuminated with a stroboscope, the cross appears stationary at strobe frequencies of 100, 150, 200, 250 and 300 Hz. What is the most likely frequency of the fan blade with the cross on it?

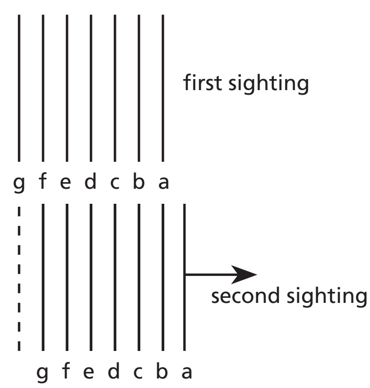
If the hand-held stroboscope is rotated so that the time it takes to rotate the stroboscope from one slit to the next is the same time taken for one wave to move to the position of the wavefront in front (one wavelength), the waves will appear to be stationary. (Refer to Figure 14.3.) This will make measurement of wavelength easier. The frequency of the waves can also be easily measured. If the stroboscope has 10 slits and is rotating at 4 times per second, 40 slits pass the eye in 1 second. Therefore, the time between each sighting through a slit, and thus the period of the waves, is 1/40 second. The frequency is therefore 40 cycles per second or 40 Hz. If electronic stroboscopes are used the job becomes much easier.

The speed of the waves can therefore be calculated using the wave equation, $\boldsymbol{v} = f\lambda$.

If the depth of the water is constant the speed of the wave will be constant, but if the depth of the water varies the speed changes. **Surface waves** on water, which are a mixture of transverse and longitudinal waves, travel more slowly in shallow water and faster in deeper water. If a water wave moves from one depth of water to another it is similar to moving from one medium to another. This will result in the wave being transmitted, and reflected in various ways as discussed in Chapter 13.

For other types of waves the speed depends on other factors. The speed of sound waves depends on the density, pressure and type of gas they pass through. The speed of earthquakes depends on the type of rock through which they move.

Figure 14.3
Waves appear stationary if the strobe is rotated at the correct speed. One wavefront moves to the position of the previous one.



Huygens's principle

Wavefronts are seen to radiate outward from a vibrating source. But how do these wavefronts move?

The movement of the source of the disturbance causes those water particles in the near vicinity to vibrate in harmony with the source. These vibrating particles cause those next to them to vibrate. Thus each particle on a wavefront is thought to be the source of a small circular secondary wavelet (Figure 14.4). This principle was put forward by the Dutch physicist **Christian Huygens** (1629–95) in the seventeenth century. Since all points on the wavefront are in phase, each produces a wavelet moving outward with the same velocity. A short time later, after these wavelets have travelled a short distance, the wavelets are connected within a common envelope, producing a new wavefront, which is the tangent to the wavelets. We thus produce a new wavefront travelling outward. All points on this new wavefront then become the source for new wavelets, and the process continues.

Straight waves can be created by dipping a straight bar such as a ruler into the ripple tank. All points on the ruler act as point sources for wavelets. Since all points are in phase the envelope enclosing all wavelets produces a straight wave whose wavefront is parallel to the source and whose direction of propagation is perpendicular to the wavefront.

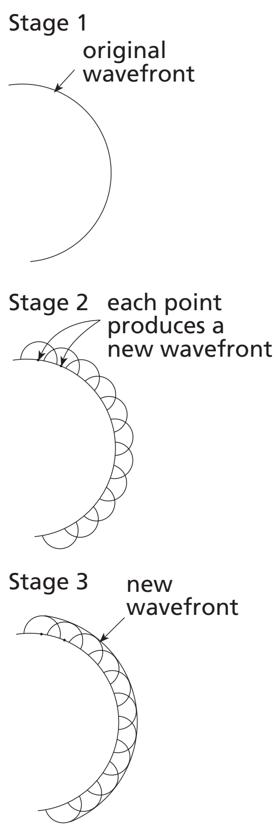


Figure 14.4
Huygens's principle says that all points on the wavefront produce secondary wavelets, which are the source for the resulting wavefront.

Questions

1 Explain clearly, with the use of diagrams, the terms 'wavefront' and 'direction of propagation'.

2 What is the relationship between the direction of propagation of a wave and the wavefront?

3 A strobe with 10 slits is used to 'freeze' the motion of water waves in a ripple tank. It is found that the highest speed of rotation of the stroboscope needed to produce a stationary wave pattern is 60 revolutions per minute. The wavelength of the waves is measured to be 10 mm. Calculate the speed of the waves in the tank.

4 The wavefronts of straight waves produced in a ripple tank are shown in Figure 14.5. Calculate the speed of the waves if the wave generator produces 5 waves per second.

5 Two dippers used to create waves in a ripple tank are 5.0 cm apart. They are oscillating at the rate of 20 Hz, and the circular waves produced travel at 25 cm s^{-1}.
- **(a)** What is the period of the waves?
- **(b)** What is the wavelength of the waves?
- **(c)** How many wavelengths fit between the two dippers?
- **(d)** If the frequency of the dippers is doubled what is the new wavelength of the waves?

REFLECTION 14.3

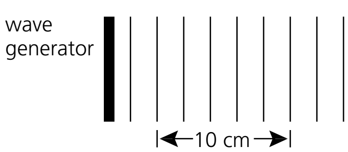


Figure 14.5
For question 4.

When a water wavefront meets a fixed barrier perpendicularly it is reflected back with the same velocity. If it meets the barrier at an angle, the reflected wavefront leaves at an angle equal to the angle of incidence. To see how this occurs examine the diagram of a wavefront ABC hitting a barrier (Figure 14.6).

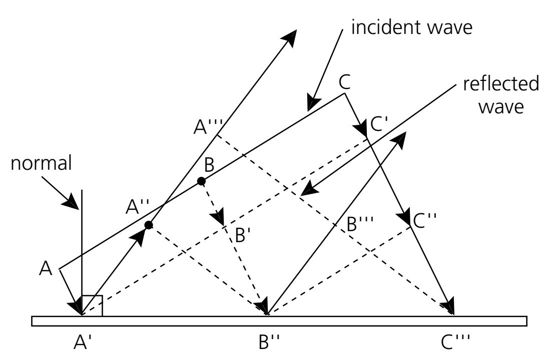


Figure 14.6
The reflection of a straight wave ABC from a straight barrier. The process is complicated by the interference between incident and reflected waves.

Point A is the first point to hit the barrier at A′ and be reflected. It hits the barrier and bounces back at the same angle to the **normal** (the line perpendicular to the barrier) as it collided, as shown in Figure 14.6. When point B on the wavefront hits the barrier at B″, B has