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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.

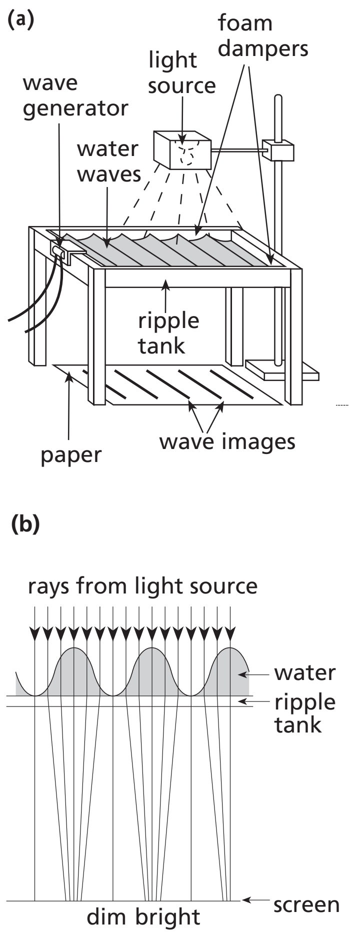


Figure 14.1
(a) A ripple tank used to study water waves. **(b)** Crests focus light to produce bright regions while troughs spread the light out to produce dark regions.

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.

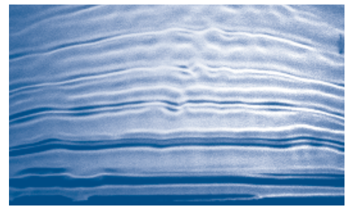
The waves produced in the ripple tank have the same characteristics as any transverse waves. They consist of crests and troughs. The crests act like converging lenses to the light from the light source and focus the light, creating bright areas on the screen. The troughs act like diverging lenses and 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.



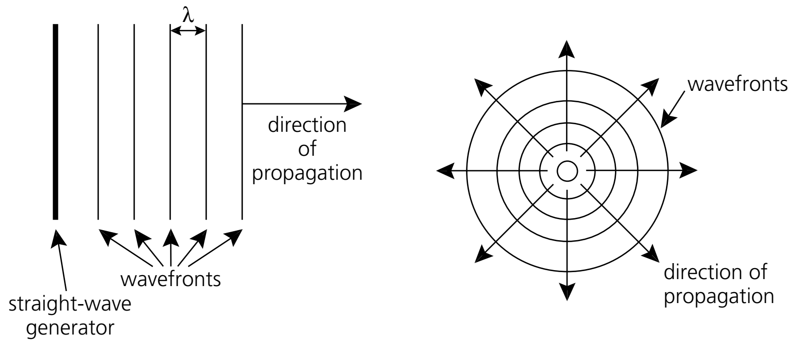


Figure 14.2
A straight-wave generator produces wavefronts that are parallel to the generator. A single dipper produces circular wavefronts that propagate radially.

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?

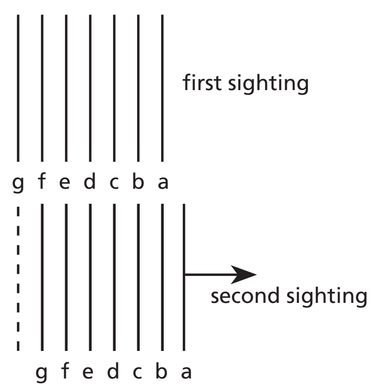
If the hand-held stroboscope is rotated so that the time it takes to rotate the stroboscope from one slit to the next is the same time taken for one wave to move to the position of the wavefront in front (one wavelength), the waves will appear to be stationary. (Refer to Figure 14.3.) This will make 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

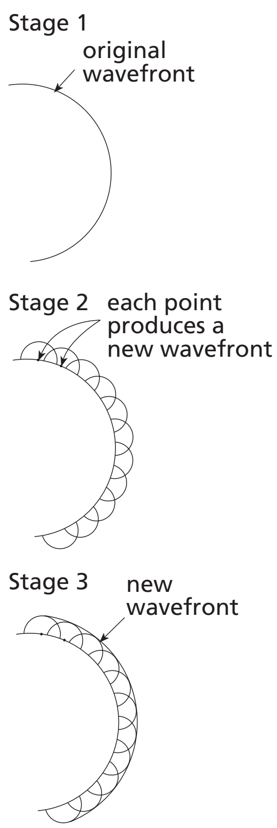


Figure 14.4
Huygens's principle says that all points on the wavefront produce secondary wavelets, which are the source for the resulting wavefront.

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.

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

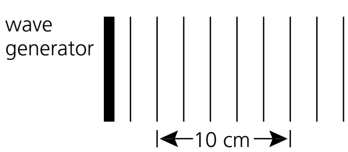


Figure 14.5
For question 4.

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).

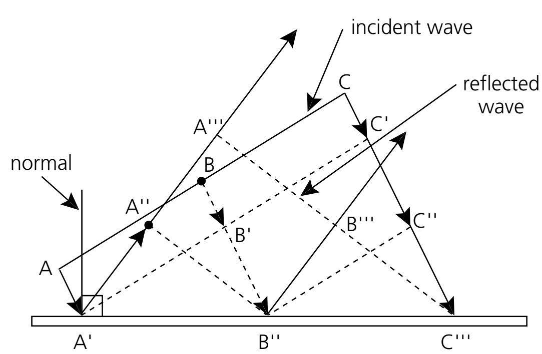


Figure 14.6
The reflection of a straight wave ABC from a straight barrier. The process is complicated by the interference between incident and reflected waves.

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

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travelled a distance of $B'B''$. This means point A has moved away from the barrier the same distance (as all points travel the same speed in the one medium). Point A moves from A' to A'' a distance equal to $B'B''$. The new wave is $A''B''C''$ as shown, with a part of the wave $A''B''$ moving away from the barrier and a part $B''C''$ still moving toward the barrier. A short time later point C hits the barrier at C'''. Point A will then have moved a further distance away from the barrier, a distance equal to $C''C'''$, to point A'''. The entire reflected wave $A'''B'''C'''$ is now moving away from the barrier as shown.

In general, water waves follow the same rules as light when reflected from a mirror, or marbles when thrown at a brick wall. (This will be discussed in Chapter 17.) The angle between the direction of propagation of the incident wave and the normal to the barrier is equal to the angle between the direction of propagation of the reflected wave and the normal as indicated in Figure 14.7.

This is stated as **the angle of incidence equals the angle of reflection**.

You can see how difficult it is to visualise, and explain, what is happening even using simple diagrams, let alone to observe this in a ripple tank. The interactions between the incoming and the reflected waves makes observation and analysis confusing. The reflection of waves and the interaction of incoming waves and reflected waves can be observed in nature when the incoming waves in the ocean interact with those reflected off the headland, off large boats or sea-walls.

Figure 14.7
When a straight wave is reflected, angle *i* equals angle *r*.

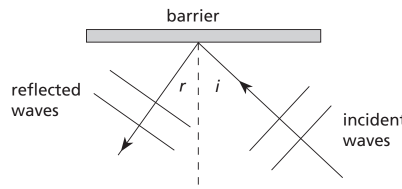
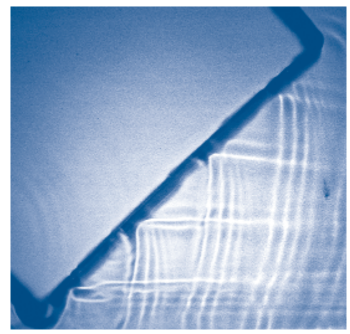


Photo 14.2
Straight waves being reflected from a barrier in a ripple tank.



Activity 14.2 REFLECTION

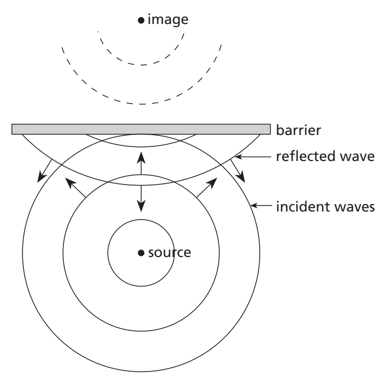
Generate straight waves in a ripple tank and observe the resulting pattern when these waves are reflected from a barrier.

The same principles of reflection apply when circular waves interact with straight barriers or when straight waves reflect from curved barriers, as shown in Figure 14.8.

Notice for the circular wave in Figure 14.8 that the front part of the wave hits the barrier first, therefore it is reflected first, creating a curved reflected wave that gives the impression that it was made by a source behind the barrier.

Straight waves reflecting from a curved barrier result in the focusing of the waves to a point. After passing through the point where this occurs (the **focal point**) the sides get further behind, resulting in a curved wave. (See Figure 14.9). Curved waves generated at the focal point and reflecting from the correctly curved barrier can produce straight waves, as shown in Figure 14.10.

Figure 14.8
When a curved wave reflects from a straight barrier the reflected wave appears to originate from a point behind the barrier.



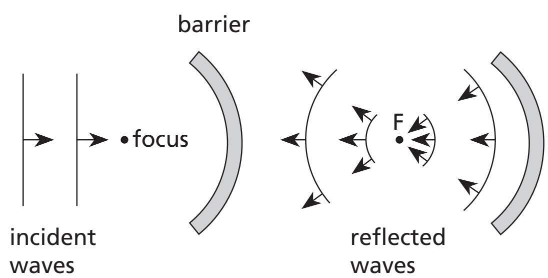


Figure 14.9
A straight wave becomes curved and passes through the focal point when reflected from a curved barrier.

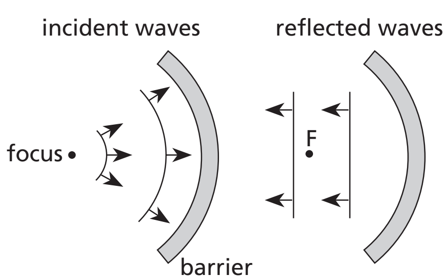


Figure 14.10
A wave originating from the focal point of a curved surface is reflected as a straight wave.

Questions

6 Give a definition of the terms 'normal', 'angle of incidence', and 'angle of reflection'. Use a diagram to help to explain the meaning of these terms.

7 A straight wave strikes a straight barrier at an angle of incidence of 25°. Draw a diagram to show the incident and reflected waves.

8 For each situation in Figure 14.11 where waves are incident on reflecting barriers, draw the wavefronts of the waves after reflection.

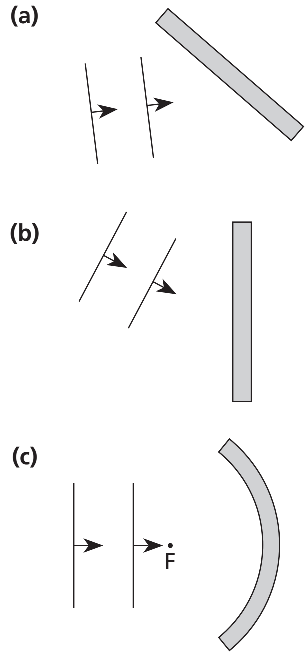


Figure 14.11
For question 8.

REFRACTION 14.4

When waves pass from one medium to another further properties of waves can be observed. To change the medium for water waves only requires changing the depth of the water. This can be accomplished by placing a sheet of glass or Perspex in the ripple tank so the depth of water over it is less than the surrounding water in the tank. This divides the tank into two areas, as shown in Figure 14.12.

If straight waves are created so that the wavefronts hit the shallow area parallel to the boundary, they will pass from the deep region into the shallow region without change in direction. However, waves travel more slowly in shallow water compared with deep water, and since the frequency of waves in both regions is the same because they are produced by the one source, the wavelength of the waves changes. Since $\boldsymbol{v} = f\lambda$, and because '$\boldsymbol{v}$' becomes less in the shallow water, and 'f' remains the same, 'λ' must decrease. The resulting pattern is shown in Figure 14.13. Table 14.1 shows the relationship between the depth of water, speed, and wavelength of waves.

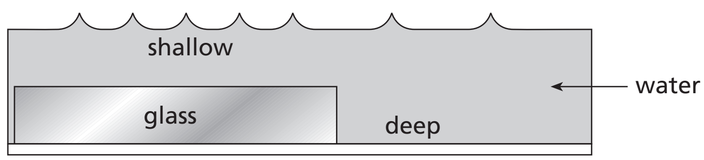


Figure 14.12
Placing a piece of Perspex or glass in a ripple tank divides the water into two regions of different depths so refraction of waves can be investigated.

Table 14.1

Depth	shallow	deep
Wavelength	short	long
Speed	slow	fast

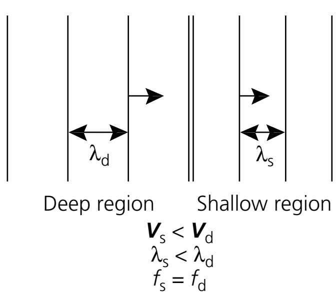


Figure 14.13
When a wave passes from one depth to another its speed and wavelength change.

Remember it this way: shallow, short, slow (the 3 s rule).

The reverse is also true. When waves go from a shallow to a deeper region they speed up and their wavelength increases. However, if the waves hit the junction between media at an angle other than 90° they change direction. This change in direction of the waves as they go from one medium to another is called **refraction**, which comes from the Latin *refractus* meaning 'broken off'. This property is explained in Figure 14.14.

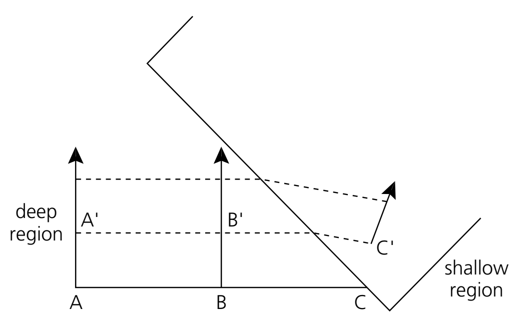


Figure 14.14
When a wave hits the boundary between two depths of water at an angle, it changes direction.

When wave ABC, travelling in a deep region, hits a junction between a deep and shallow region at an angle, as shown, C hits the junction first. A short time later A and B have moved a small distance to A′ and B′, but because C is travelling in a medium where the wave travels more slowly it has fallen behind and only moved to C′. The wave now becomes A′B′C′. As the direction of propagation of the wave is perpendicular to the wavefront, the wave has changed direction in the shallower region.

If a set of periodic waves is moving from one medium (deep) to another (shallow) as shown in the photo, all waves change direction and the wavelength decreases.

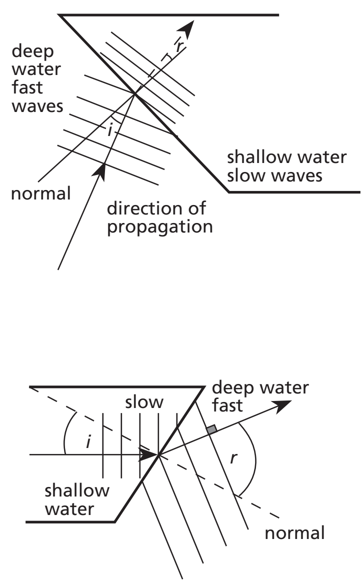
The size of the change in direction and the wavelength will depend on the relative change in depth of the water. If the difference between the depths of water is large the waves change direction and wavelength a great deal.

Again the reverse is also true. If waves move from a shallow to a deeper region at an angle to the junction, the wavelength becomes larger as the waves get further ahead. The angle between the direction of the propagation of the incident wave and the normal is called the **angle of incidence**. The angle between the normal and the direction of propagation of the refracted wave is called the **angle of refraction** (see Figure 14.15). These will be discussed more fully in Chapter 17 (Optics) where they can be viewed and measured more easily. When using light, refraction will occur when the waves propagate across the junction between air and glass, for example.

Note, however, that in going from deep to shallow water the angle of refraction is smaller than the angle of incidence. You can add this other ‘s’ word to your list: shallow, short, slow, and small. Note that while speeds, wavelengths and angles change, frequency does not.

Photo 14.3
Straight waves being refracted as they go from a deep area to a shallow area in a ripple tank.

Figure 14.15
The wavelength decreases when waves go from deep to shallow water, and increases when going from shallow to deep water.



Seismic waves

The study of waves produced by earthquakes (**seismology**) has been, and is, very important in determining the structure and properties of the Earth. Earthquakes produce three types of waves that radiate out at high speeds from the epicentre of the earthquake. They are P (primary) waves, which are longitudinal waves, S (shear) waves, which are transverse waves, and surface waves, which travel along the surface of the Earth and are transverse and more complicated elliptical waves. The speeds of these waves are given in Table 14.2. However, their speeds and direction are affected by the material in which they move.

Table 14.2 THE APPROXIMATE SPEEDS OF SEISMIC WAVES

WAVE TYPE	WAVE SPEED (km s^{-1})
P wave	8.0
S wave	4.5
Surface wave	2.0

Seismic waves can be detected by seismographs, which record the movement of the Earth. Because seismic waves travel through the whole planet and can be detected at various stations on the Earth’s surface, a great deal of information about the Earth’s crust, mantle, and core has been found. Continual research has identified the depth of the crust, the size of the mantle, the existence of a liquid outer core, and even the thickness and probable constituents of finer layers within the mantle.

Questions

9 Figure 14.16 indicates the position of straight waves in a ripple tank at a particular instant. The velocity of the waves in section A is 10 cm s^{-1}.
(a) Explain the reason for the different wavelengths in the two sections.
(b) Calculate the frequency of the waves in section A.
(c) What is the frequency of the waves in section B?
(d) What is the speed of the waves in section B?

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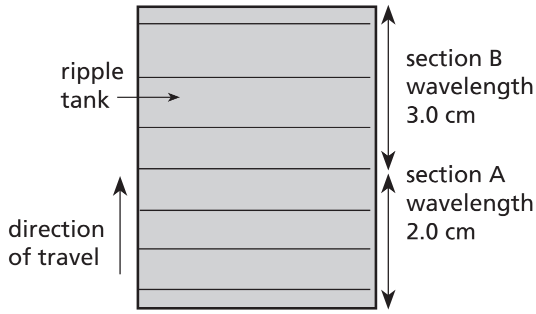
Figure 14.16
For question 9.

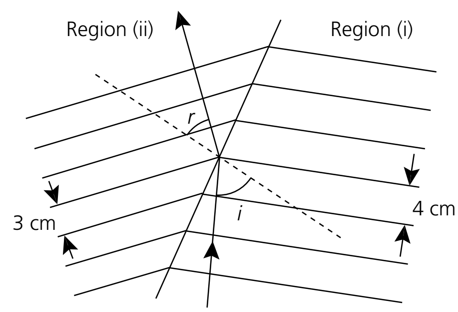


10 Straight waves of wavelength 2.5 cm have a speed of 8.0 cm s^{-1} in a region in a ripple tank where the depth of water is 2.0 cm. They pass into a region of depth 1.0 cm where the speed is determined to be 6.0 cm s^{-1}. Find the wavelength of the waves in the new region.

11 Straight waves in a ripple tank move from region **(i)** where their wavelength is 4.0 cm to region **(ii)** where their wavelength is 3.0 cm (Figure 14.17).

(a) Which region is the deeper?

Figure 14.17
For question 10.



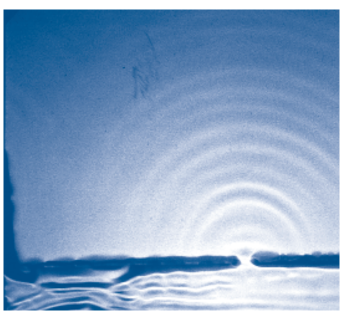
(b) Calculate the ratio of the wavelength in region **(i)** to that in region **(ii)**.

(c) Calculate the ratio of the speed of the waves in region **(i)** to the speed of the waves in region **(ii)**.

(d) Calculate the ratio of the frequency of the waves in region **(i)** to the frequency in region **(ii)**.

(e) What is the name given to this phenomenon?

Photo 14.4
Straight waves passing through a small opening in a barrier in a ripple tank are diffracted.



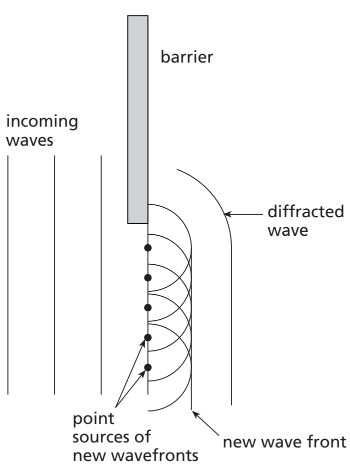
DIFFRACTION OF WATER WAVES 14.5

Another property of water waves is often observed when waves from the ocean enter an inlet. They form a circular pattern. It can be easily observed in the ripple tank by placing two large blocks of glass or metal obstacles, to produce a slit, in front of the straight waves. The waves, as they pass through the slit, produce a circular wave, as shown in the photo.

This bending of waves as they pass through a slit is called **diffraction** (from the Latin *diffractus* meaning 'to break apart'). Similar bending occurs if the waves pass around the end of an obstacle.

Diffraction can be explained in terms of Huygens's principle. As a straight wavefront enters the aperture (the slit), a secondary wavelet is produced by each point on the wave-front in the aperture. This continues to occur as the wavefront travels outward. The envelope enclosing the wavelets adds, to produce a straight wave in the centre but the edges remain curved. The wave curves around the aperture's edges, as shown in Figure 14.18.

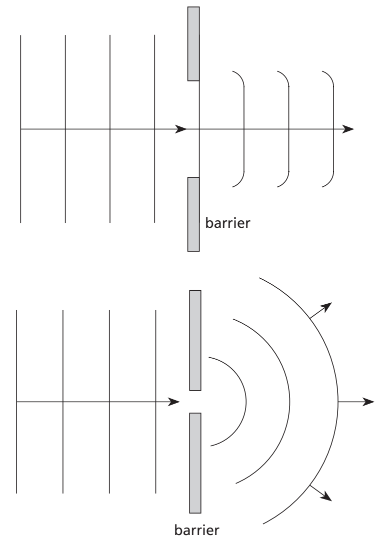
Figure 14.18
Diffraction of a wave at an edge can be explained by Huygens's principle.



Changing the slit width

It can be easily reasoned using Huygens's principle that if the aperture was smaller the shape of the waves passing through the aperture would be more curved, more circular, and if the aperture were larger the resulting waves would be straighter except for the edges. This is in fact what occurs. This can be observed easily in the ripple tank by changing the position of the obstacles making up the slit. Figure 14.19 shows the resulting patterns.

Figure 14.19
Diffraction is more noticeable when the size of the slit is comparable to the wavelength of the waves.



Changing the wavelength

Changing the wavelength of the waves also affects the diffraction pattern. Diffraction is more noticeable, that is, a more circular wave pattern is produced, if the wavelength is equal to or greater than the opening. It is the relative difference in the size of the wavelength and the size of the slit that is important (Figure 14.20).

A diffraction pattern can be observed in the ocean around boats, large rocks and buoys. However, the amount of diffraction depends on the size of the objects compared with the wavelength. If the object is large compared with the wavelength a significant diffraction pattern occurs around the edges of the object, producing a shadow zone.

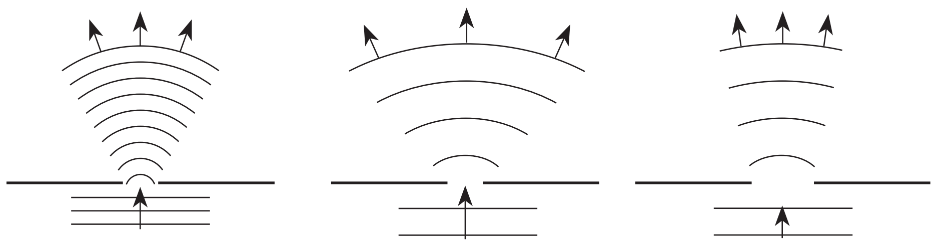


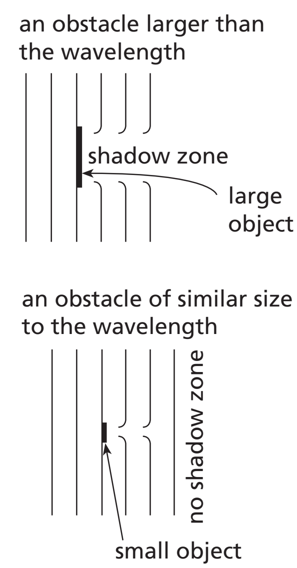
Figure 14.20
Diffraction is greater when the wavelength is large and the gap narrow.

Why don't body surfers produce diffraction patterns and shadow zones?

Diffraction of water waves in the ocean is partly responsible for the formation of many offshore islands. Consider a land formation consisting of a peninsula as shown in Figure 14.22. Straight waves parallel to the shoreline would diffract around the front of the peninsula, thus breaking on the sides of the peninsula and causing erosion. Over thousands of years the erosion would eat into the peninsula, cutting off the land and forming an island. Constant diffraction around these islands would also affect the shape of the islands.

It is advantageous to students who sit in the back of the classroom that the wavelength of common human speech, about 1 m, is larger than common classroom objects: tables, chairs, and even students. Remember, if the wavelength of waves is smaller than, or similar in size to, objects placed in their path, diffraction causes shadow zones. (See Figure 14.21.) However, if the object is much smaller than the wavelength, this effect is unnoticeable. Think what would happen if sound waves produced by the teacher were smaller than the student themselves, or their chairs, tables etc. What would the students in the back of the room hear? Can you use this as an excuse for why you cannot hear, particularly if you have a large student sitting in front of you?

Figure 14.21
An obstacle affects the waves if it is large compared with the wavelength of the waves, producing a shadow zone.



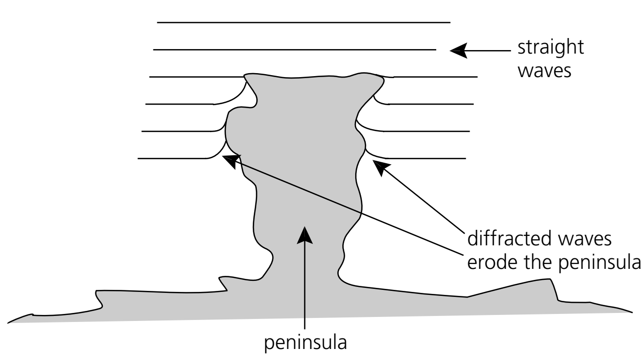


Figure 14.22
Straight waves in the ocean diffract around a peninsula, causing erosion on the sides, eventually cutting off the peninsula.

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INTERFERENCE OF WATER WAVES 14.6

Photo 14.5
Interference produced by two sources of waves in a ripple tank.

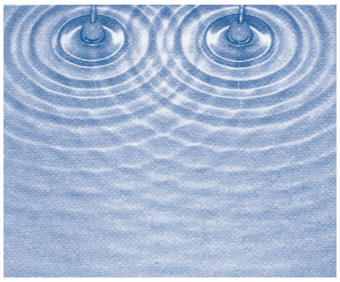


Figure 14.23
The interference pattern produced by constructive and destructive interference of waves from two sources.

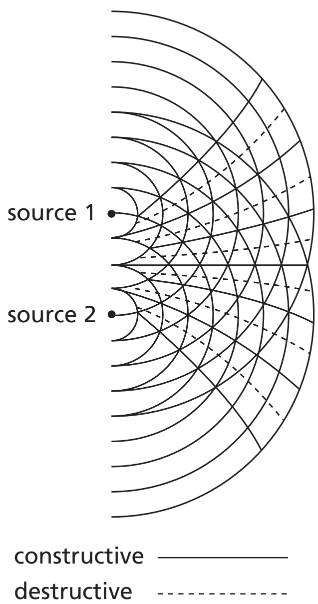


Figure 14.24
Interference pattern of waves from two sources.

As seen in Chapter 13, when waves meet they may reinforce or cancel each other out (superposition), but then continue on as though they had not met. If they are the same shape, and amplitude, and on the same side, they will **constructively interfere** to produce a wave of twice the amplitude, an **antinode**. If they are on opposite sides they will **destructively interfere**, cancelling each other out, producing a **node**. Two-dimensional water waves undergo the same phenomena but the pattern is more complicated as the waves from two sources radiate outward in all directions.

To produce waves in a ripple tank that are in phase and have the same amplitude involves the use of a wave generator that has two beads (dippers) attached to a straight rod. As the electric motor moves the rod up and down the two beads dip in and out of the water, producing two sets of circular radiating waves that are in phase and of the same amplitude. Another term for in-phase is **coherent**.

As the waves radiate outward, a crest from one dipper will meet a crest from the other, and constructive interference occurs, producing a larger crest. The same happens when a trough from one meets a trough from the other.

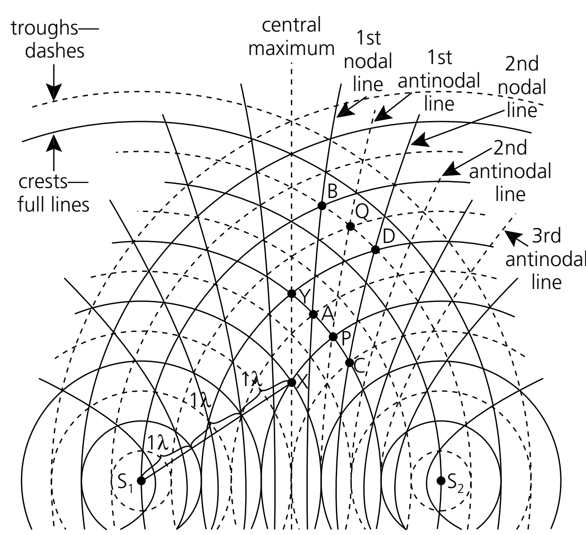
When a crest from one meets a trough from the other, destructive interference occurs and the waves cancel.

As the waves radiate outward they continue to add and cancel. The resulting pattern that occurs is the characteristic interference pattern produced by two sources in phase. (See Photo 14.5.)

It will be noticed in this photograph that there are regions that are bright, dark and grey. The grey or shadow areas are areas where cancellation has occurred, that is, where a trough from one source cancels a crest from the other. A bright area is where two crests meet, producing a larger crest. This acts like a convex lens and focuses the light on to the screen below the ripple tank, forming a bright area. When two troughs meet they produce a larger trough, which spreads the light out to form a dark region, as previously shown in Figure 14.1.

The resulting pattern can be drawn schematically with lines through the grey areas of undisturbed water, as shown in Figure 14.23. These lines are called **nodal lines**. Lines can also be drawn through the bright and dark regions — regions of constructive interference. These are **antinodal lines**.

You may understand this better when we consider some points on the pattern (Figure 14.24). Consider point X on the central antinodal line (**the central maximum**). This point is a distance of S_1X from source S_1 and a distance S_2X from source S_2. It will be noticed that X is 3λ from S_1 and is 3λ from S_2. The difference in distance from the two sources, the **path difference** (PD), is zero wavelengths.



Now look at a point Y further out but still on the central maximum. The difference in distance from the two sources S_1 and S_2 is $S_1Y - S_2Y = 4\lambda - 4\lambda = 0\lambda$.

If this is tried again it will be found that the path difference for all points on the central maximum is always zero wavelengths.

Now consider point P on the first antinodal line. The distance from S_1 to P (S_1P) is 4λ and the distance from S_2 to P (S_2P) is 3λ. The path difference is $S_1P - S_2P = 1\lambda$. If we find the path difference for point Q, further out on the first antinodal line, we will again find it to be 1λ. For all points on the first antinodal line the path difference is 1λ.

NOVEL CHALLENGE

To calculate the total number of nodal lines produced by two coherent point sources, let $\theta = 90°$, calculate 'n' and multiply by 4 (because there are four lots of 90° in a circle). Alternatively, calculate the angle between two nodal lines and divide into 360°. Each method gives a slightly different result. Why is this?

SR Activity 14.3 ANTINODAL LINES

Find the path difference for points on the second and third antinodal lines.

Antinodal line formula A general formula for antinodal lines becomes: **the path difference for points on the *n*th antinodal line = $n\lambda$.** Where $n = 1, 2, 3, \ldots$

SR Activity 14.4 NODAL LINES

1 Repeat the above exercise to find the path difference for points A and B on the first nodal line and for points C and D on the second nodal line.

2 Derive a general formula for points on the 'nth' nodal line.

Nodal line formula The general formula obtained should be: **the path difference for points on the *n*th nodal line = $(n - \frac{1}{2})\lambda$.** Where $n = 1, 2, 3, \ldots$

Example

Figure 14.25 shows the interference pattern produced by two coherent sources of waves in a ripple tank. The lines represent wave crests.

(a) Is constructive or destructive interference occurring at points **(i)** A; **(ii)** B; **(iii)** C?

(b) On what order nodal or antinodal line do the following points lie: **(i)** B; **(ii)** C?

(c) If the distance from S_1 to A is 4.0 cm and S_2 to A is 10 cm what is the wavelength of the waves?

(d) If the distances to an unknown point P are $S_1P = 8$ cm, $S_2P = 16$ cm, on which nodal or antinodal line does point P lie?

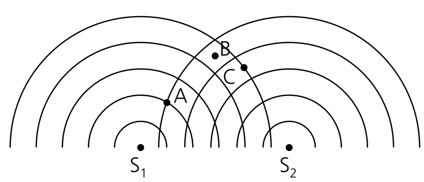


Figure 14.25
For example question.

Solution

(a) **(i)** Constructive, as A lies on a double crest.
(ii) Constructive, as B lies on a double trough.
(iii) Destructive, as C lies on a crest from S_1 and a trough from S_2.

(b) **(i)** B lies on the central maximum line as the path difference is zero wavelengths.
(ii) C lies on the second order nodal line as the path difference is one and a half wavelengths, $(n - \frac{1}{2})\lambda = 1\frac{1}{2}\lambda$.

(c) The distance from S_1 to A is 4 cm, which equals 2λ, then $\lambda = 2$ cm.

(d) The path difference is 16 cm − 8 cm = 8 cm, which equals 4λ. Therefore, this point lies on the 4th antinodal line.

These formulas can only be used when the two sources are in phase. If one source is generating waves at a different time from the other, that is, they are out of phase, the formula needs to be modified.

INTERFERENCE OF SOUND WAVES 14.7

Interference of sound waves can be observed very easily in the laboratory using two speakers connected to a single generator, as shown in Figure 14.26. It is important that the speakers are in phase. This can be checked by taking the grilles off the front of the speakers and checking to see that they both move in and out together when on a low frequency, say 1 Hz.

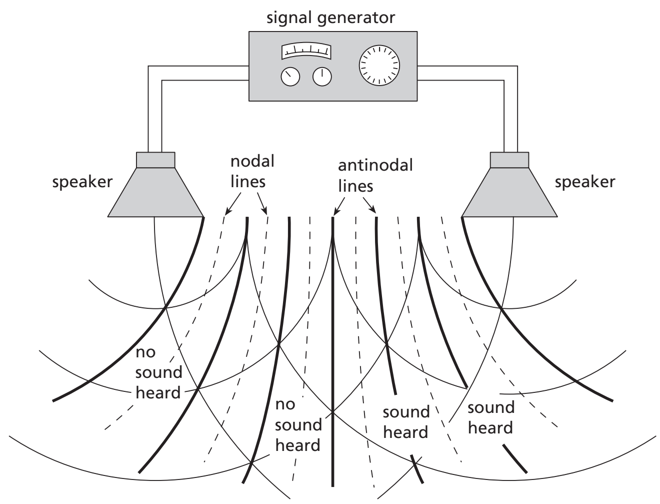


Figure 14.26
A single signal generator and two speakers produce coherent sound waves. There is an interference pattern containing nodal lines where no sound is heard.

Nodal lines are produced. If a person walks across the room in front of the speakers different degrees of loudness can be detected.

- Then why doesn't the interference of waves work at home?
- Why don't you observe this phenomenon when you move in front of the two speakers of your stereo?
- Why don't you see dark and bright light bands when you walk between two wall mounted lights in the living room at home?

The answer to the second question has already been discussed. Revise the previous section. The answer to the third question will be discussed in Chapter 15.

Questions

12 Figure 14.27 shows an interference pattern produced by two coherent sources.

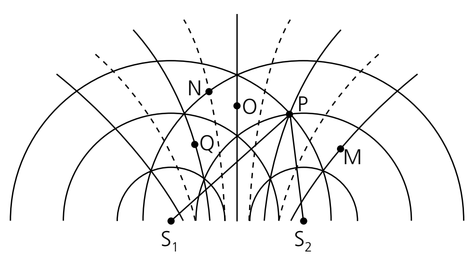


Figure 14.27
For question 12.

(a) Which of these sets of lines, the dotted lines or full lines, represents nodal lines? Why?

(b) If the distance from S_1 to point P is 6 cm and from S_2 to P is 4 cm, determine the wavelength of the waves.

(c) Is constructive or destructive interference occurring at points **(i)** M; **(ii)** N; **(iii)** O; **(iv)** Q?

Practice questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: * = low; ** = medium; *** = high.

Review — applying principles and problem solving

***13** What is meant by the terms 'wavelength' and 'direction of propagation'? Use diagrams to assist in the explanation of these terms with reference to straight and circular water waves.

***14** What is meant by the terms 'incident wavefront' and 'reflected wavefront'? Explain these terms with the use of a diagram.

***15** A dipper used in a ripple tank experiment dips into the water at the rate of 12 times in 2.0 seconds. At the end of that 2.0 seconds the outermost wavefront is found to be 15 cm from the source. Determine **(a)** the velocity of the waves; **(b)** the period of the waves; **(c)** the wavelength of the waves; **(d)** the frequency of these waves.

***16** A continuous set of straight waves is produced in a ripple tank by using a vibrator. After 1.2 s the furthest wavefront is found to have travelled a distance 6.0 cm from the source. The distance between successive crests is measured to be 1.2 cm. Calculate the speed and frequency of the waves.

***17** A set of straight waves strikes a straight barrier so that the wavefronts make an angle of 40° with the barrier. Show the incident wave and the reflected wave on a diagram.

***18** Periodic straight waves are generated in a ripple tank. They are seen through a stroboscope with 10 slits. The stroboscope is turned at its fastest speed to freeze the motion of the wave without changing the wave pattern. It is found that the stroboscope is turned at a speed of 25 revolutions in 10 seconds. Calculate **(a)** the frequency of the waves; **(b)** the speed of the waves if the distance between successive crests is 2.5 cm.

***19** A ripple tank is divided into a deep and a shallow region, by placing a thin sheet of glass to cover half the tank. In the deep region waves are found to have a velocity of 8 cm s^{-1}, and a wavelength of 6 cm. In the shallow region they have a speed of 6 cm s^{-1}.
(a) What is the frequency of the waves in the deep region?
(b) What is the wavelength of the waves in the shallow region?

***20** **(a)** Explain with the use of diagrams the meaning of diffraction.
(b) Give two examples of where diffraction occurs in nature.
(c) Show with the use of diagrams how the diffraction pattern depends on the size of the opening and the size of the wavelength of the waves.

***21** If a series of straight waves passes through a narrow slit in a ripple tank, what changes occur to the following properties of the waves as they pass through the slit: **(a)** wave pattern; **(b)** wave speed; **(c)** wavelength; **(d)** period?

***22** If noticeable diffraction of waves through an aperture is to occur, state the conditions that are necessary.

***23** How does the frequency of straight waves change as they are diffracted passing through a small opening?

***24** What is the difference between 'constructive' and 'destructive' interference?

***25** What conditions are necessary for points within an interference pattern to lie on **(a)** the 6th antinodal line; **(b)** the 3rd nodal line; **(c)** the nth antinodal line?

***26** Two point sources continually vibrate in phase in a ripple tank. An interference pattern with eight nodal lines is produced. What will happen to the number of nodal lines in each of the following cases?
(a) The frequency is halved.
(b) The distance between the sources is doubled.
(c) The wavelength is doubled.

NOVEL CHALLENGE

Make up five questions that would test a person's understanding of wave motion. Think about whether your questions are just about recall of facts or are really testing the person's understanding.

***27** Draw the reflected wavefronts after reflection in the situations illustrated in Figure 14.28.

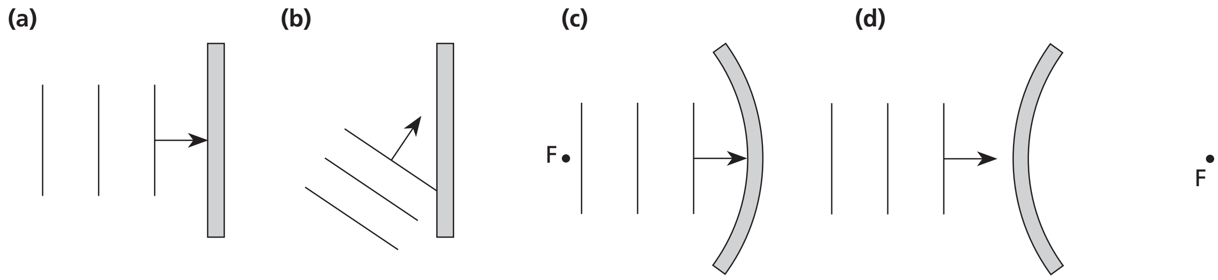


Figure 14.28
For question 27.

***28** Figure 14.29 shows a set of waves going from shallow water to deep water. Find the ratio of:

(a) $\dfrac{\text{the frequency of waves in shallow water}}{\text{the frequency of waves in deep water}}$

(b) $\dfrac{\text{the velocity of waves in shallow water}}{\text{the velocity of waves in deep water}}$

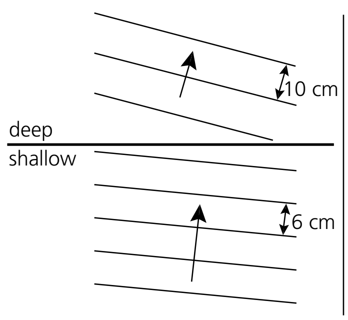


Figure 14.29
For Question 28.

***29** Straight waves of frequency 10 Hz are produced in the deep end of a ripple tank. These waves move from the deep end to the shallow end (Figure 14.30). Calculate the speed of the waves in the deep and the shallow regions of the ripple tank.

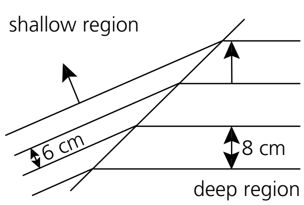


Figure 14.30
For question 29.

***30** Figure 14.31 represents three ripple tanks containing barriers to form apertures to straight waves. Redraw the diagrams to show the resulting wave pattern after the waves have passed through the openings.

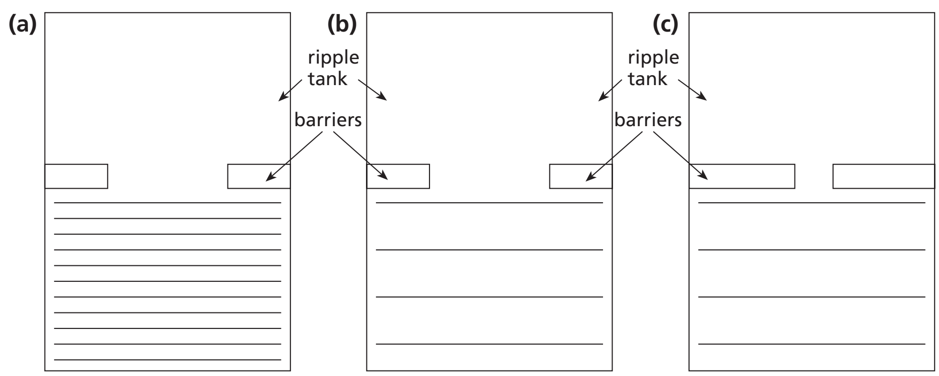


Figure 14.31
For question 30.

***31** Figure 14.32 shows sets of waves incident on openings between pairs of barriers. In which of the situations will diffraction most likely be more noticeable? State reasons.

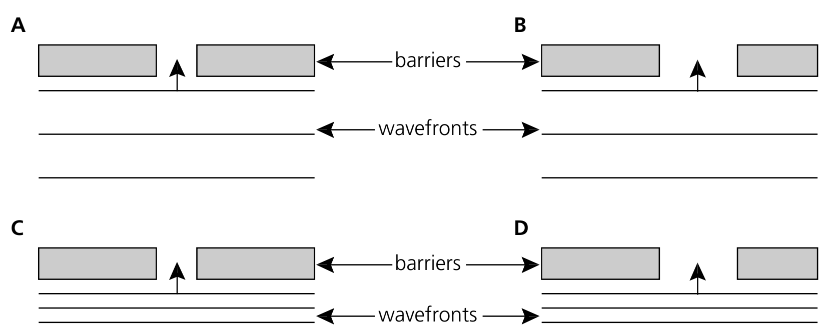


Figure 14.32
For question 31.

***32** Straight waves in a ripple tank approach a straight barrier which is parallel to the wavefronts. There is a gap of width 'w' in the barrier. The wavelength of the waves is λ. In which of the cases in Table 14.3 will the waves be most strongly diffracted?

Table 14.3 DATA FOR QUESTION 32

	A	B	C	D	E
Wavelength (cm)	1.0	1.5	2.5	0.5	2.0
Width (cm)	2.0	2.0	2.0	4.0	4.0

***33** An interference pattern is shown in Figure 14.33. Are the points A, B, and C on nodal or antinodal lines?

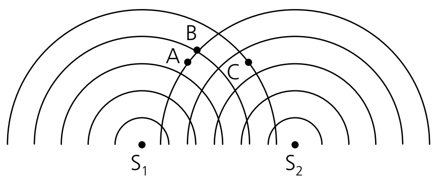


Figure 14.33
For question 33.

***34** Two dippers are separated by 8.0 cm in a ripple tank. The generator causes the dippers to oscillate 100 times in 10 seconds, and the circular waves produced travel at 20 cm s^{-1}.
(a) What is the frequency of the waves produced?
(b) What is the wavelength of the waves in the ripple tank?
(c) Draw a diagram of the resulting interference pattern labelling the nodal and antinodal lines.
(d) How many nodal lines are formed?
(e) How do the above answers change if the frequency of the dippers is doubled?

***35** Figure 14.34 shows the pattern produced when two sets of circular waves are produced by dippers in phase in a ripple tank.
(a) At point A, is constructive or destructive interference occurring?
(b) At point B, is constructive or destructive interference occurring?
(c) Is point C on a nodal line or an antinodal line? Which order line?
(d) Which nodal or antinodal line is point D on?
(e) If the frequency of the dippers is decreased what would happen to the interference pattern?
(f) If dipper X were producing waves half a period after dipper Y what would happen to the interference pattern?

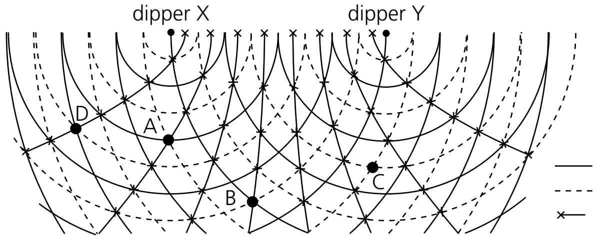
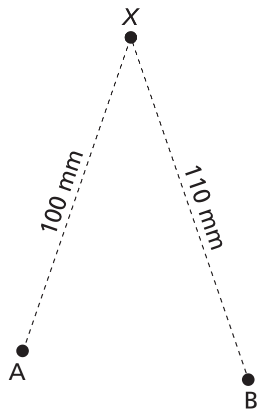


Figure 14.34
For question 35.

Figure 14.35
For question 36.



**36 Two point dippers A and B are driven by a vibrator to produce waves that are in phase and of the same frequency (10 Hz), in a ripple tank (Figure 14.35).

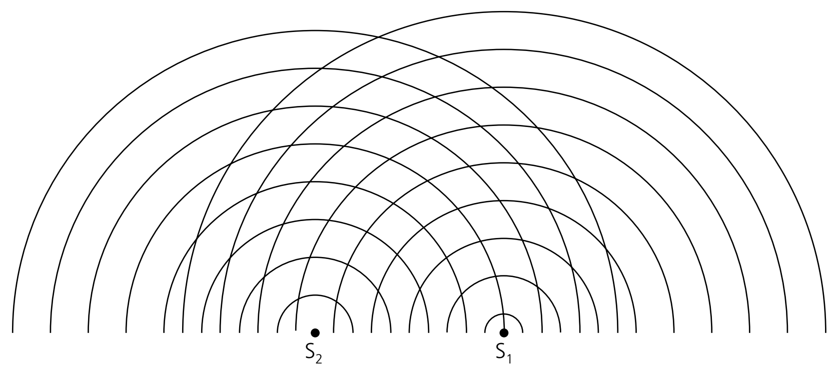
(a) If a wave takes 0.50 s to go from A to point X a distance of 100 mm, what is the speed of the waves?
(b) What will be the speed of the waves from source B?
(c) Determine the wavelength of the waves.
(d) Does constructive or destructive interference occur at point X?
(e) Which nodal or antinodal line does point X lie on?
(f) If the frequency of the sources is doubled indicate what would happen to the interference pattern. Which nodal or antinodal line does point X now lie on?

Extension — complex, challenging and novel

***37 In Figure 14.36 S_2 is producing crests when S_1 is producing troughs. They are out of phase. The resulting wave pattern is shown.

(a) Draw the first three nodal and antinodal lines.
(b) By choosing a range of points on the first, second, and third antinodal lines and the first, second, and third nodal lines, develop a general formula for the path difference between points on the *n*th antinodal and the *n*th nodal line, for this out-of-phase situation.

Figure 14.36
For question 37.



***38 It is noticed in areas close to airports that television reception is distorted when aircraft fly overhead but radio reception remains unaffected. Explain how this might occur.
Hint: you might consider calculating approximate wavelengths of radio waves and television waves.

***39 Wavefronts approaching a beach form a pattern similar to that shown in Figure 14.37. Analyse the wave pattern and deduce, with explanation, the structure of the beach that would produce such a pattern.

Figure 14.37
For question 39.