UNIT 05

Wave Motion

CHAPTER 13

Wave Motion in One Dimension

13.1 INTRODUCTION

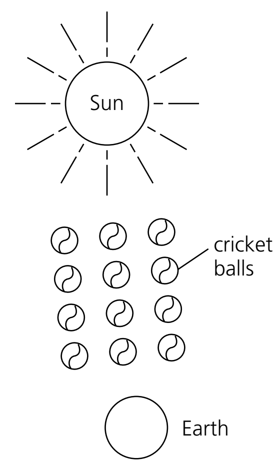
When a prize fighter trains by hitting a punching bag, energy travels from the closed fist to the bag, and if someone is holding the bag, to that person.

When a baseball is hit, energy travels with the ball to the person who catches it. The amount of energy it carries can be felt by the stinging of the hands.

But how does light energy travel from the Sun to be used by solar cells on Earth? Is the energy carried by moving cricket balls, perhaps?

There seems to be no particle like a fist or a ball to carry the energy — at least no visible particle. Where the answer lies may be seen by observing a surfboard rider in the ocean. As the unbroken wave passes the rider, he or she goes up and down but does not move forward. However, this water wave carries energy — very much energy. Consider the energy carried by a 'tidal wave'. (A poor or misleading term. A giant wave produced in the ocean often by volcanic activity or earthquakes is called a 'tsunami', and has nothing to do with the normal tide movements.) One of the largest tsunamis recorded was caused by a volcanic explosion on the island of Krakatoa on 27 August 1883. The resulting 40 m high tsunami lashed the coast of Indonesia killing some 36 000 people. This tsunami was even registered by the tide gauges in the English Channel. Tsunamis created this way often cause more deaths than the disturbance that created them. As tsunamis often cause havoc in Japan, Hawaii, and other Pacific Islands, great efforts are made to detect the epicentre of the earthquakes by measuring wave velocities. This allows determination of the expected time of arrival of the tsunami so people in low-lying areas can be warned and evacuated.

Figure 13.1
Does the energy from the Sun come like this?



The above is one example of wave motion in nature. There are many more examples. Can you think of some?

The understanding of waves is also important in modern-day conveniences. Water beds have baffles in them to stop waves when a person rolls over. Wave generators are being used to create waves in theme parks for the entertainment of patrons. The motion of the waves in oceans is one of the latest methods of generating electricity.

So waves can carry energy, but how do they do this?

13.2 WAVES

Waves are classified according to the method of transfer of energy. If a medium is required for the transfer of energy, then the waves are called **mechanical** waves. If no medium is required and the waves are able to travel through a vacuum, then the waves are called **electromagnetic**. In this chapter we will discuss only mechanical waves, while in Chapter 15 forms of electromagnetic waves such as radio waves, light and X-rays will be discussed.

A good working example of a mechanical wave can be created by dropping a stone in a pool of water. A circular wave is seen to radiate outward from the point the stone enters the water. In this case water is the 'medium'.

Photo 13.1
Circular waves produced when a stone is dropped into a pool.

Notice that, to create the wave, you have to create a **disturbance** in an undisturbed medium. The wave continues to go outward until it runs out of energy. How is this loss of energy seen? The height of the wave is called the **amplitude** of the wave. It is the maximum displacement of the wave from its equilibrium position shown as '*A*' in Figure 13.2.

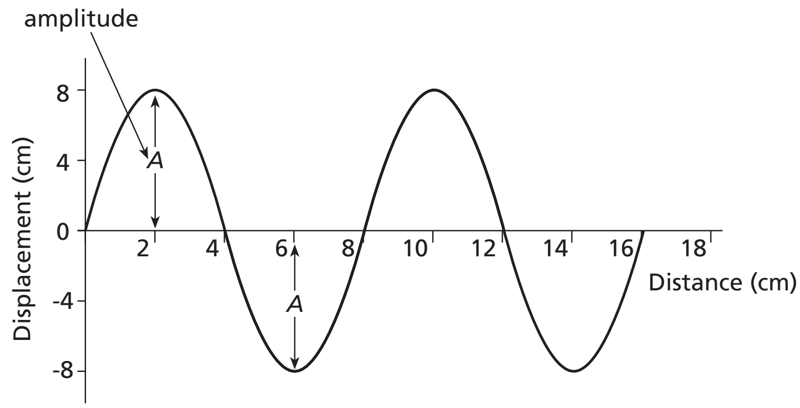


Figure 13.2
The amplitude of a wave is the maximum distance from the equilibrium position.

NOVEL CHALLENGE

Put a lit candle in a room and open a door quickly. How long will the breeze take to get to the candle? Measure the distance and the time. Do you think the breeze would travel at the speed of sound in air?

What other quantity is determined by the amplitude of a wave?

The amplitude of a large water wave might be 10 m. This suggests that the wave would have large amounts of energy. The larger the amplitude the more energy the wave possesses. The energy of the wave comes from the disturbance. Some of the energy of the stone is transferred to the water wave. As you go further from the source of the wave the amplitude of the wave becomes less as the energy dissipates. Waves similar to these water waves can be created in many objects. Children can often be seen holding the ends of a piece of skipping rope or a hose and flicking it. A wave or **pulse** moves from the flicked end to the other end. The energy put into the wave can easily be felt by the child at the other end. The energy can be so great that it may cause the rope to flick out of the hands of the receiver. Notice that the energy and the pulse moves along the rope without the particles that make up the rope moving toward the receiver.

If there is a small branch floating in a pond what happens to it as a wave passes? The branch goes up and down as the wave passes but returns to its original rest position once the wave has passed. The same thing happens to you and your small fishing dinghy as the wash from a large boat passes under you. The rest position is also called the 'equilibrium' position.

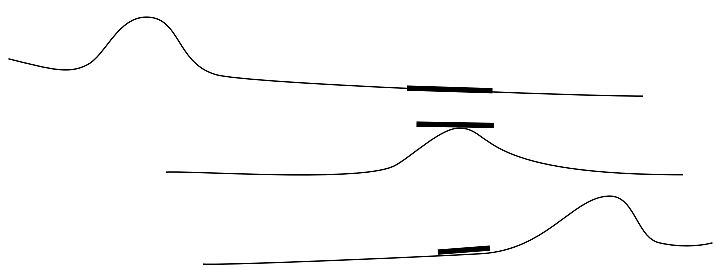


Figure 13.3
A branch in a pond moves out and back as a wave passes.

Wave types

Water waves or rope waves are particular types of waves. As seen in the water wave, the water (and branch) move upward as the wave passes. The particles that make up the water move at right angles to the direction the wave is travelling. This is the same for the rope wave. The rope moves upward as the pulse passes and then back to its original position.

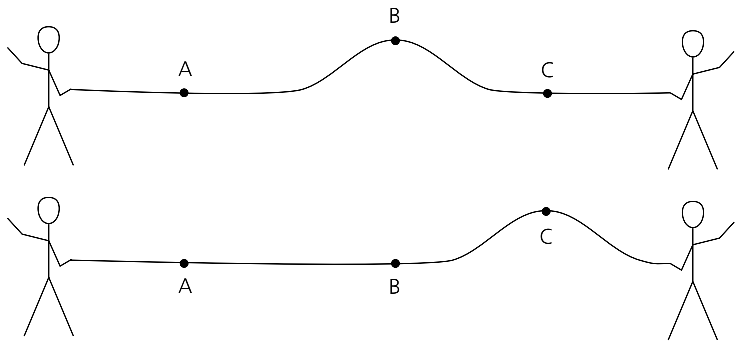


Figure 13.4
The parts of a rope move outward as waves pass.

Waves that do this are called **transverse waves**. (The word transverse comes from the Latin *transvertere* meaning 'to turn across'). Each point of the wave vibrates perpendicularly to the direction the wave is travelling — perpendicular to the direction of **propagation** of the wave (Latin *propago* = 'layer of a plant'; adds layers as it grows outwards). Examples of waves that are transverse in nature are waves in water; waves in ropes, hoses, and springs; and electromagnetic radiation, examples of which are light, radio waves, and television waves.

Notice the direction of the motion of the particles of a spring as a transverse wave passes as shown in Figure 13.5.

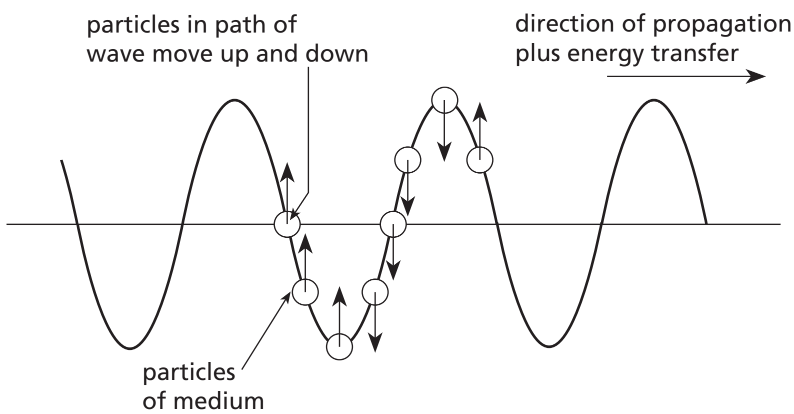


Figure 13.5
In a transverse wave the particles move at right angles to the motion of the wave. The direction of individual particles is given by the arrows.

Another type of wave is a **compressional** or **longitudinal** wave. Examples of these can be created in springs by compressing a part of a spring and then letting it go so the compression travels down the spring.

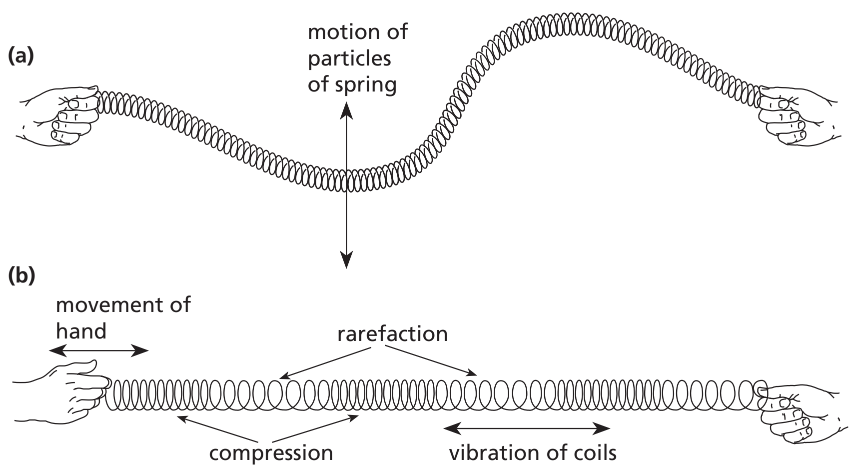


Figure 13.6
(a) Transverse waves.
(b) Longitudinal waves.

The particles of a spring propagating longitudinal waves vibrate in the same direction as the pulse is moving. This creates **compressions** and **rarefactions**. Can you think of other types of longitudinal waves?

Musical instruments create longitudinal waves by their action on the air particles in close proximity to the vibrating instrument. For example, when a drum membrane moves out it forces air particles together, generating a compression. When it moves in it produces a rarefaction. Tuning forks work in the same way (Figure 13.7). Would these instruments work in outer space?

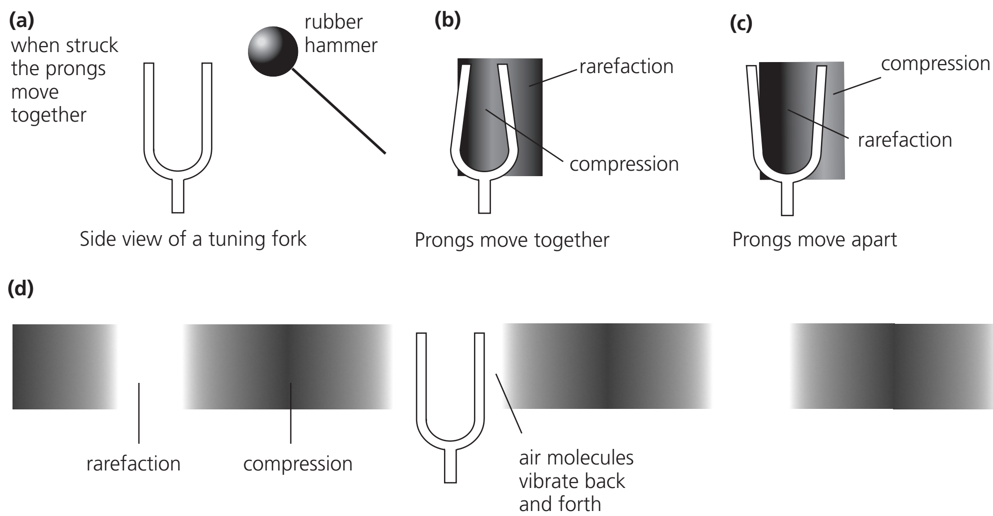


Figure 13.7
Compression and rarefaction occur in the air molecules surrounding the prongs of a tuning fork.

WAVE CHARACTERISTICS 13.3

A single disturbance produced by a source such as a flicking rope is called a **pulse**, but if a continuous set of pulses is produced by a source with a constant time interval between the generation of each pulse, the result is a wave, which has several characteristics. The **wavelength** (λ) is the minimum distance between two points on the wave that are in **phase**, for example, the distance between two consecutive **crests** or **troughs**. If the two points are in phase they are at the same distance from the rest position and are moving in the same direction at the same time. For example, D and H in Figure 13.8 are in phase, as they are on the equilibrium position and about to move up. C and E are out of phase — C is about to move down whereas E is about to move up. The wavelength of a wave is shown in Figure 13.8 between G and K, O and Q, or B and F. It is a little harder to see and measure the wavelength of a longitudinal wave. It is the distance between the middle of adjacent compressions, or adjacent rarefactions, as shown in Figure 13.9.

PHYSICS FACT

The symbol λ is the Greek 'L' (lambda) for length.

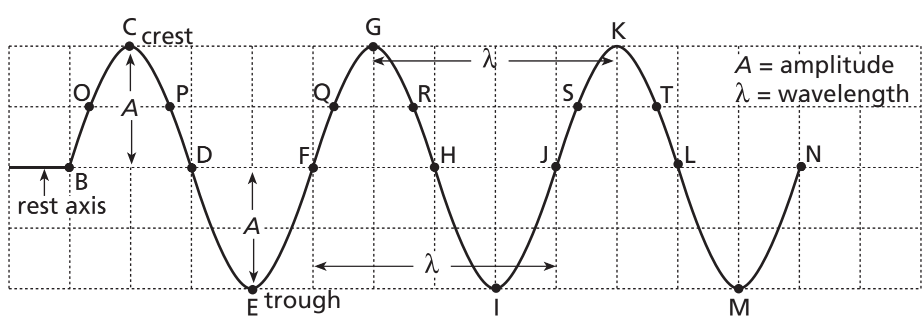


Figure 13.8
Wave characteristics of typical transverse waves.

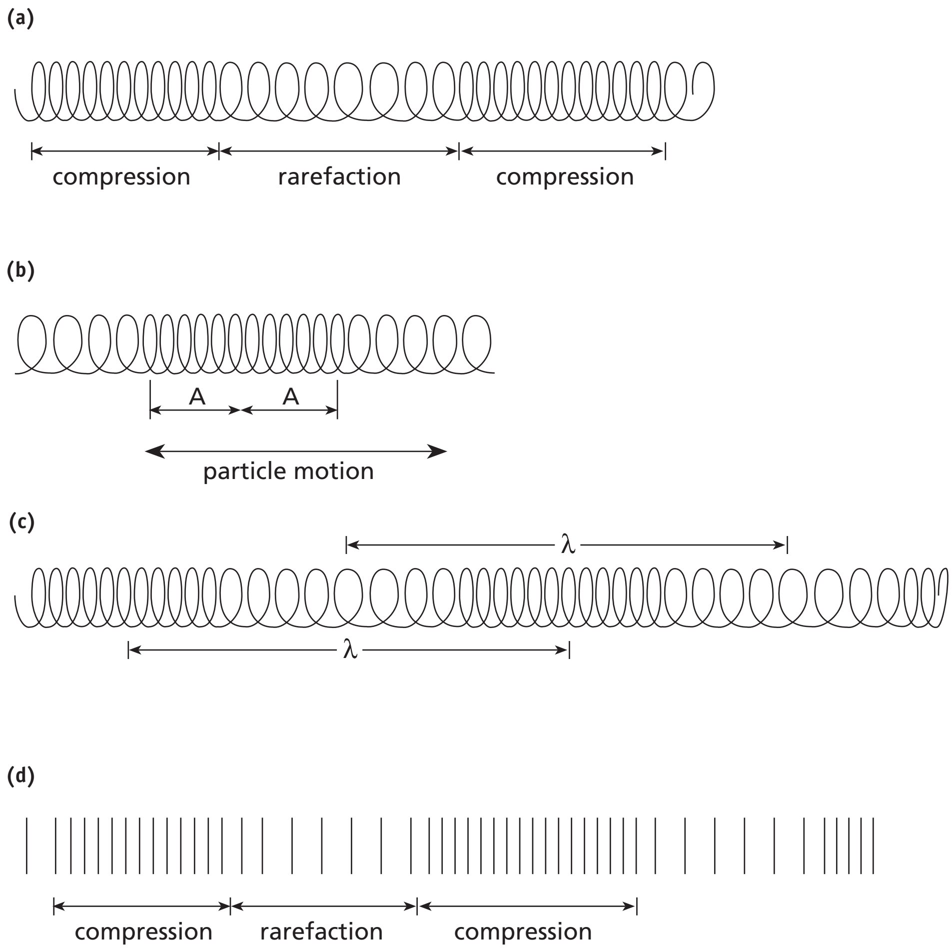


Figure 13.9
Wave characteristics of typical longitudinal waves.

NOVEL CHALLENGE

The June 2000 issue of the very prestigious *New England Journal of Medicine* reported that the average rate of jaw movement of gum chewers in the USA is 100 Hz. What do you suppose they really meant?

The **frequency** (f) of a wave is the number of waves passing a given point per second or the number of waves created by the source per second. The unit for frequency would thus become waves per second, or cycles per second (c s^{-1}), or the modern unit of a **hertz** (Hz) named after the German physicist **Heinrich Hertz** (1853–94) who in the 1880s discovered a technique for transmitting and receiving radio waves. A hertz is a cycle per second. For example, if four crests pass a point in 1 second then the frequency is 4 Hz. The frequency of visible light waves is between 4×10^{14} Hz and 8×10^{14} Hz. The ranges of frequencies heard and produced by some animals and produced by some musical instruments are given in Figure 13.10.

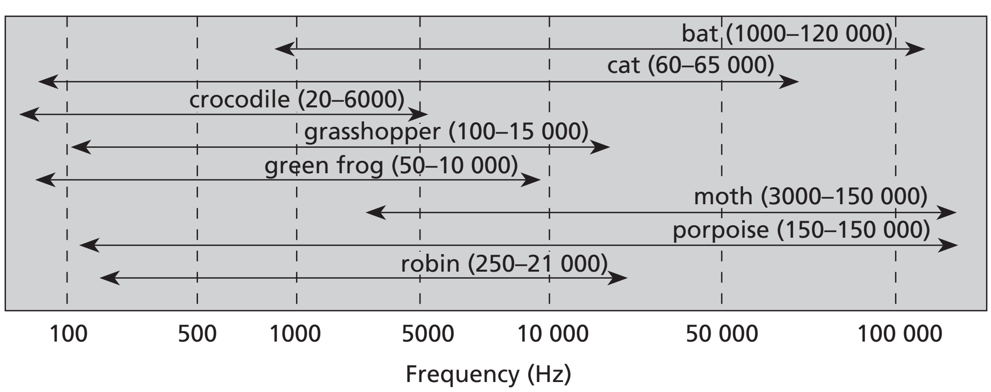


Figure 13.10
Range of frequencies of sounds produced by various animals.

Activity 13.1 HEARING RANGE

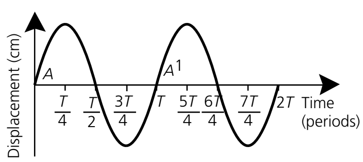
1. See if you can find out the frequency range for sounds that humans can hear.
2. How does this range change as you get older?
3. Dogs are said to be able to hear sounds of higher frequency. Find out what range of frequencies is audible to them.

The **period** of a wave is the time it takes for one full wave to pass; that is, one complete cycle to pass. If the frequency of a wave is 10 Hz or 10 cycles per second, then 10 waves pass per second. It will then take 1/10 second for one wave to pass. The period of the wave is 1/10 second. Therefore period (T) = 1/frequency.

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

The wave equation

Figure 13.11
The propagation of a transverse wave with time.



How can we measure the speed of a wave? How fast is the wave travelling? You could measure how far the wave travels in a certain time or you could use the wave characteristics (Figure 13.11). At one instant, point 'A' will be at the origin as shown. One period later point A will be at A′. This means the wave has travelled one wavelength in one period.

The speed of the wave = distance travelled/time taken.

$$\boldsymbol{v} = \frac{1\lambda}{T}$$

$$\boldsymbol{v} = \frac{1}{T}\lambda$$

$$\boldsymbol{v} = f\lambda$$

This is known as the **wave equation**, where $\boldsymbol{v}$ is the speed of the wave in m s^{-1}, λ is the wavelength of the wave in m, f is the frequency of the wave in Hz.
Note: this equation will apply to all wave forms, both mechanical and electromagnetic.

Example

An observer sitting on a shore counts the waves and finds that there are 6 waves per minute hitting the shore. She measures the distance between consecutive crests to be 10 m. What is the velocity of the waves?

Solution

$$\boldsymbol{v} = f\lambda$$
$$\boldsymbol{v} = 6/60 \text{ Hz} \times 10 \text{ m}$$
$$\boldsymbol{v} = 1 \text{ m s}^{-1}$$

PHYSICS FACT

Breweries monitor the percentage of alcohol in beer as it flows through pipes by passing it over a special beer tuning fork. The rate of vibration changes according to the density (and hence alcohol concentration) of the beer. Clever huh?

Questions

1. Two students 5.0 m apart 'flicked' a spring to create waves. They found that when they flicked it twice per second, 10 wave crests were created between the two students. Calculate the velocity of the waves.
2. The speed of light is 3.0×10^{8} m s^{-1}. If the wavelength of red light is 5.0×10^{-7} m, what is its frequency?

3 Find the frequency of the light emitted from the common laboratory laser. You will find the wavelength of the laser marked on it.
4 The frequency of a 5.0 m sound wave in water is 300 Hz. What is the speed and the period of the sound waves in the water?
5 Figure 13.8 shows a transverse wave. If this wave is travelling to the right, what is the direction of movement of points B, G, P, D, and M at this time?

13.4 WAVES AND BOUNDARIES

The speed of a wave is a characteristic of the medium in which it is moving, and changes when a wave moves from one medium to another. This is shown in Table 13.1.

Table 13.1 SPEED OF WAVES IN VARIOUS MEDIA

WAVE TYPE	MEDIUM	SPEED ($m\ s^{-1}$)
Sound	carbon dioxide	260
	air	331
	hydrogen	1290
	pure water	1410
	salt water	1450
	glass	5500
Light	vacuum	2.997×10^8
	air	2.988×10^8
	glass (crown)	2.0×10^8
Earthquake	crust	3500 (transverse)
		8000 (longitudinal)
	mantle	6500 (transverse)
		11 000 (longitudinal)

How can we best explain what happens when a wave hits a barrier or moves from one medium to another? For example, what happens when light hits a mirror? What happens when a pulse sent down a spring by one student hits the firm hand of another at the other end? We will use waves in springs to investigate this principle. The spring pulse is easier to visualise and to do experiments with than light waves. Why?

Figure 13.12 shows a spring attached to a wall. If a pulse is sent down this spring what happens when it hits the wall? This might be a good time to observe this.

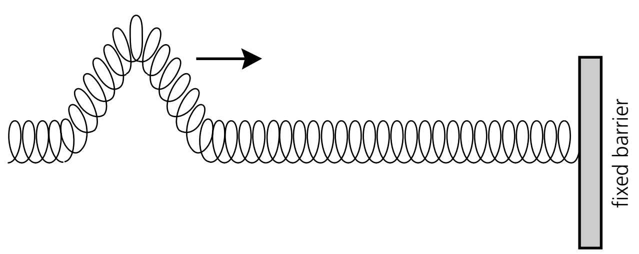


Figure 13.12
A slinky spring used to investigate how waves are reflected from fixed barriers.

NOVEL CHALLENGE

A boat catches fire and the skipper jumps overboard and swims away. The skipper hears an explosion while underwater, lifts his head out of the water and hears another explosion. Bystanders say there was only one explosion but the skipper says there were two. Who was correct? Explain.

NOVEL CHALLENGE

Scientists monitor global warming by measuring ocean temperatures. They pass a 57 Hz signal at Heard Island in the southern Indian Ocean and time its arrival at points in major ocean basins of the world. How does speed vary with water temperature? Draw a graph.

Activity 13.2 REFLECTION OF PULSES

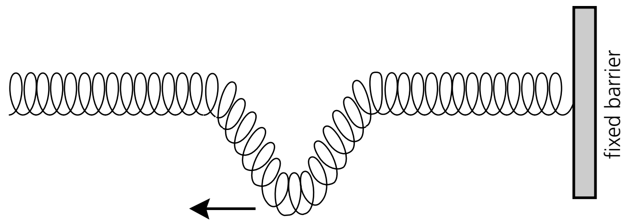
Attach a spring to a wall or have a friend hold it firmly. This is called a 'fixed end'.

1. Send a pulse (the **incident pulse**) down the spring and observe the reflection of the pulse from this fixed end.
2. Measure the time taken for the pulse to travel from the source to the wall and from the wall back to the source.

The pulse is **reflected**, which means it comes back along the spring. But on what side of the spring does it return?

It will be observed to come back on the opposite side of the spring with approximately the same amplitude. The **reflected pulse** is said to be inverted, **out of phase**, or **180° out of phase** with the incident pulse. It is said to have undergone a **phase reversal.** The speed of the reflected pulse and the incident pulse will be the same, as the speed in a particular medium remains constant.

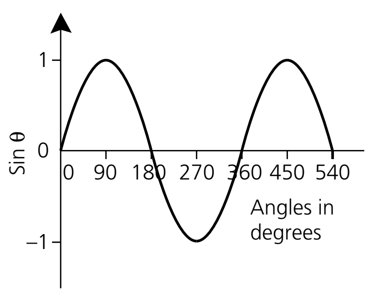
Figure 13.13
A pulse reflects from a fixed end with a phase change of 180°.



Activity 13.3 PHASE

This activity will help you to understand phase change in relation to angular degrees. Rule up a piece of graph paper, making the vertical axis the value of the 'sin' of the angle. Make about 5 cm equal to one unit. Place the angle in degrees on the horizontal axis. Using your calculator find sin θ, where θ = 0°, 90°, 180°, 270°, 360°, 450°, and 540°. On the graph paper plot the value obtained for the sine of the angle against the angle. Draw a smooth curve through the points. You should obtain something similar to Figure 13.14.

Figure 13.14
The wave produced by plotting the value of sin θ against the angle θ.



This curve resembles a perfect transverse wave. Notice the position of the points on the curve at 90°, and 270°. They are the same distance on opposite sides of the *x*-axis with 180° between them. When waves are reflected from fixed ends the reflected waves are on the opposite side of the spring. This might help to explain why the reflected wave is said to be 180° out of phase with the incident wave.

Another way of understanding this is to view an object going around in a vertical circular path, such as a seat on a Ferris wheel. When viewing from the side you will notice a particular seat on the wheel appears to go up and down like a cork in water when waves are passing. The cork on a crest would correspond to the particular seat on the Ferris wheel being at the top, and the cork would be in a trough when the seat is at the bottom. Since you go through 360° to complete a single circle, then half a circle corresponds to 180°, which is the difference between the cork being on a crest or in a trough.

Reflection can also occur if the spring has a free end, that is, it is not fixed to a wall. However, this time the pulse comes back on the same side as (in phase with) the incident pulse.

EI Activity 13.4 REFLECTION FROM FREE ENDS

Try it!

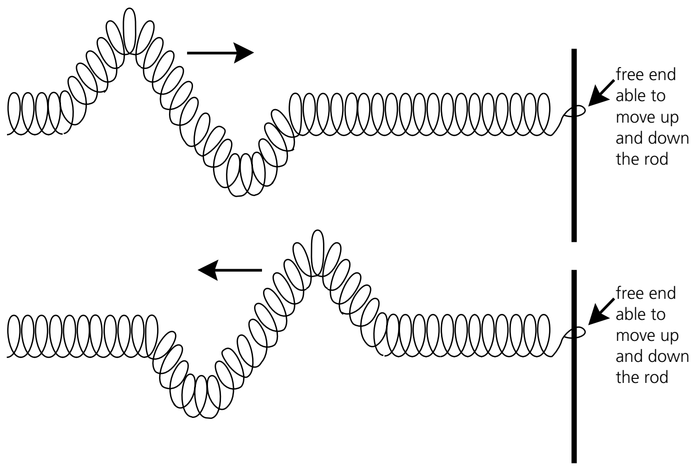


Figure 13.15
A pulse reflects from an open end with no phase change.

The above cases are the two extremes. We will now consider a wave that meets a boundary between two different springs.

EI Activity 13.5 LIGHTER TO HEAVIER SPRINGS

Try generating a pulse that travels from a lighter (less dense) spring to a heavier (more dense) one as shown in Figure 13.16, and observe the resulting pulse(s) after the pulse meets the boundary.

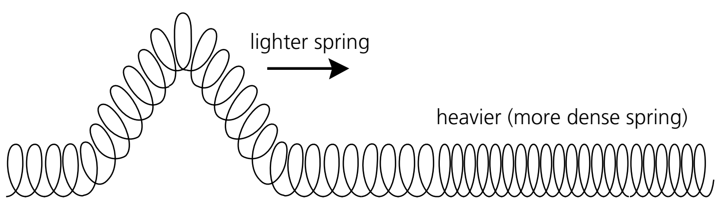


Figure 13.16
Two media — a lighter spring and a heavier spring.

When it meets the boundary (or join) some of the pulse is **transmitted** (continues on into the more dense spring) and some is reflected. At this point it will be noticed that the transmitted pulse is upright, in phase, or on the same side of the spring as the incident pulse, but the reflected pulse is upside-down or out of phase. As far as the reflected pulse is concerned, the boundary is behaving like a 'fixed end'.

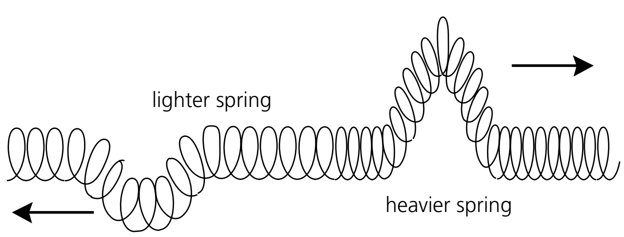


Figure 13.17
Waves going from a lighter spring to a heavier one are reflected, inverted and transmitted in phase.

Since the pulse has broken up, the amplitudes of both reflected and transmitted pulses are smaller than the incident pulse. The amplitudes of the transmitted pulse and reflected pulse are determined by the relative densities of the two media. If the second medium is much heavier, the transmitted pulse will be small and the reflected pulse will be large. If the second medium is only a little more dense, the transmitted pulse will be larger and the reflected pulse will be smaller. The velocity of the transmitted pulse depends on the medium but will be less than the incident or reflected pulses. However, the velocity of the reflected pulse will be the same as the incident pulse as the pulses are travelling in the same medium.

EI Activity 13.6 HEAVIER TO LIGHTER SPRINGS

Now create a pulse that goes from a heavier spring to a lighter spring as shown in Figure 13.18, and observe the resulting pulses.

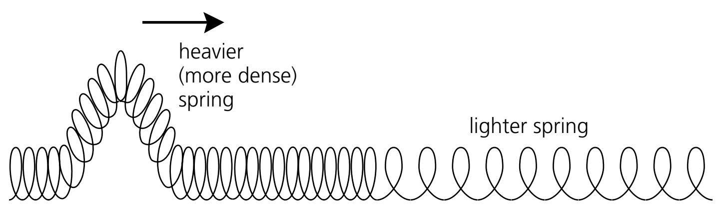


Figure 13.18
Waves going from a heavier spring to a lighter spring.

It will be observed that both reflection and transmission occur. In this case both the transmitted and reflected pulses will be seen to be on the same side of the spring as (in phase with) the incident pulse. The boundary is behaving like a 'free end', as far as the reflected pulse is concerned.

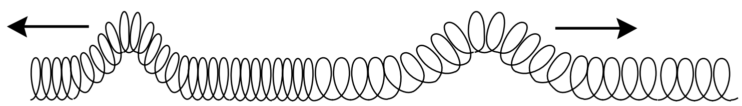


Figure 13.19
Waves going from a heavier spring to a lighter spring are reflected in phase and transmitted in phase.

In general when waves go from a less dense to a more dense medium the reflected pulse will be out of phase and the transmitted pulse will be in phase; and when waves go from a more dense medium to a less dense medium the reflected and transmitted pulses will both be in phase. This is summarised in Table 13.2.

Table 13.2 THE PHASE RELATIONSHIPS BETWEEN REFLECTED AND TRANSMITTED PULSES, WITH RESPECT TO THE INCIDENT PULSE WHEN IT MEETS VARIOUS BOUNDARIES

BOUNDARY	REFLECTED PULSE	TRANSMITTED PULSE
Fixed end	out of phase	—
Free end	in phase	—
Light medium to heavy medium	out of phase	in phase
Heavy medium to light medium	in phase	in phase

This principle of reflection of waves is important when applied to musical instruments, such as open and closed wind instruments. This will be discussed in Chapter 15.

13.5 SUPERPOSITION OF WAVES

You may have noticed that there are many instances when one wave meets another, either those produced by nature or those produced by man. For example, what happens when waves produced by two passing boats in the ocean cross over one another? What happens when two sound waves or two light waves meet? Do they cancel each other out, resulting in the elimination of both waves?

The intersection of two waves can be seen by producing pulses in a spring, one from each end.

EI Activity 13.7 INTERSECTION OF PULSES

1 Produce pulses simultaneously from either end of a spring with:
 (a) pulses on the same side of the spring;
 (b) pulses on the opposite side of the spring.
2 Observe the resulting wave form when they meet, and after they pass.
3 Draw diagrams to represent these interactions.

In the above activity pulses are seen to add together when they pass over each other, producing a much larger, or smaller, or differently shaped wave. The type of resulting wave depends on whether the pulses were produced on the same side or on opposite sides of the spring. However, once they have passed they continue as though they had not met. Figure 13.20 shows the resulting pattern produced when two pulses intersect. If they are produced on opposite sides of the spring **destructive interference** occurs, producing a smaller wave, or no wave at all at that instant. If they are produced on the same side of the spring **constructive interference** occurs, producing a super crest.

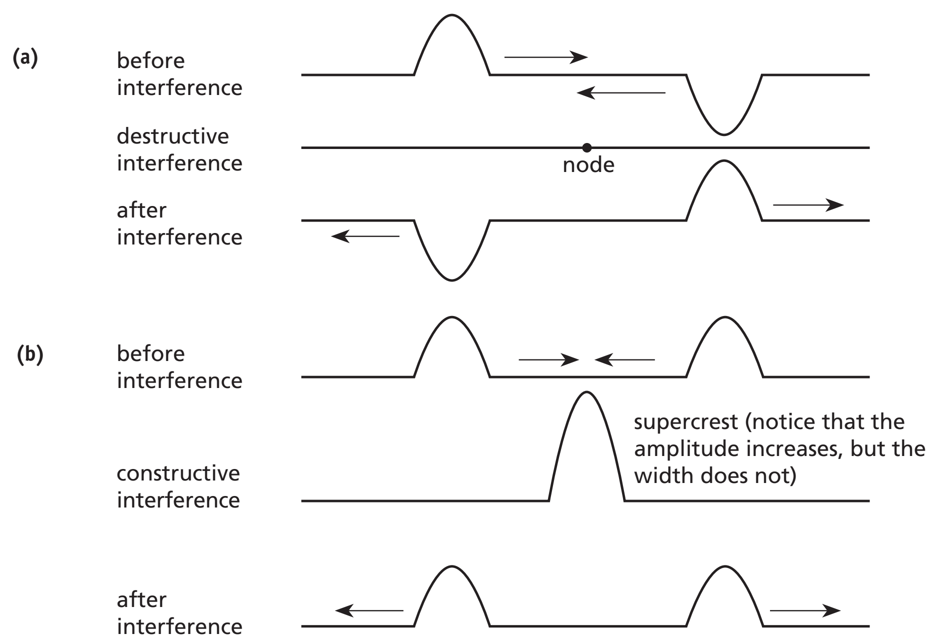


Figure 13.20
Superposition of waves may cause **(a)** destructive or **(b)** constructive interference.

This process is called the principle of **superposition**. The resulting wave can be obtained by adding the pulses' displacements, from the equilibrium positions, at several points, as shown in Figure 13.21.

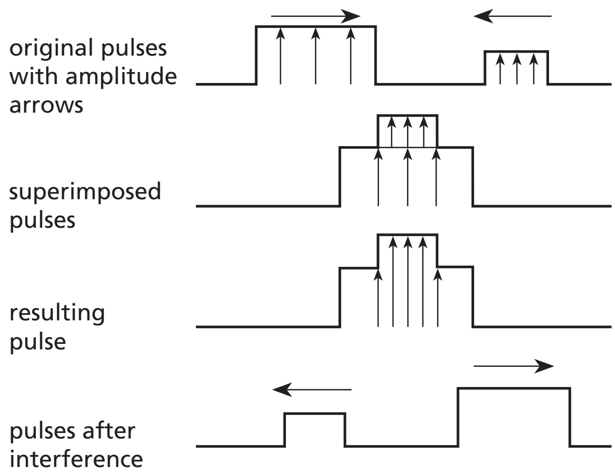
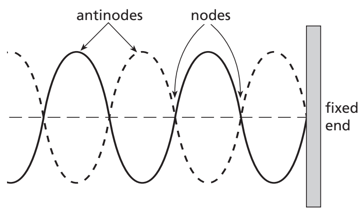


Figure 13.21
When two waves are superimposed their displacements add and they continue unaltered.

Standing waves

If a series of waves are created from each end of a spring of the **same amplitude and frequency**, a **stationary wave** or **standing wave** is created. This occurs because of the continued cancellations and additions of the waves as they travel along the spring and pass through each other. When the first crests meet they produce a pulse of twice the amplitude. A short time later (a quarter of a period) the pulses have moved so the crest of one is interacting with the trough of another, producing a point of zero displacement — a **node.** (The word 'node' comes from the Latin word *nodus*, meaning 'knot' — it looks as though the spring is knotted together.) Another quarter of a period later each pulse has moved another quarter of a wavelength and the two crests and two troughs again meet, producing super crests and troughs — **antinodes**. The characteristic standing wave pattern, as shown in Figure 13.22, is difficult to produce by two students flicking a spring from either end as they have to continually flick the spring in phase. But it is easy to produce by attaching the spring to a wall at one end and flicking the other as shown in Figure 13.22. The resulting standing wave pattern oscillates between the fixed and dotted lines as shown. Notice that the distance between two successive nodes is a half of a wavelength.

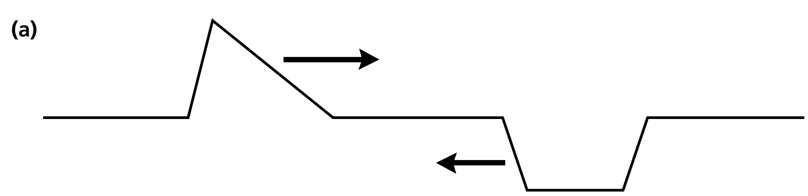
Figure 13.22
A standing wave produced by the continual generation and reflection of waves off a fixed wall. Oscillation only occurs between the dashed and solid lines.



Example

Construct the wave pattern produced when the two pulses shown in Figure 13.23 meet.

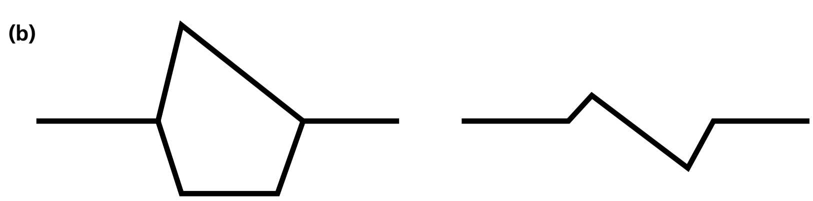
Figure 13.23
For example question.



Solution

See Figure 13.24.

Figure 13.24
For example question.



Questions

6 Use the principle of superposition to determine the resulting pulse when the pulses shown in Figure 13.25 are superimposed on each other.

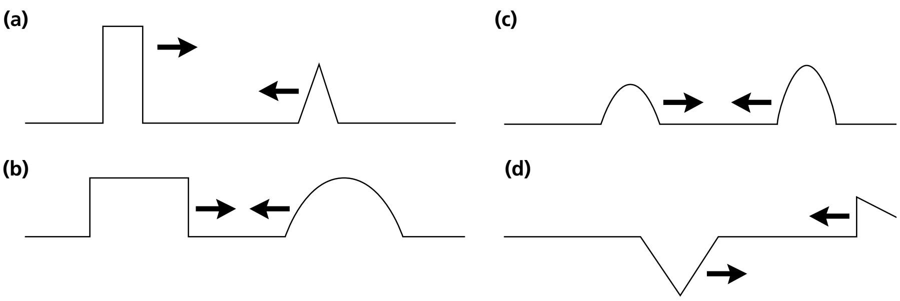
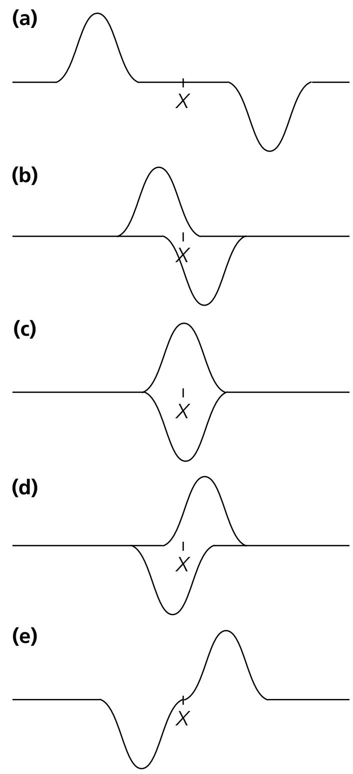


Figure 13.25
For question 6.

7 Two identical waves are produced on either side and either ends of a rope (Figure 13.26). Draw the resulting wave when they are in the positions shown. What do you notice about point X?

Figure 13.26
For question 7.



Wave motion in sports equipment

As you have seen in the chapters on force, momentum and energy there are several 'sweet spots' in bats and racquets. One is the centre of percussion — the point that produces no jarring in the hand when a ball is struck. This point is a nodal point for standing waves in the equipment.

Tennis racquet When a ball is hit, the racquet rings as waves run up and down its length (Figure 13.27). The string node is just above the centre of the strings.

Baseball bat If you hold a bat loosely by the handle and tap it with a hammer you will hear ringing at most points. But at about 16 cm from the far end (of a 78 cm aluminium bat) there will be very little sound. This is the nodal point and a ball struck here produces no stinging in the hand if held at the node at the other end. Try it!

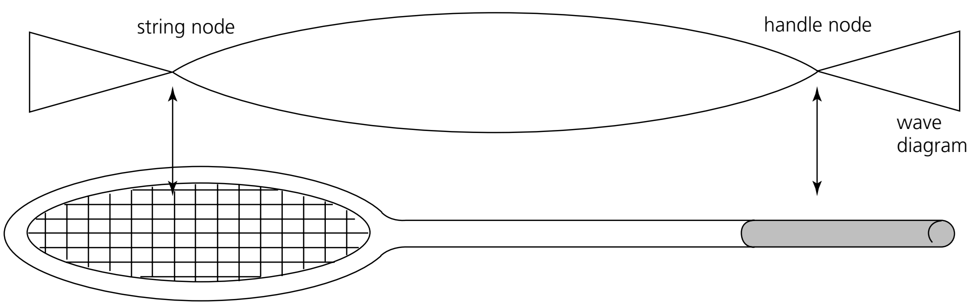
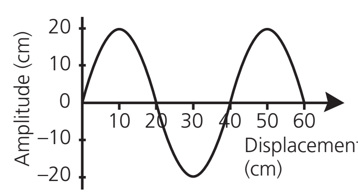


Figure 13.27
The string node of the standing wave of a tennis racquet is just above the centre of the strings.

13.6 GRAPHICAL ANALYSIS OF MOTION

Wave motion can be represented graphically in two ways: amplitude–displacement and amplitude–time graphs.

Figure 13.28
An amplitude–displacement graph for wave motion.



Amplitude–displacement graphs

The graph in Figure 13.28 represents the position of a wave at a certain time. From this graph the amplitude and the wavelength of the wave can be determined. If the position of the wave at another time is given, the characteristics of the wave that involve time, such as the speed and the frequency of the wave, can be calculated.

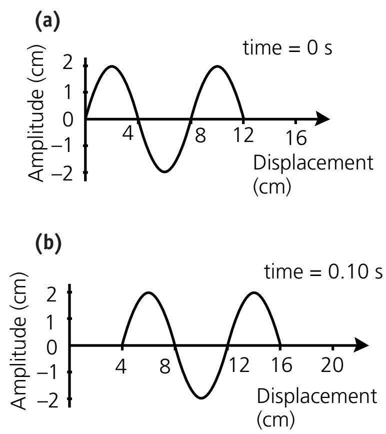


Figure 13.29
For example question.

Example

Figure 13.29**(a)** shows the position of a wave at time equals zero, and Figure 13.29**(b)** shows the position of the wave 0.10 second later.

(a) Calculate the speed and frequency of the wave.
(b) Draw the wave after another 0.2 second.

Solution

(a) The wave has travelled a distance of 4 cm in the 0.1 s. Therefore:

$$\begin{aligned} \boldsymbol{v} &= \frac{d}{t} \\ &= \frac{4\text{ cm}}{0.1\text{ s}} \\ &= 40\text{ cm s}^{-1} \\ \boldsymbol{v} &= f\lambda \\ f &= \frac{\boldsymbol{v}}{\lambda} \\ &= \frac{40\text{ cm s}^{-1}}{8\text{ cm}} \\ &= 5\text{ Hz} \end{aligned}$$

(b) See Figure 13.30.

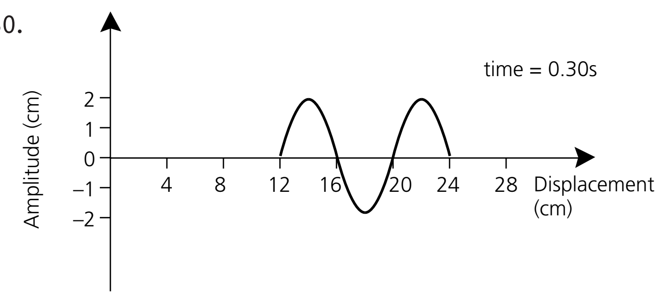


Figure 13.30
For solution to example question.

INVESTIGATING

Hold an aluminium or steel rod (unscrew a retort stand) vertically and tap the top with a hammer. Hold it at different places and note the change in sound. You can get frequencies greater than 20 000 Hz (painful). How can you get beats?

Amplitude–time graphs

As well as indicating the amplitude of the wave these graphs indicate the position of the wave and the position of points on the wave at certain times. Thus the velocity of the wave can be calculated.

Example

A wave is created on a spring as shown (Figure 13.31). The displacement of point P is given by the graph (Figure 13.32).

(a) Calculate the period of the wave.
(b) What is the amplitude of the wave?
(c) If the wave is moving at 5 cm s^{-1} to the right what is the wavelength of the wave?

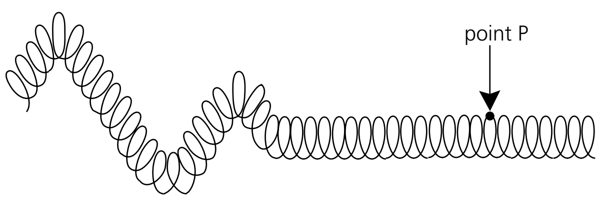


Figure 13.31
For example question.

Solution

(a) The wave repeats itself after (1.0 – 0.4) seconds, therefore the period is 0.6 s.
(b) Amplitude = 20 cm.

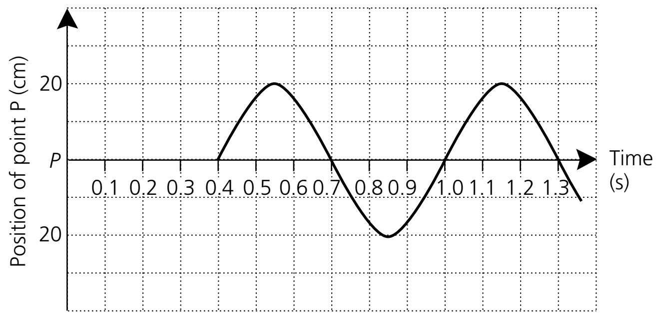


Figure 13.32
For solution to example question.

(c)

$$v = f\lambda$$

$$\lambda = \frac{v}{f}$$

$$= v \times T$$

$$= 5 \text{ cm s}^{-1} \times 0.6 \text{ s}$$

$$= 3.0 \text{ cm}$$

Questions

8 Figure 13.33 represents the displacement of particles in a rope with time as a wave passes. Calculate **(a)** the amplitude of the wave; **(b)** the period of the wave; **(c)** the frequency of the wave.

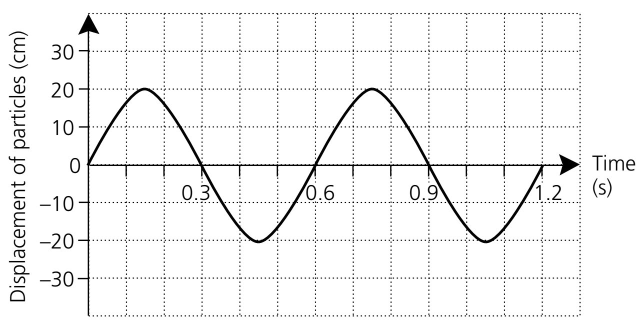


Figure 13.33
For question 8.

9 For the waveform shown in Figure 13.34 find the following:

(a) the wavelength of the disturbance;
(b) the amplitude of the wave;
(c) if the wave is travelling to the right at a speed of 80 cm s^{-1}, find the frequency of the disturbance.

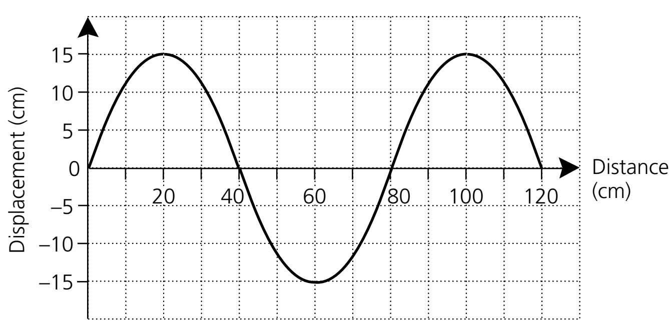


Figure 13.34
For question 9.

10 Figure 13.35 shows the position of a wave at two instances in time. From these graphs determine **(a)** the amplitude of the wave; **(b)** the wavelength of the wave; **(c)** the velocity of the wave.

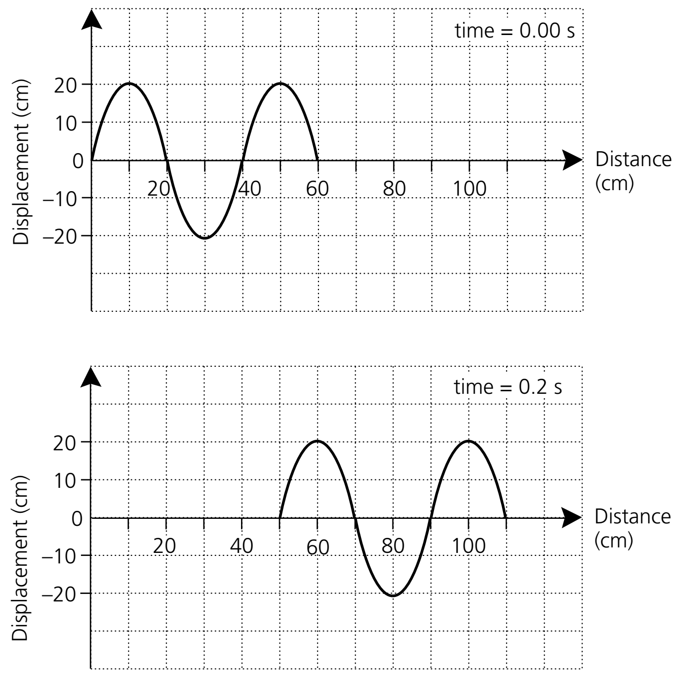


Figure 13.35
For question 10.

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

***11** What happens to the speed of a pulse in a slinky spring if it is stretched?

***12** Explain the difference between a longitudinal and a transverse wave.

***13** A dinghy anchored in the ocean is seen to bob up and down as waves pass.
- **(a)** What types of waves are they?
- **(b)** How do you know this?
- **(c)** What physical feature of the wave indicates the energy the wave possesses?

***14** Name a particular type of wave where the particles move at **(a)** right angles to the direction of propagation; **(b)** in the same direction as the wave is moving.

***15** Describe what is meant by the wavelength of a wave in relation to a longitudinal wave.

***16** State the wave equation indicating the meaning of the symbols used.

***17** Two students shaking a slinky spring create 10 waves in 5 seconds. The wavelength of the waves is 50 cm.
- **(a)** What is the frequency, period, and speed of the wave?
- **(b)** If the wave was shaken at a greater frequency **(i)** what characteristics of the wave would change; **(ii)** what characteristic would remain the same?
- **(c)** How can the speed of the wave in the spring be changed?

***18** Students creating waves in two slinky springs joined together found that the waves travelled down the first one, and were reflected upside-down from the junction of the springs.
- **(a)** What is the relationship between the heaviness of the two springs?
- **(b)** Will waves be transmitted into the second spring and if so will they be in phase or out of phase?

***19** What conditions are necessary for the creation of standing waves?

***20** Two identical waves are created from either ends of a long spring. Each wave has a wavelength of 20 cm and an amplitude of 10 cm. This produces a standing wave pattern.

(a) What is the maximum displacement of the resultant waveform as they pass through one another?

(b) How far apart are the nodes?

***21** Two weekend anglers find that their 4 m boat bobs up and down 3 times in 20 seconds, and exactly 3 wave crests can fit under the boat at any one time. What is the velocity of the waves?

***22** When a tuning fork is hit it vibrates at the rate of 300 vibrations per second. If the speed of sound in air is 340 m s^{-1}, calculate the wavelength of the sound waves produced.

***23** AM radio stations transmit radio waves that are electromagnetic waves similar to light waves, but have a frequency from about 500 kHz to 30 MHz. If they travel at 3×10^8 m s^{-1}, what is the wavelength of radio waves?

***24** The speed of sound in salt water is 1450 m s^{-1}, and 340 m s^{-1} in air. If the frequency of the sound being generated by a motor boat engine is 550 Hz, what is **(a)** the wavelength of the sound in air; **(b)** the frequency of the sound in salt water; **(c)** the wavelength of the sound in salt water?

****25** Figure 13.36 shows transverse waves being generated at the rate of 10 per second. From this diagram determine:

(a) the amplitude of the waves;

(b) the wavelength of the waves;

(c) the period of the waves;

(d) the velocity of the waves.

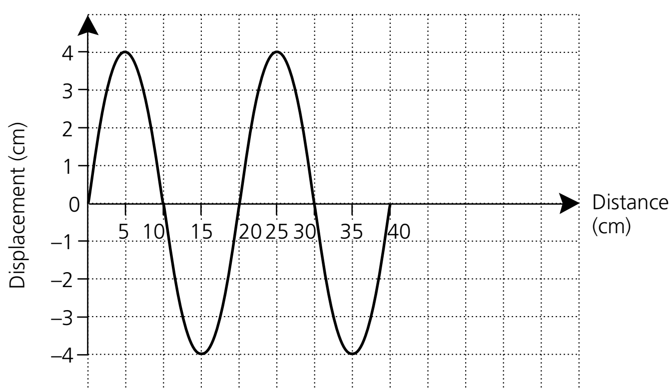


Figure 13.36
For question 25.

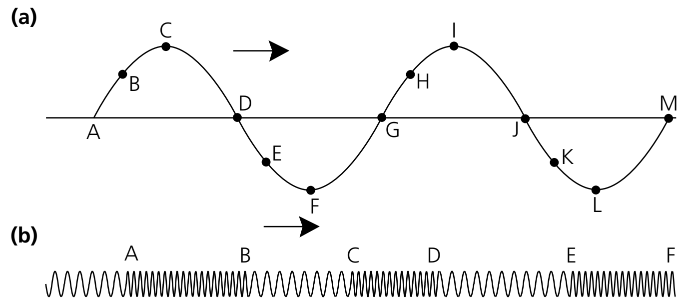
****26** When earthquakes occur they create waves that spread outward from the source. Three types of waves occur. The primary or P waves, which are caused by the back and forth movement of rocks; the secondary or S waves, which travel as a result of the up and down movement of rocks; and the L waves, which are ripples that travel on the surface and are set up when the P and S waves reach the surface. The L waves cause rocks to vibrate in an up and down motion.

(a) What type of waves are P, S, and L waves?

(b) Earthquake waves have a wavelength of 10 m and a speed of 3.0 km s^{-1}. What is their frequency?

****27** Figures 13.37 **(a)** and **(b)** show a transverse wave and a longitudinal wave moving to the right. Indicate the direction of motion of the points A and B.

Figure 13.37
For question 27.



**28 Waves are sent down a set of connected ropes and later return to the sender as shown in Figure 13.38. What is the relationship between the density of the rope sections A, B, and C?

Figure 13.38
For question 28.

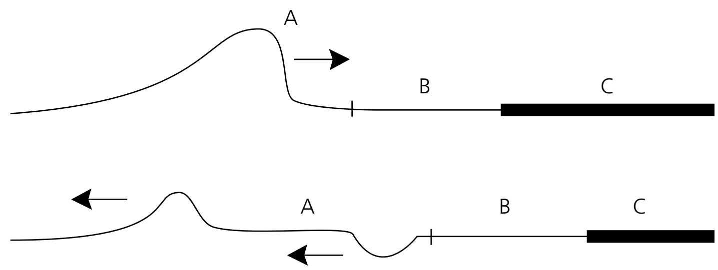
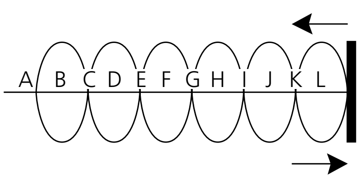


Figure 13.39
For question 29.



**29 A standing wave pattern is set up by reflecting waves off a wall as shown in Figure 13.39.

(a) Indicate the wavelength of the waves producing the standing wave.
(b) Which points are nodes?
(c) Which points are antinodes?
(d) If the distance between 'A' and 'F' is 5.0 m, what is the wavelength of the waves?

**30 Figure 13.40 shows a wave in the same section of a string at two different times. What is the greatest possible period of the wave?

**31 A transverse wave is travelling from right to left through a series of particles. At a certain instant the waveform is as shown in Figure 13.41. Each of the vibrating particles is observed to perform two complete oscillations in 20 seconds.

(a) Find the following quantities: wavelength, frequency, amplitude, and speed of the wave.
(b) At the instant shown, which of the particles (A–H) are **(i)** moving upward; **(ii)** moving downward; **(iii)** momentarily still?
(c) What will be the position of particle C one-quarter of a period later?

Figure 13.40
For question 30.

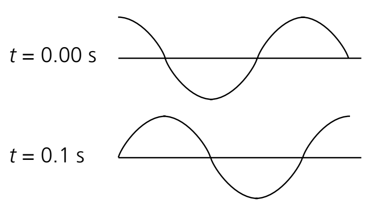
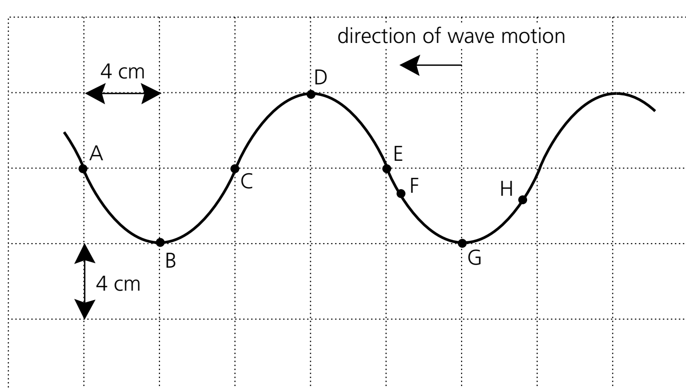


Figure 13.41
For question 31.



***32** Figure 13.42 shows a wave of frequency 10 Hz at an instant in time. The wave is travelling to the right.

(a) What is the wavelength of the wave?
(b) What is the speed of the wave?
(c) Using the letters shown, name any two points on the wave that are in phase.
(d) If a reflecting barrier is placed at F, sketch on an appropriate diagram the shape of the reflected wave.

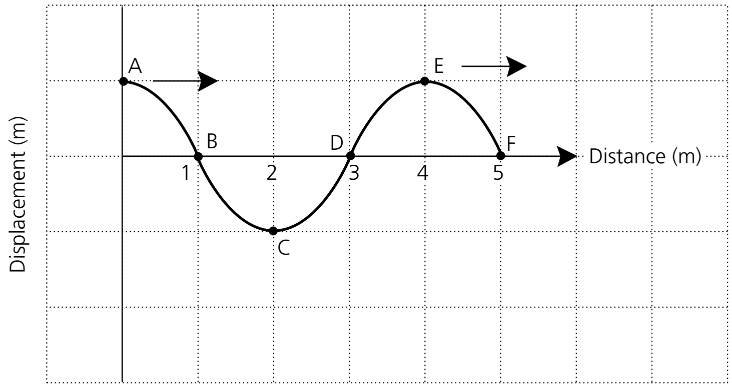


Figure 13.42
For question 32.

****33** Draw neat diagrams to illustrate the reflected pulses in the four situations shown in Figure 13.43. Each pulse is created in a rope.

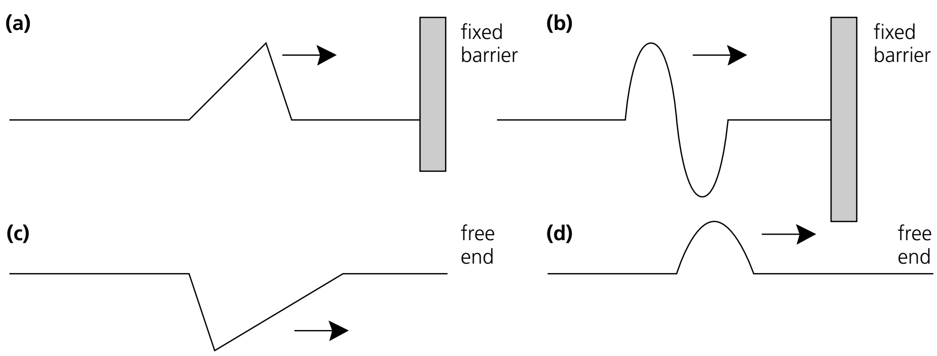


Figure 13.43
For question 33.

****34** A heavy spring is attached to a lighter spring and then fixed to a wall as shown in Figure 13.44. A pulse is sent along the heavier spring towards the wall.

(a) Draw the pulse that is transmitted into the lighter spring.
(b) Draw the shape of the pulse reflected from the lighter spring.
(c) What will happen when the pulse hits the wall?

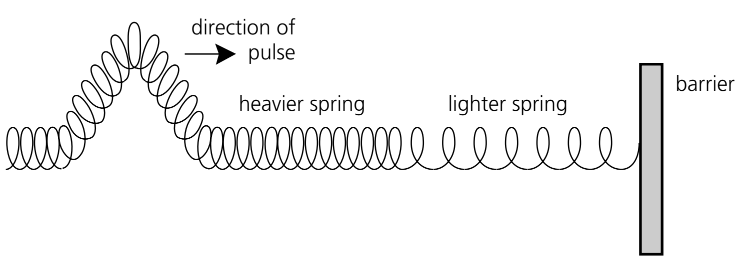


Figure 13.44
For question 34.

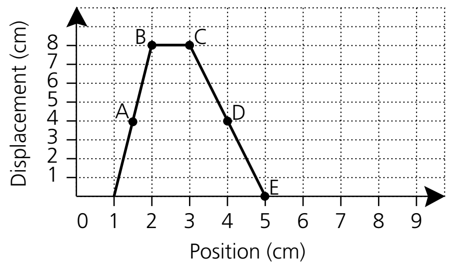
****35** Figure 13.45 illustrates a pulse that is moving to the right along a stretched rope at a speed of 4.0 cm s^{-1}.

(a) Draw the position of the pulse 1 s later.

(b) If A is a point on the rope, where will it be in 0.50 s?

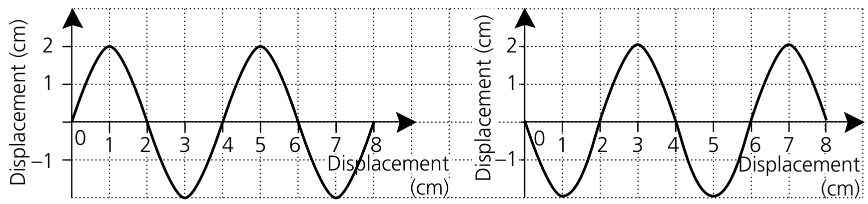
(c) What is the amplitude of the wave?

Figure 13.45
For question 35.



****36** Figure 13.46 shows the position of a wave in a rope at two instances in time. Determine **(a)** the wavelength of the wave; **(b)** the frequency of the wave; **(c)** the amplitude of the wave; **(d)** the speed of the wave.

Figure 13.46
For question 36.



Extension — complex, challenging and novel

*****37** Students sitting 50 m from the start of an athletic competition hear the starting pistol start the race. (See Figure 13.47.) They hear a second noise 0.9 s later due to the sound being reflected from the grandstand 150 m from the start. What is the speed of sound on this day?

Figure 13.47
For question 37.

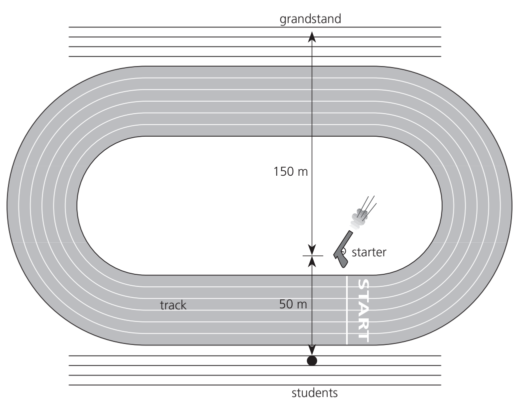
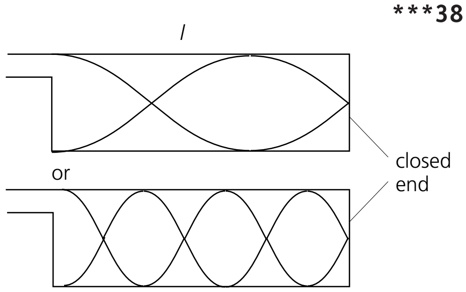


Figure 13.48
For question 38.



*****38** Sounds are produced in stringed musical instruments by setting up standing waves in strings by plucking them. Longitudinal stationary waves can be produced in the air columns of wind instruments, like a flute, by blowing in them. The air column can vibrate in a number of different ways. An example of two modes of vibration in a closed-end pipe is given in Figure 13.48. Draw the first five different modes of vibration for an open-ended pipe and determine a general formula relating the length of the pipe to the wavelength of the sound produced.

*****39** A fisherman using an echo-sounder to locate fish finds that the reflected pulses return after 0.20 s and 0.25 s. Interpret these two times and determine how far from the ocean floor are the fish (if any).

*****40** Can the 'Mexican wave', historically started at a World Cup soccer match in Mexico in 1986 to distract the competitors, be regarded as a wave? Critically analyse the features of this phenomenon in the light of wave characteristics.

*****41** Figure 13.49 illustrates a pulse moving to the right along a stretched spring at a speed of 5.0 m s^{-1}.

(a) Which of the points A, B, C has the greatest speed at this instant?

(b) Calculate the instantaneous velocity of point C.

(c) Draw the displacement–time graph and the velocity–time graph for the point X on the spring. Take the zero for time at the instant shown in the graph.

(d) Suggest why this particular situation is very unlikely.

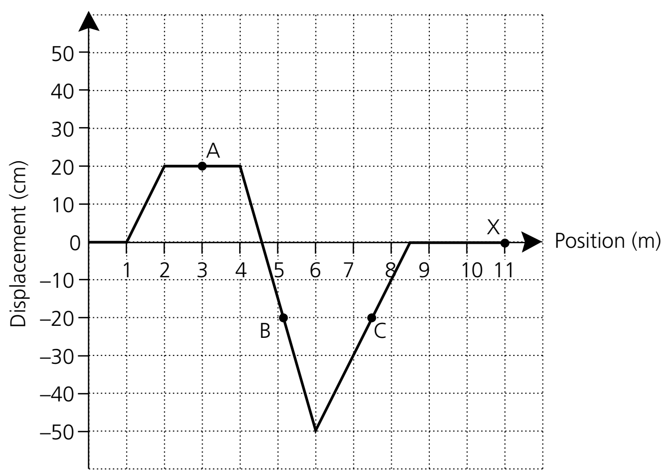


Figure 13.49
For question 41.