8 General Wave Properties

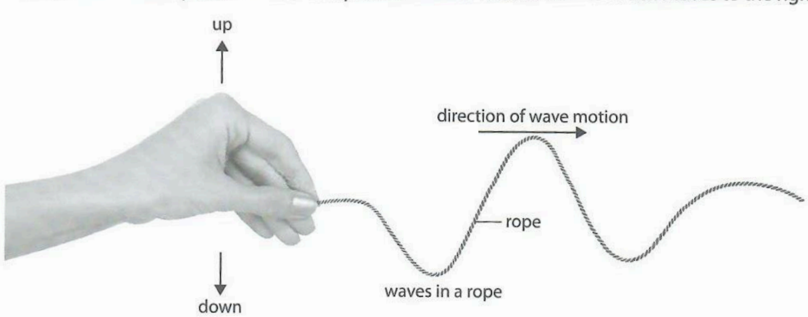
Study Station ▸▸

A Wave Properties

Learning Outcomes

- Describe wave motion as shown by vibrations in ropes and springs and by waves in a ripple tank using related terms such as wavefront.
- Understand that waves can transfer energy without transferring matter.
- Compare transverse and longitudinal waves and give examples.
- Define and use the quantities speed, frequency, wavelength, period and amplitude, and represent them graphically.
- Recall and apply the relationship *speed of wave = frequency × wavelength* to real-world situations and solve related problems.

1. The wave motion is a special type of *motion which transfers energy without transferring particles of matter.*
2. In the example below, when you continuously move one end of a rope up and down, *each point of the rope also moves up and down*. This repetitive motion creates a wave which moves to the right.



- When you move one end of a rope, you are transferring energy to the rope at that point.
- In turn, that point pulls along the neighbouring point on its right (and thus transfers energy to it).
- This process continues along the rope (and transfers energy to the right).

Tip

Note that another way to transfer energy without transferring matter is by conduction in non-metal solids, which involves vibrational motions (covered in Chapter 8).

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1. Figure 8.1 shows a jug of boiling water where convection currents are set up as the water boils.

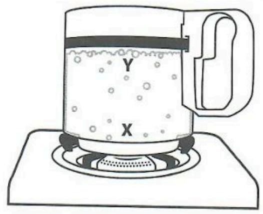


Figure 8.1

Which of the following statements is **not** correct?

A At point **X**, water is flowing upwards.

B At point **X**, energy is being transferred upwards.

C The temperature of the water at point **X** is higher than that at point **Y**.

D The density of the water at point **X** is higher than that at point **Y**.

2. The body hair of some mammals 'stand up' when the mammals feel cold. What is the main role of body hair in helping them cope with the cold?

A Body hair traps an insulating layer of air between the skin and the surrounding cold air.

B Body hair prevents the development of convection currents in the surrounding air.

C Body hair reduces the rate of radiation emission from the body.

D Body hair increases the rate of radiation absorption by the body.

3. When a drop of water falls onto an extremely hot frying pan, a layer of water vapour is created between the water droplet and the hot surface. This water droplet takes a much longer time to boil away than usual. This phenomenon is known as the Leidenfrost effect.

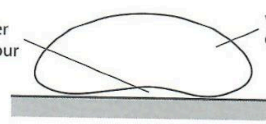


Figure 8.2

(a) Is the layer of water vapour a good or poor heat conductor? [1]

(b) Explain why the same amount of water will boil away more quickly if the initial temperature of the frying pan is lower. [2]

4. Global warming, which contributes to climate change, is considered to be a global challenge. The United Nations holds a conference to discuss this matter almost every year.

(a) Explain how the energy from the sun could reach Earth. [1]

(b) Some scientists suggest painting buildings white. Explain how this action can help combat global warming. [2]

(c) When average global temperature increases, snow on Earth's surface melts faster. Discuss why this rate of snow melting increases as temperature increases. [4]

(d) Hence, discuss the risk of global warming to a small island like Singapore. [3]

5. *Teppanyaki* is a Japanese dish with meat that is cooked on a hot metal plate.

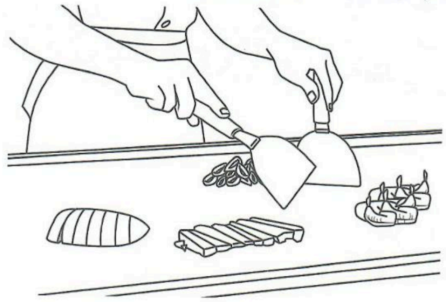


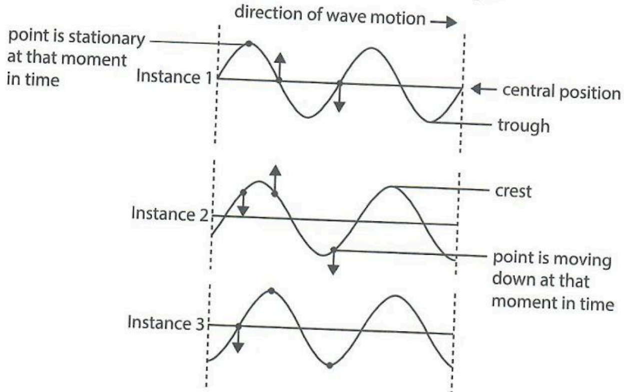
Figure 8.3

(a) State the main thermal process of energy transfer during the cooking of meat. [1]

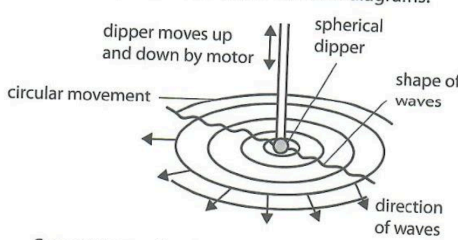
(b) If a piece of meat is too thick, the inner part of the meat may still be raw even though the surface of the meat is already burnt. Explain why. [3]

(c) Explain why it is impossible for the meat to be hotter than the metal plate during the process of cooking. [3]

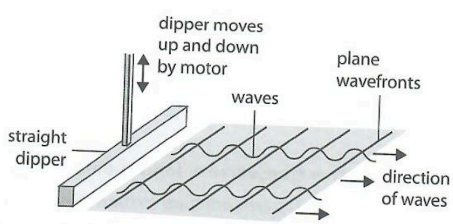
3. If we take photos of the rope's wave motion at three consecutive instances of time, we will be able to see that:
   - each point *moves up and down* and not left to right,
   - the ***waveform*** (shape of wave or wave profile), with its **crests** (points with maximum height) and **troughs** (points with minimum height), *moves from left to right*.



4. The movement of **surface water** is also a type of wave motion. We can use a **dipper in a ripple tank** to generate the water waves.
   - A spherical dipper generates circular water waves that move outwards.
   - A straight dipper generates plane water waves that move in one direction.
   - We can use **wavefront**, which are *imaginary lines connecting the crests or troughs that are generated at the same time*, to represent the water waves in diagrams.

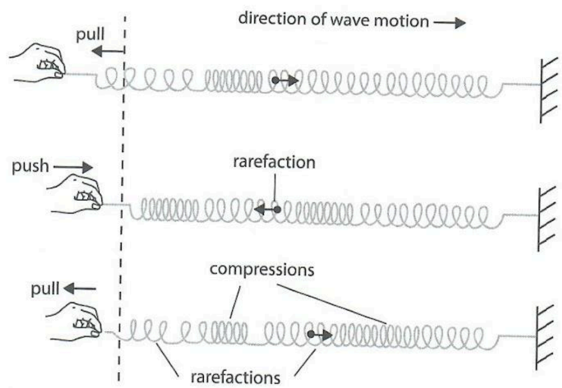


Concentric wavefronts are represented by circles.

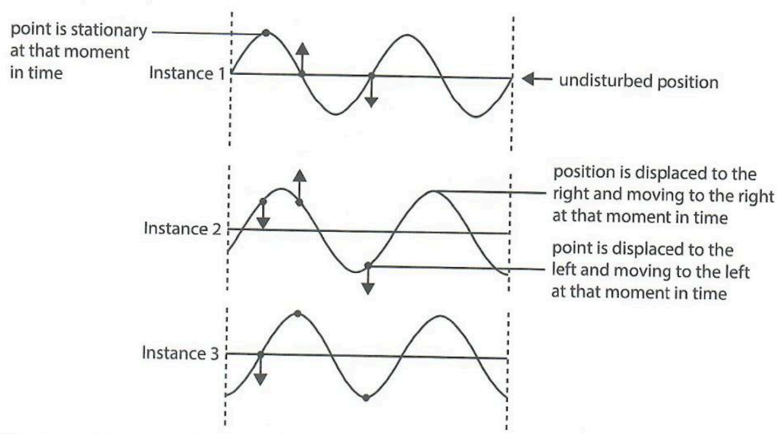


Evenly spaced straight lines represent the plane water waves produced.

5. When you continuously move one end of a **spring** forward and backward (push and pull) and the other end is fixed to a wall, *each point of the spring also moves forward and backward.*
   - Each point *moves left and right* about its undisturbed position (position when you have not started the wave motion).
   - This repetitive motion creates a series of **compressions** and **rarefactions** that move to the right.

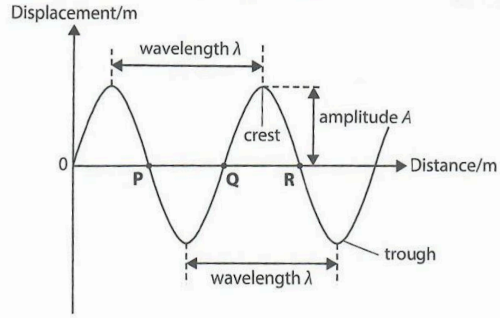


6. We can take photos of the spring's motion at three consecutive instances of time to investigate its wave motion.
   - Firstly, measure the *displacement of various points on the spring* from their undisturbed positions (take to the right as positive direction)
   - Plot graphs with a vertical axis indicating the displacement values of each point to get graphs with a wave shape.



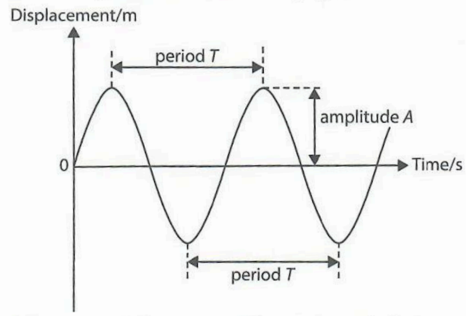
7. All waves can be categorised as either **transverse** or **longitudinal** waves.
   - Each point in a transverse wave *moves* ***perpendicular*** *to the motion of the wave*. Some examples of transverse waves are waves made on ropes and water waves.
   - Each point in a longitudinal wave *moves* ***parallel*** *to the motion of the wave*. An example of a longitudinal wave is a wave in a spring.

8. We can draw the **displacement–distance graph** for all waves.



- A set of points are said to be **in phase** if they have the *same displacement and are moving in the same direction*. In the graph above, points **P** and **R** are in phase. Point **Q** is not in phase with points **P** and **R**.
- **Wavelength** λ is the *distance between any two consecutive points* that are in phase. Its SI unit is **metre (m)**. It can be measured between two consecutive crests or troughs (for transverse waves) or centres of compressions or rarefactions (for longitudinal waves).
- **Amplitude** *A* is the *maximum displacement from the central or undisturbed position*. Its SI unit is **metre (m)**.

9. If we measure the *displacement of a single point in the wave motion at different moments in time*, we can draw the corresponding **displacement–time graph**.



- **Period *T*** is the *time taken to complete one cycle* (recall the period of a pendulum). Its SI unit is **second (s)**.
- Inversely, **frequency *f*** is the *number of cycles completed per unit time*. Its SI unit is **hertz (Hz)**.

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

10. The **wave speed *v*** is equal to the distance travelled by one crest to replace another crest, which is one wave cycle, divided by the time taken, $v = \frac{\lambda}{T}$ or:

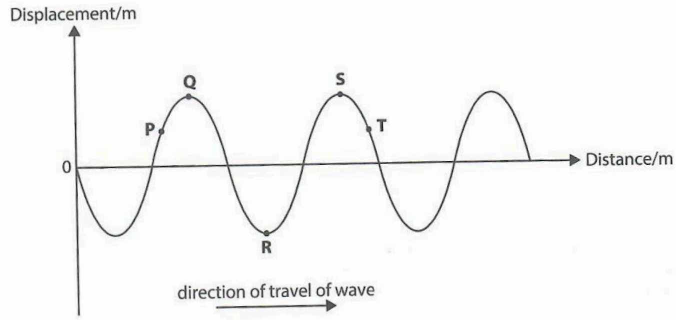
$$v = f\lambda$$

Its SI unit is metre per second (m/s).

Worked Example 9.1

The diagram below shows the graph of displacement of a wave against distance.

The wavelength and period of the wave are known to be 10 cm and 2 s respectively.



(a) State the direction of motion of point **P**.

(b) State the direction of motion of point **T**.

(c) State the distance between points **Q** and **R**.

(d) Calculate the speed of the wave.

Strategy

Imagine how the graph changes a short moment before and later.

Solution

(a) Downwards

(b) Upwards

(c) Distance between points Q and R $= \frac{1}{2} \times \lambda$

$= \frac{1}{2} \times 10$ cm

$= 5$ cm

(d) $v = \frac{\lambda}{T} = \frac{0.10\text{ m}}{2\text{ s}} = 0.05$ m/s

Common Error

✗ The speed of a transverse wave refers to how fast a point on the wave moves along the direction of travel of the wave.

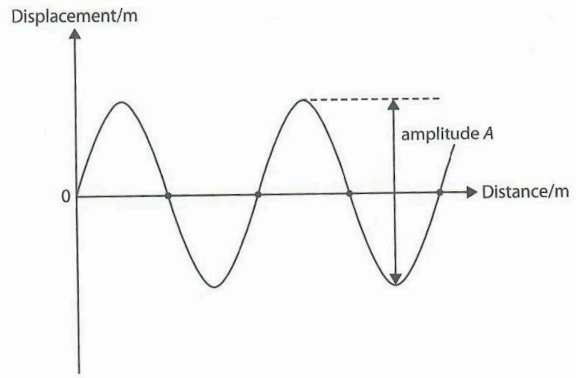
✓ The speed of a transverse wave refers to how fast a crest or a trough travels along the direction of travel of the wave.

Explanation

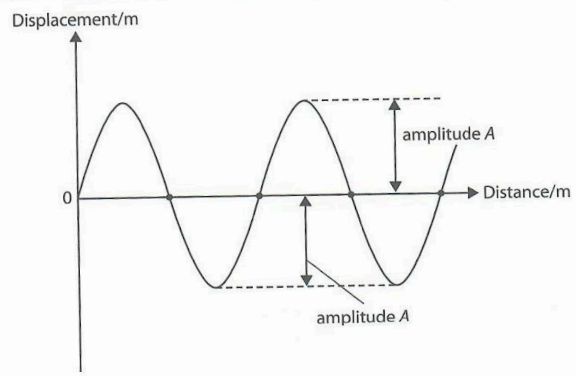
The point on the wave does not move along the direction of travel of the wave.

Common Error

✗ The amplitude is the vertical distance between a peak and a trough.



✓ The amplitude is the vertical distance between a crest and the centre position or between a trough and the centre position. Amplitude is always given as a positive value.



Explanation

The amplitude of a wave is the maximum displacement from the central position.

Tip

Summary notes for this chapter:

- Wave motion transfers energy without transferring matter.
- Examples of transverse waves are waves of ropes and water waves.
- An example of longitudinal waves is waves in springs.
- In transverse waves, each point moves perpendicular to the wave motion.
- In longitudinal waves, each point moves parallel to the wave motion.
- A displacement–distance graph of a wave shows the position of a point in a wave relative to its rest position, at a particular moment in time.
- A displacement–time graph of a wave shows the displacement of a point from the rest position over time.
- Wavelength λ is the distance between two consecutive peaks or troughs.
- Amplitude A is the maximum displacement from the central position.
- Period T is the time for one complete cycle.
- Frequency $f = \frac{1}{T}$
- Wave speed $v = f\lambda$

Link — Discover Physics (5th Edition) Textbook — Sections 9.1 and 9.2

Checkpoint 9.1

1. When wind is blowing at 37 km/h, sea waves are observed to travel at 7 m/s with wavelength of 35 m. Calculate its frequency.

Tip

Questions regarding wave speed have often appeared in examinations, e.g., GCE 'O' Level Science Physics Oct/Nov 2020, Paper 1, Q23.

Test Station ▸▸

1. The lines in Figure 9.1 represent the wavefronts of a longitudinal wave moving to the right.

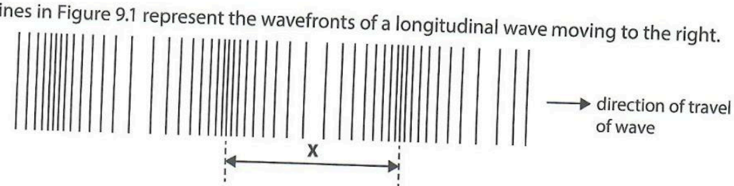


Figure 9.1

What does **X** represent?

A Period

B Amplitude

C Wavelength

D Frequency

2. Which quantities can be determined from the displacement–distance graph of a wave?

A Amplitude and wavelength

B Amplitude and period

C Wavelength and period

D Period and frequency

3. Figure 9.2 shows the displacement of a point in a water wave of speed 10 m/s and wavelength 5.0 m.

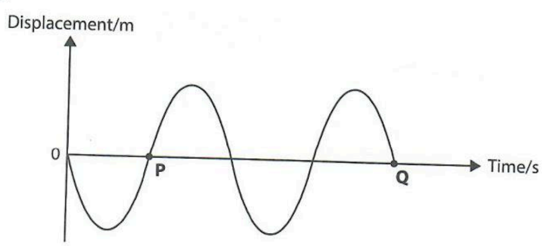


Figure 9.2

(a) Calculate the frequency of the wave. [2]

(b) Determine the time difference between **P** and **Q** in the graph. [3]

(c) If wavefronts are drawn to represent all the points at the crests, determine the number of wavefronts that have passed through the point during the time period corresponding to (b). [2]

4. Figure 9.3 shows a bicycle saddle that has two springs to increase the comfort level of cycling.

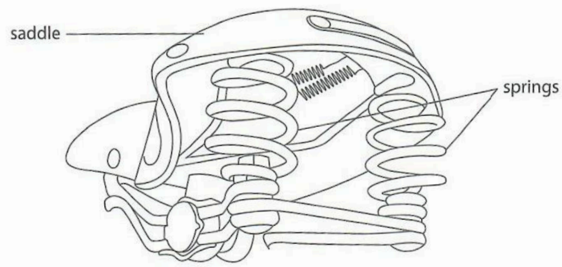
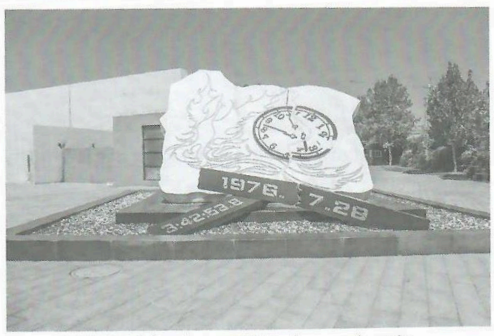


Figure 9.3

(a) Describe how cycling on uneven ground affects the shape of the springs. [2]

(b) Compare the direction of wave motion in the springs and the direction of energy transfer. [2]

5. An earthquake is a sudden shaking of the ground which can create large vibrations. It can cause massive damage and a high death toll. For example, more than 200 000 people died in the 1976 Tangshan earthquake in China.



Memorial to the 1976 Tangshan earthquake

The longitudinal waves caused by an earthquake moved from the point of origin of the earthquake at a speed of 5000 m/s in the rocky ground.

(a) The frequency of the waves was measured to be 10 Hz. Calculate the wavelength of the waves. [2]

(b) A town is 10 km away from the point of origin of the earthquake. Calculate the time taken for the waves to reach the town, from the point of origin. [2]

(c) Suggest why a town located 20 km away from the point of origin suffered less damage than the town located 10 km away. [1]