Transverse pulses and waves

Objectives

- Define a transverse pulse and a transverse wave.
- Define the principle of superposition, constructive interference and destructive interference.
- Apply the principle of superposition to pulses using diagrams.
- Define amplitude, wavelength, frequency, period, crest and trough.
- Explain the wave concepts of in phase and out of phase.
- Use the relationship between frequency and period to solve problems.
- Define wave speed and use the wave speed equation to solve problems.

Transverse pulses

What is a pulse? [D]

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What is a disturbance?

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What is a medium?

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A medium provides the 'pathway' for the energy of the disturbance to move from one place to another. Examples of mediums include the air, water or a rope.

A pulse can either have a crest or a trough.

What is a crest?

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What is a trough?

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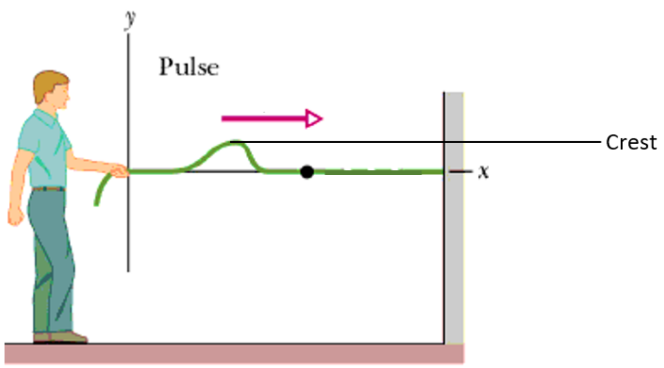
A pulse typically has either a crest or a trough, but not both, because it is a single disturbance. It represents just one movement in the medium. On the diagram below, we see a disturbance in the form of a crest moving through a rope.



A pulse with a crest

In any material, the particles that make it up are typically evenly distributed. When a short, sudden force is applied to one end of the material, it creates a chain reaction of disturbances that travel through neighbouring particles. Each group of particles transfers energy to the next group, causing them to move and pass the disturbance along. The particles move temporarily from their rest position, but the position of the medium is the same before and after the disturbance has travelled through it.

A pulse has two important properties:

Pulse length, measured in **meters** (m).

Amplitude, measured in **meters** (m). What is amplitude? D

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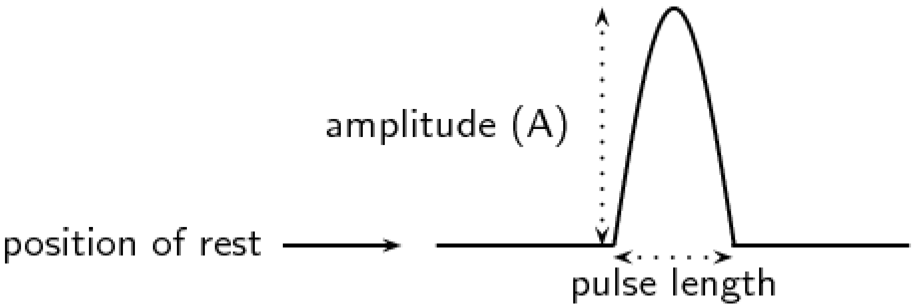
The diagram below shows the pulse length and amplitude of a pulse.



A pulse has pulse speed. What is speed? D

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The equation for speed is:

$$speed = \frac{distance}{time}$$

In the case of a pulse, the distance is represented by the pulse length. The speed of a pulse may be calculated as:

$$pulse\ speed = \frac{pulse\ length}{pulse\ duration}$$

Where:
- **Pulse length** is measured in **meters** (m).
- **Pulse duration**, or the amount of time it takes for the pulse to pass a certain point, is measured in **seconds** (s).
- **Pulse speed** is measured in **meters per second** ($m.s^{-1}$).

Examples

1. A pulse has a pulse length of 12 m and takes 4s to pass a certain point in a rope. What is the speed of the pulse?

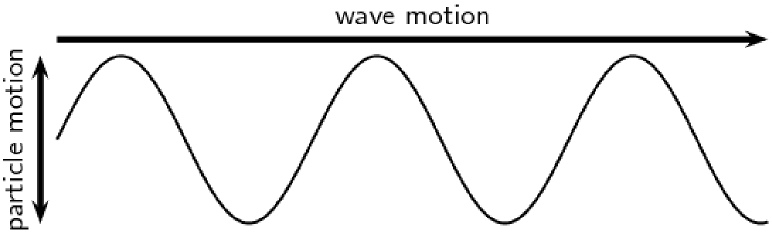
2. A pulse travels through a medium at a speed of 5 $m.s^{-1}$. What is the pulse length of the pulse if the pulse passes a certain point in 2 seconds?

The speed of the propagation (motion through a medium) of a pulse (or a wave) depends **only** on the **medium** through which it travels. If you have a rope of a certain thickness and density, you may flick the rope harder or faster, but the speed of the pulse will not change. The pulse may have a bigger amplitude if you flick it harder, or more energy if you flick it faster, but the speed will not change in a specific medium.

When a transverse pulse (or a transverse wave) moves through a medium, there are two different motions that take place at the same time:

- The motion of the pulse in the x (horizontal) direction. This is the direction of the propagation of the pulse or wave.
- The motion of the particles in the medium in the y (vertical) direction. This is the direction in which the particles in the medium are disturbed.

This means that propagation of the wave and medium **travel at right angles** to one another, as can be seen on the diagram below:



Representation of a transverse wave where the wave motion and particle motion are perpendicular

What is a transverse pulse? [D]

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Superposition of pulses

When two pulses meet, they superpose, meaning that they combine to form a new pulse. What is the principle of superposition? [D]

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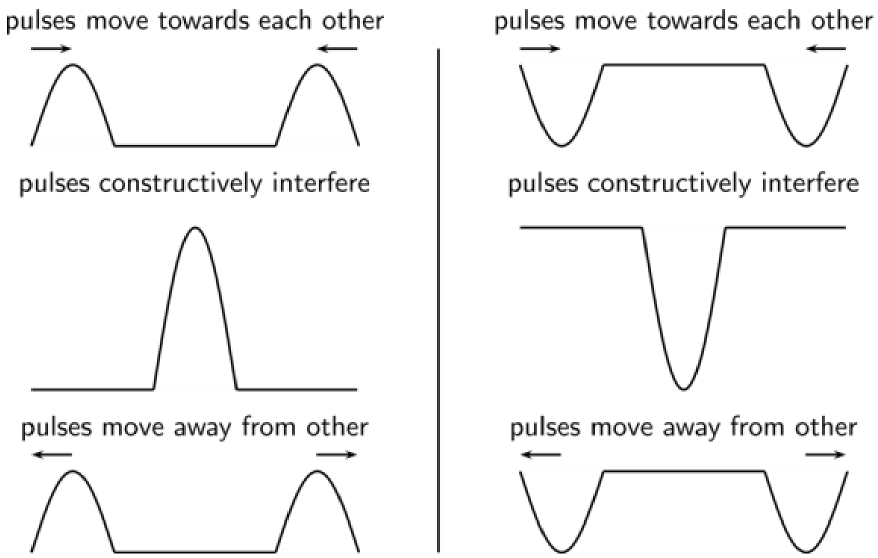
When two pulses superpose, the displacement (action of moving something from its original position) of the particles in the medium caused by each pulse are added together to create a combined effect. After the pulses pass through each other, each pulse continues along its original direction of travel, and their original amplitudes remain unchanged.

Superposition can happen through **constructive interference** or through **destructive interference**.

Constructive interference

Constructive interference takes place when two pulses meet to create a larger pulse. The amplitude of the resulting pulse is the sum of the amplitudes of the two initial pulses. This could be the addition of the amplitudes of two crests or two troughs.

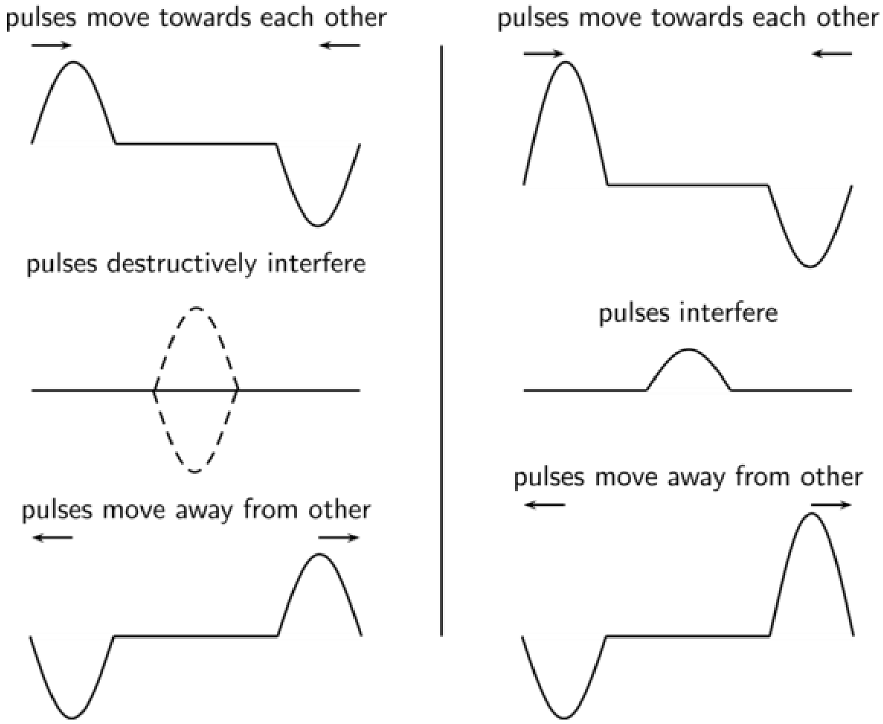


On the left, constructive interference of two crests, on the right, constructive interference of two troughs

Destructive interference

Destructive interference takes place when two pulses meet to create a smaller pulse. The amplitude of the resulting pulse is the sum of the amplitudes of the two initial pulses. The crest will have a positive value, while the trough will have a negative value.

Complete destructive interference takes place when the effect of two pulses results in zero displacement of the particles that make up the medium. This means that the amplitude of the crest and the amplitude of the trough are the same, so that when they meet, they cancel each other out.



On the left, complete destructive interference where the crest and trough have the same amplitude, on the right, destructive interference of a crest and a trough, resulting in a smaller crest

Rogue waves

Rogue waves, also known as monster waves, are large and unexpectedly high waves that occur in open water, especially in deep oceans. They are characterized by their extreme heights of up to 30 m and appear suddenly and unpredictably.

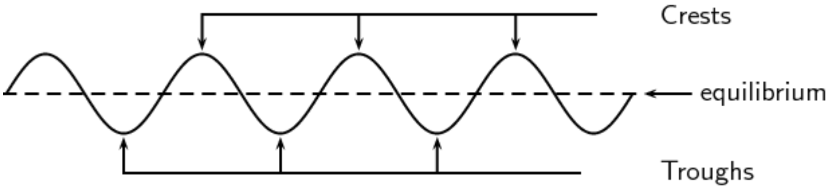
Rogue waves can be caused by a variety of factors, such as ocean currents, winds and storms that disturb the water. It is theorised that ocean currents, winds and storms cause waves to superpose, resulting in a monster wave. However, not all rogue waves occur in strong ocean currents or during storms, and scientists believe that some rogue waves may be caused by the random superposition of waves. Dozens of waves could interact at the same time and superpose to create one huge wave in relatively calm seas.

Rogue waves are extremely dangerous for ships, as they can capsize ships and cause significant damage. Throughout history, they are believed to have been responsible for many shipping accidents and shipwrecks.


A rogue wave

Transverse waves

While a pulse is a single disturbance, a wave is a series of disturbances. A transverse wave is made up of a series of transverse pulses with crests and troughs.



A transverse wave with crests and troughs

What is a wave? [D]

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What is a transverse wave? [D]

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Examples of transverse waves include water waves, electromagnetic (light) waves and certain seismic waves that results in earthquakes.

Comparison of transverse pulses and transverse waves

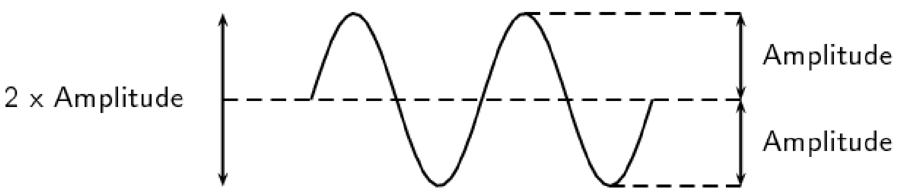
A wave shares some properties with a pulse, but it also has additional characteristics that make it distinct.

1. Both a wave and a pulse involve the transfer of energy through a medium.

2. A pulse is a single disturbance while a wave is a continuous disturbance.

3. A pulse has one moving crest or trough. A wave has a series of moving crests and troughs.

4. Both a wave and a pulse have an amplitude measured in meters (m). Recall that the amplitude is the distance of the maximum disturbance of the medium from the equilibrium (rest) position. In the case of a wave, the amplitude of the crest is equal to the amplitude of the trough from the equilibrium position.



The amplitude of a wave is from rest position to crest and from rest position to trough

5. A pulse has a pulse length, while a wave has a wavelength.

   What is wavelength? [D]

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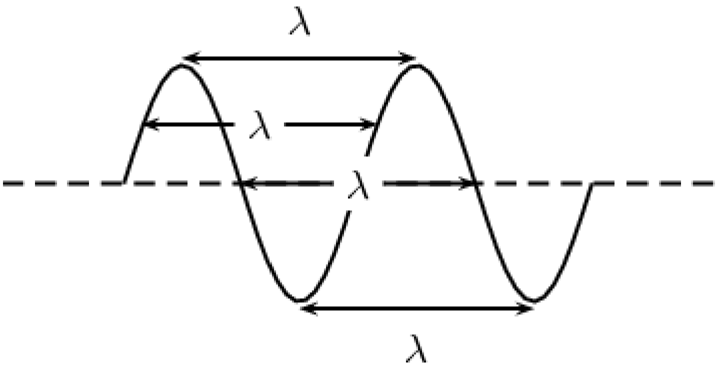
   Wavelength is represented by the Greek symbol lambda, λ, and is measured in meters (m). The wavelength is often, but not necessarily, measured as the distance between two crests or two troughs.



   Distances representing a full wavelength on a wave

   Points that are successive and in phase are separated by a full wavelength. If not separated by a full wavelength, they are considered out of phase. From the graph below, identify any three points that are successive and in phase, representing a full wavelength.

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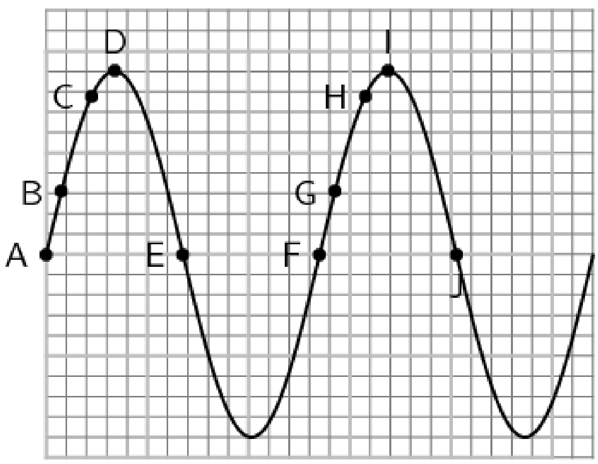

6. A wave has a period and a frequency, whereas a pulse does not. This will be described in more detail below.

7. A pulse has a pulse speed that uses the pulse length in the calculation. A wave has a wave speed that uses the wavelength in the calculation. This will be described in more detail below.

Period and frequency of a wave

Period

Imagine you are sitting by a pond watching the waves move past you. You see a crest and you start the timer. You stop the timer the moment you see the next crest pass the same point. This time interval is called the period of a wave. Period is represented by time (t) and is measured in seconds (s).

What is the period of a wave? [D]

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Frequency

Imagine the pond again. Just as a crest passes you, you start your timer and count each crest going past. After 1 second you stop the timer. The number of crests that you counted in 1 second is the frequency of the wave. Frequency is represented by the symbol f and is measured in hertz (Hz). You may think of hertz as cycles per second.

What is the frequency of a wave? [D]

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The frequency and the period of a wave are inversely proportional, which means that:

$f = \frac{1}{t}$ and $t = \frac{1}{f}$

For example, if the time between two consecutive crests passing a fixed point is 0.5 s, then the period of the wave is 0.5 s. Therefore, the frequency of the wave may be calculated as:

This means that if it takes half a second for a one full cycle to pass you by, then two cycles will pass you by in one second.

If the number of cycles that pass a given point in one second is 2 (meaning 2 cycles per second), then the frequency of the wave is 2 Hz. Therefore, the period of the wave may be calculated as:

This means that if two cycles pass you by in one second, then it takes half a second for one full cycle to pass you by.

This inverse relationship means that a wave with a higher frequency has a shorter period, and a wave with a lower frequency has a longer period. A **higher frequency** (more cycles per second) leads to a **shorter period** (less time per cycle). A **lower frequency** (fewer cycles per second) leads to a **longer period** (more time per cycle).

Wave speed

We have already defined speed as distance travelled per unit time.

The equation for speed is:

$$speed = \frac{distance}{time}$$

In the case of a wave, the distance is represented by the wavelength of the wave and the time is represented by the period of the wave. The speed of a wave may be calculated as:

$$wave\ speed = \frac{wavelength}{period}$$

Or

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

Where:
- **Wavelength** (λ) is measured in **meters** (m).
- **Period** (t) is measured in **seconds** (s).
- **Speed** (v) is measured in **meters per second** ($m.s^{-1}$).

Because $f = \frac{1}{t}$ wave speed may also be calculated as:

$$wave\ speed = wavelength\ \times frequency$$

Or

$$v = \lambda f$$

Where:
- **Wavelength** (λ) is measured in **meters** (m).
- **Frequency** (*f*) is measured in **hertz** (Hz).
- **Speed** (v) is measured in **meters per second** ($m.s^{-1}$).

Examples

1. A wave is travelling along a rope that is 15 m long. 10 full wave cycles fit along the rope. The wave travels at 9 $m.s^{-1}$.

a. What is the wavelength of the wave?

b. What is the frequency of the wave?

c. If the frequency of the wave is changed to 3 Hz, what would be the speed of the wave?

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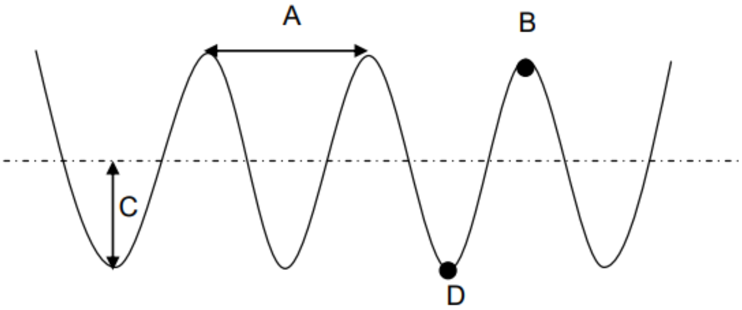
d. If the frequency of the wave is changed to 3 Hz, what would be the wavelength of the wave?

2. A transverse wave has a frequency of 15 Hz. The horizontal distance from a crest to the nearest trough is measured to be 2.5 cm.

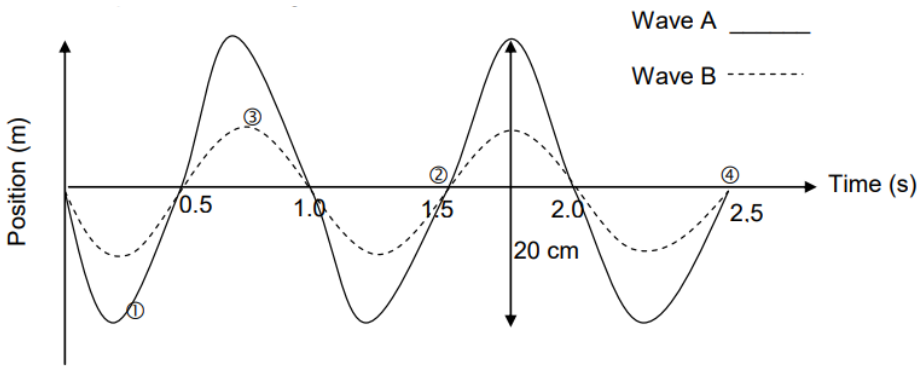
a. What is the period of the wave?

b. What is the speed of the wave?

3. Study the following diagram and label parts A – D.



4. The diagram below shows two waves, A and B, of the same wavelength but with different amplitudes, crossing each other. The amplitude of wave B is half the amplitude of wave A.



a. What type of wave is represented by the pattern above?

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b. Define the wave type above.

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c. Which circled number (1 – 4) points represent one wavelength?

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d. From the graph, determine the frequency, period and amplitude of wave A.

e. Draw the shape of the resulting pulse as two pulses (A and B) cross and indicate the resulting amplitude.

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f. Which pulse property is illustrated in the question above?

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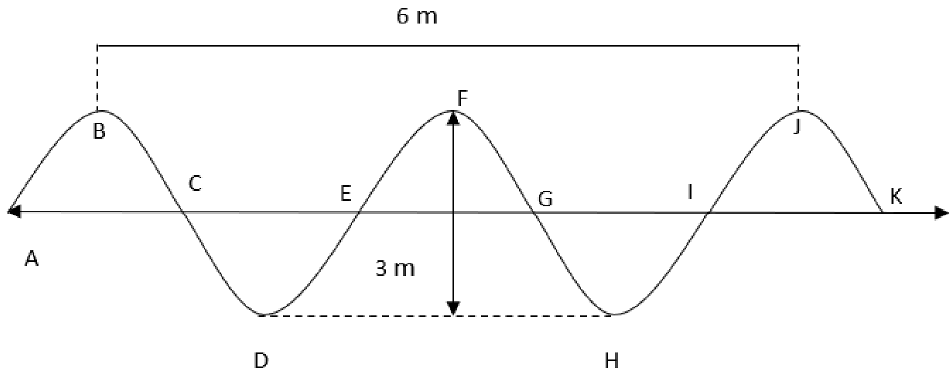
5. Waves generated by flicking one end of a rope are shown below. The waves are moving to the right such that time taken for three consecutive crests to pass a point is 0.4 s.



a. Determine the amplitude of the wave.

b. Determine the wavelength of the wave.

c. Determine the period of the wave.

d. Determine the frequency of the wave.

e. Determine the speed of the wave.

f. Which two points are in phase with point G?

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