

Waves

Matthew Williams • Physics • May 20, 2026

Waves

A **wave** is a transfer of energy from one place to another by means of a disturbance, without any net transfer of matter.

A single disturbance that travels through a medium is a **pulse**. When disturbances are repeated continuously, a **progressive wave** is produced.

Types of Waves

Transverse Waves

In a transverse wave, the particles of the medium oscillate **perpendicular** to the direction of wave travel.

Examples: light (all electromagnetic waves), water waves, waves on a rope.

Longitudinal Waves

In a longitudinal wave, the particles of the medium oscillate **parallel** to the direction of wave travel, producing compressions (regions of high pressure and density) and rarefactions (regions of low pressure and density).

Examples: sound waves, seismic P-waves.

Wave Parameters

| Quantity | Symbol | Definition | Unit |
|------------|-----------------|---|------|
| Amplitude | [Math: A] | Maximum displacement of a particle from its rest (equilibrium) position | m |
| Wavelength | [Math: \lambda] | Distance between two successive points in phase (e.g. crest to crest) | m |
| | | | |

| | | | |
|------------|--------------|---|-------------------|
| Period | [Math: T] | Time for one complete oscillation | s |
| Frequency | [Math: f] | Number of complete oscillations per second; [Math: $f = 1/T$] | Hz |
| Wave speed | [Math: v] | Speed at which the wave pattern moves through the medium | m s^{-1} |

The Wave Equation

$$v = f\lambda$$

where v is the wave speed (m s^{-1}), f is frequency (Hz), and λ is wavelength (m).

Displacement-Position Graph

A **displacement-position** (or displacement-distance) graph shows the displacement of every particle at one instant in time. It is a "snapshot" of the wave. The wavelength can be read directly from the graph.

<PlotlyGraph

data={

{

x: [0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4.0],

y: [0, 0.31, 0.59, 0.81, 0.95, 1.0, 0.95, 0.81, 0.59, 0.31, 0, -0.31, -0.59, -0.81, -0.95, -1.0, -0.95, -0.81, -0.59, -0.31, 0, 0.31, 0.59, 0.81, 0.95, 1.0, 0.95, 0.81, 0.59, 0.31, 0, -0.31, -0.59, -0.81, -0.95, -1.0, -0.95, -0.81, -0.59, -0.31, 0],

type: 'scatter',

mode: 'lines',

name: 'Displacement',

line: {color: '#2563eb', width: 2.5, shape: 'spline'},

},

}}

layout={{

xaxis: {title: {text: 'Position / m'}},

```

yaxis: {title: {text: 'Displacement / m'}},
annotations: [
{x: 2, y: 1.2, text: '≈ 2 m', showarrow: true, arrowhead: 2, ax: 0, ay: -30, font: {size: 11}},
{x: 0.5, y: 1.15, text: 'A = 1 m', showarrow: true, arrowhead: 2, ax: 40, ay: -20, font: {size: 11}},
],
shapes: [
{type: 'line', x0: 0, y0: 0, x1: 2, y1: 0, line: {color: '#dc2626', width: 1.5, dash: 'dot'}},
],
}}
caption="Displacement-position graph: wavelength is the distance between successive crests
(or troughs). Amplitude is the maximum displacement from equilibrium."
height={260}
/>

```

Displacement-Time Graph

A **displacement-time** graph shows how the displacement of **one particle** varies over time. The period T can be read from this graph.

```

<PlotlyGraph
data={[
{
x: [0, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95,
1.0, 1.05, 1.1, 1.15, 1.2, 1.25, 1.3, 1.35, 1.4, 1.45, 1.5, 1.55, 1.6, 1.65, 1.7, 1.75, 1.8, 1.85, 1.9, 1.95,
2.0],
y: [0, 0.31, 0.59, 0.81, 0.95, 1.0, 0.95, 0.81, 0.59, 0.31, 0, -0.31, -0.59, -0.81, -0.95, -1.0, -0.95, -0.81,
-0.59, -0.31, 0, 0.31, 0.59, 0.81, 0.95, 1.0, 0.95, 0.81, 0.59, 0.31, 0, -0.31, -0.59, -0.81, -0.95, -1.0,
-0.95, -0.81, -0.59, -0.31, 0],
type: 'scatter',
mode: 'lines',
name: 'Displacement',
line: {color: '#16a34a', width: 2.5, shape: 'spline'},
},
]}
layout={{

```

```

xaxis: {title: {text: 'Time / s'}},
yaxis: {title: {text: 'Displacement / m'}},
annotations: [
{x: 1.0, y: 1.2, text: 'T = 1 s ' f = 1 Hz', showarrow: false, font: {size: 11}},
],
}}
caption="Displacement-time graph for one particle: the period T is the time for one complete oscillation."
height={260}
/>

```

Wave parameters from a graph (2017 Paper 02, Q2)

From a sinusoidal wave graph (displacement vs position):

Suppose amplitude $A = 0.3$ m, wavelength $\lambda = 2.0$ m, and period $T = 0.5$ s.

$$f = \frac{1}{T} = \frac{1}{0.5} = 2\text{Hz}$$

$$v = f\lambda = 2 \times 2.0 = 4.0\text{m s}^{-1}$$

From the 2017 exam: a wave of frequency 10 Hz and wavelength 250 m has speed:

$$v = f\lambda = 10 \times 250 = 2\,500\text{m s}^{-1}$$

Wave Behaviours

All waves (including light, sound, and water waves) can exhibit the following four behaviours.

Reflection

When a wave meets a boundary, part of it bounces back. The angle of incidence equals the angle of reflection (measured from the normal).

Refraction

When a wave passes from one medium into another where its speed is different, it changes direction (unless it arrives perpendicular to the boundary). The frequency is unchanged; wavelength and speed change. A wave that slows down bends toward the normal.

Diffraction

When a wave passes through a gap or around an obstacle, it spreads out. Diffraction is most pronounced when the gap size is similar to the wavelength. Sound diffracts easily around corners because its wavelength (0.1 m to 10 m) is comparable to everyday obstacles.

Interference

When two waves overlap, their displacements add algebraically (principle of superposition).

- **Constructive interference:** crests meet crests; amplitude increases.
- **Destructive interference:** crests meet troughs; amplitude decreases.

Exam Tip

On a displacement-position graph, wavelength is crest to crest (or trough to trough, or any point to the next identical point). Do not confuse this with a displacement-time graph, on that graph, you read off the period, not the wavelength.

Frequency and period are always reciprocals: $f = 1/T$

. Learn to state both the value and the unit when reading from a graph.