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3.1 Longitudinal & Transverse Waves

PHYSICS

AQA A Level Revision Notes

EXAM PAPERS PRACTICE

A Level Physics AQA

3.1 Longitudinal & Transverse Waves

CONTENTS

Properties of Oscillations

- A progressive wave is defined as:

  A wave that transfers energy from one point to another without transferring the medium itself

Properties of a Progressive Wave

- **Displacement (x)** of a wave is the distance of a point on the wave from its equilibrium position
  - It is a vector quantity; it can be positive or negative
- **Amplitude (A)** is the maximum displacement of a particle in the wave from its equilibrium position
- **Wavelength (λ)** is the distance between points on successive oscillations of the wave that are in phase
  - These are all measured in **metres (m)**

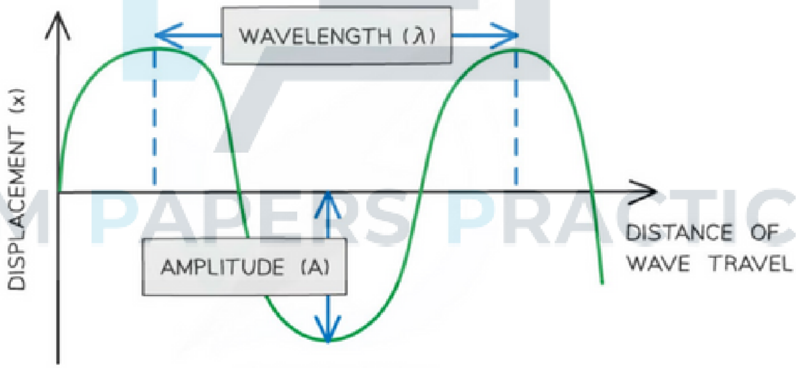


Diagram showing the amplitude and wavelength of a wave

- **Period (T)** or time period, is the time taken for one complete oscillation or cycle of the wave
  - Measured in **seconds (s)**

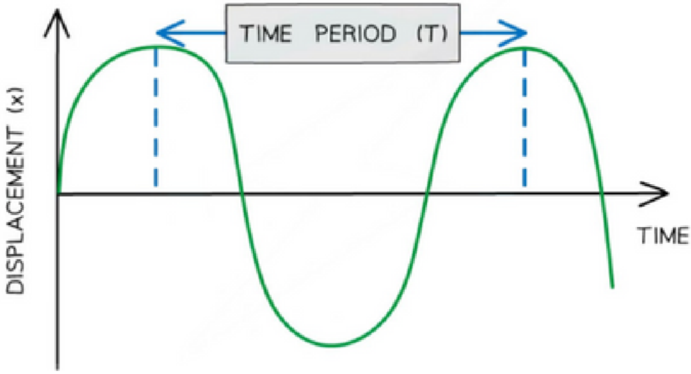


Diagram showing the time period of a wave

- **Frequency (*f*)** is the number of complete oscillations per unit time. Measured in **Hertz (Hz)** or s^{-1}

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

FREQUENCY (Hz)
TIME PERIOD (s)

Frequency-period equation

- **Speed (v)** is the distance travelled by the wave per unit time
    - Measured in **metres per second ($m s^{-1}$)**

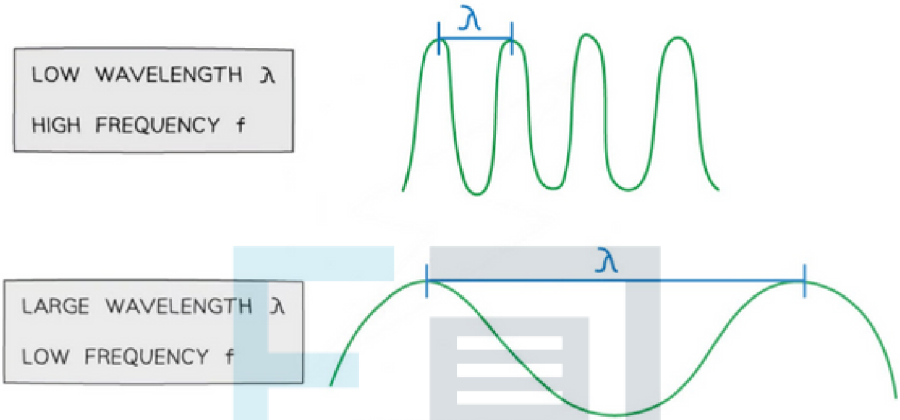
- The wave equation links the **speed**, **frequency** and **wavelength** of a wave
- This is relevant for both transverse and longitudinal waves

$$v = f\lambda$$

FREQUENCY (Hz OR s^{-1})
SPEED OF A WAVE (ms^{-1})
WAVELENGTH (m)

The Wave Equation

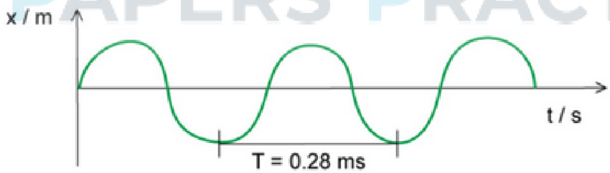
- The wave equation shows that for a wave of constant speed:
  - As the wavelength **increases**, the frequency **decreases**
  - As the wavelength **decreases**, the frequency **increases**



The relationship between frequency and wavelength of a wave

Worked Example

The wave in the diagram below has a speed of 340 m s^{-1}.



What is the wavelength of the wave?

STEP 1 — WAVE EQUATION

$$v = f\lambda$$

STEP 2 — REARRANGE FOR WAVELENGTH

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

STEP 3 — CALCULATE f

$$f = \frac{1}{T} = \frac{1}{0.28 \times 10^{-3}\,s} = 3571.43\ \text{Hz}$$

STEP 4 — SUBSTITUTE VALUE BACK INTO WAVE EQUATION

$$\lambda = \frac{340}{3571.43} = 0.095\ \text{m}\ \ (2\ \text{s.f.})$$

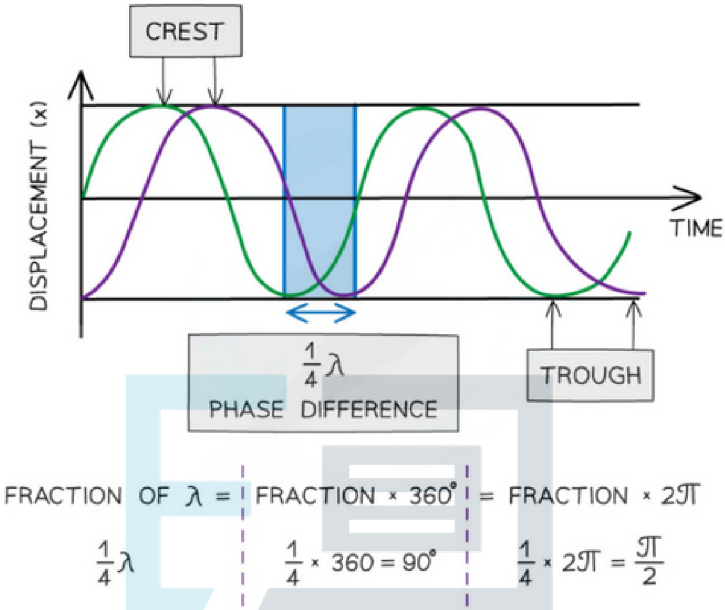
Exam Tip

You may also see the wave equation be written as $c = f\lambda$ where c is the wave speed. However, c is often used to represent a specific speed ≡ the speed of light (3×10^8 m s^{-1}). Only electromagnetic waves travel at this speed, therefore it's best practice to use *v* for any speed that isn't the speed of light instead.

Phase Difference

- The phase difference between two waves is a measure of **how much a point or a wave is in front or behind another**
- This can be found from the relative positive of the crests or troughs of two different waves of the same frequency
  - When the crests or troughs are aligned, the waves are **in phase**
  - When the crest of one wave aligns with the trough of another, they are in **antiphase**

- The diagram below shows the green wave **leads** the purple wave by ¼ λ

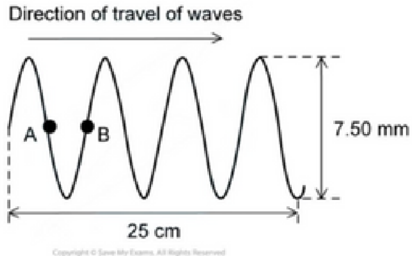


Two waves ¼ λ out of phase

- In contrast, the purple wave is said to **lag** behind the green wave by ¼ λ
- Phase difference is measured in **fractions of a wavelength, degrees** or **radians**
- The phase difference can be calculated from two different points on the same wave or the same point on two different waves
- The phase difference between two points can be described as:
  - **In phase** is **360°** or 2π radians
  - **In anti-phase** is **180°** or π radians

Worked Example

Plane waves on the surface of water at a particular instant are represented by the diagram below.



The waves have a frequency of 2.5 Hz. Determine:

a) The amplitude

b) The wavelength

c) The phase difference between points **A** and **B**

A. THE AMPLITUDE

MAXIMUM DISPLACEMENT FROM THE EQUILIBRIUM POSITION

7.50 mm ÷ 2 = 3.75 mm

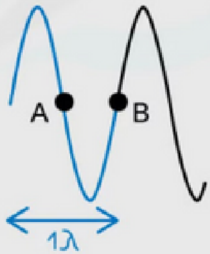
B. THE WAVELENGTH

DISTANCE BETWEEN POINTS ON SUCCESSIVE OSCILLATIONS OF THE WAVE THAT ARE IN PHASE

FROM DIAGRAM: $25\text{cm} = 3\frac{3}{4}$ WAVELENGTHS

$$1\lambda = 25 \text{ cm} \div 3\frac{3}{4} = 6.67 \text{ cm}$$

C. THE PHASE DIFFERENCE BETWEEN POINTS A AND B



POINTS A AND B HAVE $\frac{1}{2}\lambda$ DIFFERENCE $= \frac{1}{2} \times 360° = 180°$

Exam Tip

When labelling the wavelength and time period on a diagram:

- Make sure that your arrows go from the **very top** of a wave to the very top of the next one
- If your arrow is too short, you will lose marks
- The same goes for labelling amplitude, don't draw an arrow from the bottom to the top of the wave, this will lose you marks too.

Defining Transverse & Longitudinal Waves

- In mechanical waves, particles **oscillate** about fixed points
- There are two types of wave: **transverse** and **longitudinal**
- The type of wave can be determined by the direction of the oscillations in relation to the direction the wave is travelling

Transverse Waves

- A transverse wave is defined as:

  A wave in which the particles oscillate perpendicular to the direction of the wave travel (and energy transfer)

- Transverse waves show areas of **crests** (peaks) and **troughs**

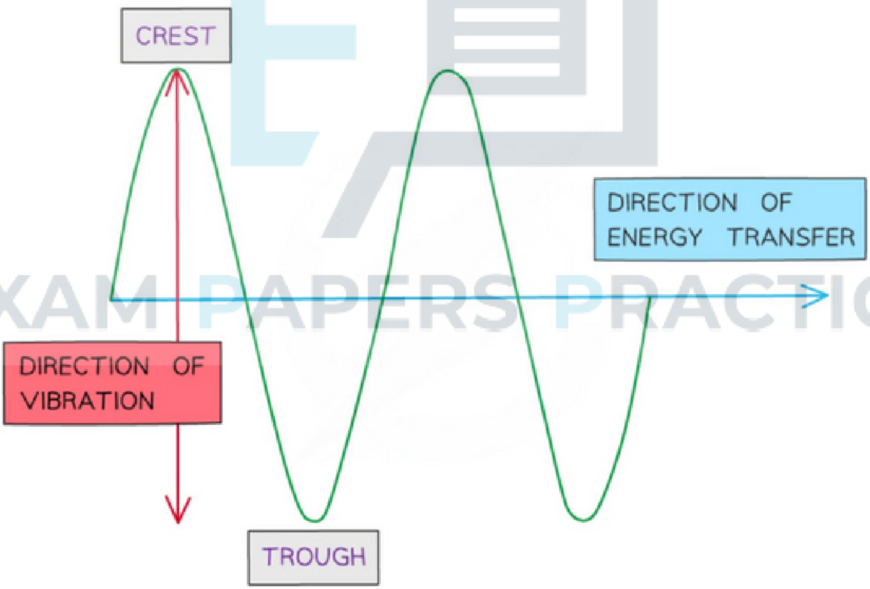


Diagram of a transverse wave

- Examples of transverse waves are:
  - Electromagnetic waves e.g. radio, visible light, UV
  - Vibrations on a guitar string

- Transverse waves can be shown on a **rope**
- Transverse waves **can** be polarised

Longitudinal Waves

- A longitudinal wave is defined as:

  A wave in which the particles oscillate parallel to the direction of the wave travel (and energy transfer)

- Longitudinal waves show areas of **compressions** and **rarefactions**
  - Compressions are regions of **increased** pressure
  - Rarefactions are regions of **decreased** pressure

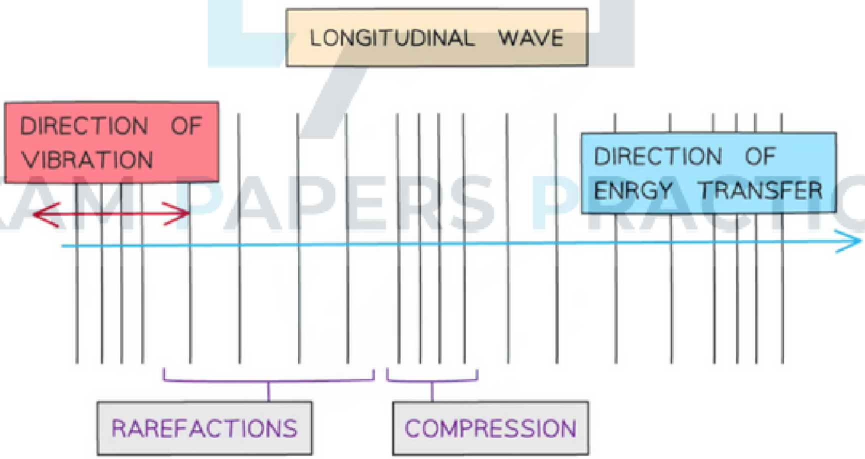
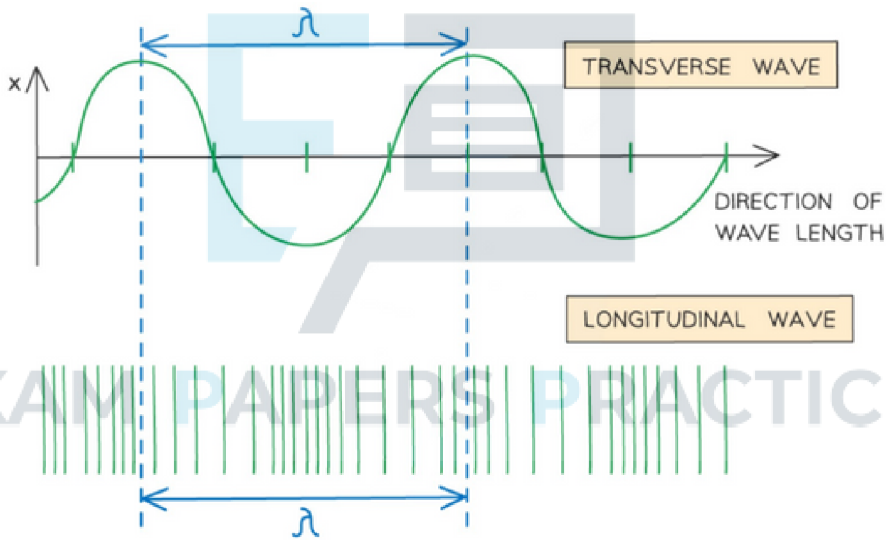


Diagram of a longitudinal wave

- Examples of longitudinal waves are:
  - Sound waves
  - Ultrasound waves

- Longitudinal waves can be shown on a **slinky spring**
- Longitudinal waves **cannot** be polarised
- Energy is transmitted through the wave by:
  - The particles in the medium vibrating as they are given energy
  - The compressions cause the nearby particles to also vibrate with more energy
  - This produces a compression further along in the medium

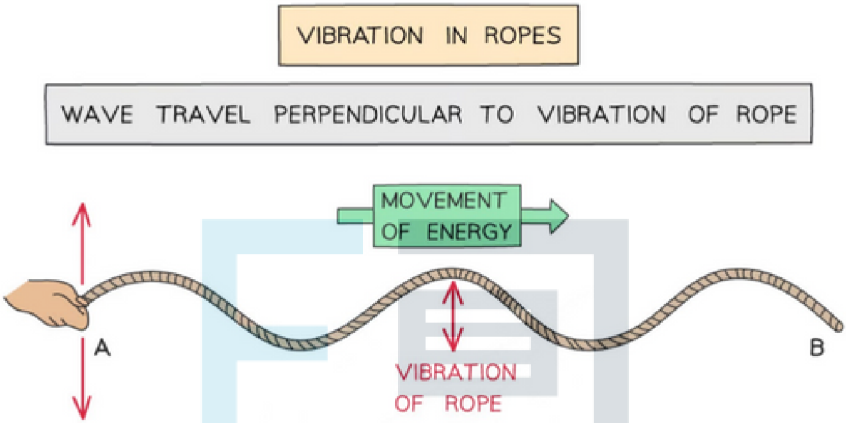


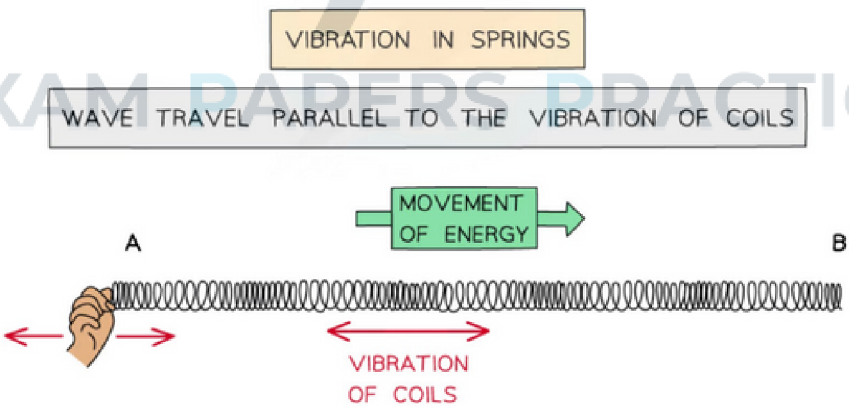
A wavelength on a longitudinal wave is the distance between two compressions or two rarefactions

> **Exam Tip**
>
> The definition of transverse and longitudinal waves are often asked as exam questions, make sure to remember these definitions by heart!

Examples of Transverse Waves & Longitudinal Waves

- Energy is transferred through moving **oscillations** or **vibrations**. These can be seen in vibrations of ropes or springs





Waves can be shown through vibrations in ropes or springs

- The oscillations / vibrations can be perpendicular or parallel to the direction of wave travel:
  - Waves which oscillate in a **perpendicular** direction are **transverse** waves
  - Waves which oscillate in a **parallel** direction are **longitudinal** waves

- Examples of transverse waves are:
  - Electromagnetic waves e.g. radio, visible light, UV
  - Vibrations on a guitar string
  - Waves on a string
  - Seismic (S) waves

- Examples of longitudinal waves are:

- Sound waves
- Ultrasound waves
- Waves through a slinky coil
- Seismic (P) waves

3.1.3 Polarisation

Polarisation

- Polarisation is when:

  Particle oscillations occur in only one of the directions perpendicular to the direction of wave propagation

- Polarisation can only occur in transverse waves
  - This is because transverse waves oscillate in **any plane** perpendicular to the propagation direction

- When transverse waves are **polarised**, this means:
  - Vibrations are restricted to **one** direction
  - These vibrations are still **perpendicular** to the direction of propagation / energy transfer

- The difference between unpolarised and polarised waves is shown in the diagram below:

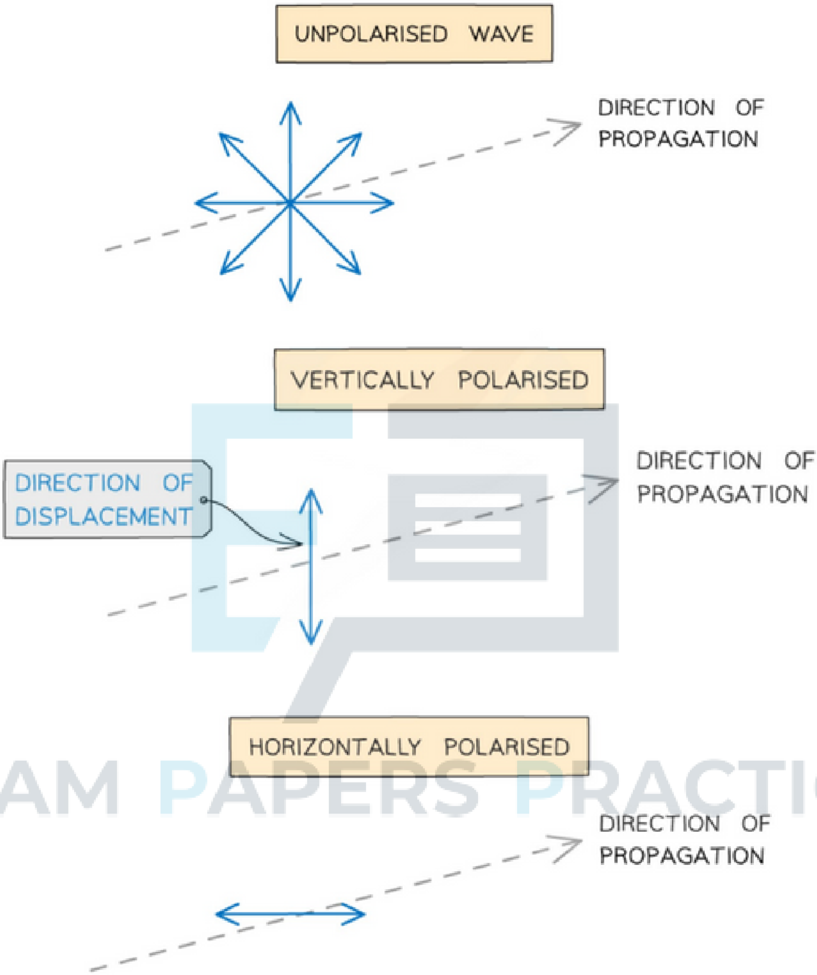


Diagram showing the displacement of unpolarised and polarised transverse waves

- Longitudinal waves (e.g. sound waves) **cannot** be polarised
  - This is because they oscillate parallel to the direction of travel
- Waves can be polarised through a **polariser** or **polarising filter**
  - This only allows oscillations in a certain plane to be transmitted

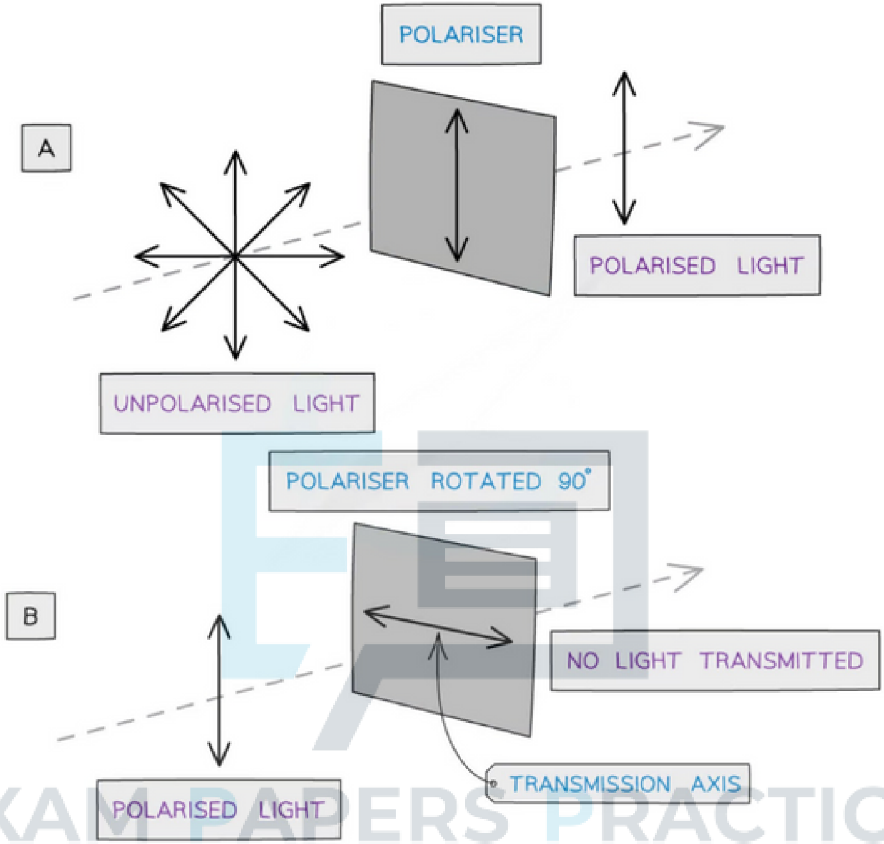


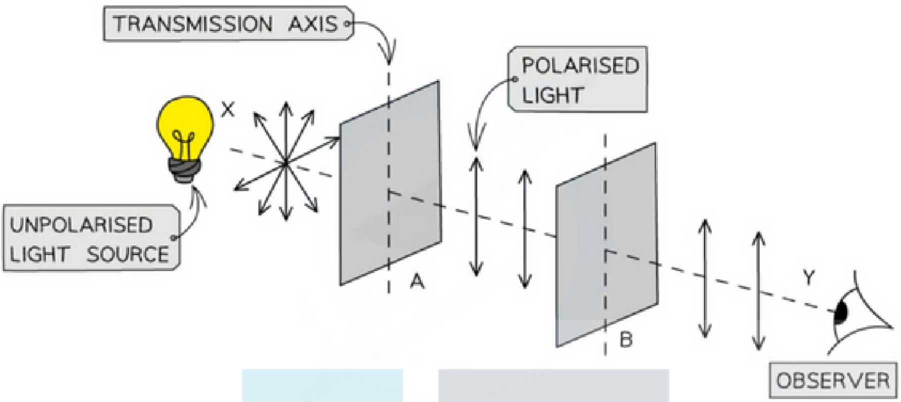
Diagram showing an unpolarised and polarised wave travelling through polarisers

- Diagram **A** shows:
  - Only unpolarised waves can be polarised
- Diagram **B** shows:
  - When a polarised wave passes through a filter with a transmission axis perpendicular to the wave, none of the wave will pass through
- Light can also be polarised through reflection, refraction and scattering

Investigating Light Intensity with Two Polarisers

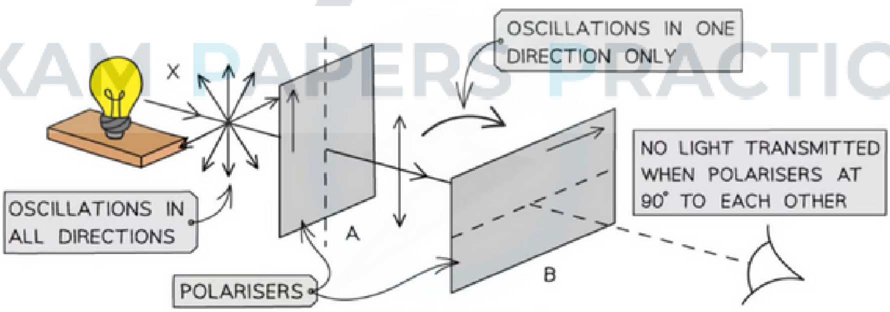
- If an unpolarised light source is placed in front of two identical polarising filters, **A** and **B**, with their transmission axes **parallel**:
  - Filter **A** will polarise the light in a certain axis
  - All of the polarised light will pass through filter **B** unaffected

- In this case, the **maximum** intensity of light is transmitted



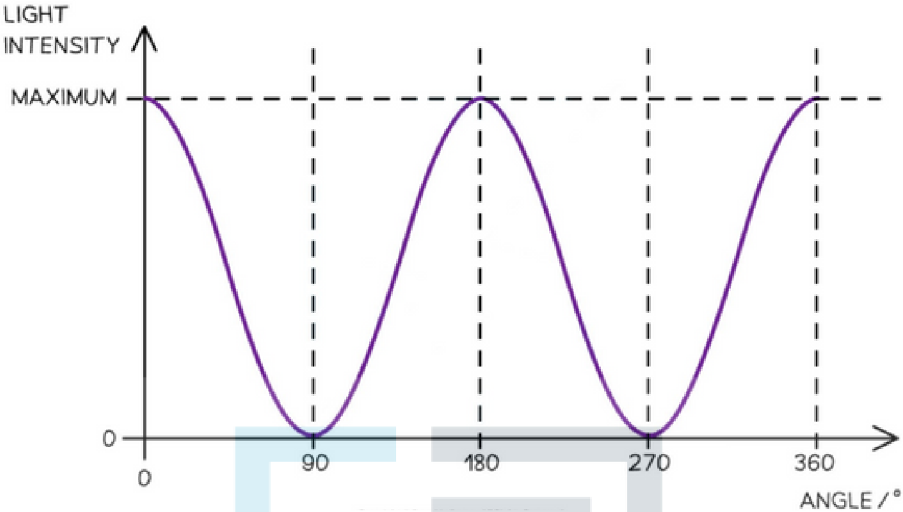
When both polarisers have the same transmission axis, the intensity of the transmitted light is at its maximum

- As the polarising filter **B** is rotated anticlockwise, the intensity of the light observed changes periodically depending on the angle **B** is rotated through
- When **A** and **B** have their transmission axes **perpendicular** to each other:
  - Filter **A** will polarise the light in a certain axis
  - This time none of the polarised light will pass through filter **B**
  - In this case, the **minimum** intensity of light is transmitted



When one of the polarisers is rotated through 90°, the intensity of the transmitted light drops to zero

- The resulting graph of the light intensity with angle, as the second polariser is rotated through 360°, looks as follows:



Graph showing how the intensity of the transmitted beam varies with the angle between the transmission axes of the two polarisers

- In real life, the intensity of the unpolarised electromagnetic wave **reduces** after it passes through a polarising filter

Worked Example

Which statement below describes a situation in which polarisation should happen?

A. Radio waves pass through a metal grid**B.** Surface water waves are diffracted**C.** Sound waves are reflected**D.** Ultrasound waves pass through a metal grid

ANSWER: A

- Radio waves are transverse waves – they can be polarised by a metal grid so only the waves that fit through the grid will be transmitted, therefore, **A** is correct
- **B** cannot be correct as waves are not polarised when diffracted, but are polarised only when **reflected**, **refracted** or **scattered**
- **C** & **D** cannot be correct as **polarisation only occurs for transverse waves**, therefore, **C** & **D** can be ruled out as sound and ultrasound are both longitudinal waves

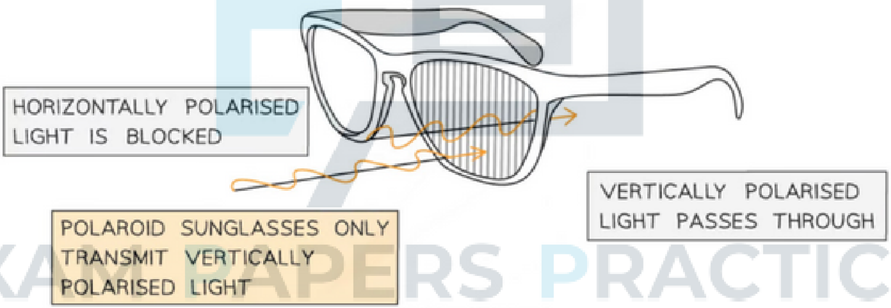
Exam Tip

You may be expected to describe the intensity, or even draw the graph of intensity v angle, for light with two polarisers, however, the good news is that you won't be expected to perform any calculations (Malus's Law) in relation to this.

Applications of Polarisers

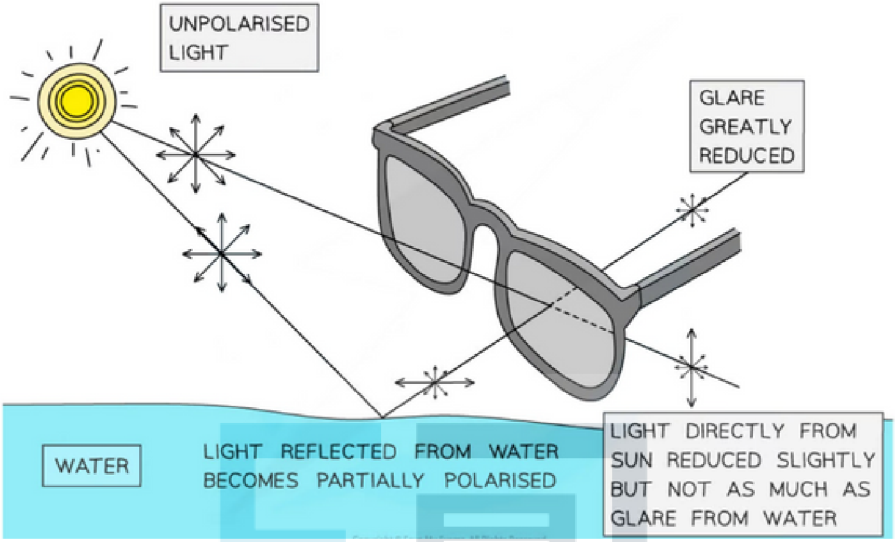
Polaroid Sunglasses

- Polaroid sunglasses are glasses containing lens with polarising filters with transmission axes that are **vertically oriented**
  - This means the glasses do not allow any **horizontally polarised light** to pass through



Polaroid sunglasses contain vertically oriented polarising filters which block out any horizontally polarised light

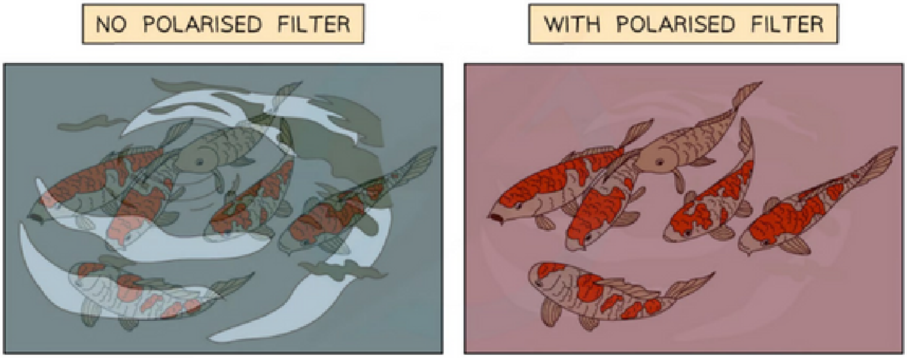
- When light is reflected from a reflective surface e.g. the surface of water or a wet road, it undergoes **partial plane polarisation**
  - This means if the surface is horizontal, a proportion of the reflected light will oscillate more in the horizontal plane than the vertical plane
- Therefore, polaroid sunglasses are useful in reducing the glare on the surface of the water (or any reflective surface) as the partially-polarised light will be eliminated by the polarising filter
- As a result of this, objects under the surface of the water can be viewed more clearly



When sunlight reflects off a horizontal reflective surface, such as water, the light becomes horizontally polarised. This is where polaroid sunglasses come in useful with their vertically aligned filter

Polaroid Photography

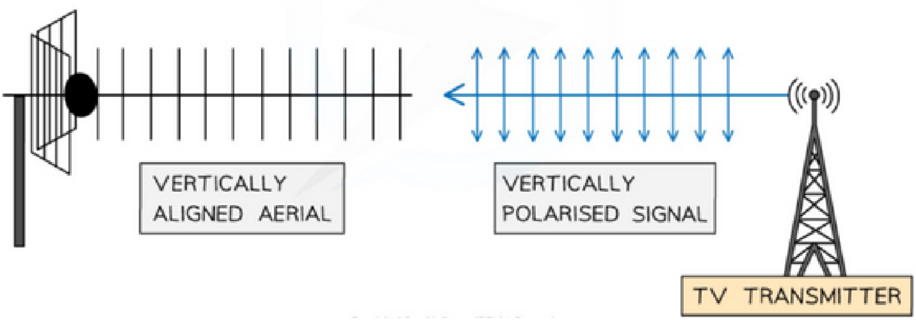
- Polaroid cameras work in the same way as polaroid sunglasses
  - They are very useful for capturing intensified colour and reducing glare on particularly bright sunny days
- Polarising filters also enable photographers to take photos of objects underwater
  - This is because the light reflected on the surface of the water is partially polarised in the horizontal plane
  - This glare is **eliminated** by the polarising lens
  - However, the light from the underwater object is **refracted** by the surface of the water, not reflected, so it is **not** plane-polarised
  - Therefore, the light from the underwater object is more intense than the glare and shows up much more brightly in the photo



As well as giving a cool look to photographs, polaroid filters are extremely useful for reducing glare in photos and snapping pictures of objects underwater

Polarisation of Radio & Microwave Signals

- Radio and television services are broadcast either horizontally-polarised or vertically-polarised
- Therefore, the reception aerial needs to be mounted flat (horizontal), or on its side (vertical),
  - The particular orientation of an aerial will depend on the transmitter it is pointing towards and the polarity of the services being broadcast



Broadcasting towers always transmit either vertically or horizontally polarised signals. This is why aerials must be positioned accordingly otherwise they won't pick up the TV signal correctly