OCR A Level Physics

Your notes

Longitudinal & Transverse Waves

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* Progressive Waves: Longitudinal & Transverse
* Calculating Frequency
* The Wave Equation
* Graphical Representations of Transverse & Longitudinal Waves
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Progressive Waves: Longitudinal & Transverse

Your notes

Longitudinal & Transverse Waves

- In mechanical waves, particles **oscillate** about fixed points
- A **progressive** wave is an oscillation that transfers energy and information
  - The substance in which the waves move through are disturbed (eg. water, air)
  - The particles of the substance oscillate about a fixed position
  - This is sometimes called a **travelling wave**
- There are two types of waves
  - **Transverse**
  - **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)

- 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

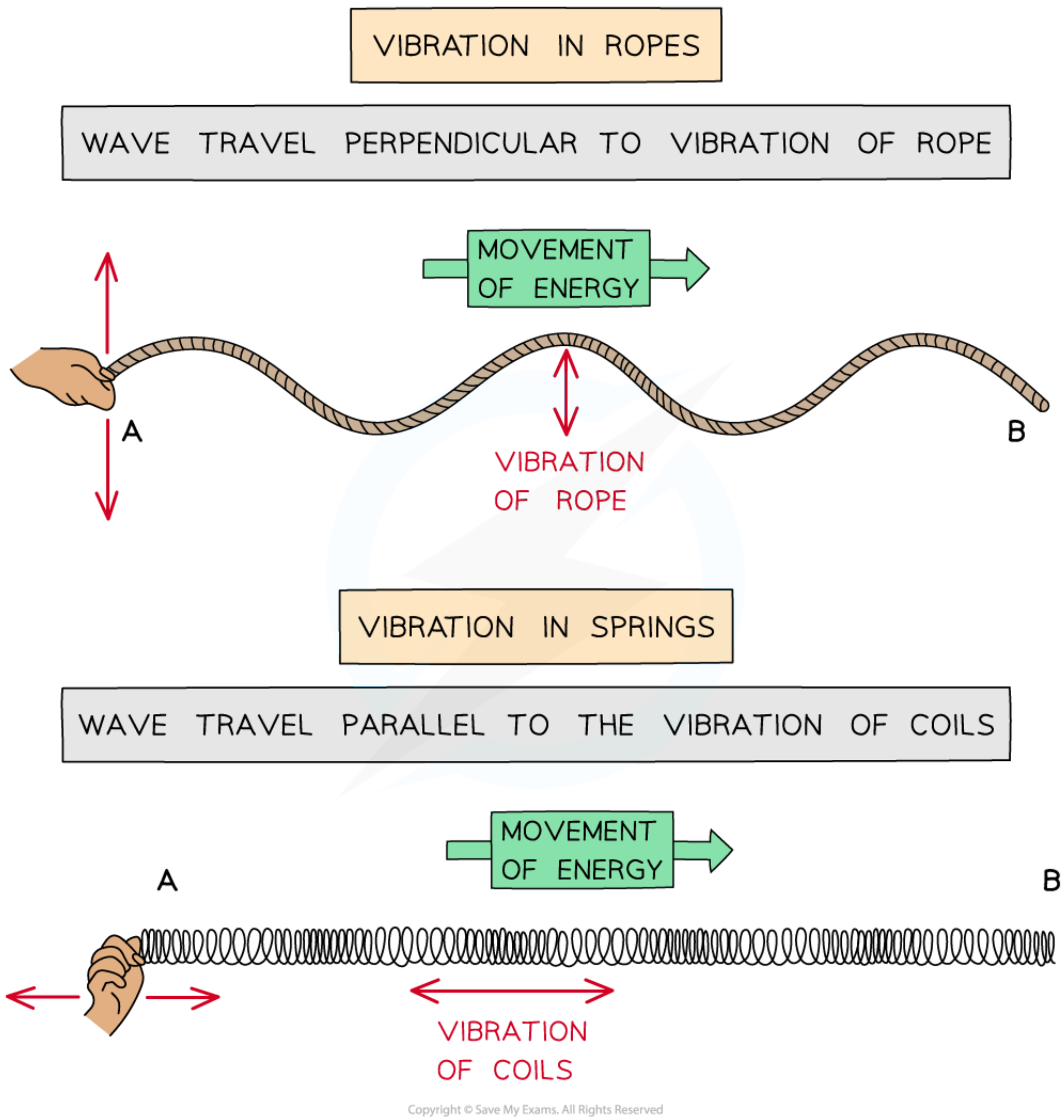
Longitudinal Waves

- A longitudinal wave is defined as:

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

- Examples of longitudinal waves are:
  - Sound waves

- Ultrasound waves
- Longitudinal waves can be shown on a **slinky spring**
- Longitudinal waves **cannot** be polarised



Waves can be shown through vibrations in ropes or springs

Your notes

Your notes

Examiner Tips and Tricks

The definitions of transverse and longitudinal waves are often asked as exam questions, make sure to remember these!

General Wave Properties

- **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

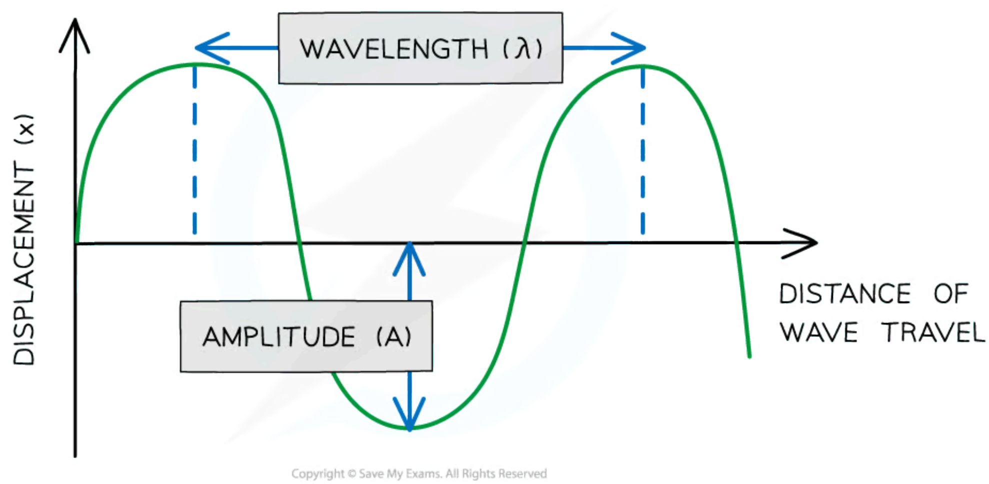


Diagram showing the amplitude and wavelength of a wave

- **Wavelength (λ)** is the distance between points on successive oscillations of the wave that are in phase
- Displacement, amplitude and wavelength are all measured in **metres (m)**

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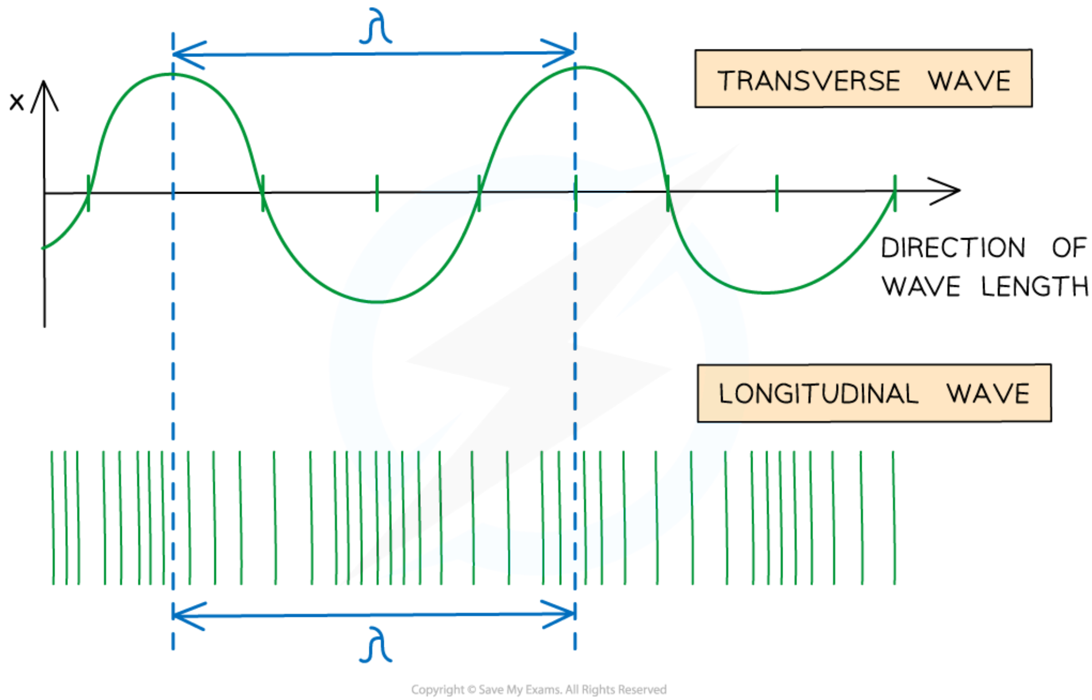


A wavelength on a longitudinal wave is the distance between two compressions or two rarefactions

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

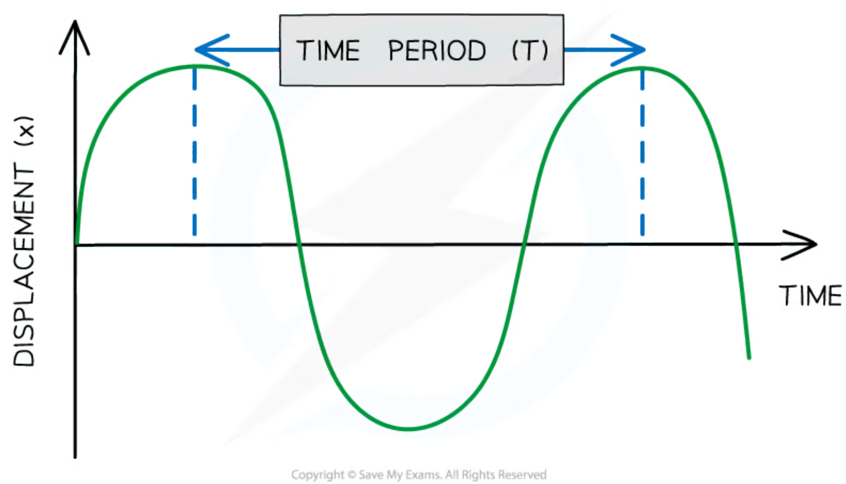


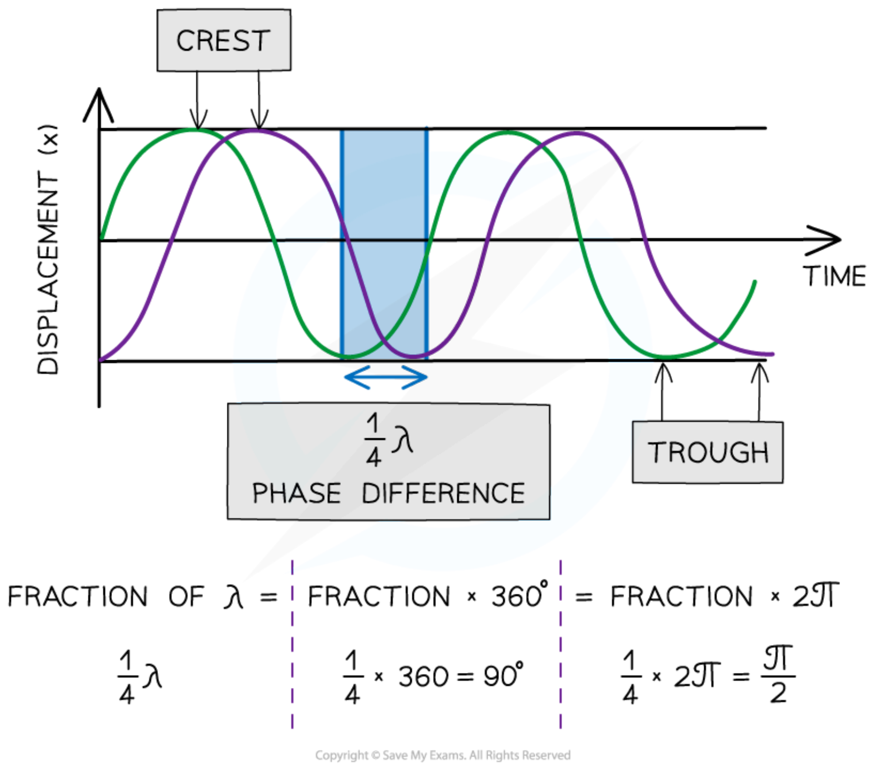
Diagram showing the time period of a wave

- **Frequency (*f*)** is the number of complete oscillations or wavelengths passing a point per unit time
  - Measured in **Hertz** (**Hz**) or **s^{-1}**
- **Speed (*v*)** is the distance travelled by the wave per unit time, and defined by the wave equation
  - Measured in **metres per second ($m\ s^{-1}$)**

Phase

- The phase difference tells us **how much a point or a wave is in front or behind another**
- It is defined as:

  How far the cycle of one point is compared to another point on the same wave
- 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



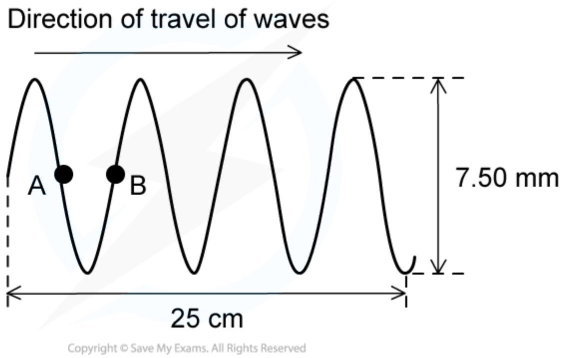
Two waves ¼ λ out of phase

- 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:
  - **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.

Your notes



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**

Answer:

Your notes

A. THE AMPLITUDE

MAXIMUM DISPLACEMENT FROM THE EQUILIBRIUM POSITION

$7.50 \text{ mm} \div 2 = 3.75 \text{ mm}$

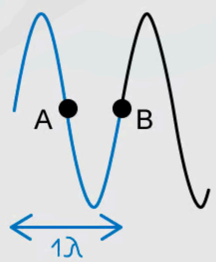
B. THE WAVELENGTH

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 $= \frac{1}{2} \times 360° = 180°$

Examiner Tips and Tricks

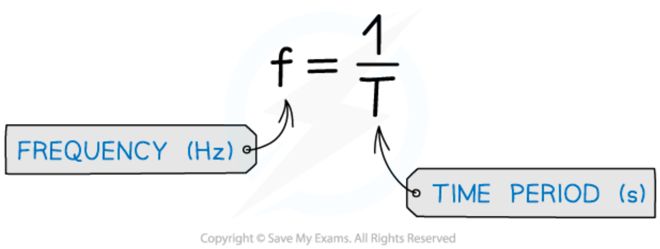
When labelling the wavelength and time period on a diagram, make sure that your arrows go from the **very top** of a wave to the very top of the next one. If your arrow is too short, you will lose marks. The same goes for labelling amplitude, don't draw an arrow from the bottom to the top of the wave,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

Calculating Frequency

Your notes

Calculating Frequency

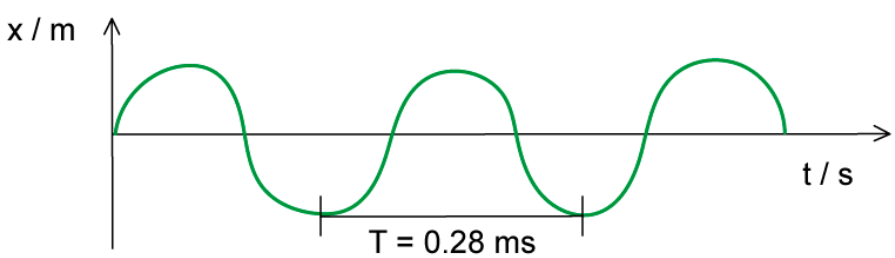
- **Frequency (*f*)** is defined by the equation:



- Where *T* is the time period, the time taken for one complete oscillation or cycle of the wave

Worked Example

Calculate the frequency of the following wave:



Answer:

Step 1: List the known quantities

- Period, T = 0.28 ms = 0.28×10^{-3} s

Step 2: Write down the frequency equation

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

Your notes

Step 3: Substitute in the values

$$f = 1 \div (0.28 \times 10^{-3}) = 3571.4 = 3.57 \text{ kHz}$$

Examiner Tips and Tricks

When using the frequency equation, always make sure the time period is in seconds to get the value of the frequency in Hertz (Hz)

Determining Frequency from an Oscilloscope

- A Cathode-Ray Oscilloscope (CRO) is a laboratory instrument used to display, measure and analyse waveforms of electrical circuits
- The x-axis is the **time-base** and the y-axis is the **voltage (**or **y-gain)**
  - The time-base is important for calculating the frequency of the signal

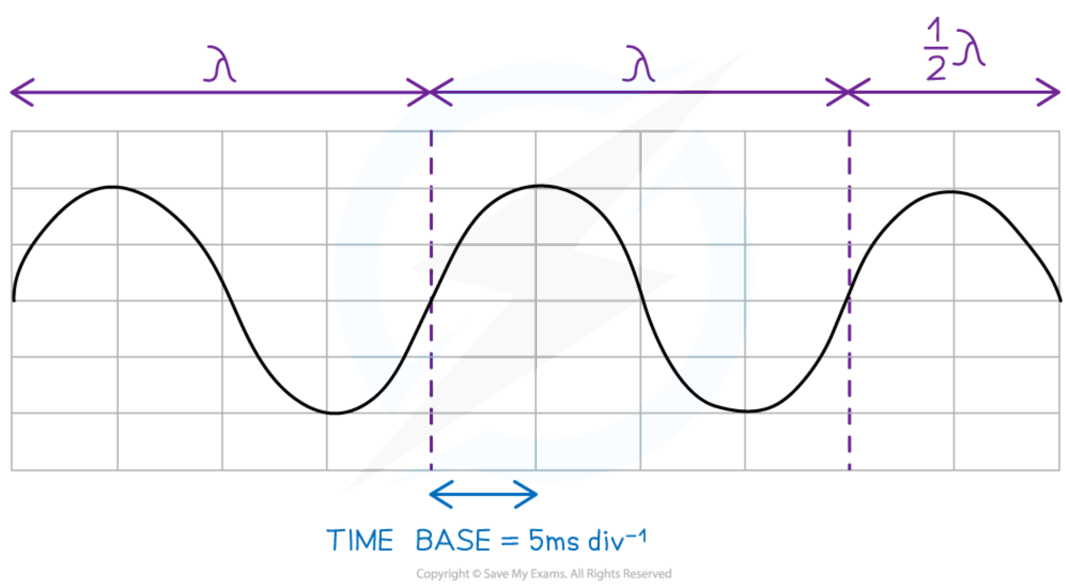
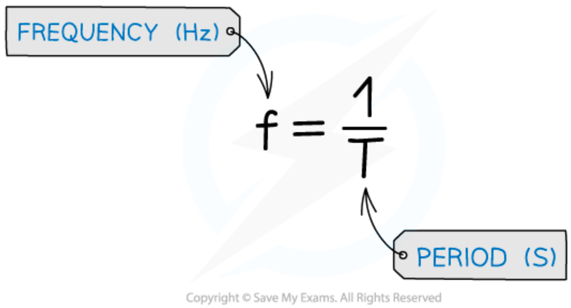


Diagram of Cathode-Ray Oscilloscope display showing wavelength and time-base setting

- The frequency of a wave is determined from the time period of the wave

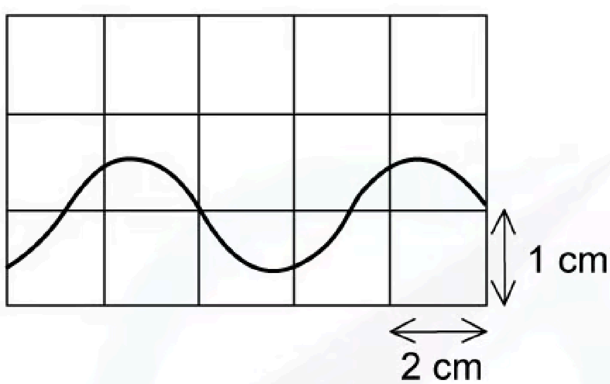
- The period can be determined from the **time-base**
  - This is **how many seconds each division represents** measured commonly in **s div^{-1}** or **s cm^{-1}**
- Dividing the total time by the number of wavelengths will give a value for *T*
  - Use as many wavelengths shown on the screen as possible to reduce uncertainties
- The **frequency** is then determined using the equation:



Your notes

Worked Example

A cathode-ray oscilloscope (c.r.o.) is used to display the trace from a sound wave. The time-base is set at 7 μs mm^{-1}.



What is the frequency of the sound wave?

A. 2.4 Hz

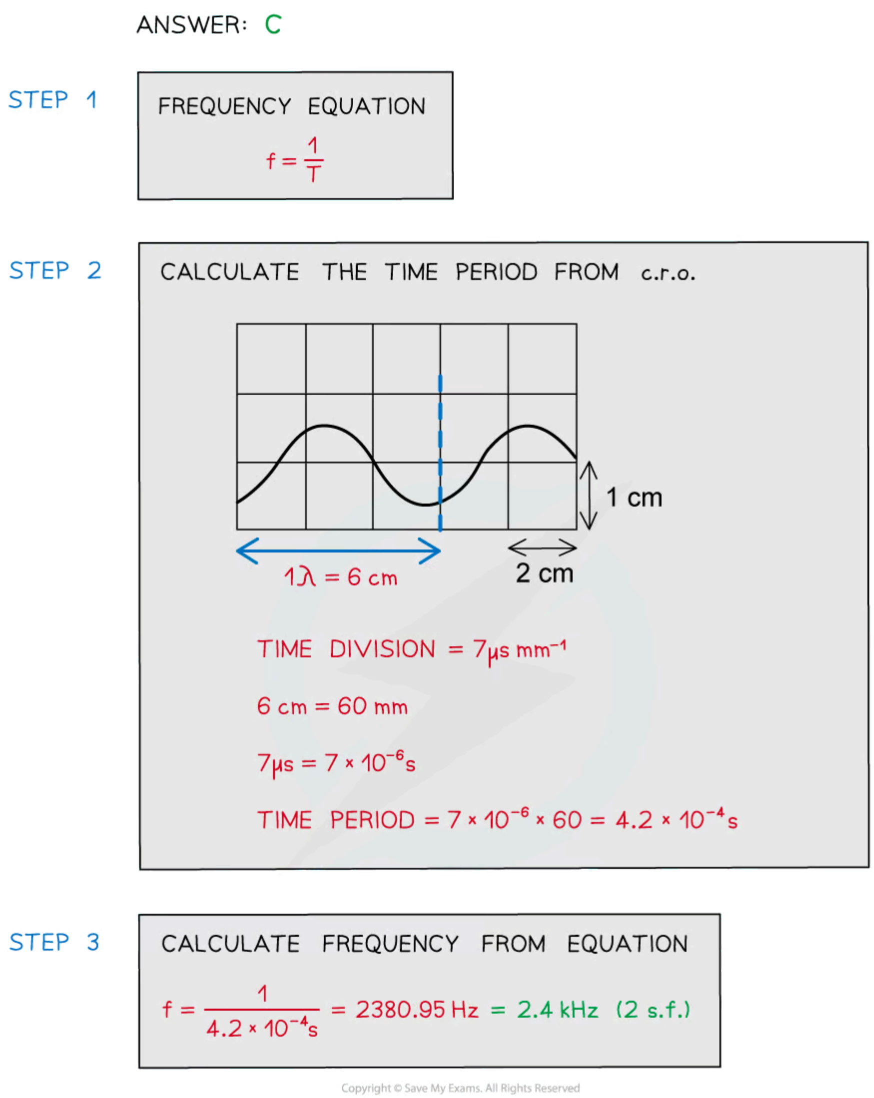
B. 24 Hz

C. 2.4 kHz

D. 24 kHz

Answer:

Remember that the time base is the scale of the horizontal c.r.o. axis, so one division represents 7 μs mm^{-1}



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The time base has units of μs mm^{-1} which means that the cm division needs to be converted to mm first.

Your notes

Examiner Tips and Tricks

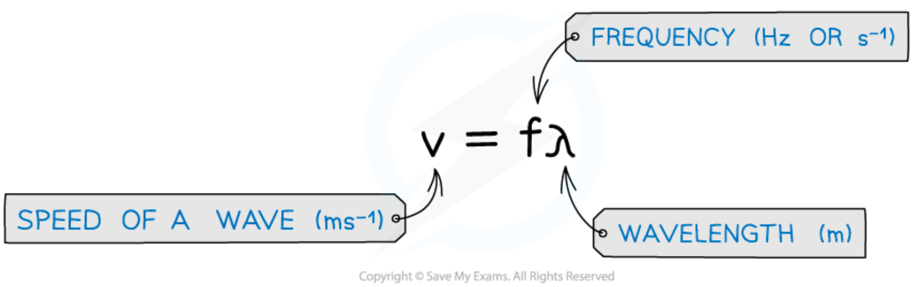
The time-base setting varies with units for seconds (commonly ms) and the unit length (commonly mm). Unit conversions are very important when calculating the time period and frequency.

The Wave Equation

Your notes

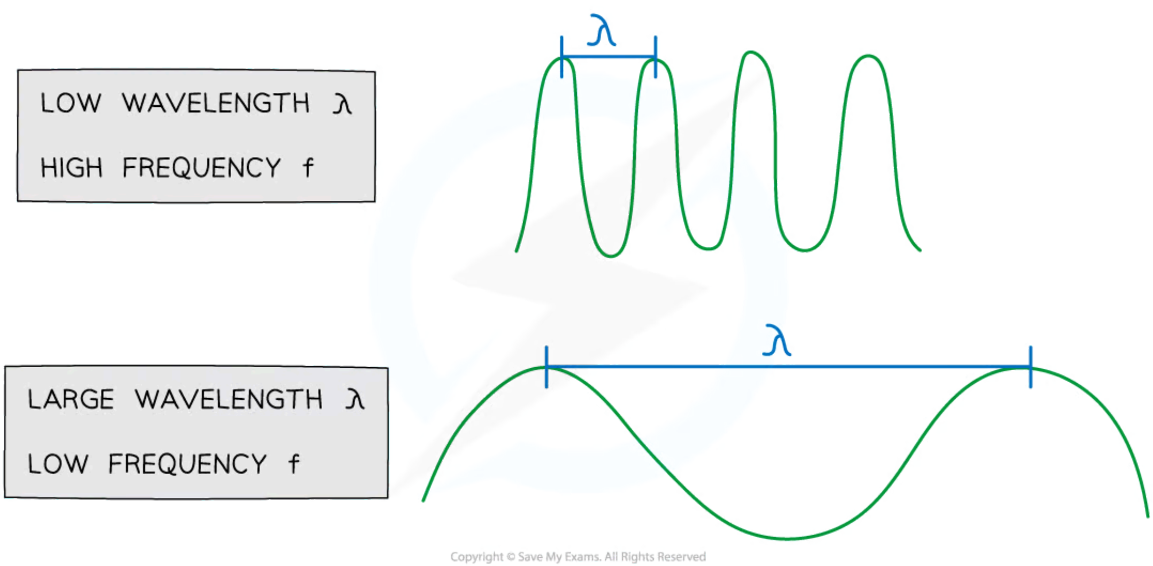
The Wave Equation

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



- 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**

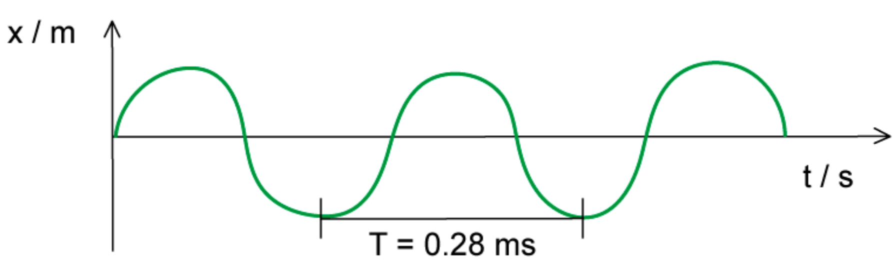
Your notes



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?

Answer:

Your notes

STEP 1

WAVE EQUATION

$$v = f\lambda$$

STEP 2

REARRANGE FOR WAVELENGTH

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

STEP 3

CALCULATE f

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

STEP 4

SUBSTITUTE VALUE BACK INTO WAVE EQUATION

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

Examiner Tips and Tricks

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.

Graphical Representations of Transverse & Longitudinal Waves

- Transverse and longitudinal waves can be represented graphically

Transverse Waves

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

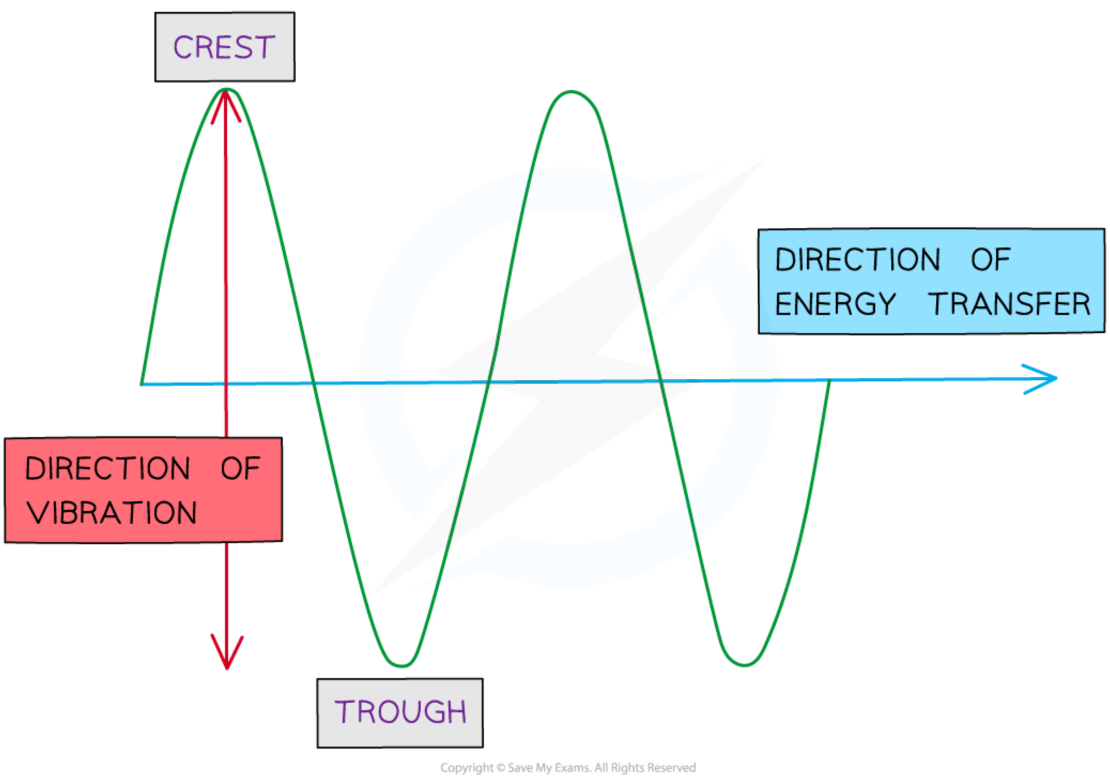


Diagram of a transverse wave

- The **peaks** are the maximum positive displacements
- The **troughs** are the maximum negative displacements
- The direction of the energy transfer is **perpendicular** to the direction of vibration of the particles in the wave

Longitudinal Waves

- Longitudinal waves show areas of **compressions** and **rarefactions**

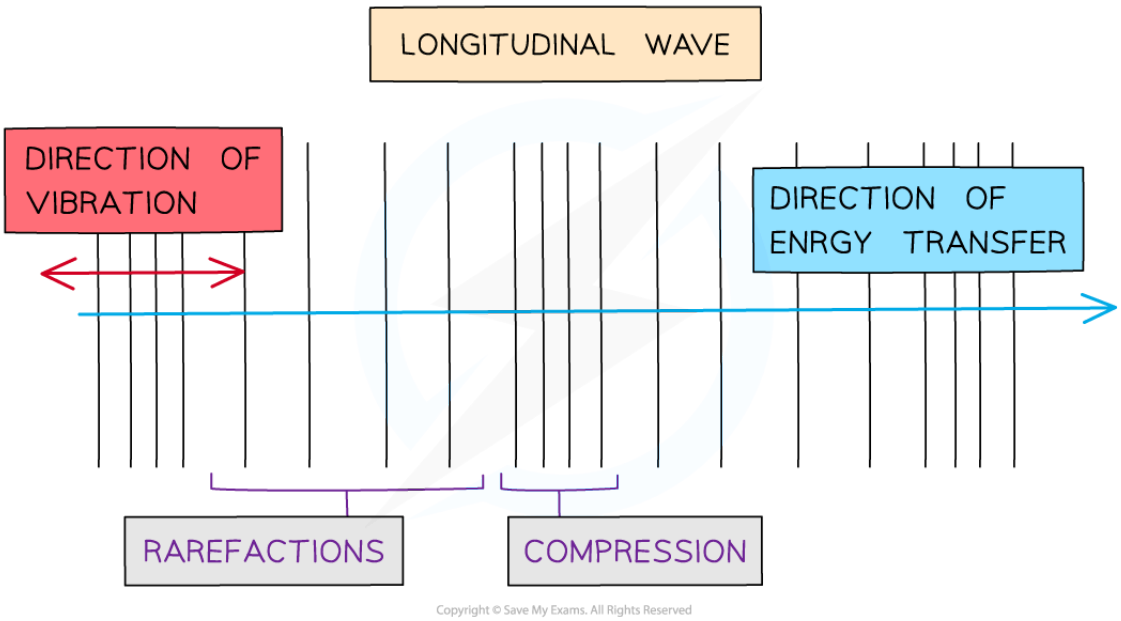


Diagram of a longitudinal wave

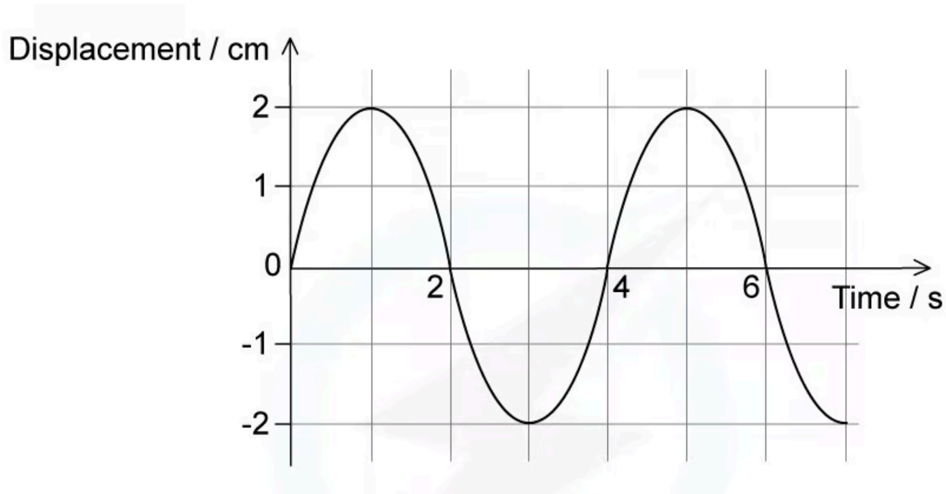
- The **compressions** are areas of high pressure due to particles being close together.
- The **rarefactions** are areas of low pressure due to the particles spread further apart
- The direction of energy transfer is **parallel** to the direction of vibration of the particles in the wave

Worked Example

The graph shows how the displacement of a particle in a wave varies with time.

Your notes

Your notes



Which statement is correct?

A. The wave has an amplitude of 2 cm and could be either transverse or longitudinal.

B. The wave has an amplitude of 2 cm and has a time period of 6 s.

C. The wave has an amplitude of 4 cm and has a time period of 4 s.

D. The wave has an amplitude of 4 cm and must be transverse.

Answer: A

THE WAVES AMPLITUDE IS THE DISPLACEMENT FROM THE EQUILIBRIUM POSITION

FROM THE GRAPH, THIS IS 2 cm

THE GRAPH IS DISPLACEMENT AGAINST TIME, NOT DISPLACEMENT AGAINST DIRECTION OF WAVE TRAVEL

THEREFORE, THE WAVE COULD BE EITHER TRANSVERSE OR LONGITUDINAL

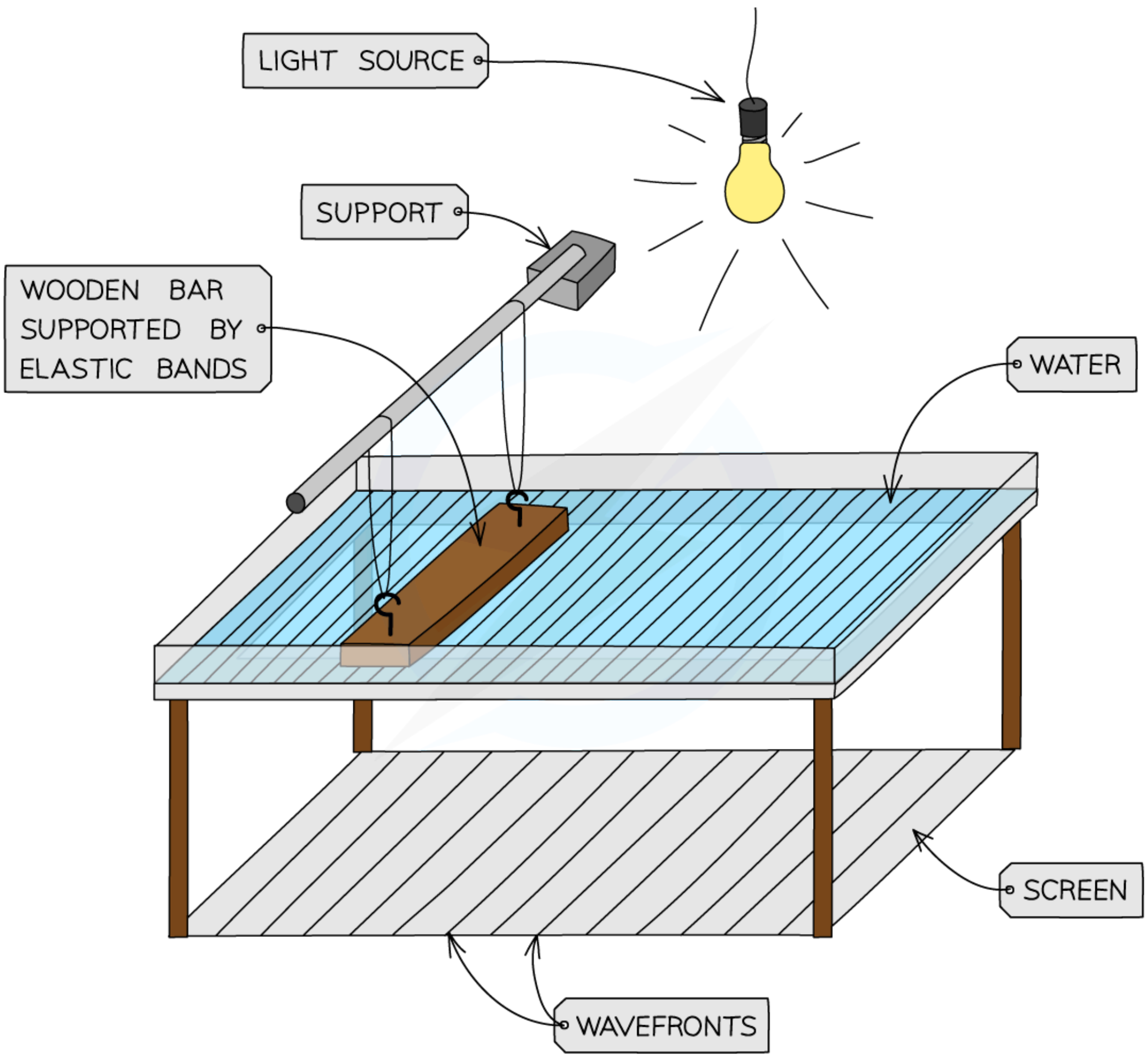
Your notes

Examiner Tips and Tricks

Both transverse and longitudinal waves can look like transverse waves when plotted on a graph - make sure you read the question and look for whether the wave travels **parallel** (longitudinal) or **perpendicular** (transverse) to the direction of travel to confirm which type of wave it is.

Demonstrating Waves Using a Ripple Tank

- Waves can also be demonstrated by ripple tanks
  - These produce a **combination** of transverse and longitudinal waves



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Wave effects can be demonstrated using a ripple tank

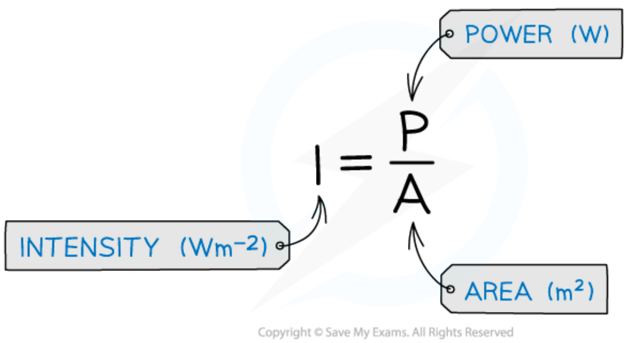
- In a ripple tank, a motorised wooden straight-edged bar produces plane (straight) waves while a small dipper produces circular waves
- When a light is shone from above, the bright bands seen on the screen below the tank show the wave crests (wavefronts)
    - This makes it possible to measure the wavelength of the water waves and investigate the angles of **reflection** and **refraction**
- **Reflection** can be investigated using plane and curved surfaces, and the angles of incidence and reflection measured with respect to the normal
- **Refraction** can be investigated using a glass sheet to decrease the water depth and produce a region with a different wave speed
    - If the separation of the wavefronts decreases, this shows they are travelling more slowly and vice versa
- Changing the angle of the wooden bar causes the wavefronts to go in a different direction
    - The ripple tank, therefore, can also be used to study **interference** and **diffraction**

Your notes

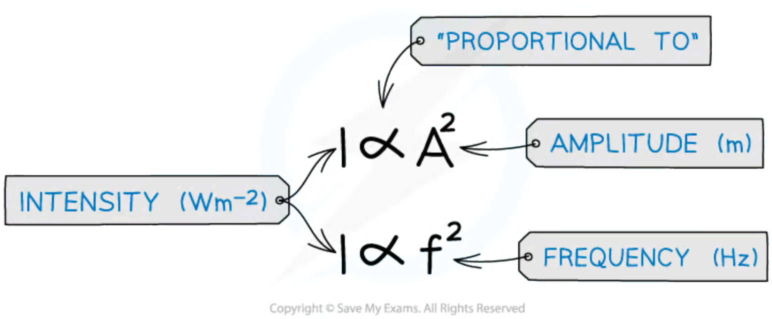
Intensity of a Wave

Intensity of a Progressive Wave

- Progressive waves transfer **energy**
- The amount of energy passing through a unit area per unit time is the **intensity** of the wave
  - Therefore, the **intensity** is defined as **power per unit area**



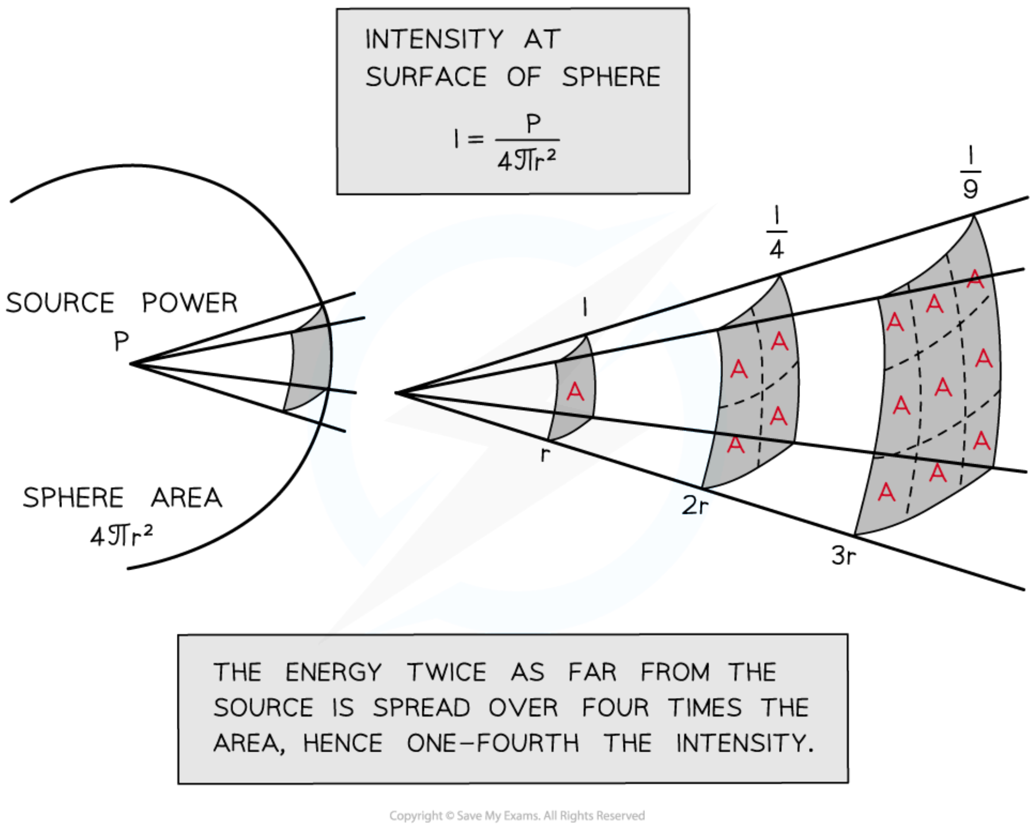
- The unit of intensity is **Watts per metre squared (W m^{-2})**
- The area the wave passes through is **perpendicular** to the direction of its velocity
- The intensity of a progressive wave is also proportional to its **amplitude squared** and frequency squared



- This means that if the frequency or the amplitude is doubled, the intensity increases by a factor of 4 (2^2)

Spherical waves

- A spherical wave is a wave from a point source which spreads out equally in all directions
- The area the wave passes through is the **surface area** of a sphere: $\mathbf{4\pi r^2}$
- As the wave travels further from the source, the energy it carries passes through increasingly larger areas as shown in the diagram below:



Intensity is proportional to the amplitude squared

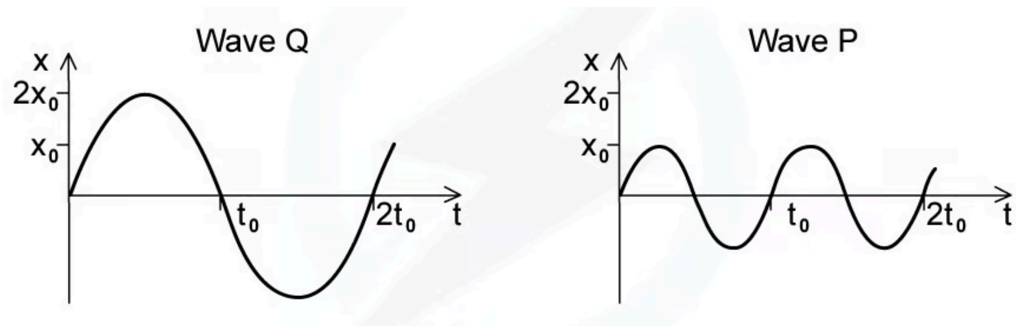
- Assuming there's no absorption of the wave energy, the intensity *I* decreases with increasing distance from the source
- Note the intensity is proportional to $1 / r^2$
  - This means when the source is twice as far away, the intensity is 4 times less
- The $1 / r^2$ relationship is known in physics as the **inverse square law**

Your notes

Your notes

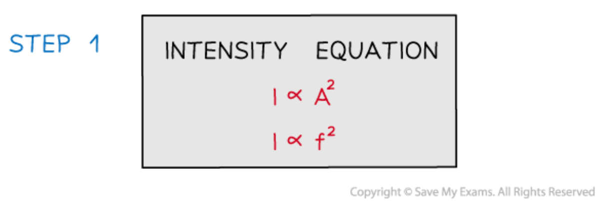
Worked Example

The intensity of a progressive wave is proportional to the square of the amplitude of the wave. It is also proportional to the square of the frequency.The variation with time *t* of displacement *x* of particles when two progressive waves **Q** and **P** pass separately through a medium are shown on the graphs.



The intensity of wave **Q** is I_0.What is the intensity of wave **P**?

Answer:



STEP 2

CALCULATE HOW MUCH THE AMPLITUDE HAS INCREASED/DECREASED

WAVE P IS HALF THE AMPLITUDE OF WAVE Q

$$A_P = \frac{1}{2^2} A_Q$$

WAVE $P = \frac{1}{4} I_0$ OF WAVE Q

STEP 3

CALCULATE HOW MUCH THE FREQUENCY HAS INCREASED/DECREASED

WAVE P IS DOUBLE THE FREQUENCY OF WAVE Q

$$f_P = 2^2 f_Q$$

WAVE $P = 4I_0$ OF WAVE Q

STEP 4

SUBSTITUTE BACK INTO INTENSITY EQUATION

$$I_0(P) \propto \left(\frac{1}{4} \times 4\right) I_0(Q)$$

INTENSITY OF WAVE P = INTENSITY OF WAVE Q $= I_0$

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Examiner Tips and Tricks

The key takeaway here is:

Intensity has an inverse square relationship with distance (not a linear one)

This means the energy of a wave decreases **very rapidly** with increasing distance