Volume

One

ST MARY'S SCIENCE DEPARTMENT:

PHYSICS

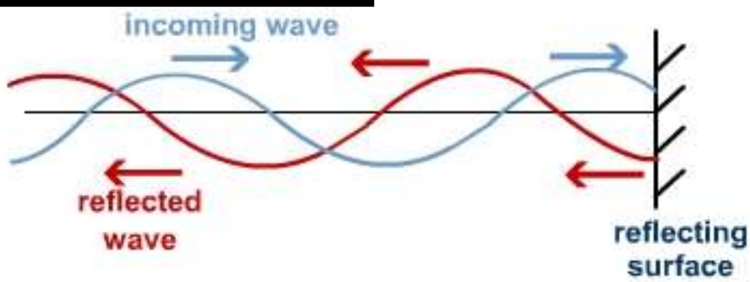
A LEVEL PHYSICS YEAR 1
STUDENT CLASS BOOK
WAVES
3.3.1: PROGRESSIVE AND STATIONARY WAVES

NAME	
PHYSICS CLASS	
MODULE TEACHER	
ALPS GRADE	

A-LEVEL PHYSICS

TOPIC 3

CLASS BOOK



THIS MUST BE BROUGHT TO ALL PHYSICS LESSONS.

Contents

Overview

GCSE studies of wave phenomena are extended through a development of knowledge of the characteristics, properties, and applications of travelling waves and stationary waves.
Topics treated include refraction, diffraction, superposition and interference.

IMPORTANT NOTE
This booklet, along with the preparatory reading notes, must be brought to all Physics lessons with the appropriate teacher.

This booklet may be used as a learning resource in lessons, you are not fully equipped to learn if this is not used in lesson.

This booklet may also be used as a revision resource for intervention, internal assessments and external assessments.
Please keep this in your student file.

There are several activities in this book which may not be covered in lessons.

It is advised that students complete these activities outside of lessons as revision aides.

Definition List

Definitions you must learn for this module are…

Key Word	Definition
Amplitude	The maximum displacement of a vibrating particle; for a transverse wave, it is the distance from the middle to the peak of the wave.
Antinode	The fixed point in a stationary wave pattern where the amplitude is a maximum.
Coherent	When two sources of waves have a constant phase difference and the same frequency.
Cycle	The interval of a vibrating particle (or a wave) from a certain displacement and velocity to the next time the particle (or the next particle) that has the same displacement and velocity.
First harmonic	The pattern of stationary waves on a string when it vibrates at its lowest possible frequency. Each further harmonic is a multiple of the first harmonic.
Frequency	The number of complete cycles of a wave that pass a point each second.
Interference	The formation of points of cancellation and reinforcement where two coherent waves pass through each other.
Longitudinal waves	Waves with a direction of vibration parallel to the direction of propagation of the waves.
Path difference	The difference in distances from two coherent sources to an interference fringe.
Period	The time for one complete cycle of a wave to pass a point.
Phase difference	The fraction of a cycle between the vibrations of two vibrating particles, measured either in radians or degrees.
Plane-polarised waves	Transverse waves that vibrate in one plane only.
Progressive waves	Waves which travel through a substance or through space if electromagnetic. It is a transfer of energy.
Stationary waves	Wave patterns with nodes and antinodes formed when two or more progressive waves of the same frequency and amplitude pass through each other. It is a display of energy.
Superposition	Effect of two waves adding displacements together when they meet.
Transverse waves	Waves with a direction of vibration perpendicular to the direction of propagation of the waves.
Wavefront	Lines of constant phase (e.g. wave crests) on a wave.
Wavelength	The shortest distance between two consecutive points on a wave which are in phase.

IMPORTANT NOTE
These definitions must be memorised by students.

You will be tested on these definitions.

The Language of Measurement

The following subject specific vocabulary provides definitions of key terms used in the A-level Science specifications.

Accuracy
A measurement result is considered accurate if it is judged to be close to the true value.

Calibration
Marking a scale on a measuring instrument.
This involves establishing the relationship between indications of a measuring instrument and standard or reference quantity values, which must be applied.
For example, placing a thermometer in melting ice to see whether it reads 0 °C, to check if it has been calibrated correctly.

Data
Information, either qualitative or quantitative, that has been collected.

Errors
See also uncertainties.

Measurement error
The difference between a measured value and the true value.
anomalies
These are values in a set of results which are judged not to be part of the variation caused by random uncertainty.

Random error
These cause readings to be spread about the true value, due to results varying in an unpredictable way from one measurement to the next.
Random errors are present when any measurement is made, and cannot be corrected. The effect of random errors can be reduced by making more measurements and calculating a new mean.

Systematic error
These cause readings to differ from the true value by a consistent amount each time a measurement is made.
Sources of systematic error can include the environment, methods of observation or instruments used.
Systematic errors cannot be dealt with by simple repeats. If a systematic error is suspected, the data collection should be repeated using a different technique or a different set of equipment, and the results compared.

Zero error
Any indication that a measuring system gives a false reading when the true value of a measured quantity is zero, e.g. the needle on an ammeter failing to return to zero when no current flows.
A zero error may result in a systematic uncertainty.

Evidence
Data which has been shown to be valid.

Fair test
A fair test is one in which only the independent variable has been allowed to affect the dependent variable.

Hypothesis
A proposal intended to explain certain facts or observations.

Interval
The quantity between readings, e.g. a set of 11 readings equally spaced over a distance of 1 metre would give an interval of 10 centimetres.

Precision
Precise measurements are ones in which there is very little spread about the mean value. Precision depends only on the extent of random errors – it gives no indication of how close results are to the true value.

Prediction
A prediction is a statement suggesting what will happen in the future, based on observation, experience or a hypothesis.

Range
The maximum and minimum values of the independent or dependent variables; important in ensuring that any pattern is detected.
For example, a range of distances may be quoted as either:
'From 10 cm to 50 cm'
or
'From 50 cm to 10 cm'

Repeatable
A measurement is repeatable if the original experimenter repeats the investigation using same method and equipment and obtains the same results.

Reproducible
A measurement is reproducible if the investigation is repeated by another person, or by using different equipment or techniques, and the same results are obtained.

Resolution
This is the smallest change in the quantity being measured (input) of a measuring instrument that gives a perceptible change in the reading.

Sketch graph
A line graph, not necessarily on a grid, that shows the general shape of the relationship between two variables. It will not have any points plotted and although the axes should be labelled they may not be scaled.

True value
This is the value that would be obtained in an ideal measurement.

Uncertainty
The interval within which the true value can be expected to lie, with a given level of confidence or probability, e.g. "the temperature is 20 °C ± 2 °C, at a level of confidence of 95%.

Validity
Suitability of the investigative procedure to answer the question being asked. For example, an investigation to find out if the rate of a chemical reaction depended upon the concentration of one of the reactants would not be a valid procedure if the temperature of the reactants was not controlled.

Valid conclusion
A conclusion supported by valid data, obtained from an appropriate experimental design and based on sound reasoning.

Variables
These are physical, chemical or biological quantities or characteristics.

Categoric variables
Categoric variables have values that are labels. E.g. names of plants or types of material.

Continuous variables
Continuous variables can have values (called a quantity) that can be given a magnitude either by counting (as in the case of the number of shrimp) or by measurement (e.g. light intensity, flow rate etc.).

Control variables
A control variable is one which may, in addition to the independent variable, affect the outcome of the investigation and therefore must be kept constant or at least monitored.

Dependent variables
The dependent variable is the variable of which the value is measured for each change in the independent variable.

Independent variables
The independent variable is the variable for which values are changed or selected by the investigator.

IMPORTANT NOTE
These definitions must be memorised by students.

You will be tested on your knowledge of these definitions.

TOPIC: 3.3.1.1 Progressive Waves
SPEC CHECK

Specification	Completed?
Oscillation of the particles of the medium;	
amplitude, frequency, wavelength, speed, phase, phase difference, $c = f\lambda$, $f = 1/T$	
Phase difference may be measured as angles (radians and degrees) or as fractions of a cycle.	
Laboratory experiment to determine the speed of sound in free air using direct timing or standing waves with a graphical analysis.	

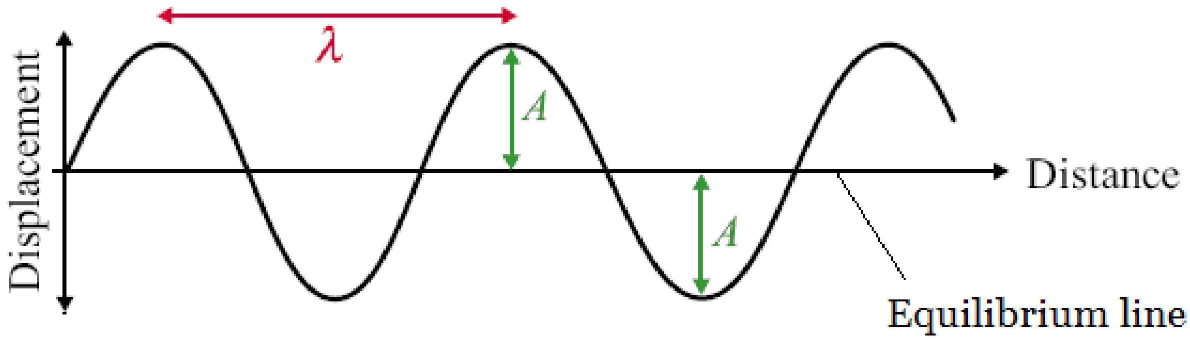
These notes are brief.

More detailed notes are found in the student preparatory reading book.

Please read the preparatory reading notes.

NOTES
Waves
All waves are caused by oscillations and all transfer energy without transferring matter. This means that a water wave can transfer energy to you sitting on the shore without the water particles far out to sea moving to the beach.

Here is a diagram of a wave; it is one type of wave called a transverse wave.
A wave consists of something (usually particles) oscillating from an equilibrium point. The wave can be described as progressive; this means it is moving outwards from the source.



We will now look at some basic measurements and characteristics or waves.

Amplitude, *A* — Amplitude is measured in metres, m
The amplitude of a wave is the maximum displacement of the particles from the equilibrium position.

Wavelength, λ — Wavelength is measured in metres, m
The wavelength of a wave is the length of one whole cycle. It can be measured between two adjacent peaks, troughs or any point on a wave and the same point one wave later.

Time Period, T

Time Period is measured in seconds, s

This is the time is takes for one complete wave to happen. Like wavelength it can be measured as the time it takes between two adjacent peaks, troughs or to get back to the same point on the wave.

Frequency, f

Frequency is measured in Hertz, Hz

Frequency is a measure of how often something happens, in this case how many complete waves occur in every second.

It is linked to time-period of the wave by the following equations: $T = \frac{1}{f}$ and $f = \frac{1}{T}$

Wave Speed, c

Wave Speed is measured in metres per second, m s^{-1}

The speed of a wave can be calculated using the following equation: $c = f\lambda$

Here c represents the speed of the wave, f the frequency and λ the wavelength.

For an electromagnetic wave, the speed of the wave is constant for all electromagnetic waves. For mechanical waves, the speed of the wave varies depending on the mechanical wave.

Phase Difference

Phase Difference is measured in radians, rad

If we look at two particles a wavelength apart (such as C and G) we would see that they are oscillating in time with each other. We say that they are *completely in phase*.

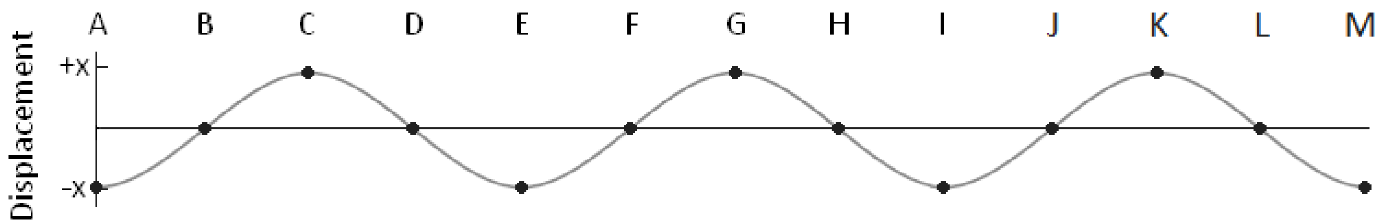
A full wavelength is 360° of phase. `In phase' occurs at whole multiples of the wavelength (nλ). If two points are in phase, the two points are moving at the same velocity, meaning speed and direction.

Two points half a wavelength apart (such as I and K) we would see that they are always moving in opposite directions. We say that they are *completely out of phase or in anti-phase*.

`In anti-phase' occurs at whole plus half multiples (n + ½λ) of a wavelength. If two points are in anti-phase, the two points are moving with the same speed but travel in opposite directions.

Phase relates the relative motion of one part of a wave compared to the relative motion of one part of another wave.

The phase difference between two points depends on what fraction of a wavelength lies between them



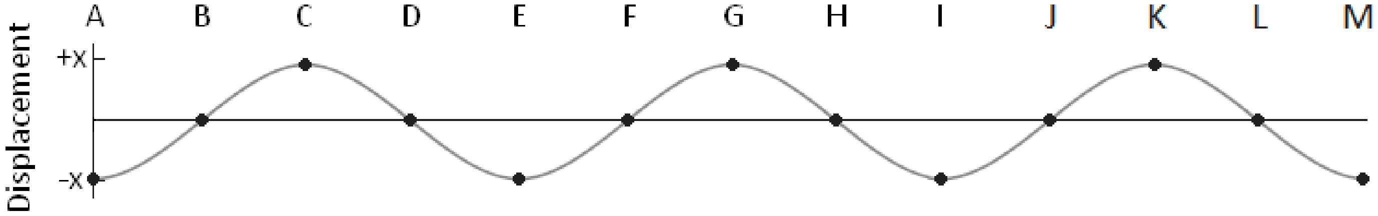
	B	C	D	E	F	G	H	I	J	K	L	M
Phase Difference from A (radians)	½π	1π	1½π	2π	2½π	3π	3½π	4π	4½π	5π	5½π	6π
Phase Difference from A (degrees)	90	180	270	360	450	540	630	720	810	900	990	1080

Path Difference

Path Difference is measured in wavelengths, λ

If two light waves leave a bulb and hit a screen the difference in how far the waves have travelled is called the path difference. Path difference is measured in terms of wavelengths.

Path difference is the difference in metres between the lengths of two paths (the distance along the wave).



	B	C	D	E	F	G	H	I	J	K	L	M
Path Difference from A	¼λ	½λ	¾λ	1λ	1¼λ	1½λ	1¾λ	2λ	2¼λ	2½λ	2¾λ	3λ

Two waves leaving A with one making it to F and the other to J will have a path difference of 1 wavelength (1λ).

REVISION SHEET

Highlight or underline the key information on the revision sheet to consolidate your understanding.

A Wave Transfers Energy Away From Its Source

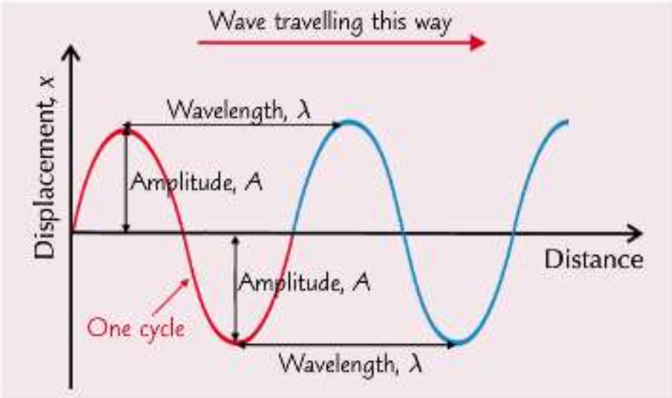
A **progressive** (moving) wave carries **energy** from one place to another **without transferring any material**. The transfer of energy is in the **same direction** as the wave is **travelling**. Here are some ways you can tell waves carry energy:

1) Electromagnetic waves cause things to **heat up**.
2) **X-rays** and **gamma rays** knock electrons out of their orbits, causing **ionisation**.
3) Loud **sounds** cause large oscillations in air particles which can make things **vibrate**.
4) **Wave power** can be used to **generate electricity**.

Since waves carry energy away, the **source** of the wave **loses energy**.

You Need to Know These Bits of a Wave

1) **Displacement**, x, metres — how far a **point** on the wave has **moved** from its **undisturbed position**.
2) **Amplitude**, A, metres — the **maximum magnitude** of the **displacement**.
3) **Wavelength**, λ, metres — the **length** of **one whole wave cycle**, e.g. from **crest** to **crest** or **trough** to **trough**.



4) **Period**, T, seconds — the **time taken** for a **whole cycle** (vibration) to complete.
5) **Frequency**, f, hertz — the **number** of **cycles** (vibrations) **per second** passing a given **point**.
6) **Phase** — a measurement of the **position** of a certain **point** along the wave cycle.
7) **Phase difference** — the amount one wave lags behind another.

Phase and phase difference are measured in angles (in degrees or radians). See p.74.

The Frequency is the Inverse of the Period

$$\text{Frequency} = \frac{1}{\text{Period}}$$

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

It's that simple.
Get the **units** straight: **1 Hz = 1 s^{-1}**.

The Wave Equation Links Wave Speed, Frequency and Wavelength

1) **Wave speed** can be measured just like the speed of anything else:

$$\text{Wave speed } (v) = \frac{\text{Distance } (d)}{\text{Time } (t)}$$

2) You can use this equation to derive the **wave equation** (but thankfully you don't have to do that, you just need to be able to use it).

Speed of wave (v) = frequency (f) × wavelength (λ)

$$v = f\lambda$$

Remember, you're not measuring how fast a physical point (like one molecule of rope) moves. You're measuring how fast a point on the **wave pattern** moves.

Additional Note Space

Additional Note Space

PUZZLES QUESTIONS

1 Draw a displacement–time graph for three complete oscillations of a wave with amplitude 3 cm and time period 2 s. Mark on your wave a crest and a trough, and show its period.

2 You are finding the time period for a pendulum. Your teacher tells you to start timing from the equilibrium position, but you time the swings from one of the maximum displacement positions. Sketch on the same axes the two graphs of displacement–time for the pendulum bob. Write an equation for each graph.

3 The speed of radio waves in air can be taken to be 3.0×10^8 m s^{-1}. If a radio station broadcasts on 252 kHz, what is the wavelength of the waves?

4 Electricity is transmitted at 50 Hz in Britain. What is the time period of this wave?

5 Water waves are viewed with a stroboscope. The wavelength is 10 cm and the amplitude is 2 cm. (Remember that $y = 0$ when $t = 0$.) Calculate the wave displacement at 8 cm and 35 cm. What are the phase angles at these points?

6 A sound wave can be written as $y = 3 \times 10^{-3} \sin(520t - 1.57x)$. Find (i) amplitude, (ii) frequency, (iii) wavelength, (iv) speed, (v) time period of the wave. (vi) Would the sound be audible?

7 Write an equation in terms of y, t and x for a water wave of amplitude 0.3 m, whose time period is 0.2 s and speed 1.3 m s^{-1}.

8 A television transmitter has an output of 100 kW and radiates equally in all directions. Calculate the intensity of the radio wave 70 km from the transmitter.

ANSWERS

1 Check that three complete oscillations have been drawn and that the period has been correctly marked.

2 Teacher's graph would give $x = x_0 \sin 2\pi ft$. Pupil's graph would give $x = x_0 \cos 2\pi ft$.

3 1.19×10^{3} m

4 0.02 s

5 –0.019 m; the minus sign indicates downward displacement; phase angle is 1.6 rad.
Zero displacement and phase angle of 7π rad

6 (i) 3×10^{-3} m (ii) 82.8 Hz (iii) 4.0 m (iv) 331 m s^{-1} (v) 0.012 s (vi) yes

7 $y = 0.3 \sin(31.42t + 24.17x)$

8 1.62×10^{-6} W m^{-2}

SAMPLE QUESTION

S1.(a) For a sound wave travelling through air, explain what is meant by *particle displacement, amplitude* and *wavelength*.

Particle displacement

displacement is distance of particle **- 1 mark**

from mean [or equilibrium] position **- 1 mark**

in direction of wave (energy) **- 1 mark**

amplitude

amplitude is maximum displacement **- 1 mark**

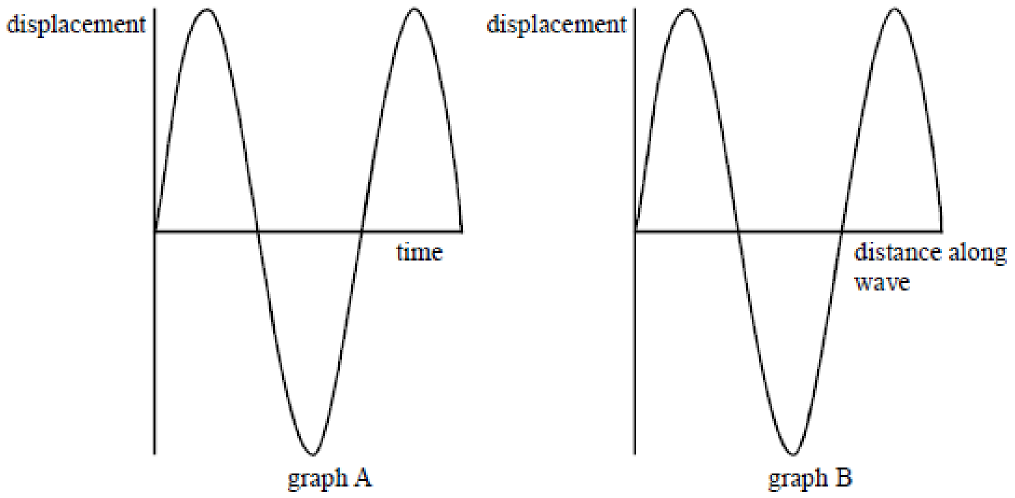
wavelength

wavelength is shortest distance **- 1 mark**

between two points in phase **- 1 mark**

(4)

(b)



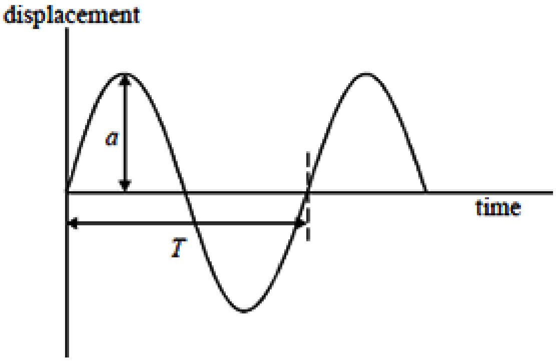
Graph A shows the variation of particle displacement with **time** at a point on the path of a progressive wave of constant amplitude.

Graph B shows the variation of particle displacement with **distance** along the same wave at a particular instant.

(i) Show on graph A

(1) the wave amplitude, a,

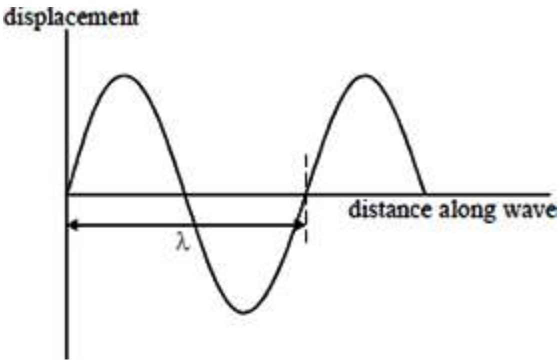
(2) the period, T, of the vibrations providing the wave.



(ii) Show on graph B

(1) the wavelength of the wave, λ,

(2) two points, P and Q, which are always $\pi/2$ out of phase.



(2) any two points $\frac{\lambda}{4}$ apart **- 1 mark**

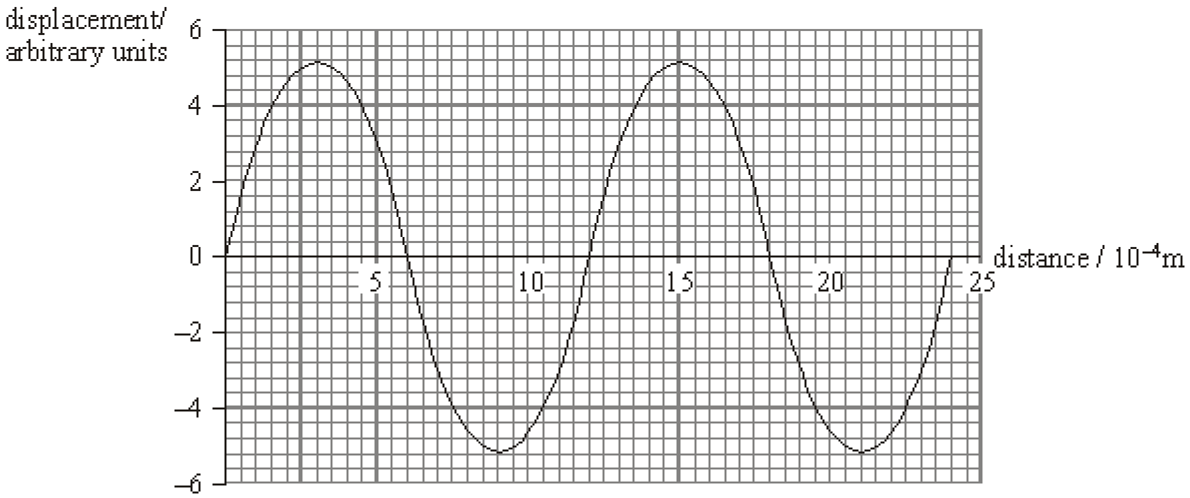
(4)
(Total 8 marks)

Reference: AQA Legacy A Examination Material

SELF ASSESSMENT

1. Figure 1 shows the displacement of particles in an ultrasound wave at different distances from the source at a particular time. The wave travels at 3200 m s^{-1}.

Figure 1



1.1 Use the graph to find the wavelength of the wave in **Figure 1**.

[1 Mark]

....

....

....

....

wavelength ....

1.2 Calculate the frequency of the ultrasound wave.

[2 Marks]

....

....

....

....

frequency ....

One industrial use for ultrasound waves is to detect flaws inside a metal block.

Figure 2a shows the arrangement in which the waves are fired downwards in short pulses from a transmitter.

Figure 2b shows the amplitudes of the initial pulse and the reflected signals recorded by the receiver.

You may assume that there is no reflected pulse received from the upper surface of the block.

Figure 2a

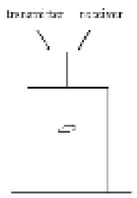
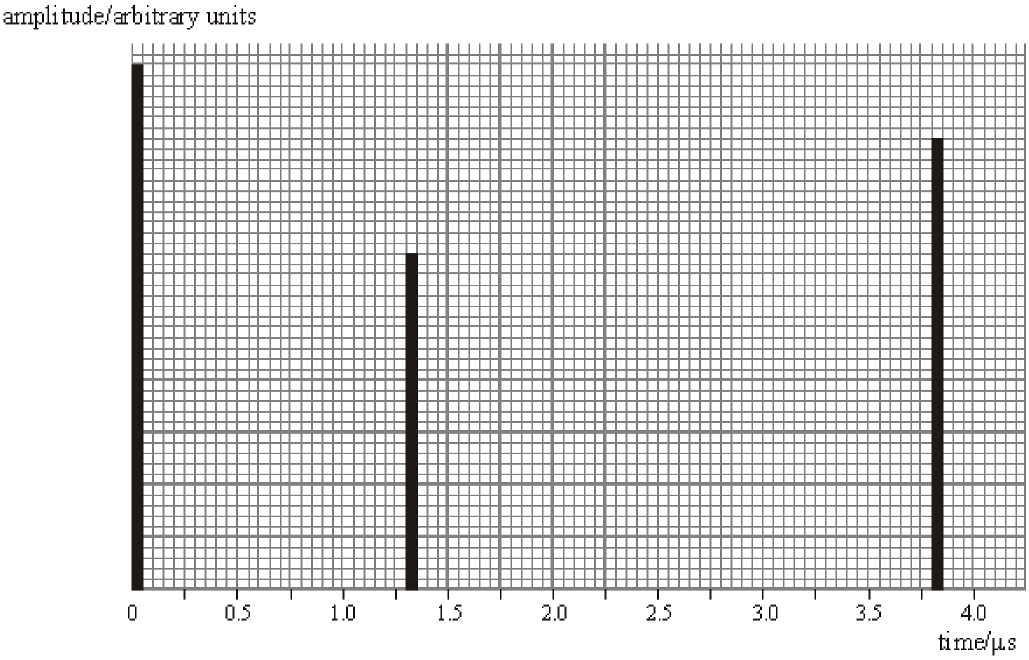


Figure 2b



1.3 The ultrasound wave travels at 3200 m s^{-1}. Use data from **Figure 2b** to calculate the distance of the flaw below the top of the block.

[3 Marks]

....

....

....

....

distance ....

Reference: AQA Legacy B Examination Material

Q2. Figure 1 shows three particles in a medium that is transmitting a sound wave. Particles **A** and **C** are separated by one wavelength and particle **B** is half way between them when no sound is being transmitted.

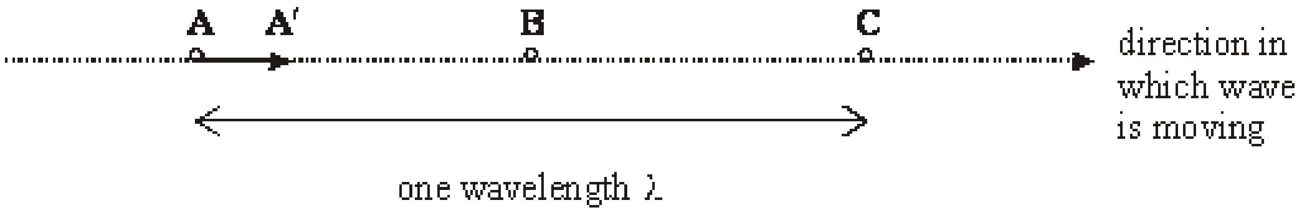


Figure 1

2.1 Name the type of wave that is involved in the transmission of this sound.

[1 Mark]

....

2.2 At one instant particle **A** is displaced to the point **A'** indicated by the tip of the arrow in **Figure 1**. Show on **Figure 1** the displacements of particles **B** and **C** at the same instant. Label the position **B'** and **C'** respectively.

[1 Mark]

2.3 Explain briefly how energy is transmitted in this sound wave.

[2 Marks]

....

....

....

....

Reference: AQA Legacy B Examination Material

Q3. Figure 1 shows how the displacement *s* of the particles in a medium carrying a pulse of ultrasound varies with distance *d* along the medium at one instant.

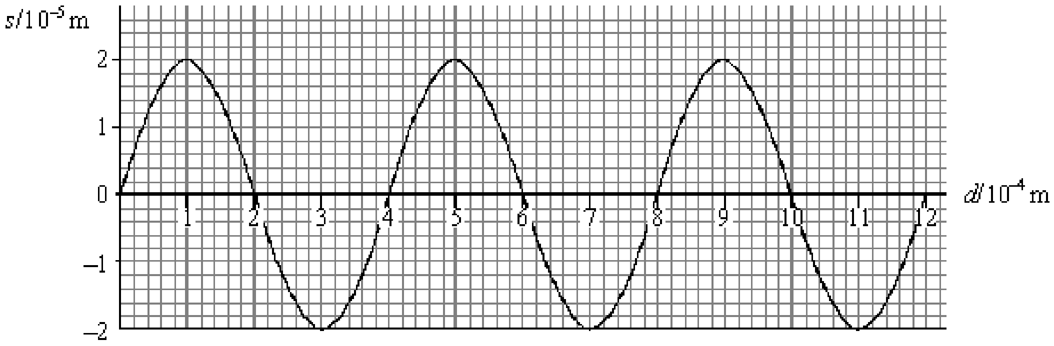


Figure 1

3.1 State the amplitude of the wave.

[1 Mark]

....

3.2 The speed of the wave is 1200 m s^{-1}. Calculate the frequency of oscillation of the particles of the medium when the ultrasound wave is travelling through it.

[3 Marks]

....

....

....

Frequency of oscillation ....

An ultrasound transmitter is placed directly on the skin of a patient. **Figure 2** shows the amplitudes of the transmitted pulse and the pulse received after reflection by an organ in the body. amplitude

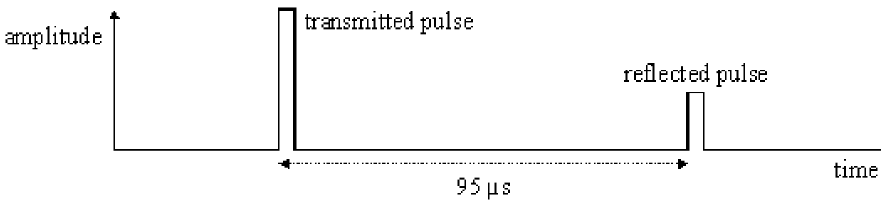


Figure 2

3.3 Give **two** possible reasons why the amplitude of the received pulse is lower than that which is transmitted.

[2 Marks]

Reason 1

....

....

Reason 2

....

....

3.4 The speed of ultrasound in body tissue is 1200 m s^{-1}. Calculate the depth of the reflecting surface below the skin.

[2 Marks]

....

....

....

....

Depth of reflecting surface ....

Reference: AQA Legacy B Examination Material

TOPIC: 3.3.1.2 Longitudinal and Transverse Waves

SPEC CHECK

Specification	Completed?
Nature of longitudinal and transverse waves.	
Examples to include: sound, electromagnetic waves, and waves on a string.	
Students will be expected to know the direction of displacement of particles/fields relative to the direction of energy propagation and that all electromagnetic waves travel at the same speed in a vacuum.	
Polarisation as evidence for the nature of transverse waves.	
Applications of polarisers to include Polaroid material and the alignment of aerials for transmission and reception.	
Students can investigate the factors that determine the speed of a water wave.	

NOTES

These notes are brief.

More detailed notes are found in the student preparatory reading book.

Please read the preparatory reading notes.

Waves

All waves are caused by oscillations and all transfer energy without transferring matter. This means that a sound wave can transfer energy to your eardrum from a far speaker without the air particles by the speaker moving into your ear.
We will now look at the two types of waves and how they are different

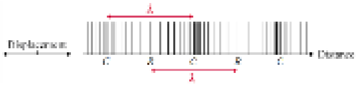
Longitudinal Waves

A longitudinal wave is a wave where the oscillations of the wave are parallel to the **direction of propagation (travel).**

Where the particles are close together we call a compression (labelled C on the diagram) and where they are spread we call a rarefaction (labelled R on the diagram).

The wavelength is the distance from one compression or rarefaction to the next corresponding compression or rarefraction.

The amplitude is the maximum distance the particle moves from its equilibrium position to the right of left.



<u>Example</u>:
Sound waves, P- seismic waves, Water waves

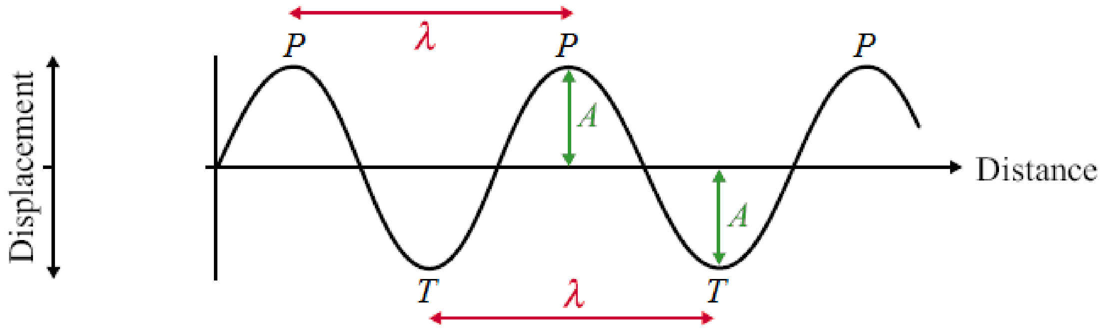
Transverse Waves

In a transverse wave the oscillations of the wave are perpendicular **to the direction of propagation (energy transfer).**

Where the particles are displaced above the equilibrium position we call a peak and below we call a trough.

The wavelength is the distance from one peak or trough to the corresponding peak or trough on the next wave.

The amplitude is the maximum distance the particle moves from its equilibrium position up or down.



<u>Examples</u>: Water waves, Mexican waves, S-seismic waves and waves of the EM spectrum

Electromagnetic waves are produced from varying electric and magnetic field in a material.

Polarisation

Polarisation is the restriction of the oscillations of a wave to only one plane of oscillation.

In the diagrams below, the light is initially oscillating in all directions; a wave which vibrates in all planes is called unpolarised.
A piece of Polaroid only allows light to oscillate in the same direction as it – it will polarise unpolarised waves.

In the top diagram the light passes through a vertical plane Polaroid and becomes polarized in the vertical plane. This can then pass through the second vertical Polaroid.

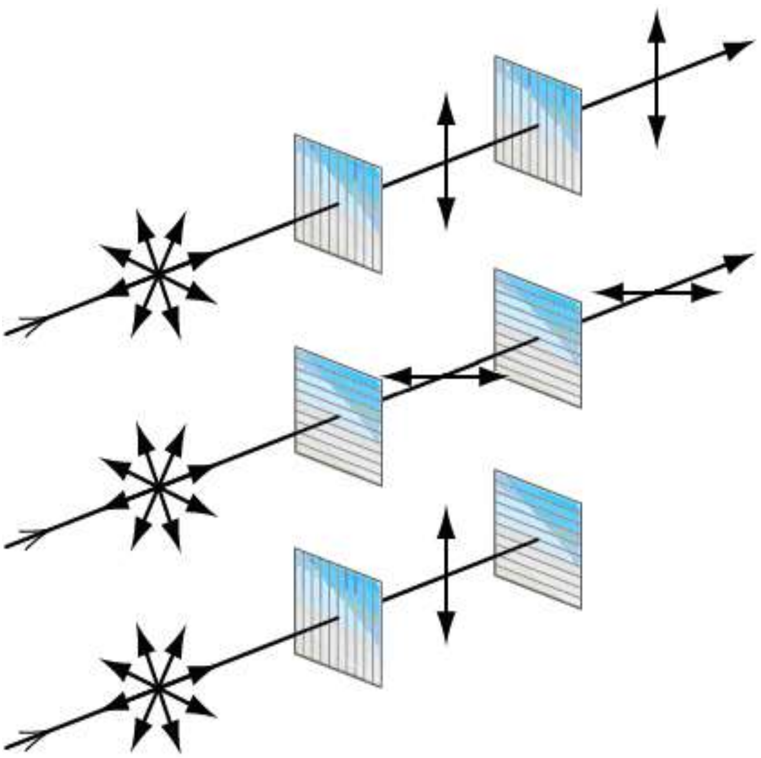
In the middle diagram the light becomes polarized in the horizontal plane.

In the bottom diagram the light becomes vertically polarized but this cannot pass through a horizontal plane Polaroid.

Only transverse waves can be polarised, longitudinal waves cannot be polarised by a Polaroid.

This is proof that the waves of the electromagnetic spectrum are transverse waves, this is because all electromagnetic waves can be polarised.

If they were longitudinal waves the forwards and backwards motion would not be stopped by crossed pieces of Polaroid; the bottom set up would emit light.



Polarisation is an example of attenuation since some of the wave (a number of the planes) is being absorbed.

This attenuation does not result in any loss of signal, but the bars of the polaroid often get hot, since the polaroid is absorbing the energy from those waves which it blocks.

Applications

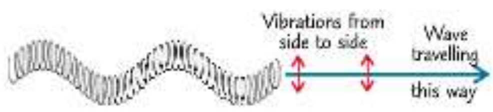
TV aerials get the best reception when they point to the transmission source so they absorb the maximum amount of the radio waves.
Reflection of waves causes partial polarisation as it reduces some planes of polarisation – this is the same way in which sunglasses work.

REVISION SHEET

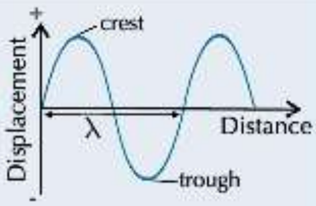
Highlight or underline the key information on the revision sheet to consolidate your understanding.

In *Transverse Waves*, *Vibration* is at Right Angles to the *Direction* of Travel

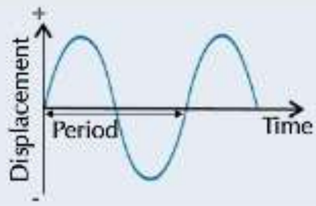
1) All **electromagnetic waves** are **transverse**. Other examples of transverse waves are ripples on water or waves on strings.
2) There are **two** main ways of **drawing** transverse waves:



They can be shown as **graphs** of **displacement** against **distance along the path of the wave.**



Or, they can be shown as graphs of **displacement against time** for a point as the wave passes.

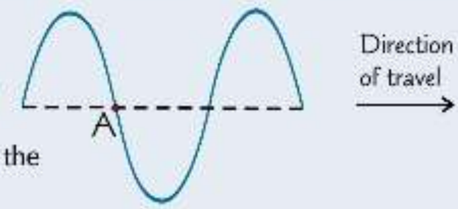


Displacements **upwards** from the centre line are given a **+ sign**. Displacements downwards are given a **– sign**.

3) Both sorts of graph often give the **same shape** (a **sine wave**), so make sure you check out the label on the ***x*-axis**.
4) You can work out what **direction** a point on a wave is moving in when given a snapshot of the wave.

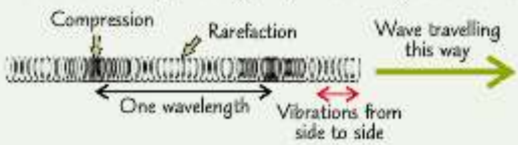
Example: Look at the snapshot of the wave on the right. Which direction is point A on the wave moving in?

1) Look at which **direction** the wave is **travelling** in — here the wave is moving from **left** to **right**.
2) The displacement of the wave **just to the left** of point A is **greater** than point A's. So as the wave travels along, point A will need to move **upwards** to have that displacement. (If the displacement to the left was less than point A's, point A would need to move down.)



In *Longitudinal Waves* the *Vibrations* are *Along* the Direction of Travel

The most **common** example of a **longitudinal wave** is **sound**. A sound wave consists of alternate **compressions** and **rarefactions** of the **medium** it's travelling through. (That's why sound can't go through a vacuum.)



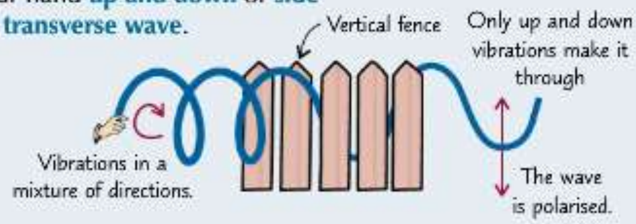
Some types of earthquake shock waves are also longitudinal.

The compressions and rarefactions create **pressure variations** in the medium the wave is travelling through — at the points of compression, the **molecules** of the medium are **closer** together, **increasing** the pressure at that point. At the points of rarefaction, the molecules are **further apart**, which means a **lower** pressure at that point.

It's hard to **represent** longitudinal waves **graphically**. You'll usually see them plotted as **displacement** against **time**. These can be **confusing** though, because they look like a **transverse wave**.

A Polarised Wave Only Oscillates in One Direction

1) If you shake a rope to make a wave you can move your hand up and down or side to side or in a mixture of directions — it still makes a transverse wave.
2) But if you try to pass waves in a rope through a vertical fence, the wave will only get through if the vibrations are vertical. The fence filters out vibration in other directions. This is called polarising the wave.



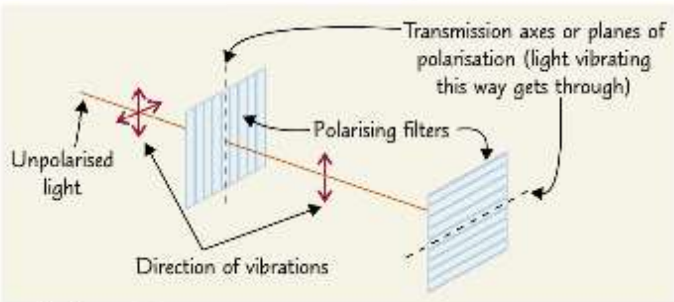
3) The plane in which a wave vibrates is called the plane of polarisation — e.g. the rope wave was polarised in the vertical plane by the fence.
4) Polarising a wave so that it only oscillates in one direction is called plane polarisation.
5) Ordinary light waves are a mixture of different directions of vibration. (The things vibrating are electric and magnetic fields).

Polarisation can only happen for transverse waves. So polarising light is one piece of evidence that it's a transverse wave.

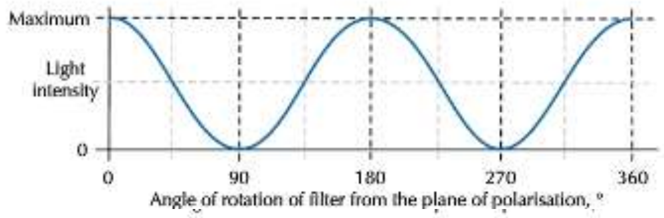
For polarised light, the direction of the vibrations (or the plane of polarisation) is always perpendicular to the direction of the propagation of light.

Polarising Filters Only Transmit Vibrations in One Direction

1) Ordinary **light waves** can be **polarised** using a **polarising filter**.
2) When the transmission axes of the two filters are **aligned**, **all** of the light that passes through the first filter also passes through the second.
3) As you rotate the second filter, the amount of light that passes through the second filter **varies**.
4) As the second filter is rotated, **less** light will get through it as the **vertical** component of the second filter's transmission axis **decreases**. This means the **intensity** of the light getting through the second filter will gradually **decrease**.
5) When the two transmission axes are at **45°** to each other, the intensity will be **half** that getting through the first filter. When they're at **right angles** to each other **no** light will pass through — **intensity** is **0**.



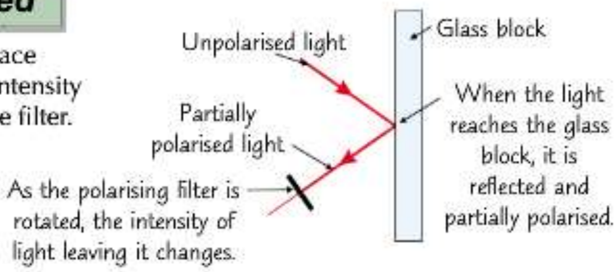
3D films use polarised light to create depth — the filters in each lens are at right angles to each other so each eye gets a slightly different picture.



6) As you continue turning, the intensity should then begin to **increase** once again.
7) When the two axes **realign** (after a 180° rotation), **all** the light will be able to pass through the second filter again.

When Light Reflects it is Partially Polarised

1) If you direct a beam of unpolarised light at a reflective surface then view the **reflected ray** through a polarising filter, the intensity of light leaving the filter **changes** with the **orientation** of the filter.
2) The intensity changes because at certain **angles**, light is **partially polarised** when it is **reflected**.
3) This effect is used to remove **unwanted reflections** in photography and in **Polaroid sunglasses** to remove **glare**.



Additional Note Space

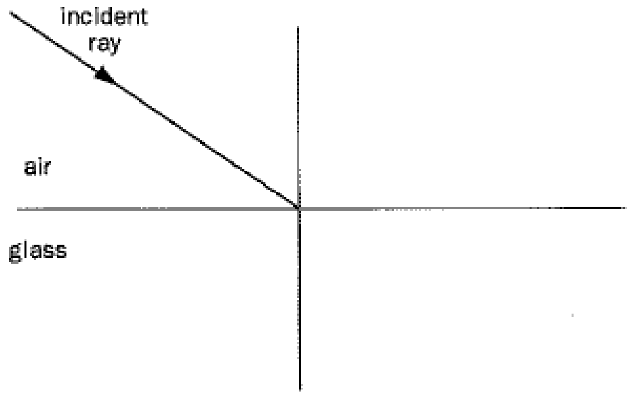
Additional Note Space

PUZZLES QUESTIONS

1 How could you demonstrate to a friend that sound waves cannot be polarised?

2 How do Polaroid sunglasses reduce the glare from the sunlight reflected off the sea?

3 Complete the diagram below to show the path of the refracted ray and the reflected ray, given that the angle between the reflected ray and the incident ray is 90°. Say which of the rays are polarised and which are unpolarised.



4 For the question above calculate the refractive index of the material.

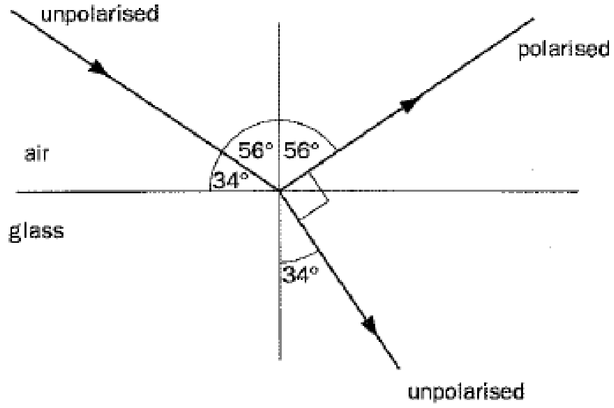
5 How would you check which of the rays were polarised?

ANSWERS

1 Place a metal grid in front of a loudspeaker, firstly in the horizontal and then in the vertical plane. A listener on the opposite side of the room will observe no difference in the sound intensity.

2 The Polaroid sunglasses absorb components of the vibrations of light that are in a particular direction. The intensity of light entering the eye is therefore reduced.

3



4 1.48

5 The reflected ray is the polarised ray, and this can be verified by observing the light through a piece of Polaroid film. As the Polaroid film is rotated, the ray will be completely absorbed by it at one point.

SAMPLE QUESTION

Q1. (a) State the characteristic features of

(i) longitudinal waves,

particle vibration (or disturbance or oscillation) - 1 mark

same as (or parallel to) direction of propagation (or energy transfer) – 1 mark

(ii) transverse waves.

particle vibration perpendicular to direction of propagation or energy transfer – 1 mark

(3)

(b) Daylight passes horizontally through a fixed polarising filter **P**. An observer views the light emerging through a second polarising filter **Q**, which may be rotated in a vertical plane about point **X** as shown in **Figure 1**.

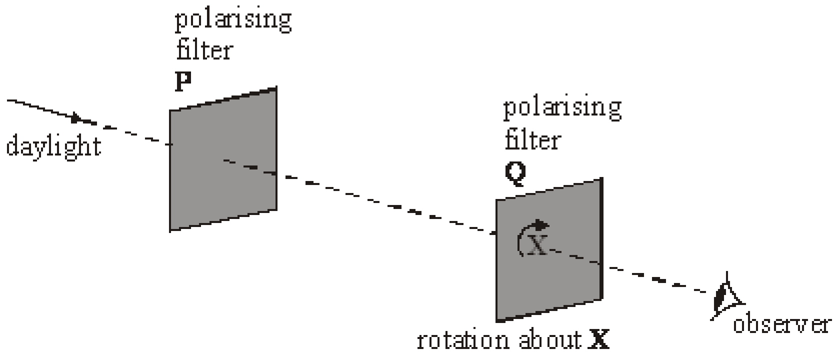


Figure 1

Describe what the observer would see as **Q** is rotated slowly through 360°.

You may be awarded marks for the quality of written communication provided in your answer.

variation in intensity between max and min (or light and dark) - 1 mark

two maxima (or two minima) in 360° rotation - 1 mark

(2)
(Total 5 marks)

Reference: AQA Legacy A Examination Material

SELF ASSESSMENT

1.1 State the difference between a longitudinal wave and a transverse wave.

[2 Marks]

....

....

....

....

1.2 State an example of a transverse wave.

[1 Mark]

....

1.3 State an example of a longitudinal wave.

[1 Mark]

....

1.4 Sound with a frequency of 560 Hz travels through steel with a speed of 4800 m s^{-1}. Calculate the wavelength of the sound wave.

[2 Marks]

....

....

....

....

Reference: AQA Legacy B Examination Material

2.1 State the difference between **transverse** and **longitudinal** waves.

[2 Marks]

....

....

....

....

2.2 State what is meant by **polarisation.**

[2 Marks]

....

....

....

....

2.3 Explain why polarisation can be used to distinguish between transverse and longitudinal waves.

[2 Marks]

....

....

....

....

Reference: AQA Legacy B Examination Material

Q3. Polarization is a property of one type of wave.

3.1 Circle below the type of wave that can be polarized.

[1 Mark]

transverse longitudinal

3.2 Give **one** example of the type of wave that can be polarized.

[1 Mark]

....

3.3 Explain why some waves can be polarized but others cannot. Space is provided for sketches should you wish to include them in your answer.

[3 Marks]

....

....

....

....

Reference: AQA Legacy B Examination Material

TOPIC: 3.3.1.3 Principle of Superposition of Waves and Formation of Stationary Waves
SPEC CHECK

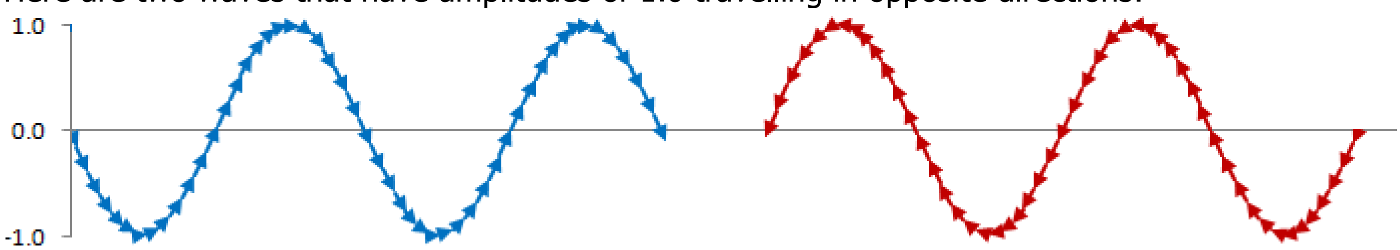
Specification	Completed?
Stationary waves.	
Nodes and antinodes on strings. f = 1/2l x √T/μ for first harmonic.	
The formation of stationary waves by two waves of the same frequency travelling in opposite directions.	
A graphical explanation of formation of stationary waves will be expected.	
Stationary waves formed on a string and those produced with microwaves and sound waves should be considered.	
Stationary waves on strings will be described in terms of harmonics. The terms fundamental (for first harmonic) and overtone will not be used.	
Students can investigate the factors that determine the frequency of stationary wave patterns of a stretched string.	

These notes are brief.

More detailed notes are found in the student preparatory reading book.

Please read the preparatory reading notes.

NOTES
Superposition
Here are two waves that have amplitudes of 1.0 travelling in opposite directions:



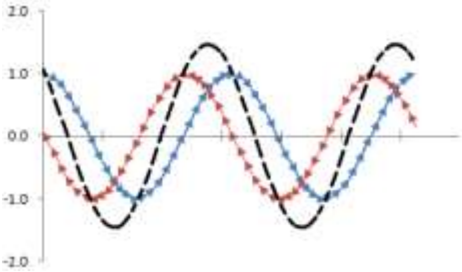
Superposition is the process by which two waves combine into a single wave form when they overlap. This is called the principle of superposition.

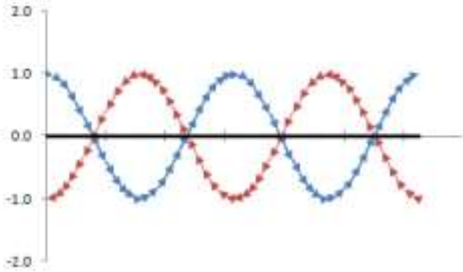
The principle of superposition states that when two waves overlap, their displacements add. **NOT THE DISTANCES BEING ADDED.**

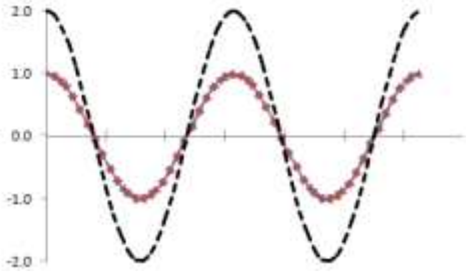
This only happens when two waves of the same type overlap.
This only happens when it is coherent waves overlapping.

If we add these waves together the resultant depends on where the peaks of the waves are compared to each other.

If the waves undergoing superposition are vibrating in the same direction, they are said to be **IN PHASE.** If the two waves have the exact same wave pattern, they are totally in phase.
If the waves undergoing superposition are vibrating in opposite direction, they are said to be **OUT OF PHASE OR IN ANTI-PHASE.**
Here are three examples of what the resultant could be: a wave with amplitude of 1.5, no resultant wave at all and a wave with amplitude of 2.0







These two waves are in phase with each other.

They superimpose to give larger peaks and larger troughs.

These two waves are completely out of phase with each other.

They superimpose to give no resultant wave at all.

These two waves are completely in phase with each other.

They superimpose to give the largest peaks and largest troughs possible.

Stationary/Standing Waves

When two similar waves travel in opposite directions they can superpose to form a standing (or stationary) wave. This is an application of the superposition discussed above.

On the next page, there is the experimental set up of how we can form a standing wave on a string.

The vibration generator sends waves down the string at a certain frequency and phase difference; they reach the end of the string and reflect back at the same frequency and phase difference.

On their way back the two waves travelling in opposite direction superpose to form a standing wave made up of nodes and antinodes.

Examiners Note

To form a standing wave, the following must occur….

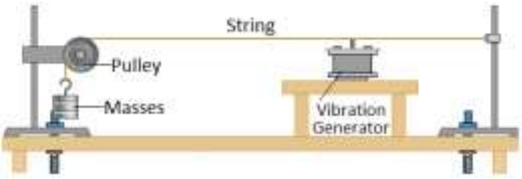
A progressive wave is reflected off a surface (1 mark).

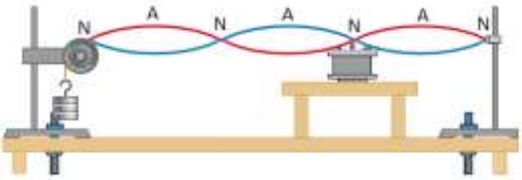
The progressive wave is coherent with itself – as the frequency and phase difference in unchanged (1 mark)

The progressive wave does not reduce in amplitude (1 mark).

The progressive wave interferes with itself and produces a standing wave (1 mark).

Nodes: Positions on a standing wave which do not vibrate.
The waves combine to give zero displacement.
Antinodes: Positions on a standing wave where there is a maximum displacement.





A progressive wave is one where the wave moves from one point to another in the Universe. It is a transfer of energy.

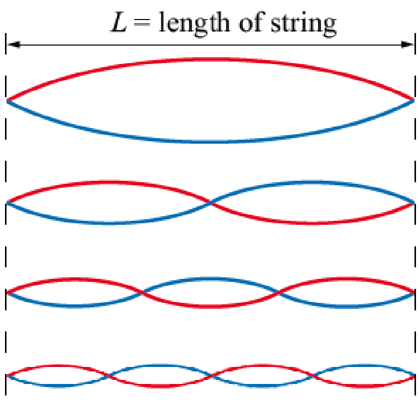
A stationary wave is one where a wave is trapped between two boundaries and reflects back on itself. It is a display of energy.

	Standing Waves	Progressive Waves
Amplitude	Maximum at antinode and zero at nodes	The same for all parts of the wave
Frequency	All parts of the wave have the same frequency	All parts of the wave have the same frequency
Wavelength	Twice the distance between adjacent nodes	The distance between two adjacent peaks
Phase	All points between two adjacent nodes in phase	Points one wavelength apart in phase
Energy	No energy translation	Energy translation in the direction of the wave
Waveform	Does not move forward	Moves forwards

Harmonics

As we increase the frequency of the vibration generator we will see standing waves being set up. The first will occur when the generator is vibrating at the fundamental frequency (or first harmonic), f_0, of the string.

First Harmonic $f = f_0$ $\lambda = 2L$
2 nodes and 1 antinode
Second Harmonic $f = 2f_0$ $\lambda = L$
3 nodes and 2 antinodes
Third Harmonic $f = 3f_0$ $\lambda = \frac{2}{3}L$
4 nodes and 3 antinodes
Fourth Harmonic $f = 4f_0$ $\lambda = \frac{1}{2}L$
5 nodes and 4 antinodes



As we increase the frequency of the signal generator, the standing wave only forms at the harmonic frequencies.

The frequencies of the harmonics are all multiples of the first harmonic.

If the frequency of the wave is not a first harmonic multiple, a standing wave will not form.

REVISION SHEET

Highlight or underline the key information on the revision sheet to consolidate your understanding.

You get Stationary Waves When a **Progressive Wave** is **Reflected** at a **Boundary**

A stationary wave is the **superposition** of **two progressive waves** with the **same wavelength**, moving in **opposite directions**.

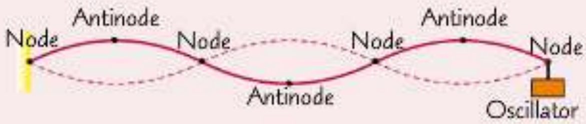
The progressive waves must also have the same speed and frequency.

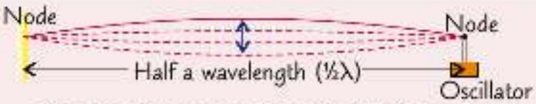
1) Unlike progressive waves, **no energy** is transmitted by a stationary wave.
2) You can demonstrate stationary waves by attaching a **vibration transducer** at one end of a **stretched string** with the other end fixed. The transducer is given a wave frequency by a **signal generator** and creates that wave by vibrating the string.
3) The wave generated by the vibration transducer is **reflected** back and forth.
4) For most frequencies the resultant **pattern** is a **jumble**. However, if you alter the **signal generator** so the **transducer** produces an **exact number of waves** in the time it takes for a wave to get to the **end** and **back again**, then the **original** and **reflected** waves **reinforce** each other.
5) At these **"resonant frequencies"** you get a **stationary** (or **standing**) **wave** where the **pattern doesn't move** — it just sits there, bobbing up and down. Happy, at peace with the world...

A sitting wave.

Stationary Waves in **Strings** Form **Oscillating "Loops"** Separated by **Nodes**

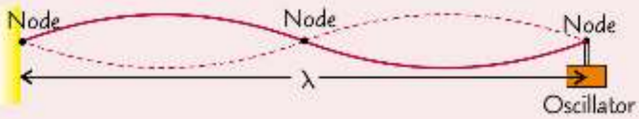
1) Each particle vibrates at **right angles** to the string.
2) **Nodes** are where the **amplitude** of the vibration is **zero**.
3) **Antinodes** are points of **maximum amplitude**.
4) At resonant frequencies, an **exact number** of **half wavelengths** fits onto the string.

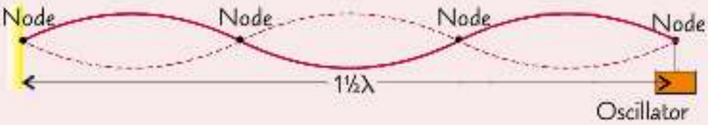




The standing wave above is vibrating at the **lowest possible** resonant frequency (the **fundamental mode of vibration** — also called the **first harmonic**). It has **one "loop"** with a **node at each end**.

This is the **second harmonic**. It is **twice** the **fundamental mode of vibration**. There are two **"loops"** with a **node** in the **middle** and **one at each end**.

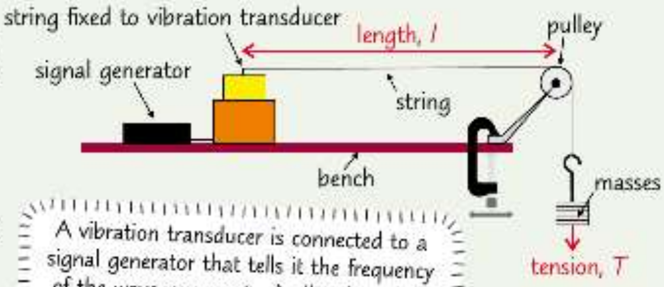




The **third harmonic** is **three times** the fundamental mode of vibration. **1½ wavelengths** fit on the string.

You Can Investigate *Factors* Affecting the *Resonant Frequencies* of a String

1) Start by measuring the **mass** (M) and **length** (L) of strings of different types using a **mass balance** and a ruler. Then find the **mass per unit length** of each string (μ) using: $\mu = \frac{M}{L}$ The units of μ are kgm^{-1}



2) Set up the apparatus shown in the diagram with one of your strings. Record μ, measure and record the **length** (l) and work out the **tension** (T) using: $T = mg$ where m is the total mass of the masses in kg

A vibration transducer is connected to a signal generator that tells it the frequency of the wave you want. A vibrating plate on the transducer creates the wave.

3) Turn on the **signal generator** and vary the frequency until you find the **first harmonic** — i.e. a stationary wave that has a **node** at each end and a single **antinode**. This is the **frequency** of the first harmonic, f.
4) The **wavelength** of the wave, λ, is given by $\lambda = 2l$ for the **fundamental mode frequency**. The **frequency**, f, and the **velocity** of the wave, v, for the first harmonic are:

$$f = \frac{1}{2l}\sqrt{\frac{T}{\mu}} \qquad v = \sqrt{\frac{T}{\mu}}$$

The equation for v is true for any transverse wave on a string.

You can investigate how the **length**, **tension** or **mass per unit length** of the string affects the **resonant frequency** by:

1) Keeping the string **type** (μ) and the **tension** (T) in it the same and altering the **length** (l). Do this by moving the **vibration transducer** towards or away from the pulley. Find the **first harmonic** again, and record f against l.
2) Keeping the string **type** (μ) and **length** (l) the same and **adding** or **removing masses** to change the tension (T). Find the first harmonic again and record f against T.
3) Keeping the **length** (l) and **tension** (T) the same, but using **different string** samples to vary μ. Find the first harmonic and record f against μ.

You can do this experiment with a different harmonic — just remember to use the same one throughout the experiment. You won't be able to use the equation for f though — this is just for the fundamental mode of vibration.

You should find the following from your investigation:

1) The **longer** the string, the **lower** the resonant frequency — because the **half wavelength** at the resonant frequency is longer.
2) The **heavier** (i.e. the more mass per unit length) the string, the **lower** the resonant frequency — because waves travel more **slowly** down the string. For a given **length** a **lower** wave speed, v, makes a **lower** frequency, f.
3) The **looser** the string the **lower** the resonant frequency — because waves travel more **slowly** down a **loose** string.

Additional Note Space

Additional Note Space

PUZZLES QUESTIONS

1 Compare and contrast a stationary wave and a progressive wave.

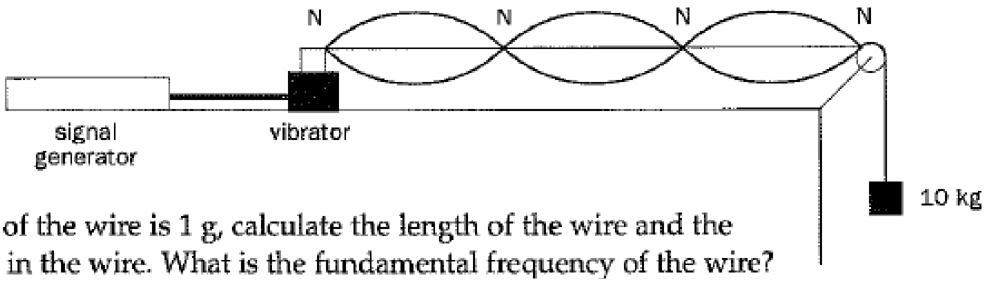
2 A string of length 80 cm has a mass of 1.3 g and is under tension of 200 N. What is the fundamental frequency? What is the frequency of the fourth harmonic?

3 A microwave transmitter emits waves of frequency 1×10^{10} Hz. It faces a metal plate, and a microwave detector moves between transmitter and plate. Calculate the wavelength of the microwaves. How far would the detector have to move from the first to the ninth consecutive node from the metal screen? Assume the speed of microwaves in air is 3×10^8 m s^{-1}.

4 Two loudspeakers are set up facing each other at a local fete, and a loud feedback signal of frequency 1000 Hz is transmitted through both speakers. If the speakers are 24 m apart, calculate the distance apart of successive nodes. Assume the speed of sound in air is 330 m s^{-1}.

5 A pipe, which is closed at one end, has a fundamental frequency of 256 Hz. What is the length of the pipe? What is the frequency of the first overtone? What would be the fundamental frequency and that of the first overtone be if the pipe was open at both ends? Assume the speed of sound in air is 330 m s^{-1}.

6 A vibrator is attached to one end of a horizontal wire, and the other end of the wire goes over a pulley to a mass of 10 kg. A note of frequency 512 Hz is produced when the following pattern is observed.



If the mass of 1 m of the wire is 1 g, calculate the length of the wire and the speed of the wave in the wire. What is the fundamental frequency of the wire?

ANSWERS

1 **Stationary waves**

All the particles between two nodes have the same phase.

Energy remains in the closed system.

The amplitude depends on position.

All the particles vibrate with the same frequency as the wave except the nodes which are at rest.

Progressive waves

All the particles in one wavelength have a different phase.

Energy is transferred with the wave.

The amplitude is the same for all particles through which the wave travels.

All the particles vibrate with the same frequency as the wave.

2 219.3 Hz; 877.2 Hz

3 3.0 cm; 12.0 cm

4 0.165 m

5 0.32 m; 768 Hz; 512 Hz; 1024 Hz

6 91.8 cm; 313 m s^{-1}; 171 Hz

SAMPLE QUESTION

Q1. Explain the differences between an undamped progressive transverse wave and a stationary transverse wave, in terms of (a) amplitude, (b) phase and (c) energy transfer.

(a) amplitude

progressive wave: **each point along wave - 1 mark**

has <u>same</u> amplitude for progressive wave - 1 mark

stationary wave

but varies for stationary wave - 1 mark

(b) phase

progressive wave **adjacent points vibrate with different phase - 1 mark**

stationary wave **stationary wave, between nodes all particles vibrate in phase [or there are only two phases] - 1 mark**

(c) energy transfer

progressive wave **energy is transferred through space – 1 mark**

stationary wave **energy is not transferred through space – 1 mark**

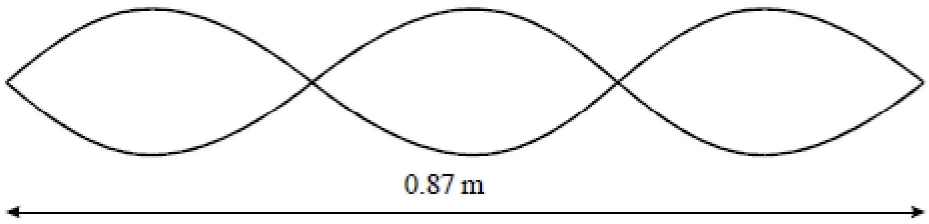
(Total 5 marks)

Reference: AQA Legacy A Examination Material

SELF ASSESSMENT

Q1. The drawing below shows a standing wave set up on a wire of length 0.87 m.

The wire is vibrated at a frequency of 120 Hz.



1.1 Calculate the speed of transverse waves along the wire.

[3 Marks]

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1.2 Show that the fundamental frequency of the wire is 40 Hz.

[2 Marks]

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Reference: AQA Legacy B Examination Material

Q2. The equation for the speed, v, of a transverse wave along a stretched string is:

$$v = \sqrt{\frac{T}{\mu}}$$

where T is the tension in the string and μ is the mass per unit length of the string.

2.1 State the quantities that would need to be measured in order to calculate a single value for the speed of the wave using the equation. Name a suitable measuring instrument for each quantity.

[4 Marks]

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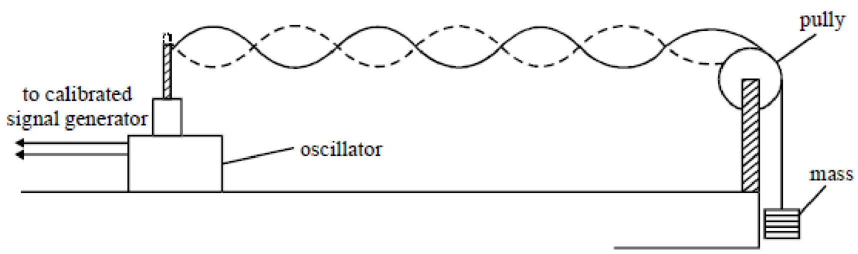
2.2 The apparatus shown in the diagram below could be used to measure a value for v.



Explain how this apparatus may be used to calculate an accurate value of the speed of the transverse wave along the string.

[4 Marks]

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2.3 With the signal generator in the diagram below set at 152 Hz, 10 loops fit the vibrating length of the string exactly.

The string is of length 2.0 m and the mass on the end of it is 0.72 kg.

The Earth's gravitation field strength, g = 9.8 N kg^{-1}

Calculate the mass of the string.

[5 Marks]

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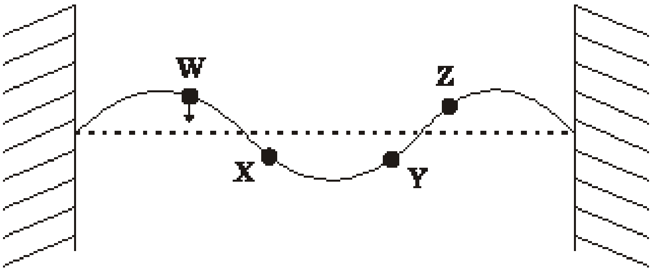
Mass = ...

Reference: AQA Legacy B Examination Material

3. The figure below shows the appearance of a stationary wave on a stretched string at one instant in time. In the position shown each part of the string has its maximum displacement. The arrow at **W** shows the direction in which the point **W** is about to move.



3.1 Mark clearly on the diagram the directions in which points **X**, **Y** and **Z** are about to move.

[2 Marks]

3.2 State the conditions necessary for a stationary wave to be produced on the string.

[2 Marks]

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3.3 In the figure above, the frequency of vibration is 120 Hz. Calculate the frequency of the fundamental vibration for this string.

[2 Marks]

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frequency of the fundamental vibration..

Reference: AQA Legacy B Examination Material

REVISION CHECKLIST

Specification reference	**Checklist questions**	
3.3.1.1	Can you explain oscillation of particles in terms of amplitude, frequency, wavelength, speed, phase, and phase difference?	☐
3.3.1.1	Can you explain that phase difference may be measured as angles (radians and degrees) or as fractions of a cycle?	☐
3.3.1.2	Can you explain the nature of longitudinal and transverse waves, including sound, electromagnetic waves, and waves on a string?	☐
3.3.1.2	Can you describe the direction of displacement of particles/fields relative to the direction of energy propagation?	☐
3.3.1.2	Can you recall that all electromagnetic waves travel at the same speed in a vacuum?	☐
3.3.1.2	Can you explain polarisation as evidence for the nature of transverse waves?	☐
3.3.1.2	Can you apply your knowledge of polarisers to explain the function of Polaroid material and the alignment of aerials for transmission and reception?	☐
3.3.1.3	Can you define stationary waves?	☐
3.3.1.3	Can you describe nodes and antinodes on strings?	☐
3.3.1.3	Can you use the formula $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$ for first harmonic?	☐
3.3.1.3	Can you describe the formation of stationary waves by two waves of the same frequency travelling in opposite directions?	☐
3.3.1.3	Can you draw a diagram to explain the formation of stationary waves?	☐

Specification reference	**Checklist questions**	
3.3.1.3	Can you describe stationary waves formed on a string and those produced with microwaves and sound waves?	☐
3.3.1.3	Can you describe stationary waves on strings in terms of harmonics?	☐
3.3.1.3	Have you carried out an investigation into how the frequency of stationary waves on a string varies with length, tension, and mass per unit length of the string?	☐

DATA

DATA – FUNDAMENTAL CONSTANTS AND VALUES

Quantity	Symbol	Value	Units
speed of light in vacuo	c	3.00×10^{8}	m s^{-1}
permeability of free space	μ_0	$4\pi \times 10^{-7}$	H m^{-1}
permittivity of free space	ε_0	8.85×10^{-12}	F m^{-1}
magnitude of the charge of electron	e	1.60×10^{-19}	C
the Planck constant	h	6.63×10^{-34}	J s
gravitational constant	G	6.67×10^{-11}	$\text{N m}^{2}\text{ kg}^{-2}$
the Avogadro constant	N_A	6.02×10^{23}	mol^{-1}
molar gas constant	R	8.31	$\text{J K}^{-1}\text{ mol}^{-1}$
the Boltzmann constant	k	1.38×10^{-23}	J K^{-1}
the Stefan constant	σ	5.67×10^{-8}	$\text{W m}^{-2}\text{ K}^{-4}$
the Wien constant	α	2.90×10^{-3}	m K
electron rest mass (equivalent to 5.5×10^{-4} u)	m_e	9.11×10^{-31}	kg
electron charge/mass ratio	$\frac{e}{m_e}$	1.76×10^{11}	C kg^{-1}
proton rest mass (equivalent to 1.00728 u)	m_p	$1.67(3) \times 10^{-27}$	kg
proton charge/mass ratio	$\frac{e}{m_p}$	9.58×10^{7}	C kg^{-1}
neutron rest mass (equivalent to 1.00867 u)	m_n	$1.67(5) \times 10^{-27}$	kg
gravitational field strength	g	9.81	N kg^{-1}
acceleration due to gravity	g	9.81	m s^{-2}
atomic mass unit (1u is equivalent to 931.5 MeV)	u	1.661×10^{-27}	kg

ALGEBRAIC EQUATION

quadratic equation $$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

ASTRONOMICAL DATA

Body	Mass/kg	Mean radius/m
Sun	1.99×10^{30}	6.96×10^{8}
Earth	5.97×10^{24}	6.37×10^{6}

GEOMETRICAL EQUATIONS

arc length	$= r\theta$
circumference of circle	$= 2\pi r$
area of circle	$= \pi r^2$
curved surface area of cylinder	$= 2\pi rh$
area of sphere	$= 4\pi r^2$
volume of sphere	$= \frac{4}{3}\pi r^3$

Particle Physics

Class	Name	Symbol	Rest energy/MeV
photon	photon	γ	0
lepton	neutrino	ν_e	0
		ν_μ	0
	electron	$e^\pm$	0.510999
	muon	$\mu^\pm$	105.659
mesons	π meson	$\pi^\pm$	139.576
		π^0	134.972
	K meson	$K^\pm$	493.821
		K^0	497.762
baryons	proton	p	938.257
	neutron	n	939.551

Properties of quarks

antiquarks have opposite signs

Type	Charge	Baryon number	Strangeness
u	$+\frac{2}{3}e$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}e$	$+\frac{1}{3}$	0
s	$-\frac{1}{3}e$	$+\frac{1}{3}$	-1

Properties of Leptons

		Lepton number
Particles:	$e^-, \nu_e; \mu^-, \nu_\mu$	$+1$
Antiparticles:	$e^+, \overline{\nu_e}, \mu^+, \overline{\nu_\mu}$	-1

Photons and energy levels

photon energy $E = hf = hc/\lambda$

photoelectricity $hf = \phi + E_{k\,(max)}$

energy levels $hf = E_1 - E_2$

de Broglie wavelength $\lambda = \frac{h}{p} = \frac{h}{mv}$

Waves

wave speed $c = f\lambda$ *period* $f = \frac{1}{T}$

first harmonic $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$

fringe spacing $w = \frac{\lambda D}{s}$ *diffraction grating* $d \sin\theta = n\lambda$

refractive index of a substance s, $n = \frac{c}{c_s}$

for two different substances of refractive indices n_1 *and* n_2,

law of refraction $n_1 \sin\theta_1 = n_2 \sin\theta_2$

critical angle $\sin\theta_c = \frac{n_2}{n_1}$ for $n_1 > n_2$

Mechanics

moments moment $= Fd$

velocity and acceleration $v = \frac{\Delta s}{\Delta t}$ $a = \frac{\Delta v}{\Delta t}$

equations of motion $v = u + at$ $s = \left(\frac{u+v}{2}\right)t$

$v^2 = u^2 + 2as$ $s = ut + \frac{at^2}{2}$

force $F = ma$

force $F = \frac{\Delta(mv)}{\Delta t}$

impulse $F\Delta t = \Delta(mv)$

work, energy and power $W = Fs\cos\theta$

$E_k = \frac{1}{2}mv^2$ $\Delta E_p = mg\Delta h$

$P = \frac{\Delta W}{\Delta t}$, $P = Fv$

$efficiency = \frac{useful\ output\ power}{input\ power}$

Materials

density $\rho = \frac{m}{V}$ *Hooke's law* $F = k\Delta L$

Young modulus $= \frac{tensile\ stress}{tensile\ strain}$ *tensile stress* $= \frac{F}{A}$ *tensile strain* $= \frac{\Delta L}{L}$

energy stored $E = \frac{1}{2}F\Delta L$

Electricity

current and pd $I = \frac{\Delta Q}{\Delta t}$ $V = \frac{W}{Q}$ $R = \frac{V}{I}$

resistivity $\rho = \frac{RA}{L}$

resistors in series $R_T = R_1 + R_2 + R_3 + ...$

resistors in parallel $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$

power $P = VI = I^2R = \frac{V^2}{R}$

emf $\varepsilon = \frac{E}{Q}$ $\varepsilon = I(R + r)$

Circular motion

magnitude of angular speed $\omega = \frac{v}{r}$

$\omega = 2\pi f$

centripetal acceleration $a = \frac{v^2}{r} = \omega^2 r$

centripetal force $F = \frac{mv^2}{r} = m\omega^2 r$

Simple harmonic motion

acceleration $a = -\omega^2 x$

displacement $x = A\cos(\omega t)$

speed $v = \pm\omega\sqrt{(A^2 - x^2)}$

maximum speed $v_{max} = \omega A$

maximum acceleration $a_{max} = \omega^2 A$

for a mass-spring system $T = 2\pi\sqrt{\frac{m}{k}}$

for a simple pendulum $T = 2\pi\sqrt{\frac{l}{g}}$

Thermal physics

energy to change temperature $Q = mc\Delta\theta$

energy to change state $Q = m\,l$

gas law $pV = nRT$

$pV = NkT$

kinetic theory model $pV = \frac{1}{3}N\,m\,(c_{rms})^2$

kinetic energy of gas molecule $\frac{1}{2}m\,(c_{rms})^2 = \frac{3}{2}kT = \frac{3RT}{2N_A}$

Gravitational fields

force between two masses $F = \frac{Gm_1m_2}{r^2}$

gravitational field strength $g = \frac{F}{m}$

magnitude of gravitational field strength in a radial field $g = \frac{GM}{r^2}$

work done $\Delta W = m\Delta V$

gravitational potential $V = -\frac{GM}{r}$

$g = -\frac{\Delta V}{\Delta r}$

Electric fields and capacitors

force between two point charges $F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$

force on a charge $F = EQ$

field strength for a uniform field $E = \frac{V}{d}$

work done $\Delta W = Q\Delta V$

field strength for a radial field $E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$

electric potential $V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$

$E = \frac{\Delta V}{\Delta r}$

capacitance $C = \frac{Q}{V}$

$C = \frac{A\varepsilon_0\varepsilon_r}{d}$

capacitor energy stored $E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$

capacitor charging $Q = Q_0(1 - e^{-t/RC})$

decay of charge $Q = Q_0 e^{-t/RC}$

time constant RC

Magnetic fields

force on a current $F = BIl$

force on a moving charge $F = BQv$

magnetic flux $\Phi = BA$

magnetic flux linkage $N\Phi = BAN\cos\theta$

magnitude of induced emf $\varepsilon = N\frac{\Delta\Phi}{\Delta t}$

$N\Phi = BAN\cos\theta$

emf induced in a rotating coil $\varepsilon = BAN\omega\sin\omega t$

alternating current $I_{rms} = \frac{I_0}{\sqrt{2}}$ $V_{rms} = \frac{V_0}{\sqrt{2}}$

transformer equations $\frac{N_s}{N_p} = \frac{V_s}{V_p}$

$efficiency = \frac{I_s V_s}{I_p V_p}$

Nuclear physics

the inverse square law for γ radiation $I = \frac{k}{x^2}$

radioactive decay $\frac{\Delta N}{\Delta t} = -\lambda N,\ N = N_0 e^{-\lambda t}$

activity $A = \lambda N$

half-life $T_{½} = \frac{\ln 2}{\lambda}$

nuclear radius $R = R_0 A^{1/3}$

energy-mass equation $E = mc^2$

OPTIONS

Astrophysics

1 astronomical unit = 1.50×10^{11} m

1 light year = 9.46×10^{15} m

1 parsec = 206265 AU = 3.08×10^{16} m

= 3.26 light year

Hubble constant, H $= 65$ km s^{-1} Mpc^{-1}

$M = \frac{\text{angle subtended by image at eye}}{\text{angle subtended by object at unaided eye}}$

in normal adjustment $M = \frac{f_o}{f_e}$

Rayleigh criterion $\theta \approx \frac{\lambda}{D}$

magnitude equation $m - M = 5\log\frac{d}{10}$

Wien's law $\lambda_{max} T = 2.9 \times 10^{-3}$ m K

Stefan's law $P = \sigma A T^4$

Schwarzschild radius $R_s \approx \frac{2GM}{c^2}$

Doppler shift for v << c $\frac{\Delta f}{f} = -\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$

red shift $z = -\frac{v}{c}$

Hubble's law $v = Hd$

Medical physics

lens equations $P = \frac{1}{f}$

$m = \frac{v}{u}$

$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

threshold of hearing $I_0 = 1.0 \times 10^{-12}$ W m^{-2}

intensity level $\text{intensity level} = 10\log\frac{I}{I_0}$

absorption $I = I_0 e^{-\mu x}$

$\mu_m = \frac{\mu}{\rho}$

ultrasound imaging $Z = \rho c$

$\frac{I_r}{I_i} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$

half-lives $\frac{1}{T_E} = \frac{1}{T_B} + \frac{1}{T_P}$

Engineering physics

moment of inertia $I = \Sigma mr^2$

angular kinetic energy $E_k = \frac{1}{2}I\omega^2$

equations of angular motion

$\omega_2 = \omega_1 + \alpha t$

$\omega_2{}^2 = \omega_1{}^2 + 2\alpha\theta$

$\theta = \omega_1 t + \frac{\alpha t^2}{2}$

$\theta = \frac{(\omega_1 + \omega_2)\,t}{2}$

torque $T = I\,\alpha$

$T = F\,r$

angular momentum $\text{angular momentum} = I\omega$

angular impulse $T\Delta t = \Delta(I\omega)$

work done $W = T\theta$

power $P = T\omega$

thermodynamics $Q = \Delta U + W$

$W = p\Delta V$

adiabatic change $pV^\gamma = \text{constant}$

isothermal change $pV = \text{constant}$

heat engines

$\text{efficiency} = \frac{W}{Q_H} = \frac{Q_H - Q_C}{Q_H}$

$\text{maximum theoretical efficiency} = \frac{T_H - T_C}{T_H}$

work done per cycle = area of loop

input power = calorific value × fuel flow rate

$\text{indicated power} = (\text{area of } p - V \text{ loop}) \times (\text{number of cycles per second}) \times (\text{number of cylinders})$

output or brake power $P = T\omega$

friction power = indicated power – brake power

heat pumps and refrigerators

refrigerator: $COP_{ref} = \frac{Q_C}{W} = \frac{Q_C}{Q_H - Q_C}$

heat pump: $COP_{hp} = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_C}$

Turning points in physics

electrons in fields $F = \frac{eV}{d}$

$F = Bev$

$r = \frac{mv}{Be}$

$\frac{1}{2} mv^2 = eV$

Millikan's experiment $\frac{QV}{d} = mg$

$F = 6\pi\eta rv$

Maxwell's formula $c = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$

$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}}$

special relativity $t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$

$l = l_0\sqrt{1 - \frac{v^2}{c^2}}$

$E = mc^2 = \frac{m_0c^2}{\sqrt{1 - \frac{v^2}{c^2}}}$

Electronics

resonant frequency $f_0 = \frac{1}{2\pi\sqrt{LC}}$

Q-factor $Q = \frac{f_0}{f_B}$

operational amplifiers: open loop $V_{out} = A_{OL}(V_+ - V_-)$

inverting amplifier $\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$

non-inverting amplifier $\frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_1}$

summing amplifier $V_{out} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \cdots\right)$

difference amplifier $V_{out} = (V_+ - V_-)\frac{R_f}{R_1}$

Bandwidth requirement:

for AM $\text{bandwidth} = 2f_M$

for FM $\text{bandwidth} = 2(\Delta f + f_M)$

Acknowledgements

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All relevant information has been credited in the document.

This document has been produced for educational purposes only.

This document has been produced for the AQA A Level Physics Specification.

Student Voice

If you when using this document, you believe there is an improvement to made, please state this in the space below….

Only constructive and reasoned feedback will be considered.