



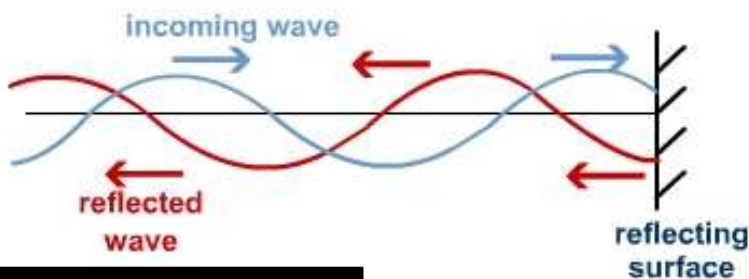
Volume
One

**ST MARY'S SCIENCE
DEPARTMENT:
PHYSICS**

**A LEVEL PHYSICS YEAR 1
STUDENT PREPARATORY READING BOOK
WAVES**

**3.3.1: PROGRESSIVE AND STATIONARY
WAVES**

NAME	
PHYSICS CLASS	
MODULE TEACHER	
ALPS GRADE	



**A-LEVEL PHYSICS
TOPIC 3
READING BOOK**

**THIS MUST
BE BROUGHT
TO ALL
PHYSICS
LESSONS.**



Contents

3.3.1.1 Progressive Waves

3.3.1.2 Longitudinal and Transverse Waves

3.3.1.3 Principle of Superposition of Waves and Formation of Stationary Waves

OVERVIEW

This booklet provides the basic information and knowledge needed to access the A Level Physics course.

Over the course of the year, you will be directed to read this information in both lessons and in your spare time.

Ensure all information in this booklet is understood and remembered before examinations.

IMPORTANT NOTE

This book, along with the student workbook and independent work book, 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 book may also be used as a revision resource for intervention, internal assessments and external assessments.

Please keep this in your student file.



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 $20\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$, 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



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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.	

Student Checklist

Have I.....	Yes or No?
Read through the notes of this section?	
Highlighted/underlined the key concepts of this section?	
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Brought the notes to be used in lesson?	



Waves

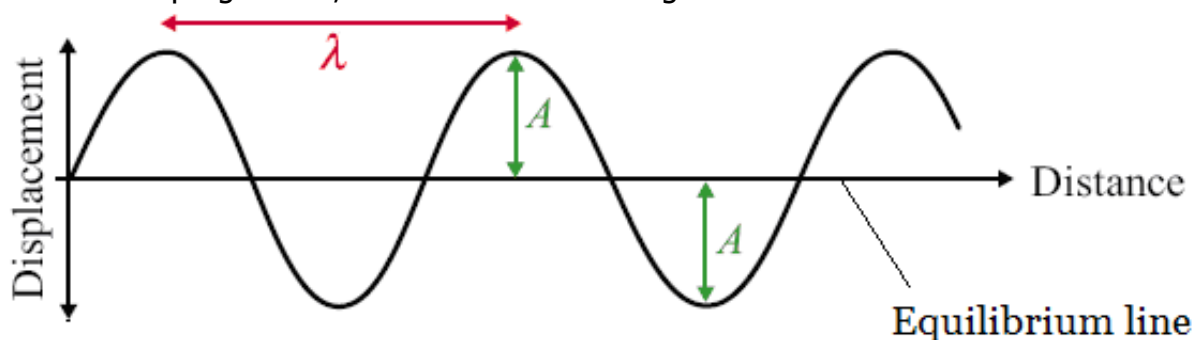
Prior Knowledge Link

This is a topic found in a previous GCSE module - **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.



Here are some basic measurements and characteristics of 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 it takes for one complete wave to happen. 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

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

Exam Tip

It is a common examination question to ask you to define the frequency of a wave...

number of (complete) waves (passing a point) in 1 second (1 mark)

number of waves / time (for the waves to pass a point) (1 mark)

(complete number of) oscillations \ vibrations per second (1 mark)



Wave Speed, c

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

Prior Knowledge Link

This is a topic found in a previous GCSE module - **Waves**

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.

Exam Tip

It is a common examination question to calculate a property with the above wave speed equation.

However, many examination questions do not give you the value of the wavelength – only a measurement along the wave.

You must work out wavelength first and then calculate either speed or frequency.

Study Tip

This equation is found in the data booklet.

Learn the key terms of each part of the equation.

Learn the SI units of each term in the equation.

Study Tip

You are not measuring how fast a physical point moves, you are measuring how fast a point on the wave pattern moves.



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.

Exam Tip

You can convert between radians and degrees for an angular measurement

$$360^\circ = 2\pi \text{ radians}$$

$$180^\circ = \pi \text{ radians}$$

$$90^\circ = \pi/2 \text{ radians}$$

$$1^\circ = 0.017 \text{ radians}$$

'In phase' occurs at whole multiples of the wavelength ($n\lambda$).

If two points are **completely in phase**, the two points are moving at the same velocity, meaning speed and direction

Exam Tip

Technically two waves are in phase if the waves are vibrating in the same direction, however you to be completely in phase, the wave must be vibrating in the same direction and the same speed.

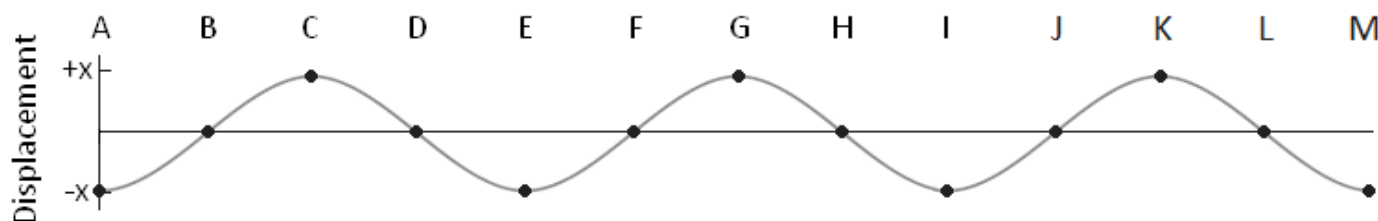
Two points half a wavelength apart (such as I and K) we would see that they are always moving in opposite directions. We say that they are **completely out of phase or in anti-phase**.

'In anti-phase' occurs at whole plus half multiples ($n + \frac{1}{2}\lambda$) of a wavelength. If two points are in anti-phase, the two points are moving with the same speed but travel in opposite directions.

If two points are out of phase, they are simply moving 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)	$\frac{1}{2}\pi$	1π	$1\frac{1}{2}\pi$	2π	$2\frac{1}{2}\pi$	3π	$3\frac{1}{2}\pi$	4π	$4\frac{1}{2}\pi$	5π	$5\frac{1}{2}\pi$	6π
Phase Difference from A (degrees)	90	180	270	360	450	540	630	720	810	900	990	1080

Exam Tip

It is a common question to ask for you to identify the phase difference between two points on a wave.

Remember one whole wavelength = 2π radians or 360 degrees then work from there.

You can an answer for phase difference in radians or degrees, however remember that phase difference is always an angular measurement.

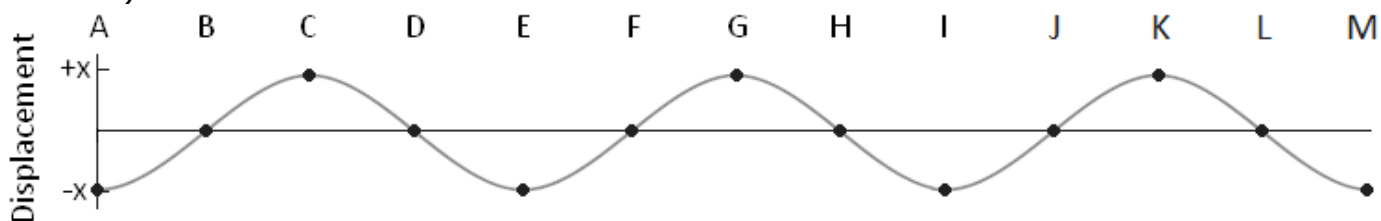


Path Difference

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	$\frac{1}{4}\lambda$	$\frac{1}{2}\lambda$	$\frac{3}{4}\lambda$	1λ	$1\frac{1}{4}\lambda$	$1\frac{1}{2}\lambda$	$1\frac{3}{4}\lambda$	2λ	$2\frac{1}{4}\lambda$	$2\frac{1}{2}\lambda$	$2\frac{3}{4}\lambda$	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).

Exam Tip

Do not confuse path difference and phase difference in examination questions.

A path difference should be given in metres or in a multiple of the wavelength.

A phase difference should be given in degrees or radians (in a multiple of π).

Study Tip

Displacement is a vector, so it has a direction and a magnitude.

If a point has move below its undisturbed position, it will have a negative displacement.

Study Tip

Waves with different frequencies and wavelengths can have very different properties.

Study Tip

Amplitude can be measured in either at a crest or a trough.

It does not have a direction, only a magnitude.

Study Tip

Phase difference is the difference between two identical points (e.g. the point where the displacement is at a maximum) on two waves.



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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.	

Student Checklist

Have I.....	Yes or No?
Read through the notes of this section?	
Highlighted/underlined the key concepts of this section?	
Made my own notes based on the notes of this section?	
Brought the notes to be used in lesson?	



Waves

Prior Knowledge Link

This is a topic found in a previous GCSE module - **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

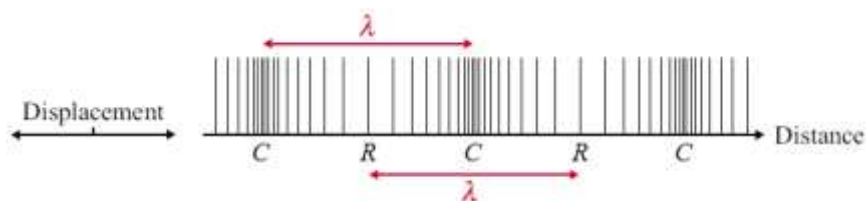
Longitudinal Waves

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 rarefaction.

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



Example:

Sound waves, P- seismic waves, Water waves

Study Tip

For a longitudinal wave, the wavelength is the distance between compressions or rarefactions instead of between crests or troughs in transverse waves.

Examination Tip

It is a common question to explain what type of wave sound is and how the particles move.

longitudinal

(they) oscillate along direction of energy transfer (1 mark)



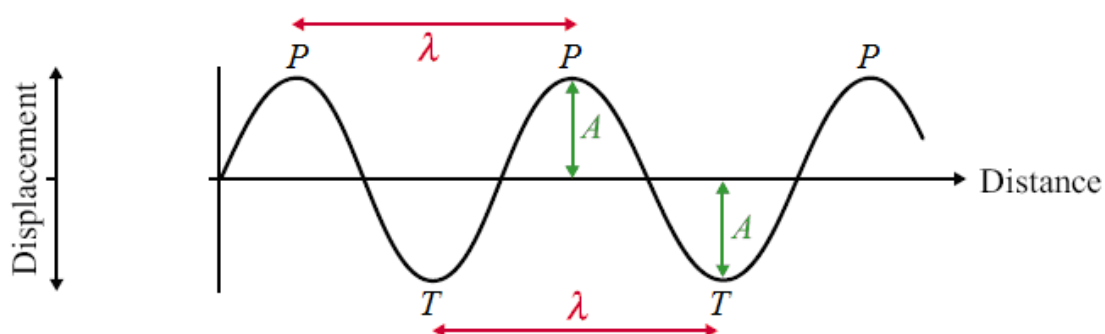
Transverse Waves

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.



Examples: 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.

Exam Tip

It is a common examination question to define longitudinal and transverse waves...

You must refer to the relative direction of oscillations to that of the direction of propagation/transfer of energy (1 mark).

For transverse waves oscillations are at right angles to direction of propagation while in longitudinal waves they are in the same direction (1 mark).

Study Tip

Transverse waves drawn on a displacement-time graph or displacement-distance graph look like they only vibrate in one direction (up and down). But unpolarised transverse waves actually vibrate in all directions on the plane perpendicular to the direction of motion.



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.

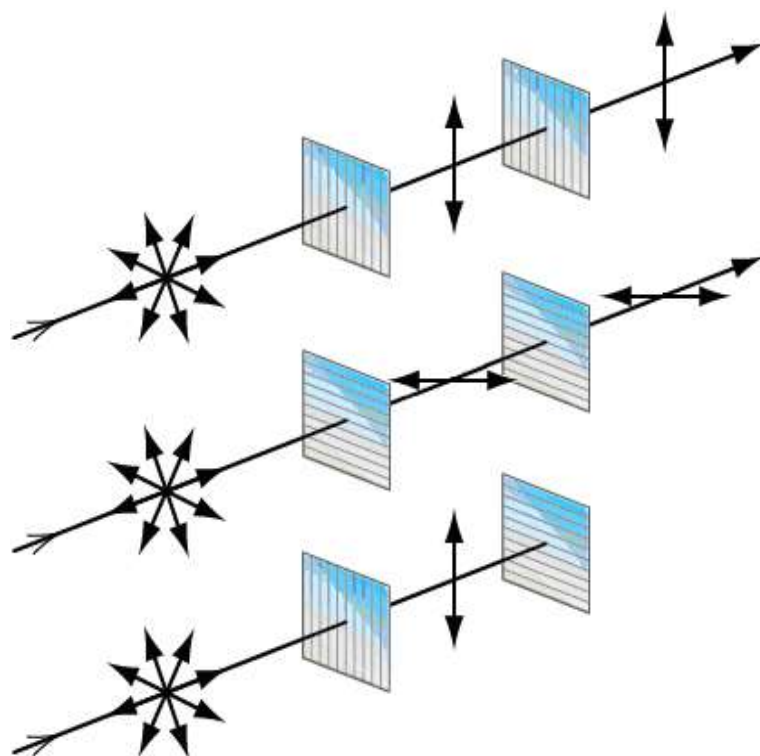
In the middle diagram the light becomes polarized in the horizontal plane.

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.

Exam Tip

It is a common examination question to ask what conclusion you can make about a wave if it polarises.

It is a transverse wave (1 mark)



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.

Examination Tip

It is a common question to consider what happens when a TV receiver is rotated 90° and how this affects the signal strength.

The signal decreases/becomes zero (1 mark).

The waves transmitted are polarised (1 mark).

The strength is zero at 90° to the transmitting aerial (1 mark).

Examination Tip

Remember passing a signal through a polariser will always reduce the signal strength.

Study Tip

Make sure you understand why the graph has peaks and troughs where it does.

At 90° and 270° , the transmission axis of the second filter will be perpendicular to the first filter, so no light will be able to get through.

At 180° and 360° , the transmission axes of both filters will be aligned, so all of the light passing through the first filter will be able to pass through the second.

Examination Tip

It is a common question to describe the difference between longitudinal waves and transverse waves.

Transverse – displacement/oscillations/vibrations at right angles/(perpendicular) to direction of energy transfer (1 mark)

Longitudinal – displacement/oscillations/vibrations along/ (parallel to) direction of energy transfer (1 mark)



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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. $f = 1/2l \times \sqrt{T/\mu}$ 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.	

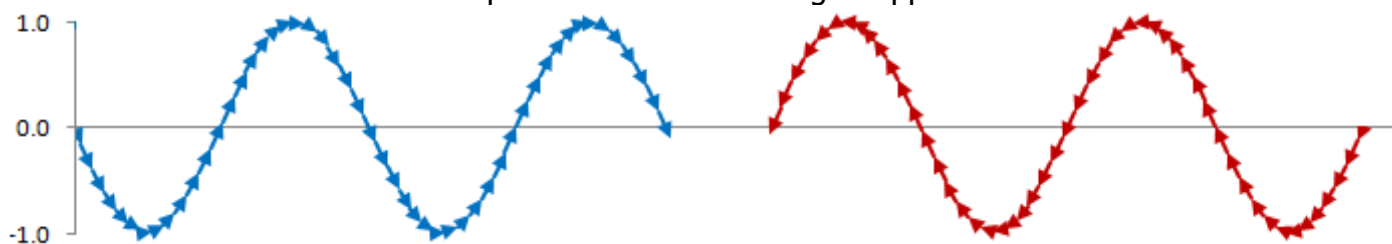
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Superposition

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.

Study Tip

Remember the vector sum is the sum of the two displacements looking at direction and magnitude.

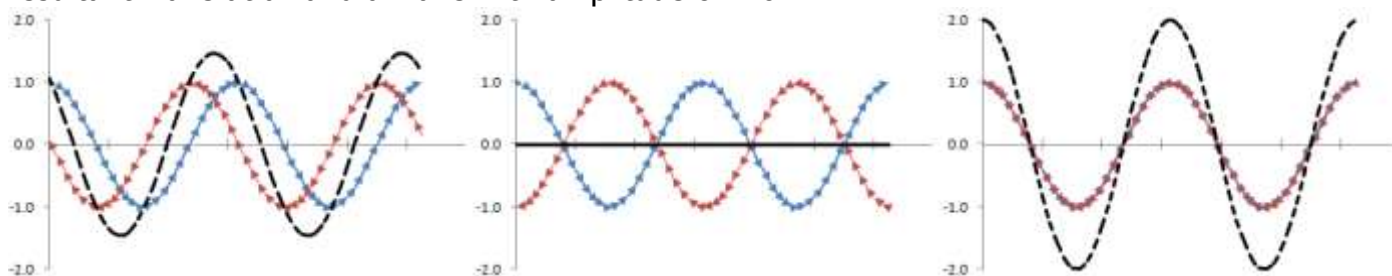
If we add these waves together the resultant depends on where the peaks of the waves are compared to each other.

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.
WAVES COMPLETELY IN PHASE LEAD TO CONSTRUCTIVE INTERFERENCE.

If the waves undergoing superposition are vibrating in opposite direction, they are said to be **OUT OF PHASE OR IN ANTI-PHASE**.

WAVES COMPLETELY IN ANTI-PHASE LEADS TO DESTRUCTIVE INTERFERENCE

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.

This called interference.

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

They superimpose to give no resultant wave at all.

This is destructive interference and a minimum.

These two waves are completely in phase with each other.

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

This is positive interference and a maximum.

**Exam Tip**

It is a common examination question to ask how the interference pattern changes throughout the superposition of two waves....

Initially the path difference is zero/the two waves are in phase when they meet/the (resultant) displacement is a maximum (1 mark)

As the waves move against relative to each other, the path difference increases and the two waves are no longer in phase, so the displacement and interference pattern decrease (1 mark)

When the path difference is one half wavelength, the two are in anti-phase and the pattern is at a minimum. (1 mark)

As the path difference continues to increase, the two waves become more in phase and the resultant interference pattern gets stronger again. (1 mark).

Study Tip

A trough and a crest will not cancel each other out completely unless they have the same magnitude.

Study Tip

Waves do not need to have the same amplitude to be in phase, they do need to have the same frequency and wavelength.

Study Tip

If two points are exactly out of phase, they are an odd integer of half cycles apart (e.g. 1 or 3)

Study Tip

Compare the position of two equivalent points on two waves to find the phase difference between them.



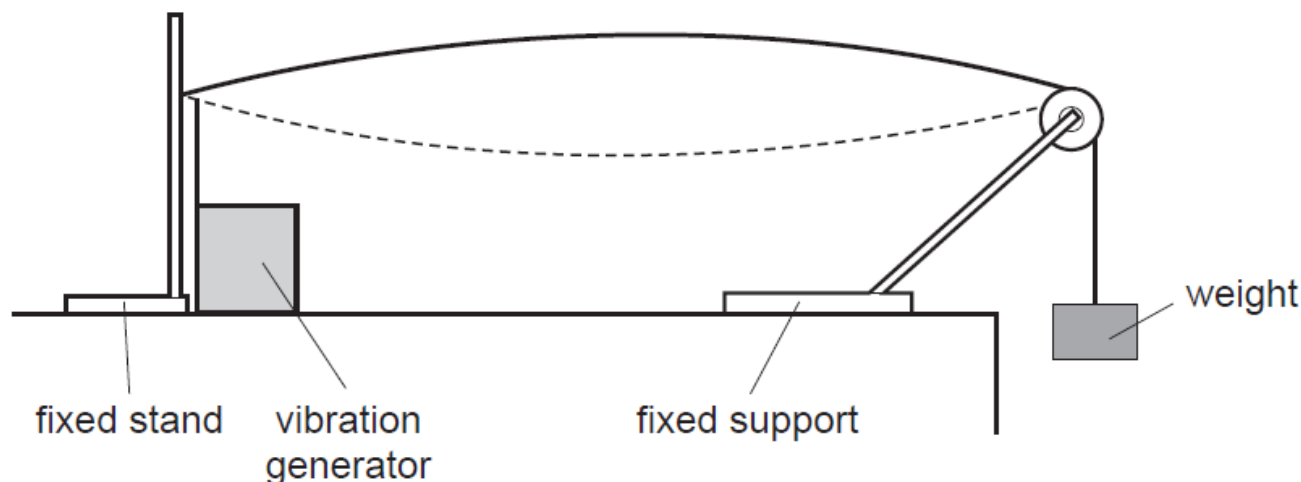
Stationary/Standing Waves

Prior Knowledge Link

This is a topic found in a previous GCSE module - **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.

In this section, 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.

Exam Tip

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 are 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).

Exam Tip

It is a common examination question to define what a stationary wave is and what a progressive wave is...

A stationary wave is a wave which contains energy (1 mark)

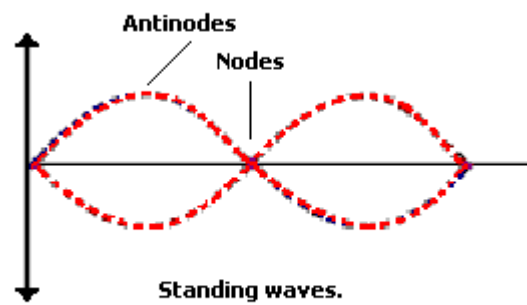
In a stationary wave all oscillating particles have constant amplitude (1 mark)

A progressive wave is a wave that transfers energy from one point to another (1 mark)

Without transferring material/ (causing permanent displacement of the medium) (1 mark)



Here is an example of a standing wave.



Study Tip

At the n th harmonic, $n/2$ wavelengths will fit on the string.

There are many examples of standing waves in the real world, the most common of which is the microwave set up in a microwave oven.

There are two points of major interest on a standing wave.

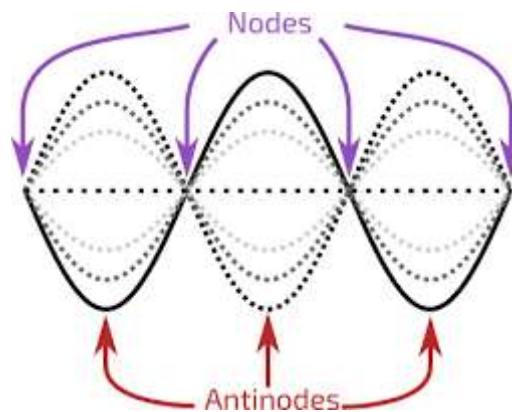
Nodes: Positions on a standing wave which do not vibrate. The waves combine to give zero displacement. This happens when the waves are completely out of phase.

Antinodes: Positions on a standing wave which show maximum vibration. Positions on a standing wave where there is a maximum displacement. This happens when the waves are completely in phase.

In reality, a standing wave is a combination of many waves.

Study Tip

If you are asked to sketch a standing wave, make sure you make it clear where the nodes and anti-nodes are.



Study Tip

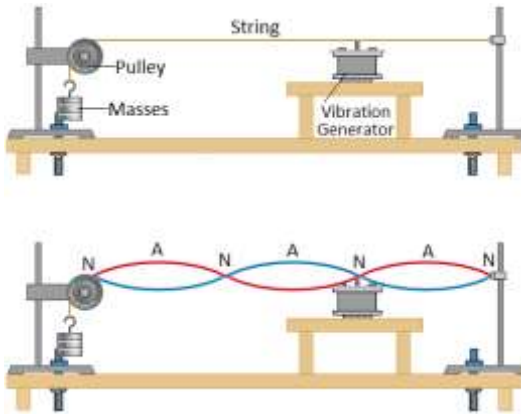
At the n th harmonic, the number of anti-nodes is equal to n , and the number of nodes is equal to $n + 1$.

Exam Tip

It is a common examination question to ask why you get melting/bright light/loud sound at the anti-node...

Energy/amplitude is a maximum (1 mark)

The food melts/there is a bright light/there is a loud sound at the antinode (1 mark)



A progressive wave is one where the wave moves from one point to another. 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.

There is a required practical where you can vary the frequencies of the standing wave produced by either changing the length of the wire, the mass per unit length of the wire or the tension the wire is placed under.

The equation which links these values is...

Study Tip

This equation is found in the data booklet.

$$\text{Frequency of Standing Wave} = \frac{1}{2 \times \text{Length of Wire}} \times \sqrt{\text{Tension of Wire} / \text{Mass per Unit Length of Wire}}$$

Remember if you are varying one value to observe the change in frequencies, the other variables must be controlled.

Exam Tip

It is a common examination question to use the above equation (it is given in the equation booklet) to derive a value of the wire e.g. length of the wire or the tension of the wire).

Remember Mass per Unit Length = Mass / Length

Note; Density = Mass/Volume

$$= (\text{Volume} \times \text{Density}) / \text{Length}$$

Exam Tip

It is a common examination question to ask how this apparatus can form a standing wave on a string and what this means.

A wave and its reflection/waves travelling in opposite directions meet/interact/overlap/cross/pass through etc (1 mark)

Same wavelength (or frequency) (1 mark)

This forms nodes – point of minimum or no disturbance (1 mark)

This forms antinode – is a point of maximum amplitude (1 mark)

The nodes form when two waves (always) cancel/ destructive interference / 180° phase difference / in antiphase [out of phase is not enough] (of the two waves at the node)[not peak meets trough] (1 mark)

The antinode occurs with – reinforcement / constructive interference occurs / (displacements) in phase (1 mark)

Mention of superposition [not superimpose] of the two waves (1 mark)

In this wave, energy is not transferred (along in a standing wave) (1 mark)

Statistically, this is the most common question on A-Level Physics examinations.



Here is a comparison between standing waves and progressive wave.

You must be able to compare the properties of each.

Do not confuse the different types of waves in examination questions.

	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

Exam Tip

It is a common examination question to ask what the motion of a particle in a progressive wave is over a complete cycle.

The particle oscillates from equilibrium to maximum positive displacement, back to equilibrium, then to max negative displacement and back to equilibrium /starting position /rest position (1 mark)

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

2 nodes and 1 antinode

Second Harmonic

3 nodes and 2 antinodes

Third Harmonic

4 nodes and 3 antinodes

Fourth Harmonic

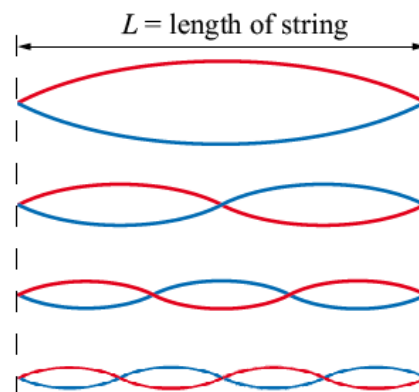
5 nodes and 4 antinodes

$$f = f_0 \quad \lambda = 2L$$

$$f = 2f_0 \quad \lambda = L$$

$$f = 3f_0 \quad \lambda = \frac{2}{3}L$$

$$f = 4f_0 \quad \lambda = \frac{1}{2}L$$



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.

Examination Tip: If asked to calculate a harmonic, calculate the fundamental (or first harmonic) using the equation given in the equation booklet, then multiply this value by the number of the harmonic.



Study Tip

A straight-line graph of distance against number of nodes can be plotted for this experiment.

The gradient of the graph gives $\lambda/2$, which you can use to work out the wave speed.

Study Tip

Remember that $c = f\lambda$

Study Tip

If you are given the first harmonic frequency, you can work out the resonant frequency, f , at the n th harmonic with

$$f = n \times \text{first harmonic frequency}$$



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REQUIRED PRACTIAL 1

Standing Wave on a String

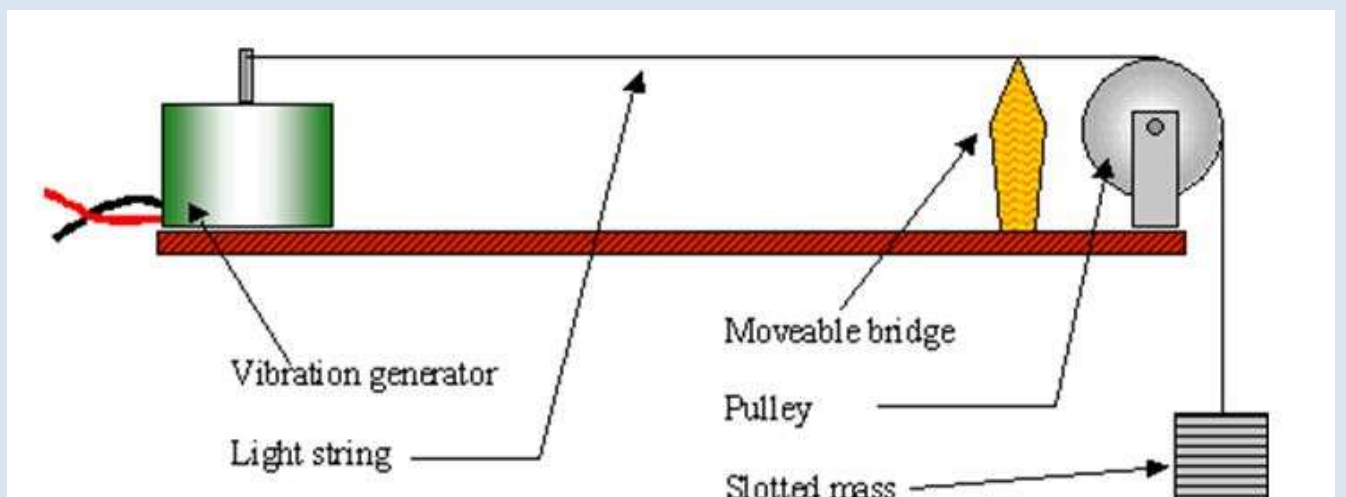
You can investigate how changing the mass, length and tension of a string changes its resonant frequency.

1. Start by measuring the mass and length of strings of different types using a mass balance and a ruler. Then find the mass per unit length of each string.
2. Set up the apparatus shown in the diagram with one string.
3. Record the mass per unit length and the length between the vibrator and pulley, and work out the tension on the string where $T = mg$.
4. Turn on the signal generator and vary the frequency at which the vibrator vibrates.
5. Find the first harmonic, where the stationary wave has a node at each end and a signal anti-node. The frequency of the signal generator indicates the frequency of the first harmonic.

You can then investigate how each factor affects the frequency of the first harmonic on a string.

Keep all the other factors constant and make one of the following changes

1. Move the vibrator towards or away from the pulley to change the length of the vibrating string.
2. Add masses to change the tension of the string.
3. Use a range of string samples of varying masses to change the mass per unit length.



Study Tip

This is only for the first harmonic, it will not work for other resonant frequencies.

Study Tip

You will never to be expected to derive the resonant frequency equation.



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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?	<input type="checkbox"/>
3.3.1.1	Can you explain that phase difference may be measured as angles (radians and degrees) or as fractions of a cycle?	<input type="checkbox"/>
3.3.1.2	Can you explain the nature of longitudinal and transverse waves, including sound, electromagnetic waves, and waves on a string?	<input type="checkbox"/>
3.3.1.2	Can you describe the direction of displacement of particles/fields relative to the direction of energy propagation?	<input type="checkbox"/>
3.3.1.2	Can you recall that all electromagnetic waves travel at the same speed in a vacuum?	<input type="checkbox"/>
3.3.1.2	Can you explain polarisation as evidence for the nature of transverse waves?	<input type="checkbox"/>
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?	<input type="checkbox"/>
3.3.1.3	Can you define stationary waves?	<input type="checkbox"/>
3.3.1.3	Can you describe nodes and antinodes on strings?	<input type="checkbox"/>
3.3.1.3	Can you use the formula $f = \frac{1}{2l} \sqrt{\frac{T}{\mu}}$ for first harmonic?	<input type="checkbox"/>
3.3.1.3	Can you describe the formation of stationary waves by two waves of the same frequency travelling in opposite directions?	<input type="checkbox"/>
3.3.1.3	Can you draw a diagram to explain the formation of stationary waves?	<input type="checkbox"/>



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?	<input type="checkbox"/>
3.3.1.3	Can you describe stationary waves on strings in terms of harmonics?	<input type="checkbox"/>
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?	<input type="checkbox"/>



DATASHEET

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 = πr^2

curved surface area of cylinder = $2\pi r h$

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	μ^\pm	105.659
mesons	π meson	π^\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:	$e^+, \bar{\nu}_e, \mu^+, \bar{\nu}_\mu$	-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 $W = F s \cos \theta$

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

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

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

Materials

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

Young modulus = $\frac{\text{tensile stress}}{\text{tensile strain}}$ 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 $R_T = R_1 + R_2 + R_3 + \dots$

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

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 $Q = ml$

gas law $pV = nRT$
 $pV = NkT$

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

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

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 $F = \frac{1}{4\pi\epsilon_0} \frac{Q_1Q_2}{r^2}$

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 $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$

electric potential $V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$

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

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

$$C = \frac{A\epsilon_0\epsilon_r}{d}$$

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

<i>force on a current</i>	$F = BIl$
<i>force on a moving charge</i>	$F = BQv$
<i>magnetic flux</i>	$\Phi = BA$
<i>magnetic flux linkage</i>	$N\Phi = BAN \cos \theta$
<i>magnitude of induced emf</i>	$\varepsilon = N \frac{\Delta \Phi}{\Delta t}$
	$N\Phi = BAN \cos \theta$
<i>emf induced in a rotating coil</i>	$\varepsilon = BAN\omega \sin \omega t$
<i>alternating current</i>	$I_{\text{rms}} = \frac{I_0}{\sqrt{2}} \quad V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$
<i>transformer equations</i>	$\frac{N_s}{N_p} = \frac{V_s}{V_p}$
	$\text{efficiency} = \frac{I_s V_s}{I_p V_p}$

Nuclear physics

<i>the inverse square law for γ radiation</i>	$I = \frac{k}{x^2}$
<i>radioactive decay</i>	$\frac{\Delta N}{\Delta t} = -\lambda N, N = N_0 e^{-\lambda t}$
<i>activity</i>	$A = \lambda N$
<i>half-life</i>	$T_{1/2} = \frac{\ln 2}{\lambda}$
<i>nuclear radius</i>	$R = R_0 A^{1/3}$
<i>energy-mass equation</i>	$E = mc^2$

OPTIONS

Astrophysics

1 astronomical unit	$= 1.50 \times 10^{11} \text{ m}$
1 light year	$= 9.46 \times 10^{15} \text{ m}$
1 parsec	$= 206265 \text{ AU} = 3.08 \times 10^{16} \text{ m}$ $= 3.26 \text{ light year}$

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

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

<i>in normal adjustment</i>	$M = \frac{f_o}{f_e}$
<i>Rayleigh criterion</i>	$\theta \approx \frac{\lambda}{D}$
<i>magnitude equation</i>	$m - M = 5 \log \frac{d}{10}$
<i>Wien's law</i>	$\lambda_{\text{max}} T = 2.9 \times 10^{-3} \text{ m K}$
<i>Stefan's law</i>	$P = \sigma AT^4$
<i>Schwarzschild radius</i>	$R_s \approx \frac{2GM}{c^2}$
<i>Doppler shift for $v \ll c$</i>	$\frac{\Delta f}{f} = -\frac{\Delta \lambda}{\lambda} = \frac{v}{c}$
<i>red shift</i>	$z = -\frac{v}{c}$
<i>Hubble's law</i>	$v = Hd$

Medical physics

<i>lens equations</i>	$P = \frac{1}{f}$ $m = \frac{v}{u}$ $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$
<i>threshold of hearing</i>	$I_0 = 1.0 \times 10^{-12} \text{ W m}^{-2}$
<i>intensity level</i>	$\text{intensity level} = 10 \log \frac{I}{I_0}$
<i>absorption</i>	$I = I_0 e^{-\mu x}$ $\mu_m = \frac{\mu}{\rho}$
<i>ultrasound imaging</i>	$Z = \rho c$ $\frac{I_r}{I_i} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right)^2$
<i>half-lives</i>	$\frac{1}{T_B} = \frac{1}{T_1} + \frac{1}{T_2}$



Engineering physics

<i>moment of inertia</i>	$I = \Sigma mr^2$
<i>angular kinetic energy</i>	$E_k = \frac{1}{2} I \omega^2$
<i>equations of angular motion</i>	$\omega_2 = \omega_1 + \alpha t$ $\omega_2^2 = \omega_1^2 + 2\alpha\theta$ $\theta = \omega_1 t + \frac{\alpha t^2}{2}$ $\theta = \frac{(\omega_1 + \omega_2) t}{2}$
<i>torque</i>	$T = I \alpha$ $T = F r$
<i>angular momentum</i>	<i>angular momentum</i> = $I \omega$
<i>angular impulse</i>	$T \Delta t = \Delta(I \omega)$
<i>work done</i>	$W = T \theta$
<i>power</i>	$P = T \omega$
<i>thermodynamics</i>	$Q = \Delta U + W$ $W = p \Delta V$
<i>adiabatic change</i>	$pV^\gamma = \text{constant}$
<i>isothermal change</i>	$pV = \text{constant}$
<i>heat engines</i>	
	$\text{efficiency} = \frac{W}{Q_H} = \frac{Q_H - Q_C}{Q_H}$
	$\text{maximum theoretical efficiency} = \frac{T_H - T_C}{T_H}$
<i>work done per cycle</i>	= <i>area of loop</i>
<i>input power</i>	= <i>calorific value</i> \times <i>fuel flow rate</i>
	<i>indicated power</i> = (<i>area of p - V loop</i>) \times (<i>number of cycles per second</i>) \times (<i>number of cylinders</i>)
<i>output or brake power</i>	$P = T \omega$
<i>friction power</i>	= <i>indicated power</i> - <i>brake power</i>
<i>heat pumps and refrigerators</i>	
<i>refrigerator:</i>	$COP_{\text{ref}} = \frac{Q_C}{W} = \frac{Q_C}{Q_H - Q_C}$
<i>heat pump:</i>	$COP_{\text{hp}} = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_C}$

Turning points in physics

<i>electrons in fields</i>	$F = \frac{eV}{d}$ $F = Bev$ $r = \frac{mv}{Be}$ $\frac{1}{2} mv^2 = eV$
<i>Millikan's experiment</i>	$\frac{QV}{d} = mg$ $F = 6\pi\eta r v$
<i>Maxwell's formula</i>	$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$ $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}}$
<i>special relativity</i>	$t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$ $l = l_0 \sqrt{1 - \frac{v^2}{c^2}}$ $E = mc^2 = \frac{m_0 c^2}{\sqrt{1 - \frac{v^2}{c^2}}}$

Electronics

<i>resonant frequency</i>	$f_0 = \frac{1}{2\pi \sqrt{LC}}$
<i>Q-factor</i>	$Q = \frac{f_0}{f_B}$
<i>operational amplifiers: open loop</i>	$V_{\text{out}} = A_{\text{OL}}(V_+ - V_-)$
<i>inverting amplifier</i>	$\frac{V_{\text{out}}}{V_{\text{in}}} = -\frac{R_f}{R_{\text{in}}}$
<i>non-inverting amplifier</i>	$\frac{V_{\text{out}}}{V_{\text{in}}} = 1 + \frac{R_f}{R_1}$
<i>summing amplifier</i>	$V_{\text{out}} = -R_f \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \dots \right)$
<i>difference amplifier</i>	$V_{\text{out}} = (V_+ - V_-) \frac{R_f}{R_1}$
<i>Bandwidth requirement:</i>	
<i>for AM</i>	<i>bandwidth</i> = $2f_M$
<i>for FM</i>	<i>bandwidth</i> = $2(\Delta f + f_M)$



Acknowledgements

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Only constructive and reasoned feedback will be considered.