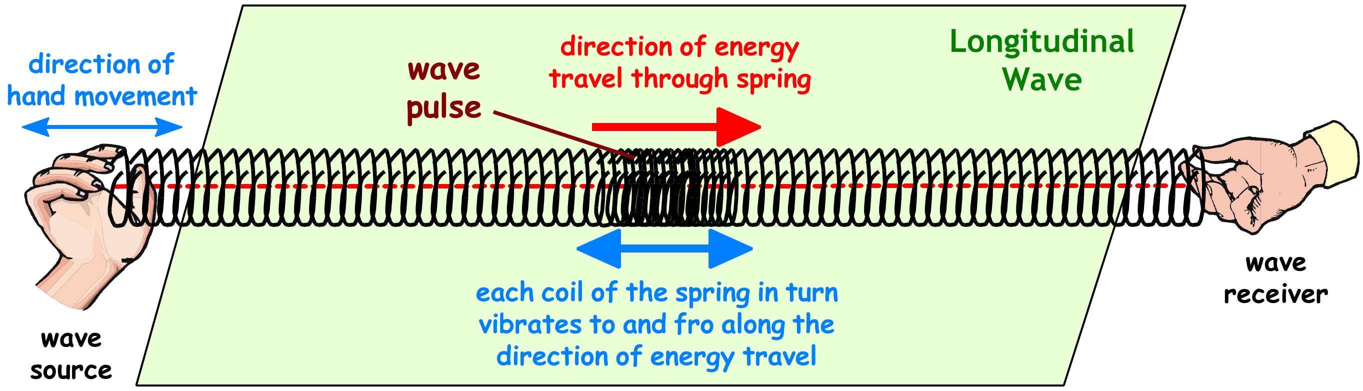
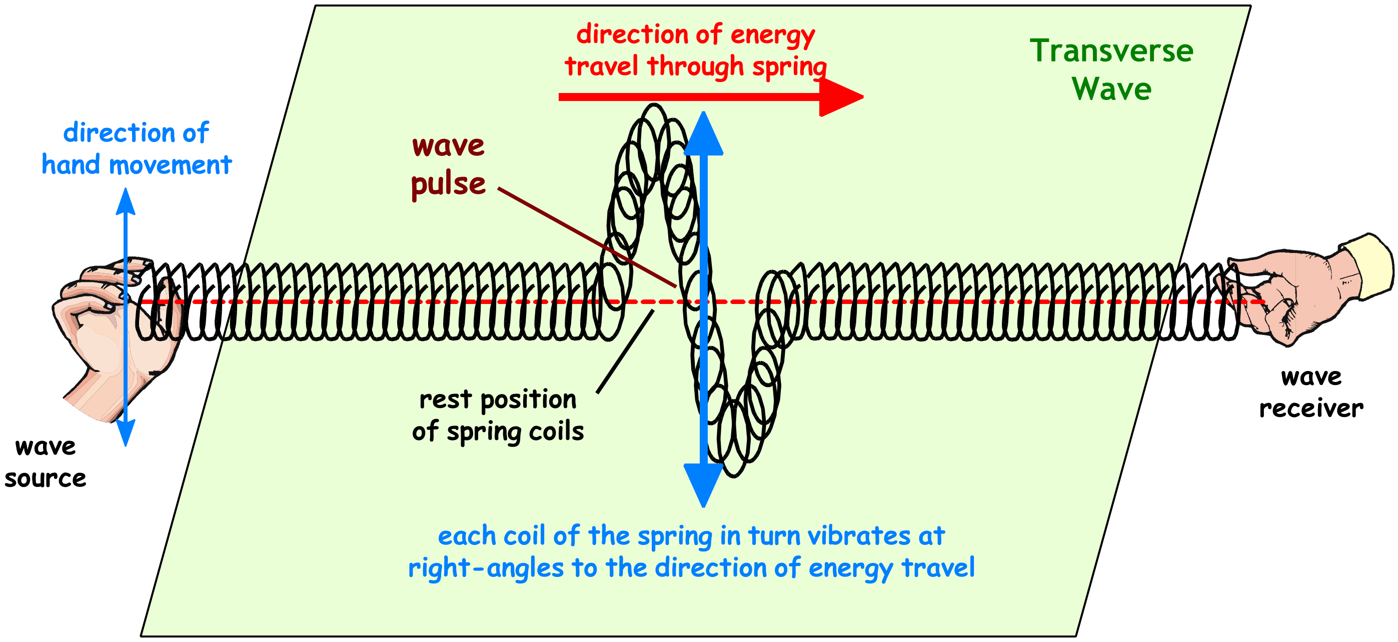
New NATIONAL 5

PHYSICS





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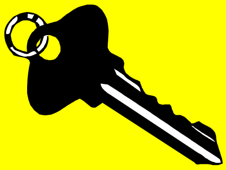
"Waves"

Introducing Waves

Key Learning Objectives



To find out:

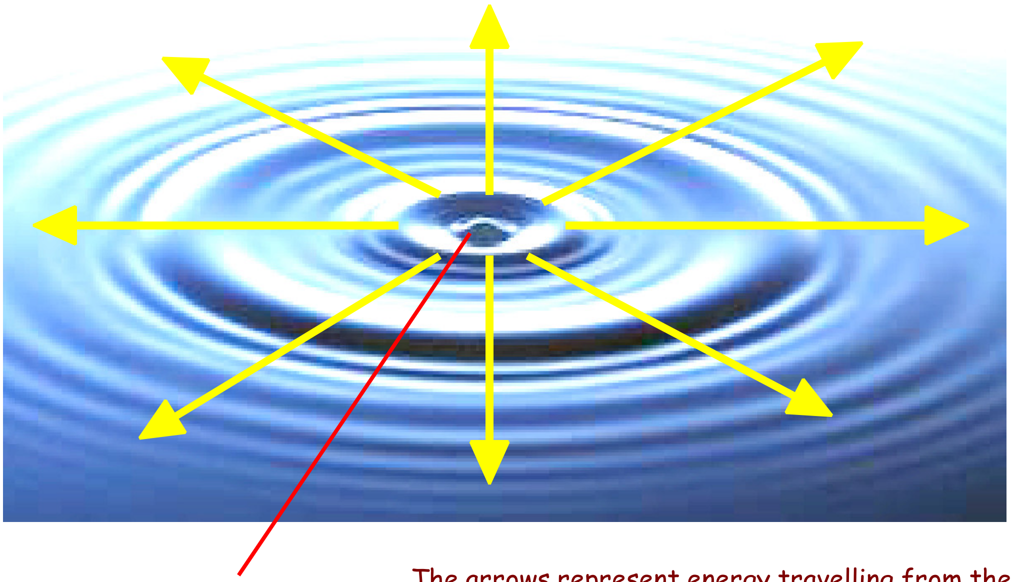
- the names of some important kinds of wave
- that all waves transfer (carry) energy from a source to its surroundings
- some examples that illustrate the transfer of energy by wave motion

1) Different Kinds of Waves

There are many different kinds of waves.

The most familiar kind of wave is probably water waves on the surface of ponds or the sea.

A water wave on the surface of a pond created by throwing a stone into the pond - wavefronts spread out from the central wave source



Other kinds of waves include:

sound waves

light waves

radar waves

X-rays

infra-red (heat) waves

ultra-violet waves

gamma rays

gravity waves

microwaves

radio waves

seismic waves

television waves

2) Energy Transferred (Carried) by Waves

The photograph of the water waves on the surface of a pond (opposite page) shows energy travelling from the wave source to its surroundings.

This situation is true for all waves.

All waves transfer (carry) energy from their source to their surroundings.

This photograph illustrates the enormous amount of energy a water wave can transfer (carry) - it shows a tsunami sea wave hitting the Japanese coastline in March 2011.

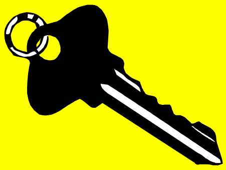
The tsunami caused great loss of life and severe damage to buildings in coastal areas.

The energy transferred (carried) by water waves will play an important part in our future generation of electrical energy (electricity).

The photograph below shows a prototype device for changing kinetic (movement) energy in water waves on the sea to electrical energy.

Longitudinal and Transverse Waves ....

Key Learning Objectives To find out:



- that there are two different types of wave motion - longitudinal and transverse
- that in a longitudinal wave, the vibrations are along the direction in which energy travels
- that sound is an example of a longitudinal wave
- that in a transverse wave, the vibrations are at right-angles to the direction in which energy travels
- that water waves and electromagnetic radiation are examples of transverse waves
- that during wave motion, only energy is transferred - any matter (material) the energy passes through does not travel along with the energy

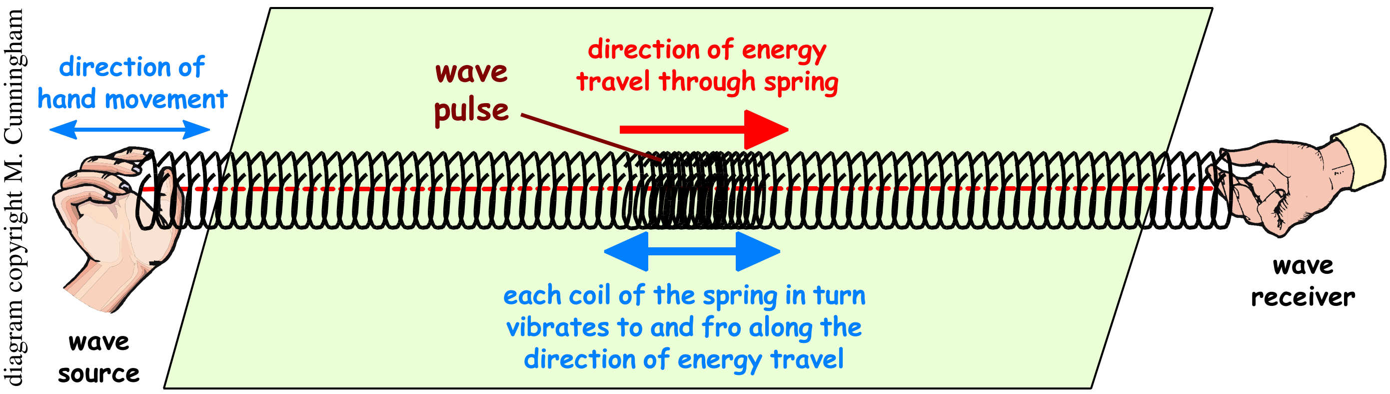
There are two different types of wave motion - longitudinal and transverse.
These will be illustrated in this double page spread.

Wave Pulses on a Long Stretched Spring

We can send energy in the form of a wave pulse through a long stretched spring from one person's hand (the source) to another person's hand (the receiver).

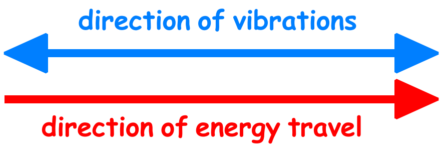
The receiver detects the energy of the pulse travelling through the spring when the pulse reaches their hand.

(a) Sending a Longitudinal Wave Pulse



As the longitudinal wave pulse travels through the spring, each coil of the spring in turn vibrates to and fro along the direction in which the energy is travelling. Each coil passes on energy to the next coil in line.

In a longitudinal wave, the vibrations are along the direction in which energy travels.

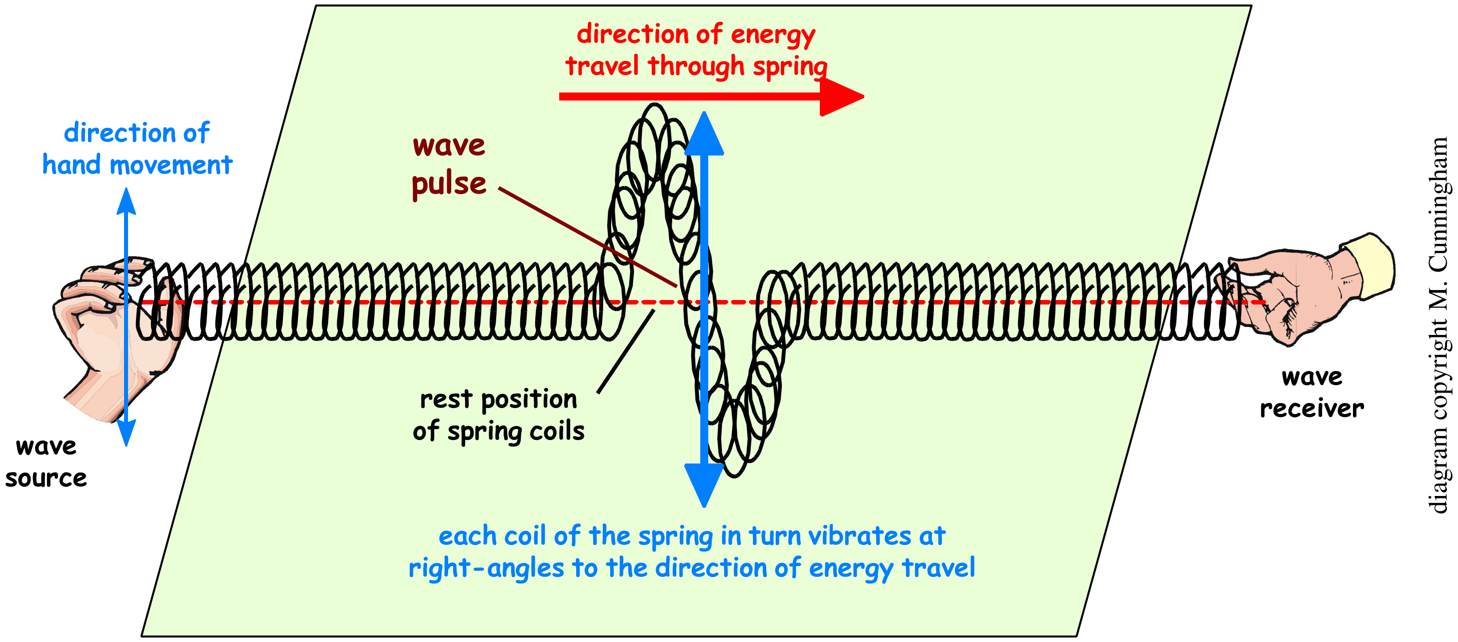


Once the pulse has passed any coil in the spring, that coil returns to its original rest position - It does not travel along the spring with the energy.

During longitudinal wave motion, only energy is transferred - any matter (material) the energy travels through, does not travel along with the energy.

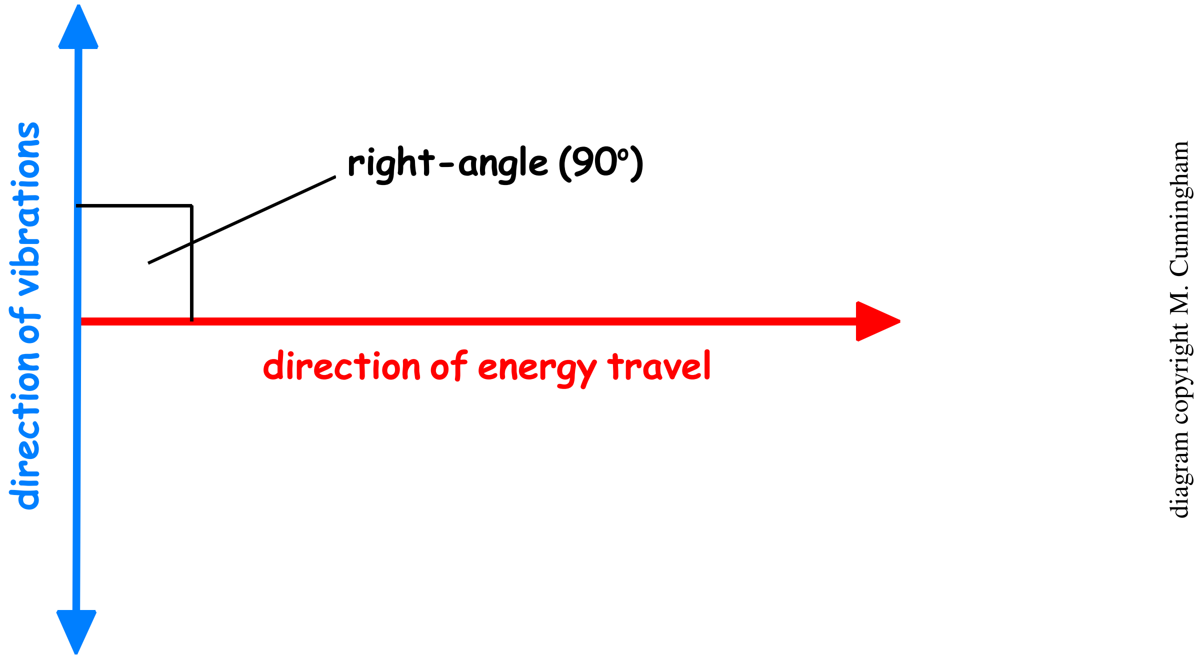
Sound energy is carried by longitudinal waves.

(b) Sending a Transverse Wave Pulse



As the transverse wave pulse travels through the spring, each coil of the spring in turn vibrates across, at right-angles to, the direction in which the energy is travelling. Each coil passes on energy to the next coil in line.

In a transverse wave, the vibrations are at right-angles to the direction in which energy travels.



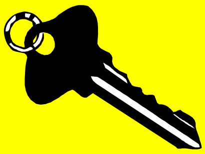
Once the pulse has passed any coil in the spring, that coil returns to its original rest position - it does not travel along the spring with the energy.

During transverse wave motion, only energy is transferred - any matter (material) the energy travels through, does not travel along with the energy.

Waves on the surface of water and electromagnetic radiation (such as visible light and X-rays) are transverse waves.

Wave Motion - Terms and Equations 1 ....

Key Learning Objectives To find out:

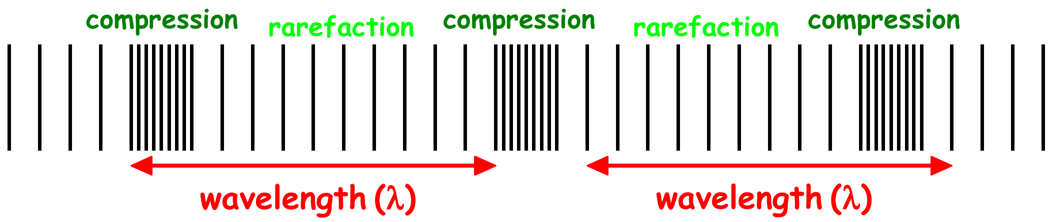


- the meaning of the terms 'amplitude', 'wavelength' and 'frequency' for longitudinal and transverse waves
- the units for 'amplitude', 'wavelength' and 'frequency'
- how to calculate the frequency of a longitudinal or a transverse wave motion given the number of pulses/ wavelengths/ crests/ troughs in a given time

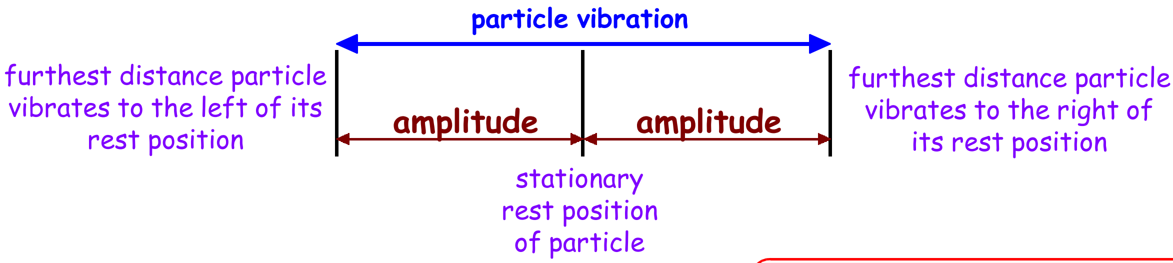
Describing Wave Motion

These general diagrams and terms can be used to describe **wave motion**.

(a) a longitudinal wave



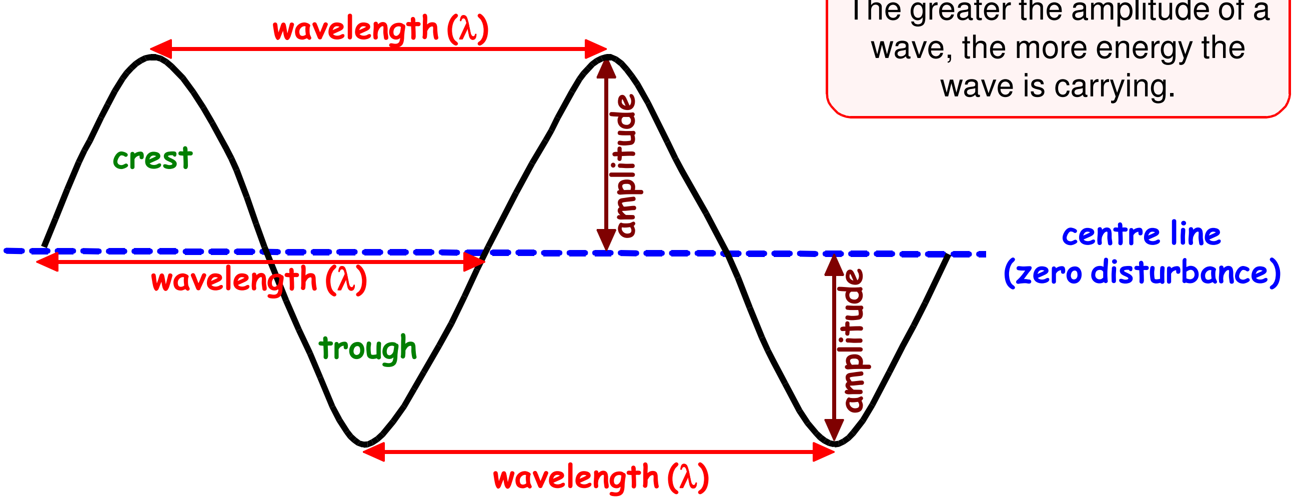
- **compression** - A region where the particles of the material the wave is travelling through are packed closely together, e.g., a wave pulse.
- **rarefaction** - A region where the particles of the material the wave is travelling through are spread apart.
- **amplitude** - The maximum distance a particle in a material vibrates from its stationary rest position when a longitudinal wave passes through the material. [Unit: metres (m)].



(b) a transverse wave

Note on Wave Amplitude

The greater the amplitude of a wave, the more energy the wave is carrying.



- **crest** - The part of the wave above the zero disturbance centre line.
- **trough** - The part of the wave below the zero disturbance centre line.
- **amplitude** - The full height of a wave crest or trough measured from the zero disturbance centre line. [Unit: metres (m)].

Wavelength [Symbol: lambda (λ) Unit: metres (m)]

The wavelength of a wave is the distance between two identical neighbouring parts of the wave.

For a longitudinal wave, this is the distance between the start of two neighbouring compressions.

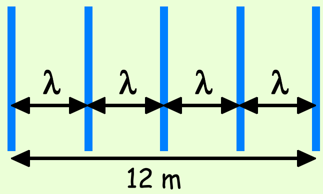
For a transverse wave, this is the distance between two neighbouring wave crests or the distance between two neighbouring wave troughs.

As shown on the wave diagrams, wavelength can be measured between other identical neighbouring parts of a wave.

"Wavelength" Problem With Solution

This diagram represents five wavefronts (crests) on the surface of the sea.

Determine the wavelength of the wave motion.



SOLUTION

Wavelength = distance between two neighbouring wave crests

$= \frac{12\text{ m}}{4}$ ← divide the total distance by the number of **gaps** between the wavefronts

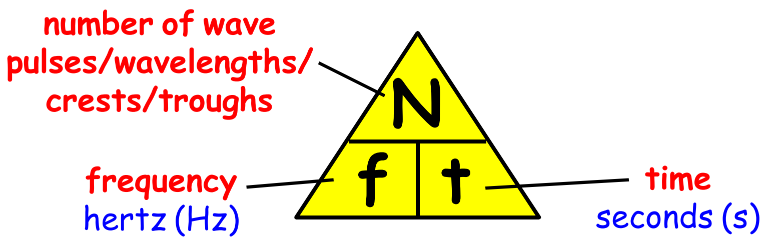
$= \underline{3\text{ m}}$

Frequency [Symbol: f Unit: hertz (Hz)]

The frequency of a wave is the number of wave pulses (or wavelengths or crests or troughs) emitted by the wave source in one second.

If we know the number of wave pulses (or wavelengths or crests or troughs) emitted by a wave source in a given time, we can apply this equation:

$$\text{frequency} = \frac{\text{number of wave pulses/wavelengths/crests/troughs}}{\text{time (in seconds)}}$$



$$f = \frac{N}{t}$$

$$N = f\,t$$

$$t = \frac{N}{f}$$

"Frequency, Number of Waves and Time" Problems With Solutions

A wave source emits 10 wave pulses in a time of 5 s.

Calculate the frequency of the wave motion.

SOLUTION $f = \frac{N}{t}$

$= \frac{10}{5}$

$= \underline{2\text{ Hz}}$

A wave source has a frequency of 15 Hz.

Calculate the number of wave troughs the source will emit in a time of 3 s.

SOLUTION $N = f\,t$

$= 15 \times 3$

$= \underline{45\text{ troughs}}$

A wave source has a frequency of 20 Hz.

Calculate the time it will take the source to emit 10 wave crests.

SOLUTION $t = \frac{N}{f}$

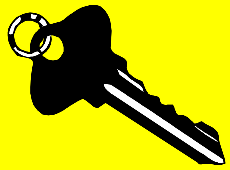
$= \frac{10}{20}$

$= \underline{0.5\text{ s}}$

Spread 4

Wave Motion - Terms and Equations 2 ....

Key Learning Objectives To find out:



- the meaning of the term 'period' for longitudinal and transverse waves
- the unit for 'period'
- how to calculate the 'period' of a longitudinal or a transverse wave motion given its 'frequency' (and vice versa)
- how to carry out wave calculations involving 'speed', 'frequency' and 'wavelength'
- how to carry out wave calculation involving 'speed', 'distance' and 'time'

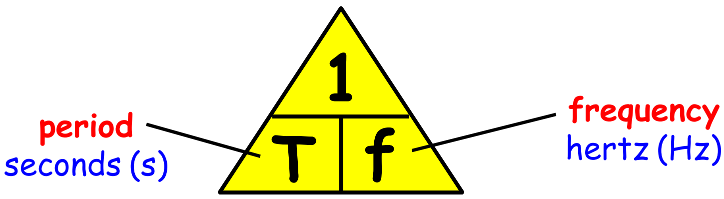
Period of a Wave

The period (T) of any wave is the time taken by the wave source to generate (produce) one whole wavelength.

Period has the symbol 'T' and is measured in seconds (s).

The period and frequency of a wave are related by this equation:

$$\text{period} = \frac{1}{\text{frequency}} \quad \text{or} \quad \text{frequency} = \frac{1}{\text{period}}$$



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

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

"Period and Frequency" Problems With Solutions

A source of longitudinal waves has a frequency of 5 Hz.

Calculate the period of the waves emitted by the source (i.e., the time taken to emit one wavelength).

SOLUTION $T = \frac{1}{f} = \frac{1}{5} = \underline{\underline{0.2\ s}}$

A source of transverse waves has a period of 0.25 s (i.e., it takes the source 0.25 s to emit one wavelength).

Calculate the frequency of the waves emitted by the source.

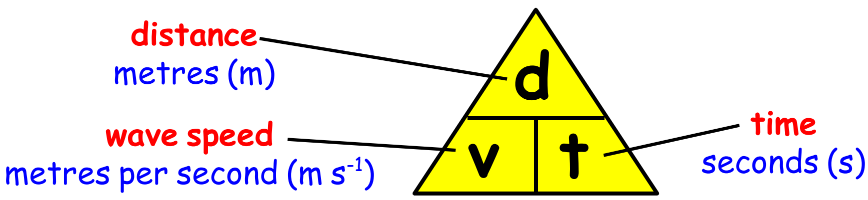
SOLUTION $f = \frac{1}{T} = \frac{1}{0.25} = \underline{\underline{4\ Hz}}$

Speed of a Wave

The speed of a wave is the distance one wave pulse (or wavelength or crest or trough) travels every second.

This leads to the following equation:

$$\text{wave speed} = \frac{\text{distance travelled by wave pulse/wavelength/crest/trough}}{\text{time (in seconds)}}$$



$$v = \frac{d}{t}$$

$$d = v\,t$$

$$t = \frac{d}{v}$$

..........Wave Motion - Terms and Equations 2 (continued)

"Speed, Distance and Time" Problems With Solutions

A sound wave pulse travels 544 m through air in a time of 1.60 s.

Calculate the speed of the sound wave pulse in air.

SOLUTION $v = \frac{d}{t}$

$= \frac{544}{1.60}$

$= \underline{\underline{340 \text{ m s}^{-1}}}$

A water wave crest has a speed of 0.75 m s^{-1}.

Calculate the distance the water wave crest will travel in a time of 20 s.

SOLUTION $d = v\,t$

$= 0.75 \times 20$

$= \underline{\underline{15 \text{ m}}}$

A wave trough travels 1.8 m along a stretched metal spring at a speed of 1.2 m s^{-1}.

Calculate the time this takes the wave trough.

SOLUTION $t = \frac{d}{v}$

$= \frac{1.8}{1.2}$

$= \underline{\underline{1.5 \text{ s}}}$

"Reflected Wave" Problem With Solutions

A cruise ship sends a pulse of sound from its hull directly towards the seabed. A reflected sound pulse is detected by the cruise ship after 0.24 s.

Calculate:

(a) The time taken for the sound pulse to reach the seabed.

(b) The depth of the sea.

(Speed of sound in sea water = 1 500 m s^{-1}).

SOLUTIONS

(a) Halve the total time.

$t = \frac{0.24}{2}$

$= \underline{\underline{0.12 \text{ s}}}$

(b) $d = v\,t$

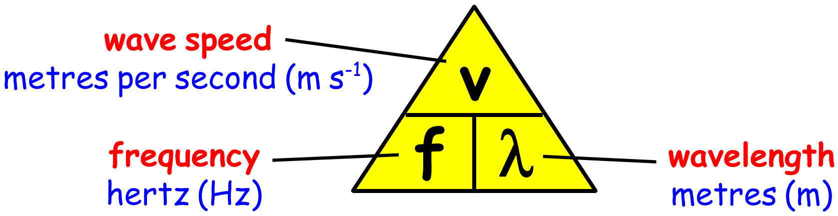
$= 1\,500 \times 0.12$

$= \underline{\underline{180 \text{ m}}}$

Equation Linking Speed, Frequency and Wavelength

The speed, frequency and wavelength of a wave are related by this equation:

wave speed = frequency x wavelength



$$v = f\,\lambda$$

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

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

"Speed, Frequency and Wavelength" Problems With Solutions

A water wave has a frequency of 1.2 Hz and a wavelength of 1.5 m.

Calculate the speed of the water wave.

SOLUTION $v = f\,\lambda$

$= 1.2 \times 1.5$

$= \underline{\underline{1.8 \text{ m s}^{-1}}}$

When a sound wave travels through air at a speed of 340 m s^{-1}, its wavelength is 2.50 m.

Calculate the frequency of the sound wave.

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

$= \frac{340}{2.50}$

$= \underline{\underline{136 \text{ Hz}}}$

A green light wave travels through air at a speed of 3.00 x 10^{8} m s^{-1}. The light wave has a frequency of 5.50 x 10^{14} Hz.

Calculate the wavelength of the green light wave.

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

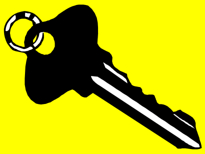
$= \frac{3.00 \times 10^{8}}{5.50 \times 10^{14}}$

$= \underline{\underline{5.45 \times 10^{-7} \text{ m}}}$

Spread 5

Diffraction of Waves ....

Key Learning Objectives



To find out:

- the meaning of the term 'diffraction'
- that longer wavelength waves diffract more than shorter wavelength waves - the longer the wavelength, the greater the diffraction
- that for waves passing through a gap in an object, the diffraction is greatest when the wavelength of the waves is equal to or greater than the width of the gap
- how to draw diagrams showing the 'diffraction' of wavefronts as the wavefronts pass through a gap in an object or around the edge of an object

The Diffraction of Waves

*NOTE - A **wavefront** is a line drawn to represent a wave pulse, crest or trough.*

When waves pass through a gap in an object or around the edge of an object, the shape of the wavefronts changes - part or all of each wavefront becomes curved as the waves bend.

This effect is known as **diffraction**.

Diffraction is the bending of waves when they pass through a gap in an object or around the edge of an object.

Longer wavelength waves diffract more than shorter wavelength waves.

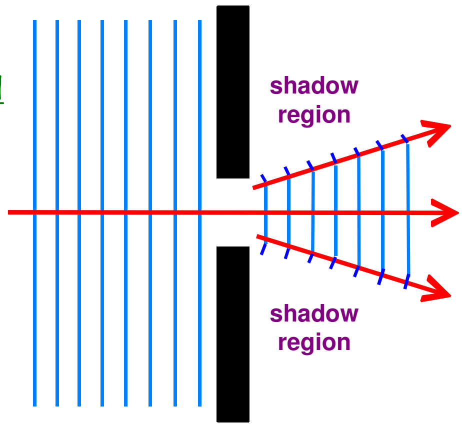
(a) Diffraction Through a Gap in an Object

The arrows on the diagrams, drawn at 90° to the wavefronts, are called 'rays'. They show the direction of energy transfer.

WAVES WITH A SHORTER WAVELENGTH - LESS THAN WIDTH OF GAP IN OBJECT

There is very little diffraction - only at the edges of each wavefront that has passed through the gap.

There are two large shadow regions, where no diffracted waves reach.



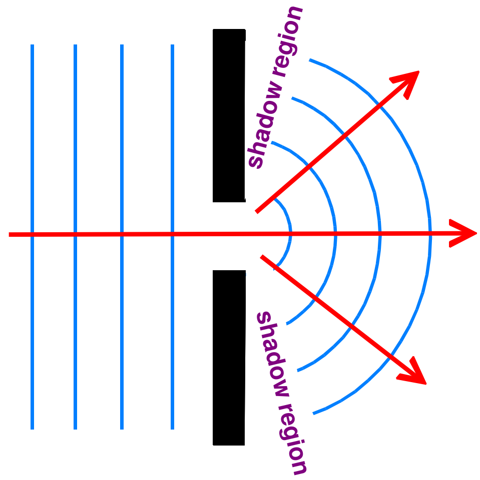
DURING DIFFRACTION, THE WAVELENGTH OF THE WAVES DOES NOT CHANGE.

THIS IS VERY IMPORTANT TO REMEMBER WHEN YOU ARE DRAWING DIAGRAMS SHOWING THE DIFFRACTION OF WAVEFRONTS.

WAVES WITH A LONGER WAVELENGTH - EQUAL TO OR GREATER THAN WIDTH OF GAP IN OBJECT

There is a great deal of diffraction - the gap in the object acts as a source of semi-circular waves.

There are two small shadow regions, where no diffracted waves reach.



The greatest amount of diffraction takes place when the wavelength of the waves is equal to or greater than the width of the gap they are passing through.

The longer the wavelength, the greater the diffraction.

WAVES

.... Diffraction of Waves (continued)

(b) Diffraction Around the Edge of an Object

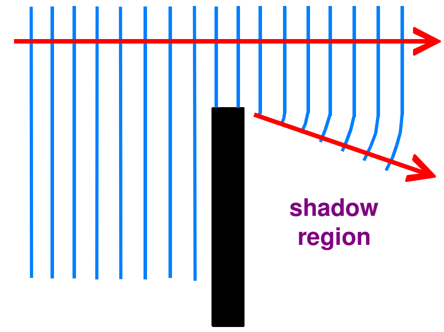
The arrows on the diagrams, drawn at 90° to the wavefronts, are called 'rays'. They show the direction of energy transfer.

(i) Around One Edge

WAVES WITH A SHORTER WAVELENGTH

There is very little diffraction at the edge of each wavefront that has passed and touched the object.

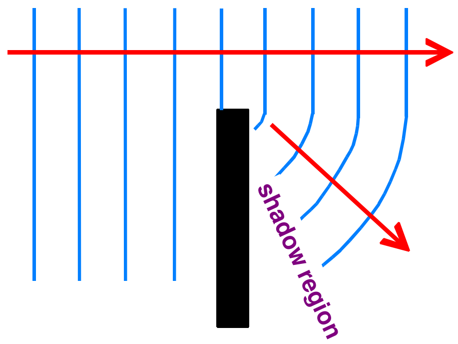
There is a large shadow region, where no diffracted waves reach.



WAVES WITH A LONGER WAVELENGTH

There is a great deal of diffraction at the edge of each wavefront that has passed and touched the object.

There is a small shadow region, where no diffracted waves reach.



DURING DIFFRACTION, THE WAVELENGTH OF THE WAVES DOES NOT CHANGE.

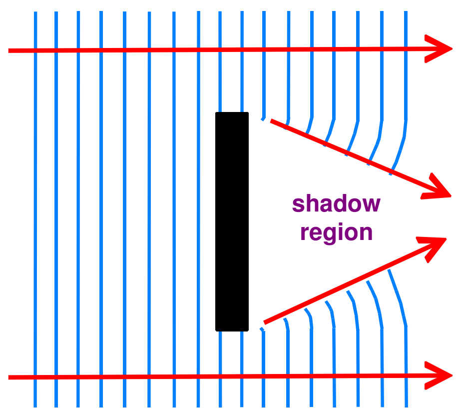
THIS IS VERY IMPORTANT TO REMEMBER WHEN YOU ARE DRAWING DIAGRAMS SHOWING THE DIFFRACTION OF WAVEFRONTS.

(ii) Around Both Edges

WAVES WITH A SHORTER WAVELENGTH

There is very little diffraction at the edge of each wavefront that has passed and touched the object.

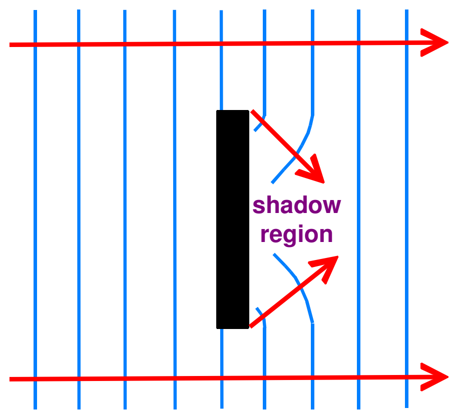
There is a large shadow region, where no diffracted waves reach.



WAVES WITH A LONGER WAVELENGTH

There is a great deal of diffraction at the edge of each wavefront that has passed and touched the object - the wavefronts join up again after travelling a short distance past the object.

There is a small shadow region, where no diffracted waves reach.



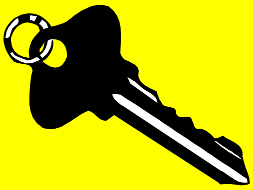
DURING DIFFRACTION, THE WAVELENGTH OF THE WAVES DOES NOT CHANGE.

THIS IS VERY IMPORTANT TO REMEMBER WHEN YOU ARE DRAWING DIAGRAMS SHOWING THE DIFFRACTION OF WAVEFRONTS.

A greater amount of diffraction takes place for waves of longer wavelength - the longer the wavelength, the greater the diffraction.

Refraction of Waves 1 ....

Key Learning Objectives



To find out:

- the meaning of the term 'refraction'
- that when waves pass from one medium (material) into another medium (material) of different density, refraction occurs - the wave speed changes, the wavelength changes and, when the 'angle of incidence' is greater than 0°, the direction of the waves changes
- how to identify the 'normal line', 'angle of incidence' and 'angle of refraction' on ray diagrams showing the refraction of 'non-white' light rays through parallel-sided blocks

The Refraction of Waves

When waves pass from one medium (material) into another medium (material) of different density, their speed changes.

This change in speed is known as **refraction**.

Refraction is the change in speed of a wave when it passes from one medium (material) into another medium (material) of different density.

When the speed of a wave changes due to refraction, the wavelength of the wave also changes. Its direction may also change.

This is described in the table below and illustrated by the diagrams for parallel-sided blocks on the opposite page.

NOTE

*A **wavefront** is a line drawn to represent a wave pulse, crest or trough.*

*A **ray** is a line drawn at 90° to a wavefront. Rays show the direction of energy transfer.*

*A **normal** is a line drawn at 90° to the boundary between two media (materials), at the point where a ray hits the boundary.*

*An **angle of incidence** is the angle between the normal line and the ray before the ray passes into the different medium (material).*

*An **angle of refraction** is the angle between the normal line and the ray after the ray passes into the different medium (material).*

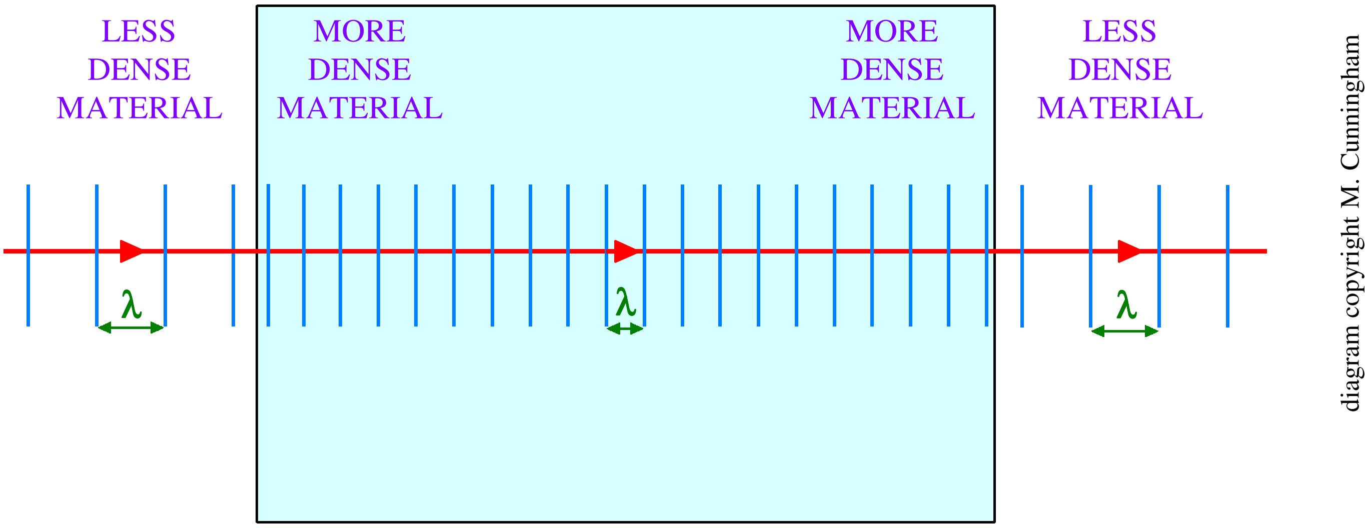
Situation	Wave Speed	Wavelength	Wave Direction
Wave passes into medium (material) of different density at 90° to the surface boundary. (Angle of incidence = 0°).	CHANGES Less dense to more dense medium: speed decreases. More dense to less dense medium: speed increases	CHANGES Less dense to more dense medium: wavelength decreases. More dense to less dense medium: wavelength increases	DOES NOT CHANGE
Wave passes into medium (material) of different density at angle of incidence other than 90° to the surface boundary. (Angle of incidence is greater than 0°).	CHANGES Less dense to more dense medium: speed decreases. More dense to less dense medium: speed increases	CHANGES Less dense to more dense medium: wavelength decreases. More dense to less dense medium: wavelength increases	CHANGES Less dense to more dense medium: angle between ray and normal line decreases. More dense to less dense medium: angle between ray and normal line increases.

.... Refraction of Waves 1 (continued)

Parallel-Sided Block

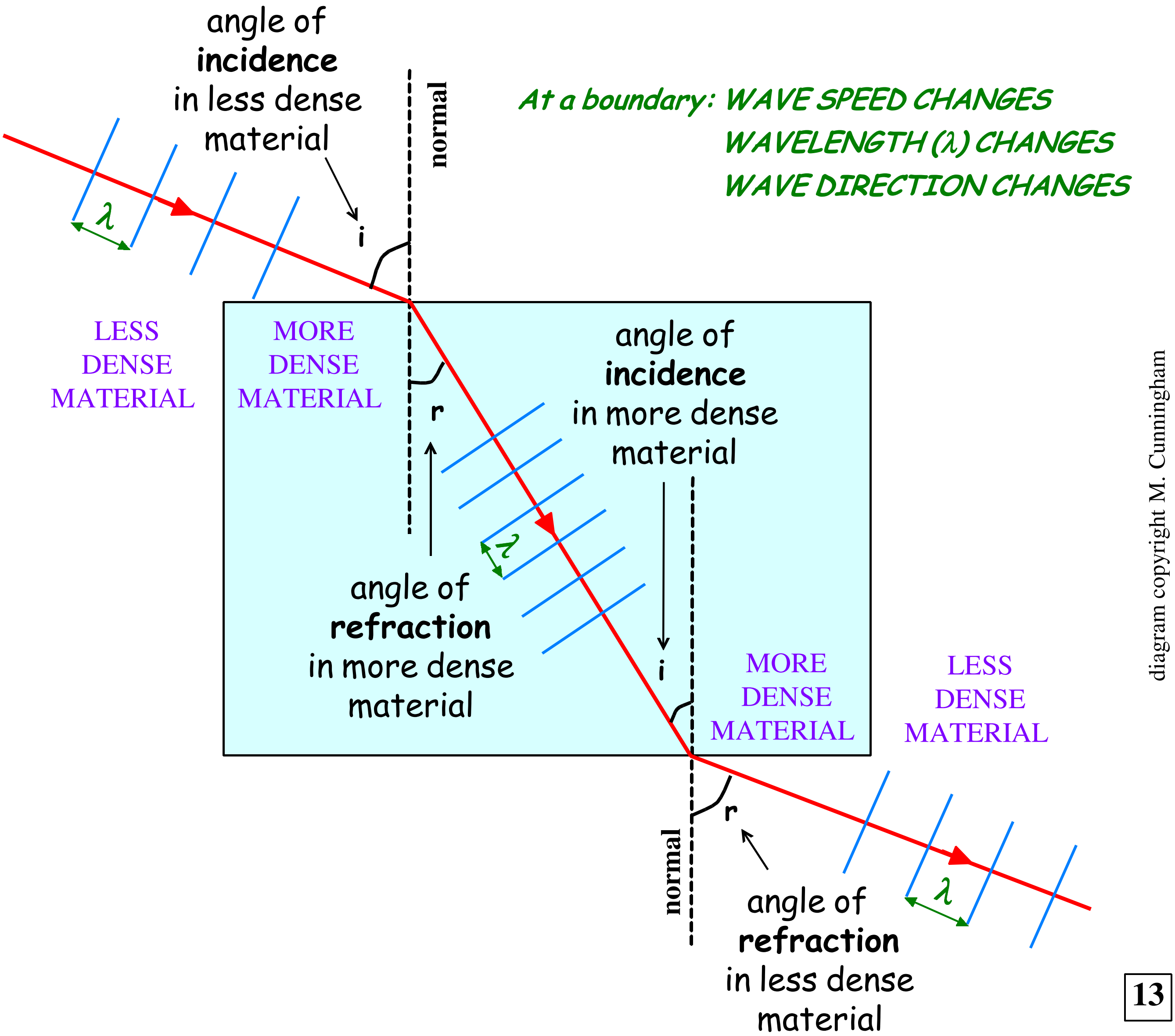
(i) Angle of Incidence = 90° to Surface Boundary

At a boundary: WAVE SPEED CHANGES
WAVELENGTH (λ) CHANGES
WAVE DIRECTION DOES NOT CHANGE



(ii) Angle of Incidence Other Than 90° to Surface Boundary

At a boundary: WAVE SPEED CHANGES
WAVELENGTH (λ) CHANGES
WAVE DIRECTION CHANGES



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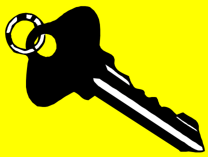
Refraction of Waves 2 ....



Key Learning Objectives To find out:

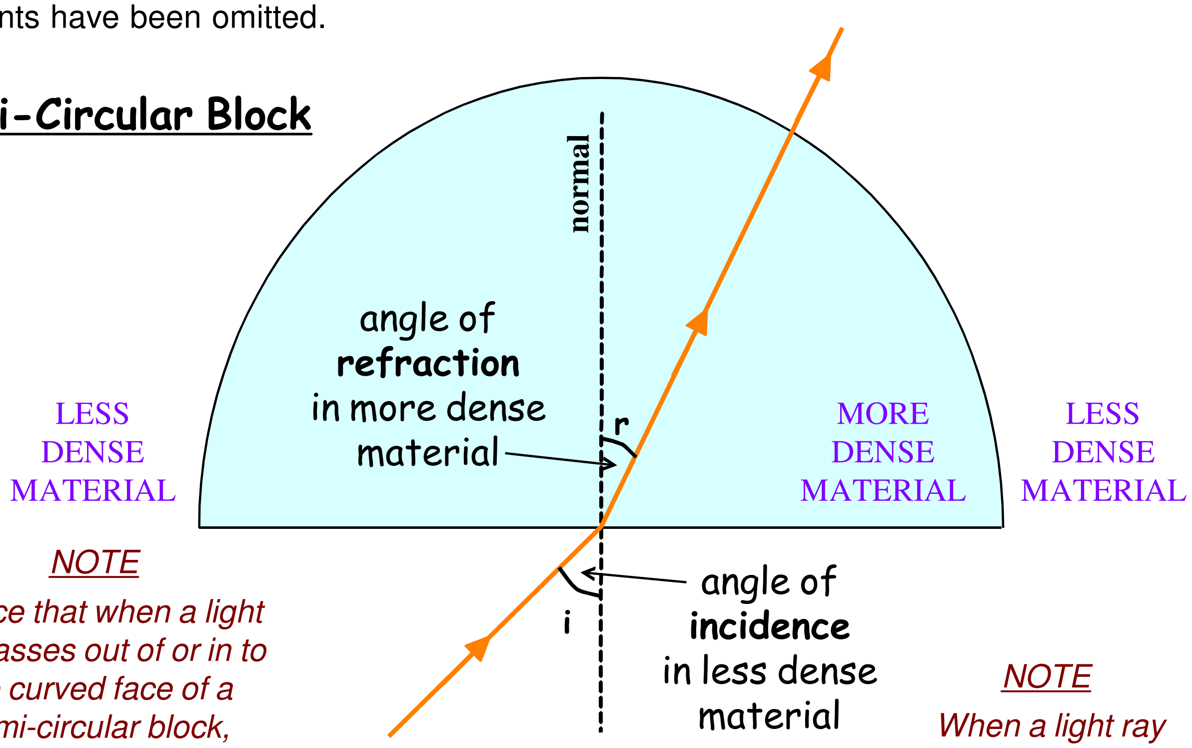
- how to identify the 'normal line', 'angle of incidence' and 'angle of refraction' on ray diagrams showing the refraction of 'non-white' light rays through non parallel-sided blocks (such as semi-circular blocks and triangular prisms)
- some important uses for refraction, e.g., splitting up white light and lenses

The Refraction of Waves (continued)

The previous double-page spread illustrated the refraction of light rays through parallel-sided glass blocks.

The diagrams on this spread show the 'normal lines', 'angles of incidence' and 'angles of refraction' for light rays travelling through non-parallel sided glass blocks. For clarity, wavefronts have been omitted.

Semi-Circular Block



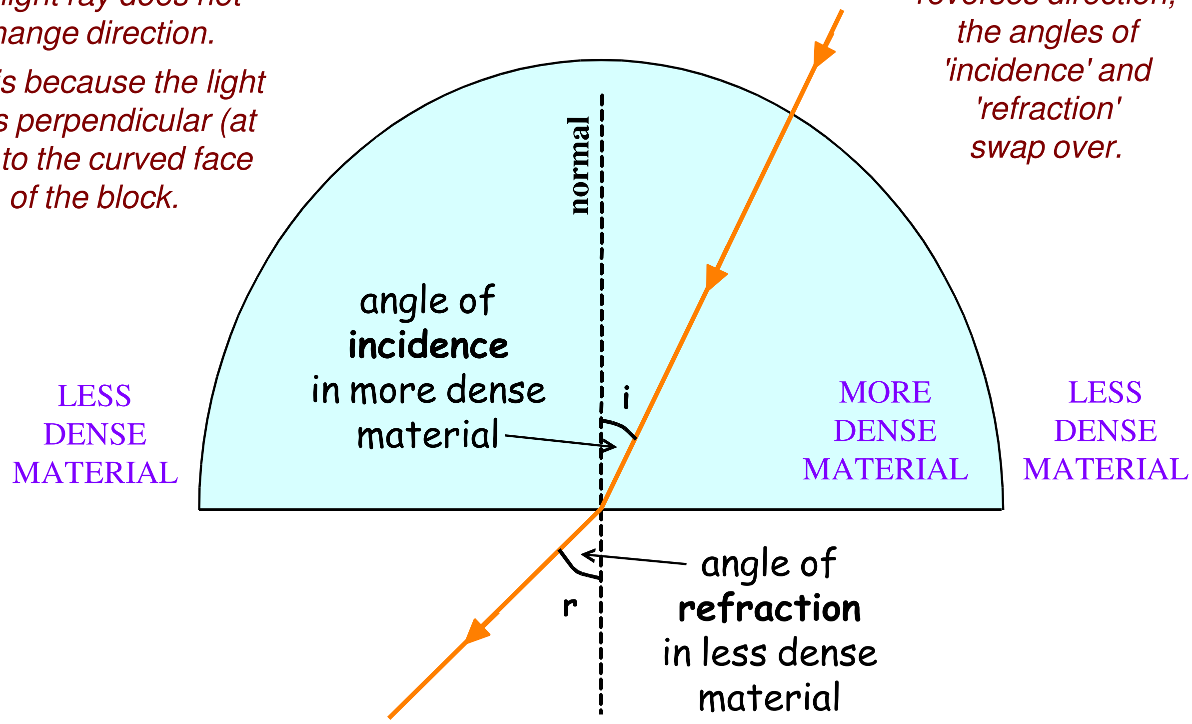
NOTE

Notice that when a light ray passes out of or in to the curved face of a semi-circular block, the light ray does not change direction.

This is because the light ray is perpendicular (at 90°) to the curved face of the block.

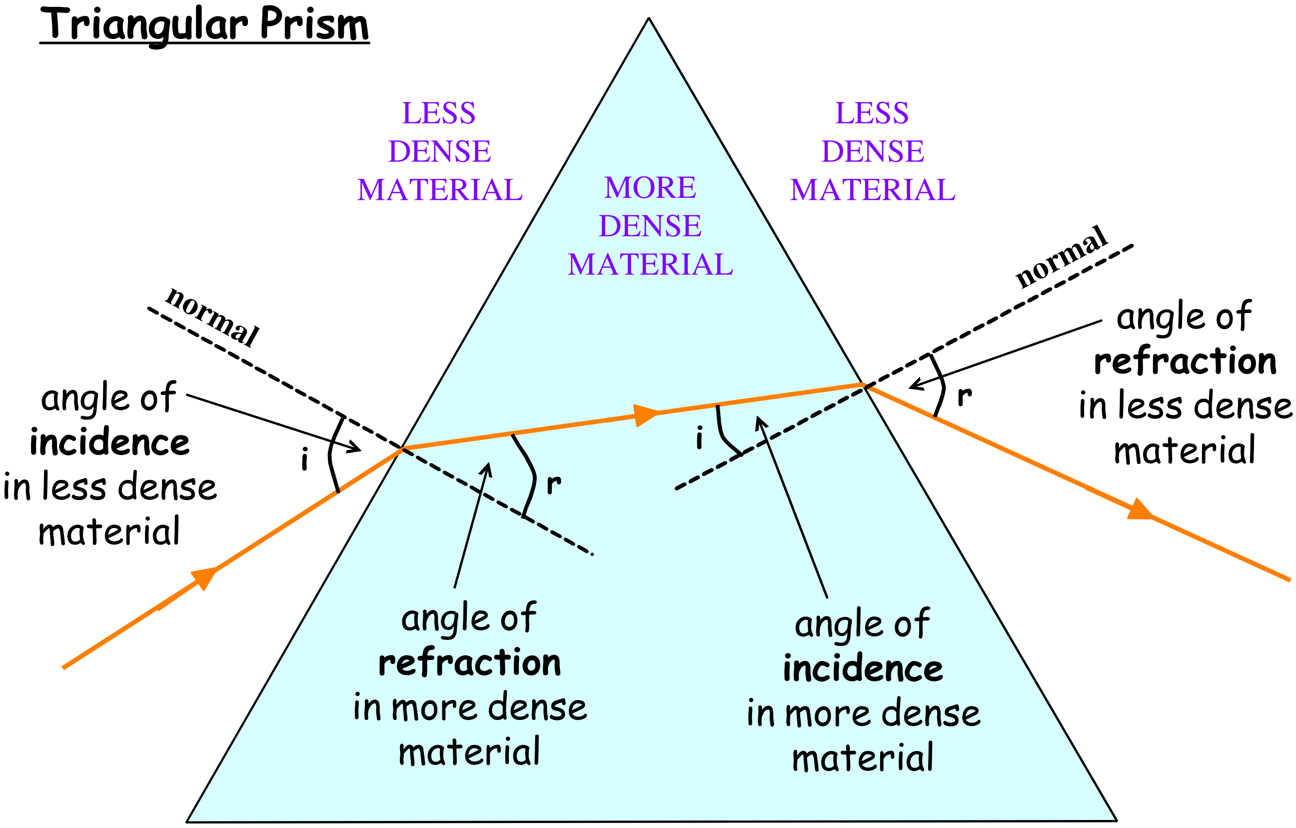
NOTE

When a light ray reverses direction, the angles of 'incidence' and 'refraction' swap over.



WAVES

Triangular Prism



Important Uses for Refraction

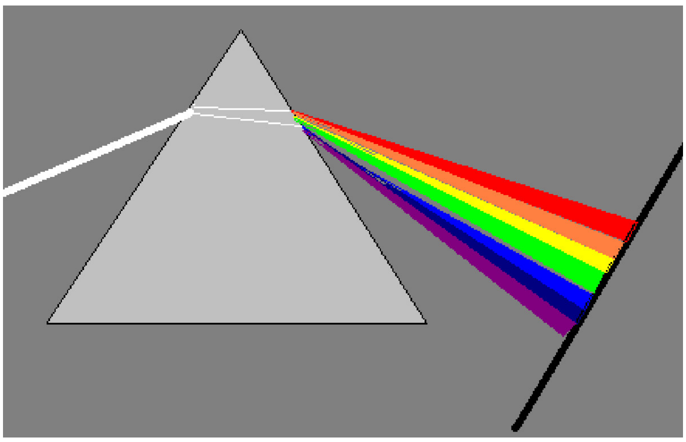
For interest:

Triangular Prism

A ray of white light can be split up into its seven constituent colours by passing the white light ray through a triangular glass prism.

This is due to refraction.

As it passes through the prism, each colour present in white light is refracted by a slightly different amount. Therefore, the white light is dispersed into its constituent colours.



Lenses

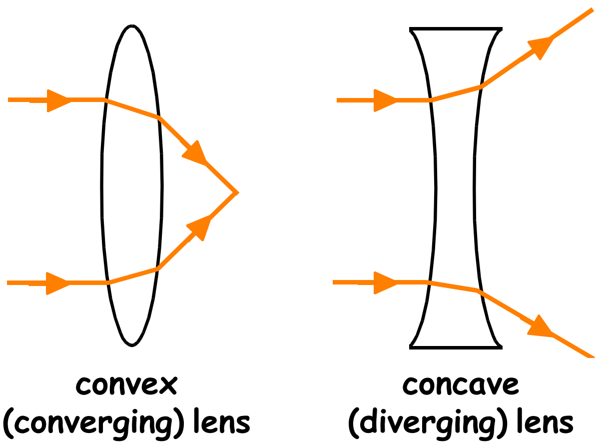
Lenses are designed to change the direction of the light rays that enter them.

This happens due to refraction.

A **convex** (**converging**) **lens** can make the light rays that enter it converge on one point - the focus point.

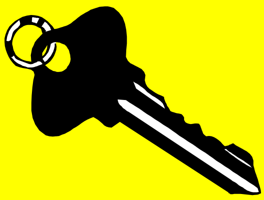
A **convex** (**diverging**) **lens** can make the light rays that enter it diverge (spread apart).

There are many important uses for lenses.



Spread 8 The Electromagnetic Spectrum ....

Key Learning Objectives To find out:



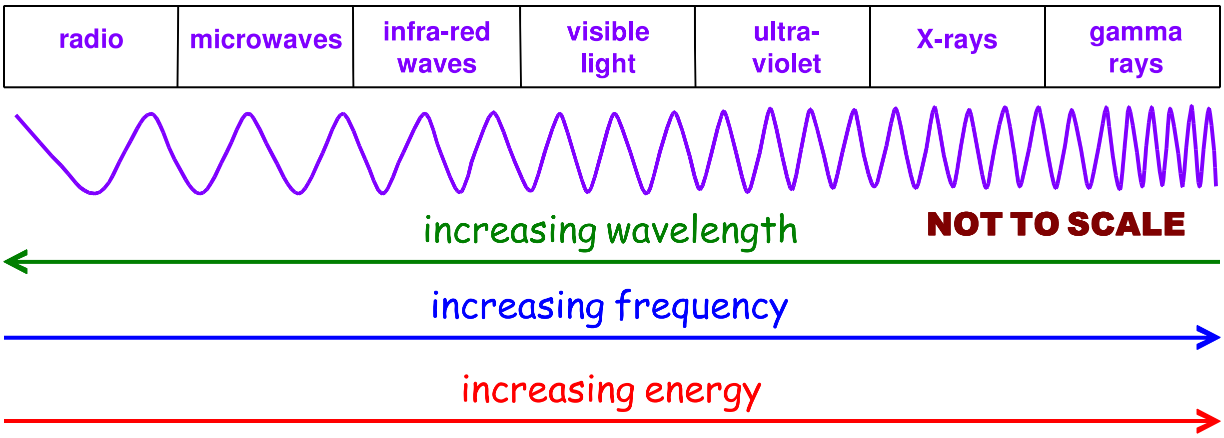
- that all members (bands) of the 'electromagnetic spectrum' are transverse waves that travel through outer space/a vacuum (where there are no particles), carrying energy at 300 000 000 m s^{-1} (3 x 10^8 m s^{-1}), the speed of light
- the name of each member (band) of the 'electromagnetic spectrum' and its frequency and wavelength ranges relative to the other members (bands)
- typical sources, detectors and applications for each member (band) of the 'electromagnetic spectrum'
- that wave calculations can be carried out for each member (band) of the 'electromagnetic spectrum' by applying appropriate wave equations

1) The Electromagnetic Spectrum

There is a very important group (family) of transverse waves - the 'electromagnetic spectrum'. These waves provide us with valuable information about the objects in the Universe. A large number of 'modern day' applications and devices depend on these waves.

The 'electromagnetic spectrum' is a family of transverse waves that can travel through outer space/a vacuum (where there are no particles), carrying energy at 300 000 000 m s^{-1} (3 x 10^8 m s^{-1}), the speed of light.

The 'electromagnetic spectrum' is represented by the diagram below:



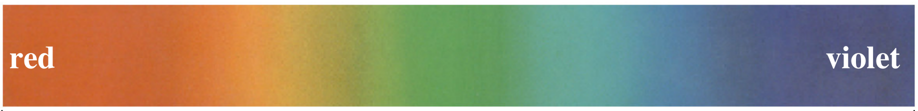
This table summarises the approximate frequency and wavelength range of the members (bands) of the 'electromagnetic spectrum'. There is overlap between the range values.

Member (band) of electromagnetic spectrum	radio waves	microwaves	infra-red waves	visible light waves	ultra-violet waves	X-rays	gamma rays
Approximate frequency range	3 x 10^3 Hz to 3 x 10^9 Hz	3 x 10^9 Hz to 3 x 10^{11} Hz	3 x 10^{11} Hz to 4.3 x 10^9 Hz	4.3 x 10^{14} Hz to 7.5 x 10^{14} Hz	7.5 x 10^{14} Hz to 3 x 10^{17} Hz	3 x 10^{17} Hz to 3 x 10^{19} Hz	3 x 10^{19} Hz and greater
Approximate wavelength range	10 cm to 100 km	1 mm to 10 cm	700 nm to 1 mm	400 nm to 700 nm	1 nm to 400 nm	0.01 nm to 1 nm	less than 0.01 nm

Note: 1 nm (nanometer) = 1 x 10^{-9} m

2) Visible Light Waves - the 'Visible Spectrum'

For interest, the visible light waves band of the electromagnetic spectrum comprises seven different colours, each with its own frequency and wavelength range - red, orange, yellow, green, blue, indigo and violet.



7.5×10^{14} Hz
700 nm
(approx)

visible light waves band
(also known as the 'visible spectrum')

4.3×10^{14} Hz
400 nm
(approx)

3) Typical Sources, Detectors and Applications for Each Member of the Electromagnetic Spectrum

The table below gives some typical sources, detectors and applications for each member (band) of the electromagnetic spectrum:

Member (Band) of Electromagnetic Spectrum	Typical Sources	Typical Detectors	Typical Applications
radio waves	radio and television transmitter aerials, stars	radio and television receiver aerials	telecommunication - carrying radio and television signals
microwaves	magnetron, mobile phone transmitter aerial, stars	mobile phone receiver aerial, diode probe	telecommunication - carrying mobile phone signals, radar, heating food
infra-red waves	any warm/hot object, stars	phototransistor, thermistor, liquid-in-glass thermometer with dull black bulb	heating, treating injured muscles, remote control for television
visible light waves	light bulbs, light emitting diodes, lasers, stars	retina of human eye, photographic film, light-dependant resistor	vision, photography, photosynthesis in plants
ultra-violet waves	ultra-violet lamps, mercury lamps, electric sparks, stars	fluorescent chemicals, ultra-violet probe	security marking/detection of forged bank notes, sterilising surgical instruments, treating acne
X-rays	X-ray tube, gas discharge tube, stars	fluorescent chemicals, photographic film, X-ray ionisation detector	detecting broken bones, CT scans, cancer treatment, airport security
gamma rays	radioactive materials, stars	Geiger-Muller tube, photographic film, cloud chamber	cancer treatment, sterilising food, measuring thickness of materials

4) Wave Calculations and the Electromagnetic Spectrum

Wave calculations can be carried out for each member (band) of the electromagnetic spectrum by applying appropriate wave equations - see pages 7-9 of this Waves booklet:

$$f = \frac{N}{t} \qquad T = \frac{1}{f} \qquad v = \frac{d}{t} \qquad v = f\lambda$$