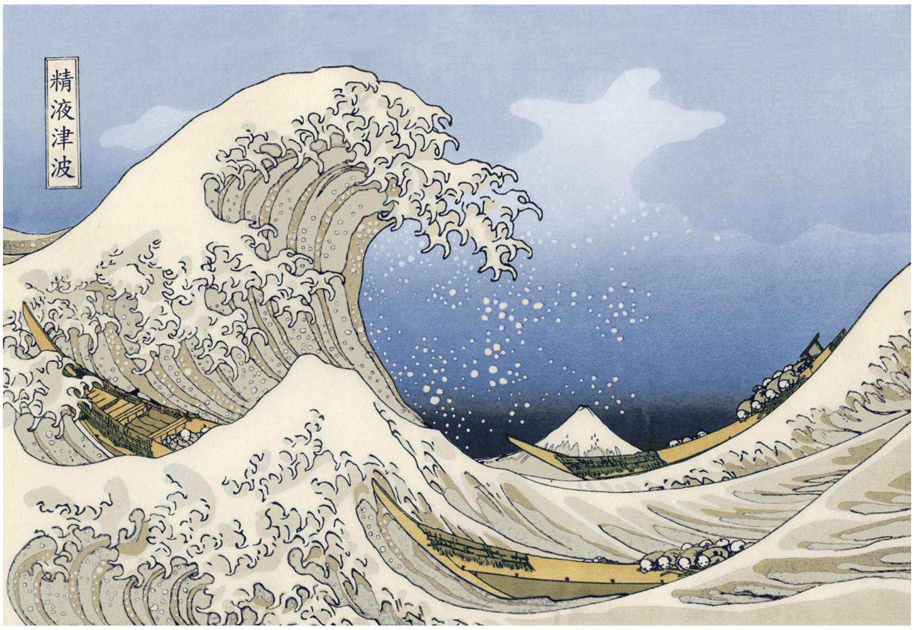
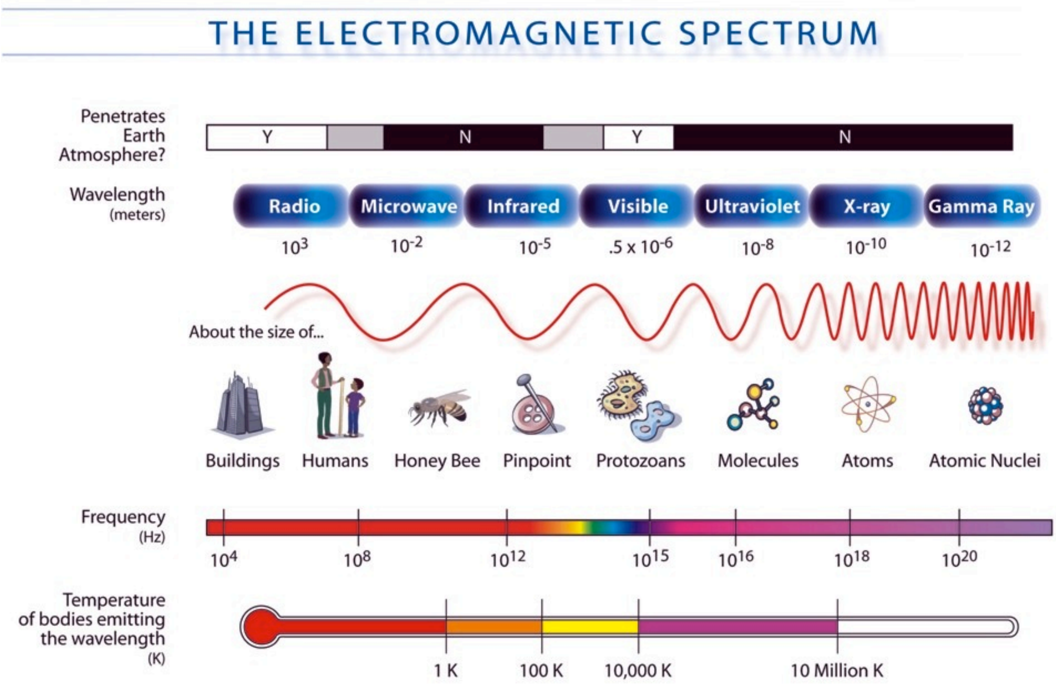
National 5 Physics

Waves





Throughout the Course, appropriate attention should be given to units, prefixes and scientific notation.

Prefix	Symbol	Notation	Operation
tera	T	10^{12}	x 1,000,000,000,000
giga	G	10^{9}	x 1,000,000,000
mega	M	10^{6}	x 1,000,000
kilo	k	10^{3}	x 1,000
centi	c	10^{-2}	/100
milli	m	10^{-3}	/1,000
micro	μ	10^{-6}	/1,000,000
nano	n	10^{-9}	/1,000,000,000
pico	p	10^{-12}	/1,000,000,000,000

In this section the prefixes you will use most often are milli (m), micro (μ), kilo (k), mega (M) and giga (G). It is essential that you use these correctly in calculations.

In Physics, the standard unit for time is the **second (s)** and therefore if time is given in milliseconds (ms) or microseconds (μs) it must be converted to seconds.

Example 1
a) A wave takes 40 ms to pass a point. How many seconds is this?

40 ms = 40 milliseconds = 40 x 10^{-3} s = 40/1 000 = 0.040 seconds.

b) A faster wave travels past in a time of 852 μs, how many seconds is this?

852 μs = 852 microseconds = 852 x 10^{-6} s = 852/1 000 000 = 0.000852 seconds.

In Physics, the standard unit for distance is the **metre (m)** and therefore if distance is given in kilometres (km) it must be converted to metres.

Example 2
A wave travels 26.1 km in 0.5 ms. How far in metres has it travelled?

26.1 km = 26.1 kilometres = 26.1 x 10^{3} m = 26.1 x 1 000 = 26 100 metres.

This unit involves calculations which use the term frequency, frequency has units of **hertz** (Hz) although often we meet the terms Megahertz and Gigahertz.

Example 3
A wave has a frequency of 99.5 MHz. How many Hz is this?

99.5 MHz = 99.5 Megahertz = 99.5 x 10^{6} Hz = 99.5 x 1 000 000 = 99 500 000 Hertz.

National 5 Physics

Waves

Contents

1. Wave parameters and behaviours

1.1. Energy can be transferred as waves.
1.2. Determination of frequency, wavelength, amplitude and wave speed for transverse and longitudinal waves.
1.3. Use of the relationship between wave speed, frequency, wavelength, distance and time.
1.4. Diffraction and practical limitations.
1.5. Comparison of long wave and short wave diffraction.

$$d = v\ t$$

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

$$v = f\lambda$$

Wave parameters and behaviours

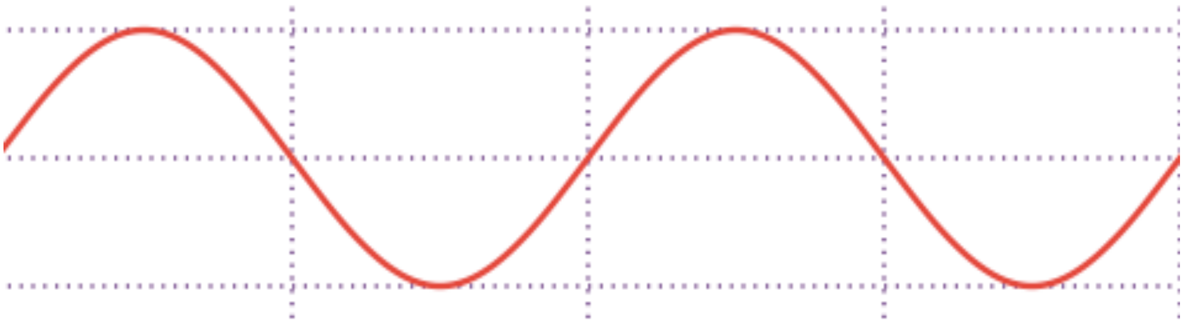
Types of wave

Waves are used to transfer energy. The substance the wave travels through is known as the medium. The particles of the medium oscillate around a fixed position but the energy travels along the wave. For example, consider waves at the beach. Seawater will move up and down as a wave passes through it but as long as the wave does not "break" there is no overall movement of any water.

There are two different types of waves you will meet in this course, transverse waves and longitudinal waves

In **transverse** waves the particles oscillate (vibrate) at right angles to the direction of energy transfer

direction of particles' motion

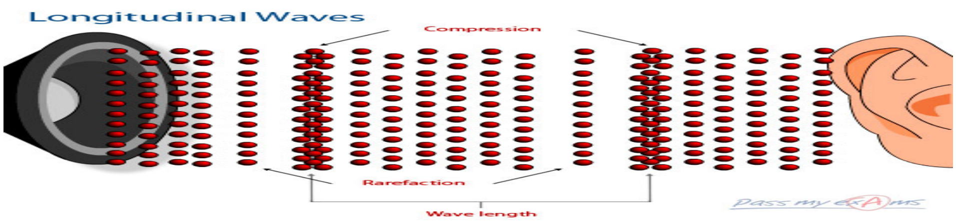


[1]

direction of the energy transfer

Examples are water waves, waves in a string, light, gamma rays, X-rays and all the other members of the Electromagnetic Spectrum (see below)

In **longitudinal** waves the particles oscillate in the same direction as the motion of the wave



direction of particles' motion

direction of energy transfer

Sound is an example of a longitudinal wave. Air particles are either squashed together to form a region of increased pressure or they are moved apart to make a region of decreased pressure.

[1] http://upload.wikimedia.org/wikipedia/commons/7/77/Waveforms.svg

Examples of Waves

All waves travel through some medium. As the wave travels it disturbs the medium through which it moves.

Mechanical Waves

Mechanical waves travel through a medium which is made up from some physical matter with particles (or molecules) in it. For example, when a water wave passes a particular point, some of the water bobs up and then down. For sound travelling through air it is the air particles that vibrate. The typical speed of a sound wave in air is 340 m/s although this varies a bit as the temperature and humidity of the air changes.

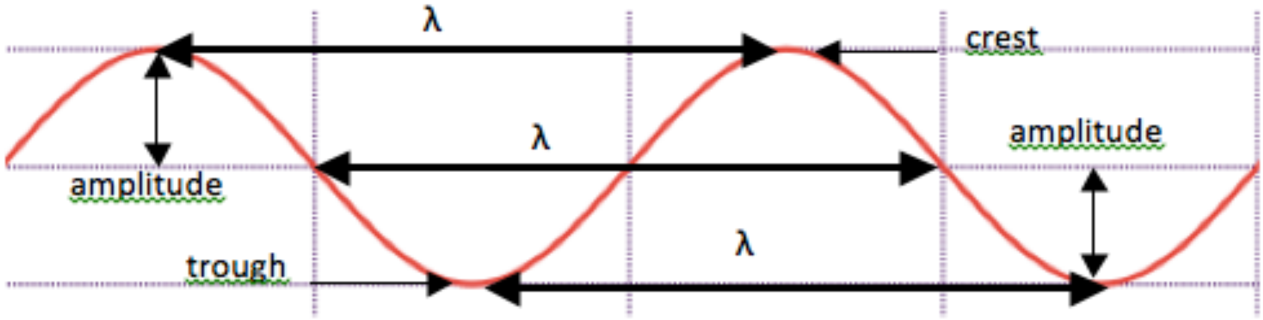
Electromagnetic Waves

Electromagnetic waves travel through two media, electric and magnetic fields. These waves cause disturbances in the electric and magnetic fields that can exist in all space. They do not need any particles of matter in order to travel, which is why light can travel through a vacuum. Different examples of electromagnetic waves are gamma rays, X-rays, ultraviolet, visible light, infrared, microwaves, TV waves and radio waves. They all travel at the same speed in a vacuum (3×10^8 m/s). This is usually referred to as the **speed of light** and is given the symbol ***c***. This very fast speed is the fastest that anything can travel.

Gravitational Waves

Research scientists are currently investigating a theory of gravity that involves gravitational waves. It has not been proven yet.

Properties of waves



Several important features of a wave are shown in the diagram. These are explained in the following table

Wave property	Symbol	Definition	Unit	Unit symbol
Crest		highest point of a wave		
Trough		lowest point of a wave		
Wavelength	λ	horizontal distance between successive crests or troughs	metre	m
Amplitude	A	half the vertical distance between crest and trough	metre	m
Wave Speed	v	distance travelled per unit time	metres per second	m/s
Period	T	the time it takes one wave to pass a point	seconds	s
Frequency	f	number of waves produced in one second	hertz	Hz

Wave Formulae

Wave Speed

The **distance** travelled by a wave travelling at a **constant speed** can be calculated using:

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

Symbol	Name	Unit	Unit Symbol
d	Distance	metre	m
v	Velocity or Speed	metres per second	m/s
t	Time	Seconds	s

Worked Examples

1. The crest of a water wave moves a distance of 4.0 metres in 10 seconds. Calculate the speed of this wave.

$$d = v\,t$$
$$4 = v \times 10$$
$$v = 4 / 10$$
$$v = 0.40 \text{ m/s}$$

Wave speeds can vary greatly from a few metres per second up to the speed of light. For example sound waves travel in air at around 340 m/s. The actual speed of a sound wave will depend on environmental factors like temperature and pressure. Light waves travel in air at 300, 000, 000 m/s (or 3×10^8 m/s). So light travels approximately 1 million times faster than sound in air.

Wave Frequency

The frequency of a wave is defined to be:

$$frequency = \frac{number\ of\ waves}{time\ for\ the\ waves}$$

Now consider the case for just one wave. The number of waves is one and the time taken is the Period. Hence,

$$frequency = \frac{1}{Period}$$

Using symbols, this becomes

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

Symbol	Name	Unit	Unit Symbol
f	Frequency	hertz	Hz
T	Period	second	s

Worked Examples

1. A certain breed of bat emits ultrasounds with a period of 23 μs. Calculate the frequency of the ultrasound.

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

$T = 23 \times 10^{-6}$ s

f = ?

$$f = \frac{1}{23 \times 10^{-6}}$$

f = 43.5 kHz

2. Given that a wave has a frequency of 50 Hz, calculate its period.

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

T = ?

f = 50 Hz

$$50 = \frac{1}{T}$$

T = 0.02 s

The Wave Equation

The other main formula related to waves is derived from the relationship between distance, speed and time.

distance = speed x time

For just one wave, the distance becomes one wavelength and time becomes one period.

wavelength = speed x period

But $\text{period} = \frac{1}{f}$

Therefore, $\text{wavelength} = \text{speed} \times \frac{1}{f}$ or $\lambda = \frac{v}{f}$

this can be rearranged to give an equation called the **wave equation**.

$$v = f\lambda$$

Symbol	Name	Unit	Unit Symbol
v	Velocity or Speed	metres per second	m/s
f	Frequency	hertz	Hz
λ	Wavelength	metre	m

Worked Example

Microwaves have a frequency of 9.4 GHz. Calculate their wavelength.

$v = 3 \times 10^8$ m/s
$f = 9.4 \times 10^9$ Hz
$\lambda = ?$

$v = f\lambda$

$3 \times 10^8 = 9.4 \times 10^9\ \lambda$

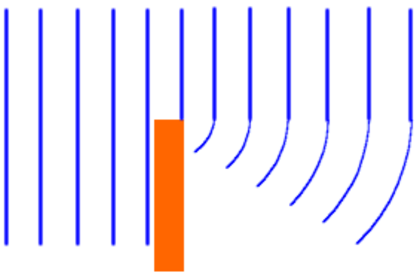
$\lambda = 3 \times 10^8 / 9.4 \times 10^9$

$\lambda = 0.032$ m

Diffraction

Waves can 'spread' in a rather unusual way when they reach a gap in a barrier or the edge of an object placed in the path of the wave - this is called **diffraction**.

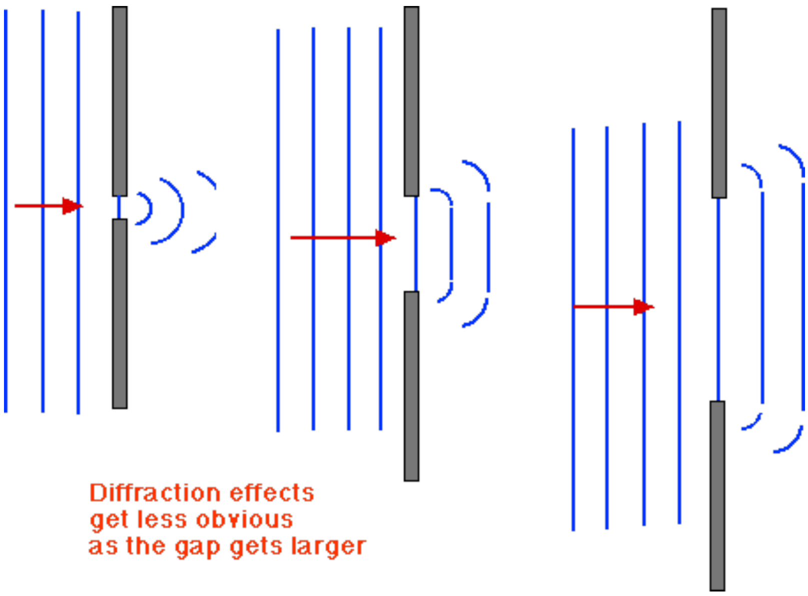
Diffraction can be clearly observed with water waves as shown in the image to the right. Notice that the parallel crests of the water waves become circular as they spread out on passing through the gap between the two harbour walls.



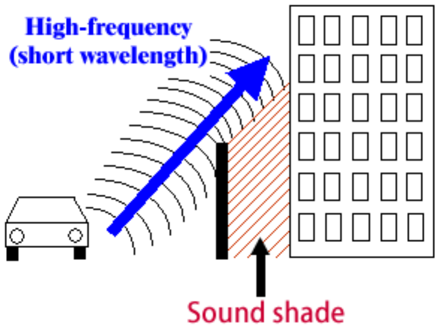
Sea waves incident on a breakwater are found to spread into the region behind the wall where we would expect the sea to be flat calm. This is an example of diffraction at an edge.

Diffraction will only be significant if the size of the gap or object is matched to the size of the wavelength of the waves.

- When the size of the gap or object is **much larger than the wavelength of the waves,** the waves are only **slightly** diffracted.
- When the size of the gap or object is **nearly the same as the wavelength of the waves,** the diffraction effect is **greatest**



Waves other than water are also affected by diffraction

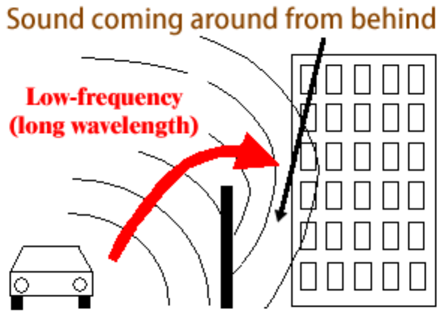


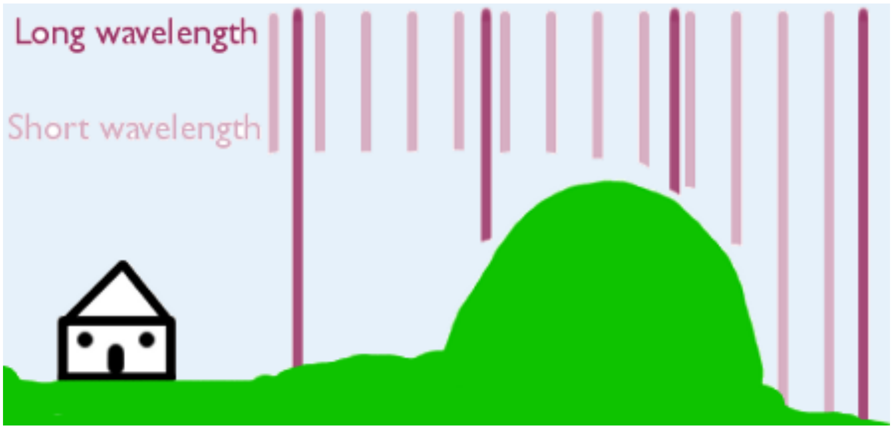
Sound

Sound can diffract through a doorway or around buildings. Lower pitched sounds travel better than high-pitched sounds. This is because low-pitched sounds have a long wavelength compared with the width of the gap, so they spread out more.

Ultrasound

Ultrasound is sound with a high frequency. It has a very short wavelength compared with most structures in the body, so there is very little spreading. This makes sharp focusing of ultrasound easier, which is good for medical scanning.





Radio waves

Long wave radio signals are much less affected by buildings and tunnels than short wave radio signals or VHF radio signals. Because of diffraction, long wave radio signals (e.g. Radio 4, λ=198 m) can sometimes be received in the shadow of hills when the equivalent VHF broadcast can not.

Light

Light has a very short wavelength compared with most everyday gaps such as windows and doors. There is little obvious diffraction, so it produces sharp shadows.

2. Electromagnetic spectrum
    2.1. Relative frequency and wavelength of bands of the electromagnetic spectrum with reference to typical sources and applications.
    2.2. Qualitative relationship between the frequency and energy associated with a form of radiation.
    2.3. All radiations in the electromagnetic spectrum travel at the speed of light.

$$\boldsymbol{v} = \boldsymbol{f}\,\boldsymbol{\lambda}$$

$$\boldsymbol{E} \;\alpha\; \boldsymbol{f}$$

Electromagnetic spectrum

Frequency and Wavelengths

Electromagnetic waves travel through two media, electric and magnetic fields. These waves cause disturbances in the electric and magnetic fields that can exist in all space. They do not need any particles of matter in order to travel, which is why they can travel through a vacuum. Electromagnetic waves travel at a very high speed. In a vacuum this speed is three hundred million metres per second – i.e. **300 000 000 m/s or 3 x 10^8 m/s**. This is usually referred to as the speed of light and is given the symbol ***c***. This is a universal speed limit – nothing can travel faster than c.

Remember that the wave equation states

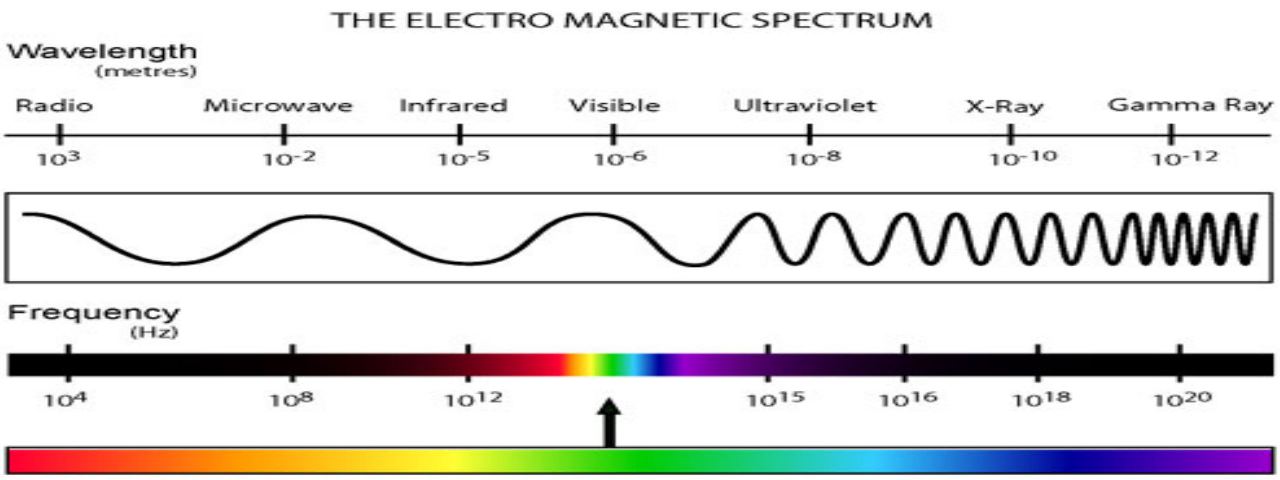
$$v = f\lambda$$

So if v is fixed, it is possible to have a whole family of electromagnetic waves whose frequencies are different but are always related by this equation, e.g. as f doubles, so λ halves such that the equation

$$c = f\lambda$$

is always true.

This family of waves is known as the electromagnetic spectrum and consists of Radio Waves, Microwaves, Infrared, Visible Light, Ultraviolet, X-Rays and Gamma Rays. The image below shows the spectrum arranged in order of increasing frequency (i.e. decreasing wavelength).



Notice how small the section is for visible light compared to the width of the whole spectrum. The colour order of the visible spectrum is expanded in the lowest section of the image and is shown in the decreasing wavelength or increasing frequency order

Red – **O**range – **Y**ellow – **G**reen - **B**lue – **I**ndigo - **V**iolet (**ROY G BIV**)

Uses and sources of electromagnetic radiation

Each member of the electromagnetic spectrum transfers energy from source to receiver/detector and as such may be called electromagnetic radiation. radiation and a typical use for each of them.

Type	Source	Typical use
Gamma Radiation	Nuclear decay, Cosmic Rays & some Stars	Killing cancer cells
X-Rays	Man-made sources & some Stars	Medical images of bones
Ultraviolet Radiation	Ultra-Hot objects, Electrical discharges/sparks, Starlight	Sunbeds
Visible Light	Very-Hot objects (lamps), Electrical discharges/sparks, Starlight	Seeing
Infrared Radiation	All hot objects, Starlight	Optical fibre communication, Remote controls, "Night" vision
Microwaves	Electrical circuits, some Stars	Cooking, Mobile Phone signals
Radio Waves	Electrical circuits, some Stars	Television signals

Frequency and Energy

A beam of electromagnetic radiation delivers energy in 'packets' called photons.
The **energy** delivered by each photon **increases with** the **frequency** of the electromagnetic waves. This means that gamma photons have the most energy, and radio photons the least.

Energy of the photon is directly proportional to frequency:

$$E \; \alpha \; f$$

This important relationship is studied in greater detail in the Higher Physics course.

3. Light

3.1. Reflection including identification of the normal, angle of incidence and angle of reflection.
3.2. Refraction of light including identification of the normal, angle of incidence and angle of refraction.
3.3. Description of refraction in terms of change of wave speed.
3.4. Ray diagrams for convex and concave lenses

Light

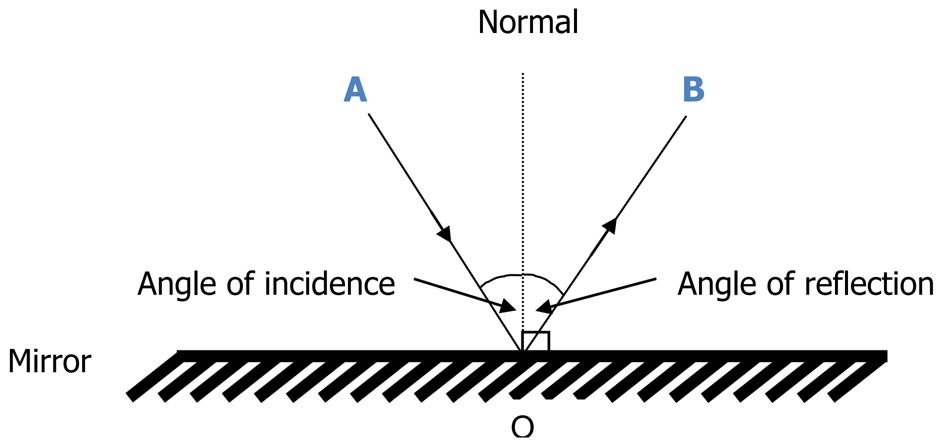
Wave behaviours

It has already been shown that waves **diffract**, or spread out, when they meet a gap or edge of an object. In addition, waves can be shown to **reflect and refract**. The next two topics of this unit cover reflection and refraction. It is particularly useful to study the reflection and refraction of visible light waves, though any waves can exhibit these phenomena.

Reflection

The diagram below shows the path of a ray of light when reflected off a mirror.
Some simple rules:

- A **ray** is a line with an arrow to show the wave direction.
- The **normal is a dotted line drawn at 90^o to the mirror** at the point where the ray of light hits the mirror.
- All angles are measured **between the ray and the normal.**
- The incoming ray is called the **incident ray** and this makes the **angle of incidence** with the normal.
- The outgoing ray is called the **reflected ray** which travels at the **angle of reflection** to the normal.

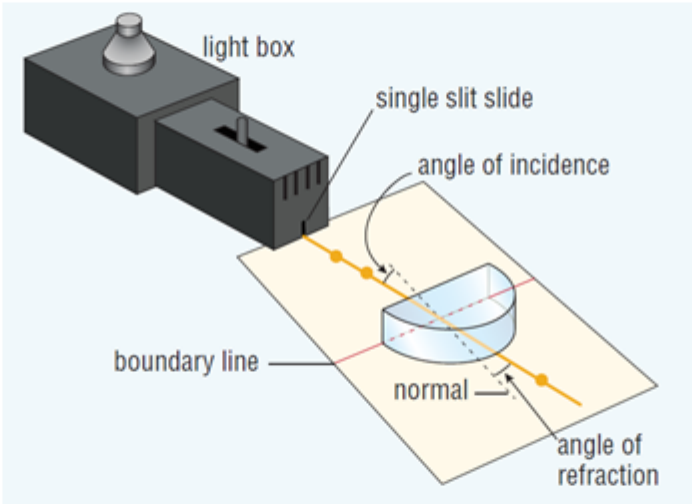


It is very important to **always put arrows** on any diagram that contains rays of light. Otherwise you would not be able to tell in which direction the light was travelling.

Refraction

The wave speed depends on the medium in which the wave travels. When a wave changes medium it's changes speed. This change of speed is called **refraction**.

In the diagram below the incident light is shown passing from air into a semicircular glass block.

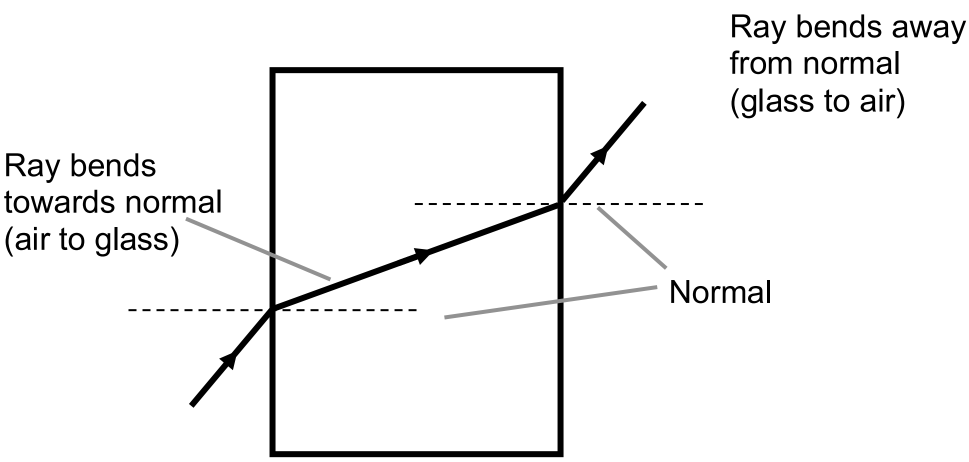


In addition to changing speed the wave changes direction inside the glass block. This change of direction only happens when the angle of incidence is non-zero, i.e. the incident ray is not along the normal. Both these changes are due to refraction.

Remember that the speed of light in a vacuum is the fastest speed possible. The speed of light in air is almost the same as in vacuum. The **light slows down as it enters the glass** and speeds up again as it leaves.

For **refraction**:

- Bigger speed = Bigger Angle between the ray and the normal
- Smaller speed = Smaller Angle between the ray and the normal



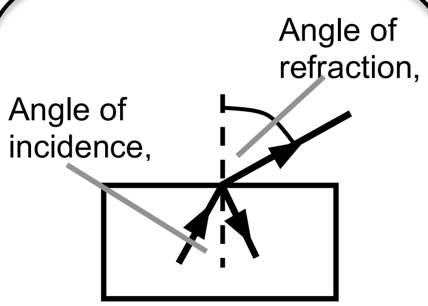
Total Internal Reflection and Critical Angle

There is a link between refraction and a phenomenon called **Total Internal Reflection.**

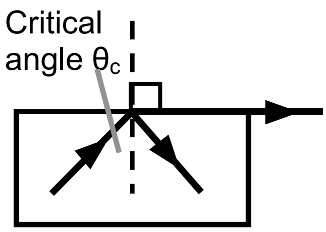
It can be shown that:

- when light travels from glass into air the direction of travel is changed (refracted) away from the normal.
- when the angle of refraction is exactly 90^0 then the angle of incidence is know as the **Critical Angle** (θ_c).
- when the angle of incidence is less than the critical angle most of the light will be refracted out into the air and some will be reflected inside the glass.
- when the angle of incidence is bigger than the critical angle the light does not pass into the air. **All** the light is **reflected** (not refracted) back into the glass.

Total Internal Reflection is used in optical instruments including periscopes, binoculars and fibre optics.



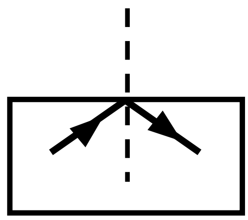
Angle of incidence is less than the critical angle.
($\theta_i < \theta_c$)



Angle of incidence is equals the critical angle.

Angle of refraction = 90^0

($\theta_i = \theta_c$)



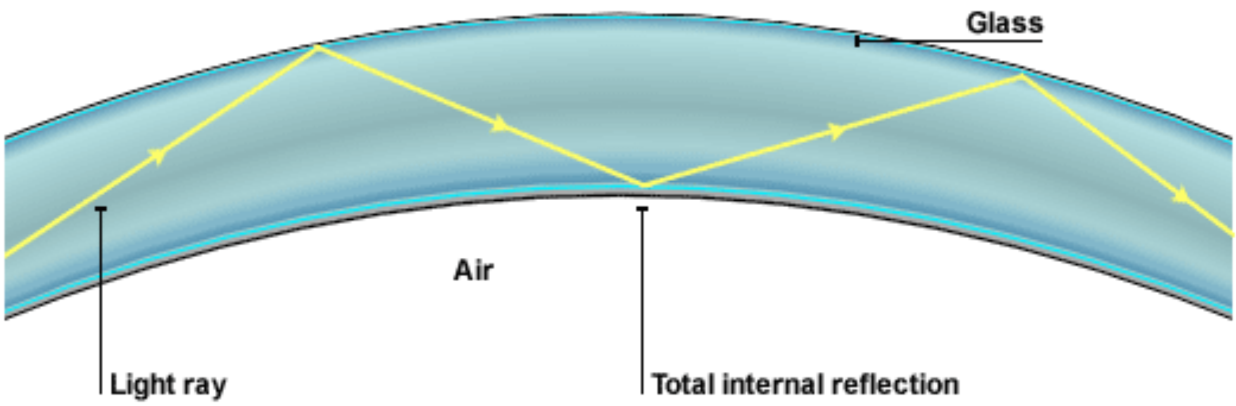
Angle of incidence is greater than the critical angle.

Ray undergoes total internal reflection.

($\theta_i > \theta_c$)

Fibre Optics

A fibre optic is a thin thread of glass. Light entering at one end always strikes the outer edges of the glass at **large angles of incidence** so that the light is always totally internally reflected back into the glass. Consequently the light never escapes and is trapped inside the glass fibre.



The fibre can be made pliable enough so that it can bend round corners. Thus, light inside the fibre optic can be made to bend round corners.

This is extremely useful:

- In medicine it is used in a "fibrescope" that allows a doctor to see inside a patient's body without having to cut them open.
- In telecommunications it is used to send pulses of laser light from one place to another, allowing enormous amounts of information to be transmitted very quickly.

Slow Down – Speed of Light in an Optic Fibre

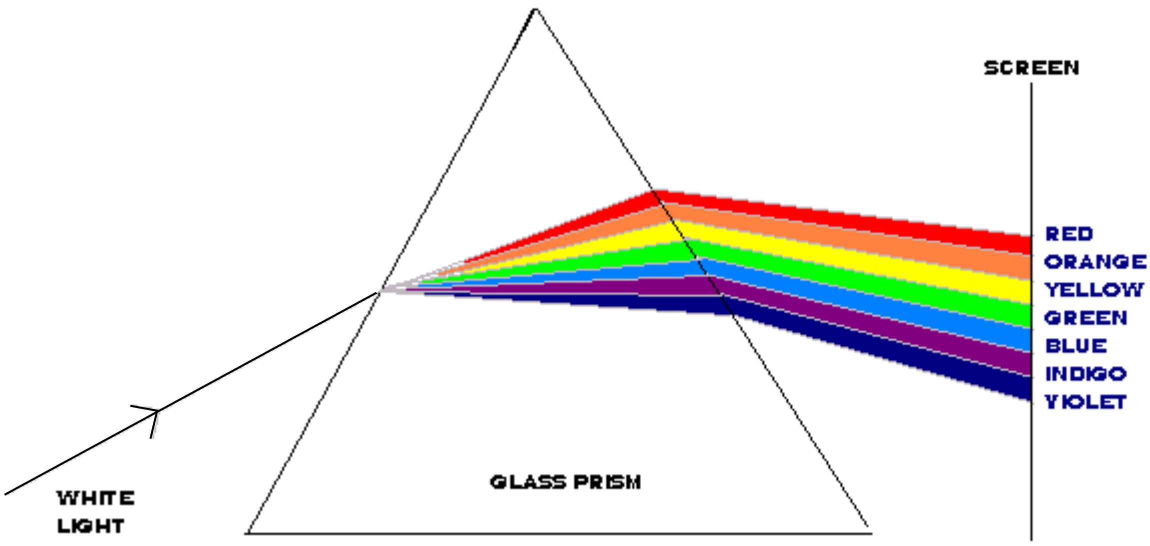
Speed of light inside a fibre optic is **2×10^8 m/s**.

If fibre optics are used in telecommunications then the information transmitted along the fibres as pulses of light will lose much less energy than if the information was transmitted using cables. As a result booster stations are required less frequently.

Refraction and frequency

The splitting of white light into different colours happens because each colour has its own unique frequency. *(All colours of light travel at the same speed)*

The amount of refraction (bending) depends on the frequency of the light and so each colour is bent by different amounts.



Dispersion of light by a prism

- **Red light** has the **lowest frequency** and so is **bent the least**.
- **Violet light** has the **highest frequency** and so is **bent the most**.

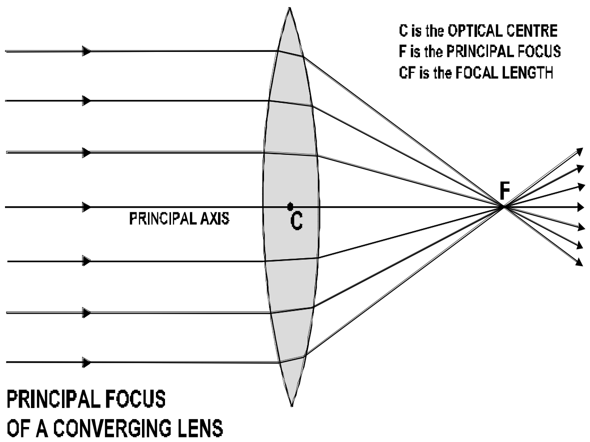
Colour	Red	Orange	Yellow	Green	Blue	Indigo	Violet
Wavelength (nm)	650	590	570	510	475	445	400
Frequency (THz)	462	508	526	588	382	674	750
Speed (m/s)	3×10^8	3×10^8	3×10^8	3×10^8	3×10^8	3×10^8	3×10^8

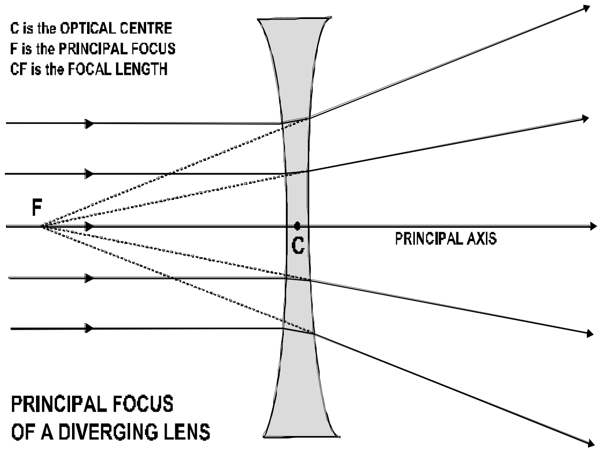
Lenses

We may make use of refraction to create lenses which alter the shape of a beam of light. There are two different types of lens.

- **Converging:** this type of lens focuses rays together**.**
- **Diverging:** this type of lens spreads rays out.

The diagrams below show rays of light approaching these two types of lens.

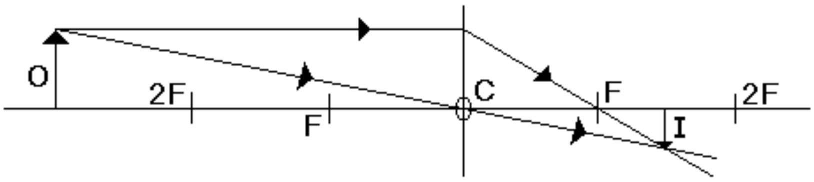




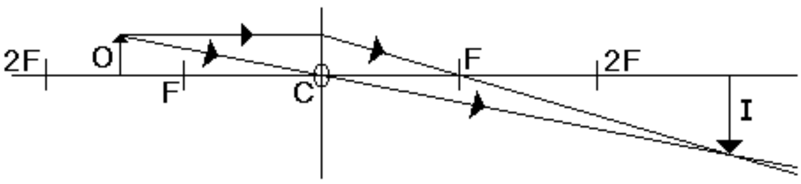
If the rays entering a lens are parallel then where they cross over is called the **principle focus.**

The distance from the centre of the lens to the principle focus is called the **focal length**.

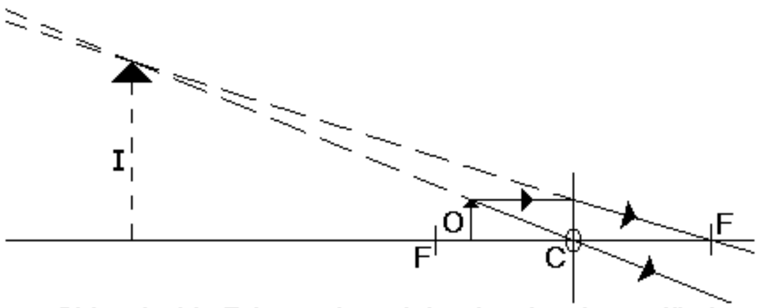
The greater the curvature of the lens, the shorter the focal length of the lens.



Object beyond 2F, image is inverted, real and diminished



Object between2F and F, image is inverted, real and magnified.



Object inside F, image is upright, virtual and magnified.

Images formed by convex lenses.

Tutorial Questions

The Nature of Waves

1. Explain, using a diagram, the difference between a transverse and longitudinal wave.

2. What type of waves are the following:
   i) sound waves
   ii) water waves
   iii) light waves.

3. A football is stuck, floating, in the middle of a pond. The owner finds a stick and hopes to use it to retrieve the ball. He can't decide whether to throw the stick at the ball, or use the stick to make waves in the water. Which would you recommend and why?

4. Explain why sound travels quicker in solids and liquids than gases. (Hint – think about the arrangement of particles in solids and liquids compared to gases.)

5. Explain why sound cannot travel through a vacuum, like outer space.

Speed of Waves

1. Thunder is heard 20 seconds after a lightning flash. If the speed of sound is 340 m/s, how far away is the storm?

2. Explain why, during a thunderstorm, you see the lightning before you hear the thunder.

3. On a day when the speed of sound in air is 330 m/s, how long would sound take to travel a distance of 1.6 km?

4. During a thunderstorm it is noticed that the time interval between the flash of lightning and the clap of thunder gets less. What does this tell you about the storm?

5. Ten pupils are standing on Calton Hill, looking at Edinburgh Castle. They measure the time difference between seeing the smoke from the one o'clock gun and hearing the bang. The measured times are 3.8 s, 4.2 s, 4.0 s, 3.8 s, 4.4 s, 3.8 s, 4.0 s, 4.2 s, 3.6 s, and 4.2 s.
   a) Calculate the average time for the group.
   b) Calculate the distance from the Castle to Calton Hill if the speed of sound is 330 m/s.

6. An explosion in Grangemouth could be heard in South Queensferry one minute later. Given they are 20 km apart, calculate the speed of sound in air.

7. On a day when the speed of sound is 330 m/s, how long would the sound take to travel a distance of 14.85 km?

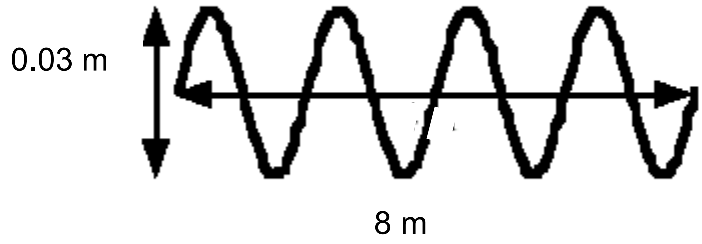
8. In a race the runners are different distances away from the starter. They will hear the starting horn at different times. Using the speed of sound as 340 m/s, calculate the time difference in hearing the horn for two runners who are 5 m and 15 m from the starter.

9. Calculate how long it would take light to travel from the sun to the earth, a distance of 1.49×10^8 km.

10. How long will it take a radio signal to travel from Britain to Australia, a distance of 1.8×10^4 km.

Wave Formulae

1. The diagram below represents a wave 0.2 s after it has started.



Calculate the following quantities for this wave:
a) wavelength
b) amplitude
c) frequency
d) speed.

2. A swimming pool is to have a wave-making machine installed. The time taken for a wave to travel the length of the 50 m pool has to be 20 s and the wavelength has to be 4 m.
   a) Calculate the speed of the waves.
   b) Calculate the required frequency of the waves.

3. Wave A has a wavelength of 6 cm and a frequency of 50 Hz. Wave B travels 250 m in 1 minute 40 seconds. Which wave travels faster and by how much?

4. 40 waves are found to pass a point in 20 s. If the waves have a wavelength of 0.015 m, calculate their speed.

5. Calculate the wavelength of a wave of frequency 0.1 Hz and speed 5 m/s.

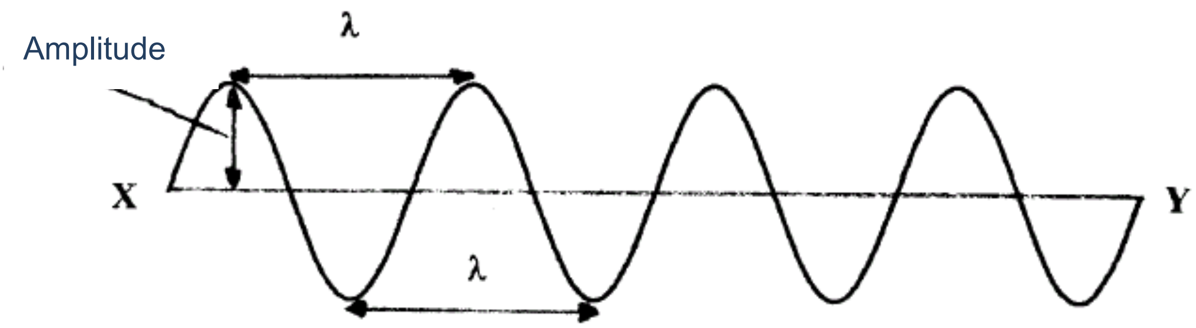
6. State what is meant by the period of a wave.

7. If the speed of a water wave is 0.6 m/s and the wavelength of each wave is 6 cm, calculate
   a) the frequency
   b) the period of the wave.

8. Waves of wavelength 5 cm travel 120 cm in one minute. Find their
    a) speed
    b) frequency
    c) period.

9. A sound generator produces 25 waves every 0.1 s. If the speed of sound is 330 m/s, find:
    a) the frequency
    b) the period of the waves
    c) the wavelength of the sound.

10. In the diagram below the distance between X and Y is 10 m.



If 20 waves pass a particular point in 5 s, find
    a) the wavelength
    b) the frequency and
    c) the period of the wave.

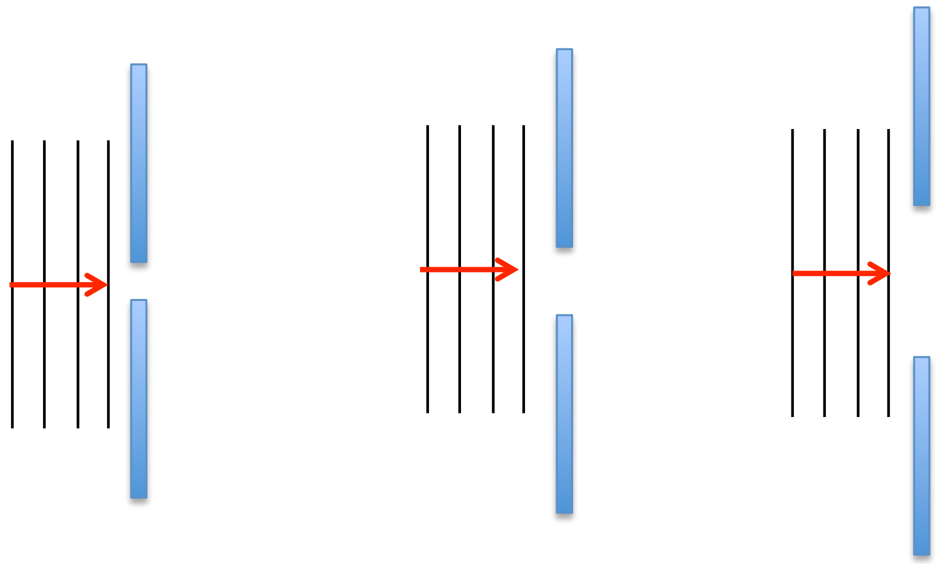
11. Tsunami is the name given to the very long waves on the ocean generated by earthquakes or other events which suddenly displace a large volume of water. The wave speed depends upon wavelength and the depth of the water for tsunamis at sea. Characteristic data is shown in the table.

    Find the largest and smallest frequency for these tsunami waves.

Depth (metre)	Velocity (km/h)	Wavelength (km)
7000	943	282
4000	713	213
2000	504	151
200	159	48
50	79	23
10	36	10.6

Diffraction

1. Sketch the diffraction patterns formed in the following circumstances;



2. Elephants can communicate with each other across distances of several kilometres, even when there is dense vegetation in the way and they cannot see each other. They do this by making low pitched noises. How does the sound get through? Why would this not work for high-pitched sounds?

Electromagnetic Spectrum

1. Complete the following paragraph.

   The part of the electromagnetic spectrum with the longest wavelength is........1........ Between X-ray and visible light in the electromagnetic spectrum is ....2........ Radiation. Some radioactive isotopes emit ....3......... radiation. Signals can be sent from remote controls to a television by ....4....... Radiation.

2. Name a type of electromagnetic radiation that
   a) is visible to the eye
   b) is emitted by hot objects
   c) is diffracted by hills
   d) is used for imaging inside the body
   e) causes tanning
   f) kills bacteria
   g) is used by mobile phones
   h) can cook food
   i) has the highest energy
   j) has the lowest energy associated with it.

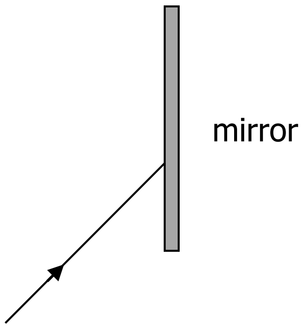
3. How far will radio waves travel in a) 2 ms b) 0.25 ms c) 1 μs.

4. Calculate the wavelength of the electromagnetic waves whose frequencies are a) 5 GHz b) 4 MHz c) 200 GHz.

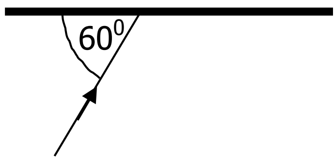
5. Calculate the transmission frequency of Radio Scotland broadcasting on 810 m on the Medium waveband. Give your answer in MHz.

Reflection Tutorial

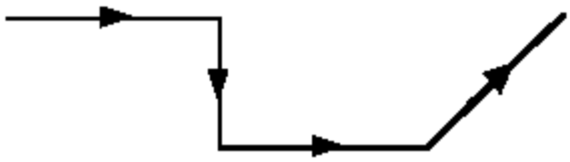
1. Complete the diagram below, labelling clearly
   a) the angle of incidence
   b) the angle of reflection
   c) the normal.



   d) What is the angle of reflection in the diagram below?



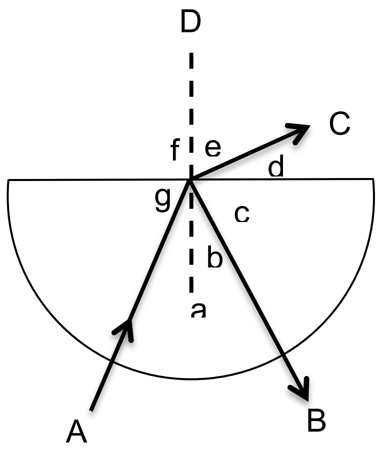
2. The diagram shows the path of a ray of light. The direction of the ray was manipulated using mirrors, but these have been left out. Complete the diagram by placing the mirrors in exactly the correct position.



Tutorial on Refraction

1. Identify the following on the diagram shown.

    i. the incident ray
    ii. the reflected ray
    iii. the refracted ray
    iv. the normal
    v. the angle of incidence
    vi. the angle of refraction
    vii. the angle of reflection.



2. Complete the following diagrams to show how the rays would pass through the glass objects.

a) b) c) d)

e) For d) above, how would your diagram be different if the ray was passing into a block filled with water rather than solid glass?

Total Internal Reflection and Critical Angle

1. Describe an experiment to demonstrate total internal reflection. You should include a list of apparatus, a diagram, and an explanation of how you would use the equipment.

2. Explain, with the aid of a diagram, what is meant by 'the critical angle'.

3. a) Describe the principle of operation of an optical fibre transmission system.

    b) Optical fibre systems use repeater stations. What is the purpose of repeater stations?

    c) Light signals travel through glass at a speed of 2×10^8 m/s. How long would it take to travel between two repeater stations which were 100 km apart?

Solutions to numerical problems

The Nature of Waves

-

Speed of Waves

1. 6 800 m
2.
3. 4.8s
4.
5. a) 4.0 s
   b) 1 320 m
6. 330 ms^{-1}
7. 45 s
8. 0.3 s
9. 497 s (or 8.3 minutes)
10. 0.06 s

Wave Formulae

1. a) 2 m
   b) 0.015 m
   c) 20 Hz
   d) 40 ms^{-1}.
2. a) 2.5 ms^{-1}
   b) 0.625 Hz.
3. Wave A by 0.5 ms^{-1}
4. 0.03 ms^{-1}
5. 50 m
6. -
7. a) 10 Hz
   b) 0.1 s
8. a) 0.02 ms^{-1}
   b) 0.4 Hz
   c) 2.5 s
9. A sound generator produces 25 waves every 0.1 s. If the speed of sound is 330 m/s, find:
   a) 250 Hz
   b) 0.004 s
   c) 1.32 m
10. a) 2.5 m
    b) 4 Hz
    c) 0.24 s
11. 3.435 Hz, 3.313Hz

Diffraction

1. -
2. -

Electromagnetic Spectrum

1. -
2. -
3. a) 600 km b) 75 km c) 300 m
4. a) 0.06 m b) 4 75 m c) 0.0015 m.
5. 0.37 MHz

Reflection Tutorial

1. -
2. -

Tutorial on Refraction

1. -
2. -

Total Internal Reflection and Critical Angle

1. -
2. -
3. a) -
   b) -
   c) 5×10^{-4} s