WAVES AND OPTICS

The knowledge and understanding for this unit is given below:

Waves

1. State that a wave transfers energy.
2. Describe a method of measuring the speed of sound in air, using the relationship between distance, time and speed.
3. State that radio and television signals are transmitted through air at 300 million m/s and that light is also transmitted at this speed.
4. Carry out calculations involving the relationship between distance, time and speed in problems on water waves, sound waves, radio waves and light waves.
5. Use the following terms correctly in context: wave, frequency, wavelength, speed, amplitude, period.
6. State the difference between a transverse and longitudinal wave and give examples of each.
7. Carry out calculations involving the relationship between speed, wavelength and frequency for waves.
8. State in order of wavelength the members of the electromagnetic spectrum: gamma rays, X-rays, ultraviolet, visible light, infrared, microwaves, TV and radio.

Reflection

1. State that light can be reflected.
2. Use correctly in context the terms: angle of incidence, angle of reflection and normal when a ray of light is reflected from a plane mirror.
3. State the principle of reversibility of a ray path.
4. Explain the action of curved reflectors on certain received signals.
5. Explain the action of curved reflectors on certain transmitted signals.
6. Describe an application of curved reflectors used in telecommunications.
7. Explain, with the aid of a diagram, what is meant by total internal reflection.
8. Explain, with the aid of a diagram, what is meant by 'the critical angle'.
9. Describe the principle of operation of an optical fibre transmission system.

Refraction

1. State what is meant by the refraction of light.
2. Draw diagrams to show the change in direction as light passes from air to glass and glass to air.
3. Use correctly in context the terms angle of incidence, angle of refraction and normal.
4. Describe the shapes of converging and diverging lenses.
5. Describe the effect of a converging and diverging lens on parallel rays of light.
6. Draw a ray diagram to show how a converging lens forms the image of an object placed at a distance of:
    a) more than two focal lengths
    b) between one and two focal lengths
    c) less than one focal length in front of the lens.
7. Carry out calculations involving the relationship between power and focal length of a lens.
8. State the meaning of long and short sight.
9. Explain the use of lenses to correct long and short sight.

Units, prefixes and scientific notation

1. Use SI units of all quantities appearing in the above Content Statements.
2. Give answers to calculations to an appropriate number of significant figures.
3. Check answers to calculations.
4. Use prefixes (m,k,M,G).
5. Use scientific notation.

WAVES

Waves can transfer **energy**, e.g. water waves can transfer energy across the water.
Radio and television signals are waves that travel through the air at 300 million m/s. (3×10^8 m/s). This is the same speed as the speed of light.
The light from a thunder storm is seen before the sound of the thunder since the speed of light is much greater than the speed of sound.

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

$$\underset{\text{distance travelled (m)}}{s} = \underset{\text{speed (m/s)}}{v}\,\underset{\text{time taken (s)}}{t}$$

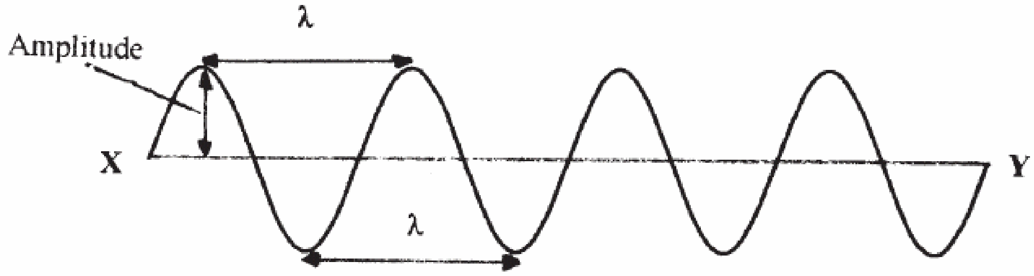
Note: these notes will have metres per second written as m/s. However you can use the negative index, e.g. m s^{-1}, if you prefer.

The **frequency, f,** of a wave is the number of waves that pass a point in 1 s.
Frequency is measured in hertz (Hz).

The **wavelength, λ,** of a wave is the horizontal distance between two adjacent troughs or crests or any two corresponding points on the wave.
Wavelength is measured in metres (m).

The **amplitude** of a wave is half the vertical distance between a trough and a crest.
Amplitude is measured in metres (m).

The **period, T,** of a wave is the time it takes one wave to pass a point.
Period is measured in seconds (s).



Example
In the diagram above the distance between X and Y is 10 m. If 20 waves pass B in 5 s, find a) the wavelength b) the frequency and c) the period of the wave.

a) *XY = 4 complete wavelengths = 10 m.* $\lambda = {}^{10}/_{4} = 2.5m$

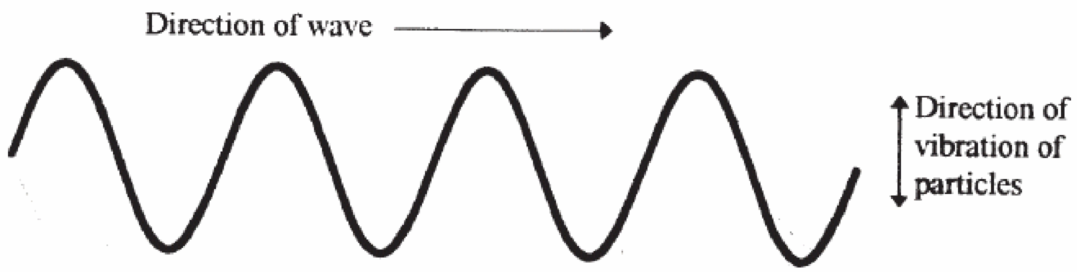
b) *In 5 s the number of waves that pass Y = 20*
In 1 s the number of waves that pass Y = ${}^{20}/_{5} = 4$ *Frequency, f = 4 Hz*

c) *20 waves pass B in 5 s*
Time for 1 wave = ${}^{5}/_{20} = 0.25$ *s* *Period of wave = 0.25 s*

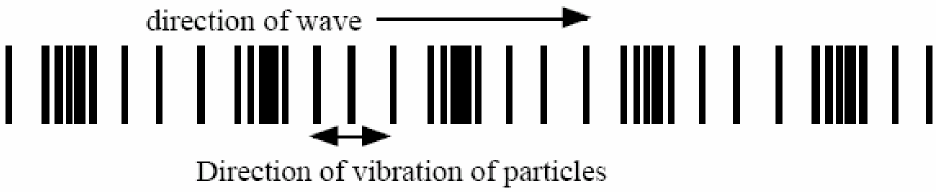
Transverse and longitudinal waves

A transverse wave is one in which the particles making up the wave vibrate at 90° to the direction of the wave.

Examples of transverse waves are water waves, light, gamma rays, X-rays and all members of the electromagnetic spectrum.



A longitudinal wave's particles vibrate along the same line as the direction of the wave. Sound travels as a longitudinal wave.



Speed, frequency and wavelength.

The relationship between these is

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

This is known as the wave equation.

The Electromagnetic Spectrum

Listed below are the members of the electromagnetic spectrum.

Gamma rays, X-rays, ultraviolet, visible light, infrared, microwaves, TV and radio.

Low λ → **increasing λ** → Long λ

High f ← **increasing f** ← Low f

Each member travels at the speed of light = 3 x 10^8 m/s

Example

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

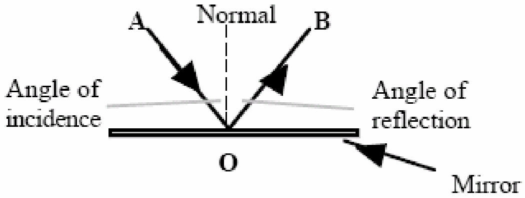
$$v = f\lambda$$

$$\lambda = \frac{v}{f} = \frac{3 \times 10^8}{9.4 \times 10^9} = 3.2 \times 10^{-2} \ (= 3.2 \text{ cm})$$

REFLECTION

Light

The diagram below shows the path of a ray of light when reflected off a mirror.
The normal is a line drawn at 90^0 to the mirror.

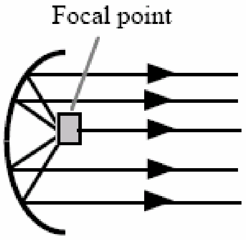


Angle of incidence = Angle of relection

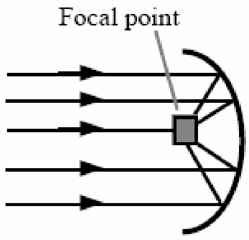
The **principle of reversibility of light** states that a ray of light which travels along any particular path from some point A to another point B travels by the same path when going from B to A, e.g. in the above diagram the ray travels from A to O to B. If the direction was reversed then the ray would follow B to O to A.

Curved Reflectors

These can be used in transmitters and receivers of waves, e.g. sound, infrared, microwaves, TV signals and satellite communication.



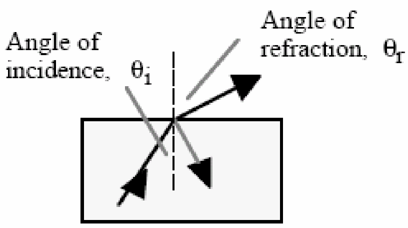
Transmitter placed at focal point.



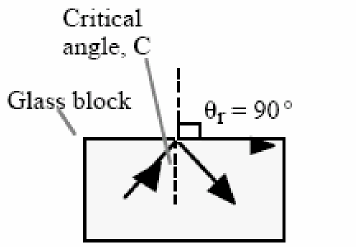
Receiver placed at focal point

Total Internal Reflection and Critical Angle

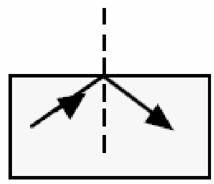
When light travels from glass to air, if the angle of incidence in glass gives an angle of refraction of 90° in air, then the angle in glass is known as the **critical angle, C.**
Beyond this angle there will be total internal reflection.



Angle of incidence less than critical angle
(θ_i < C)



Angle of incidence = critical angle
Angle of refraction = 90 °
(θ_i = C)



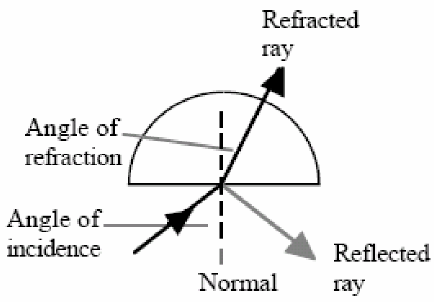
Angle of incidence greater than critical angle. Ray undergoes total internal reflection
(θ_i > C)

Optical Fibres

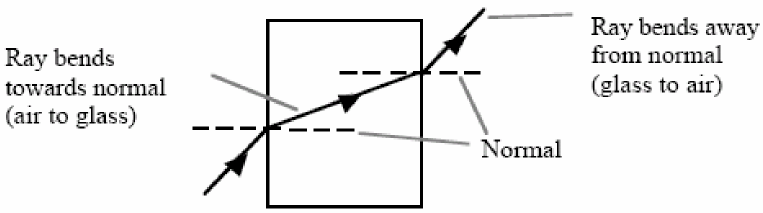
Light can travel through these by being totally internally reflected.

REFRACTION

When light passes from one medium to another, e.g. air to glass, part is reflected back into air and the rest passes through the medium with a change in direction.

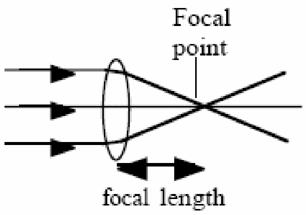


The light is said to be bent or **refracted** as it passes through the glass. This is due to the speed of light being less in glass than air. The ray will bend **towards** the normal.
The speed of a light ray increases as it leaves the medium. When a ray of light's speed increases then it will bend **away** from the normal.

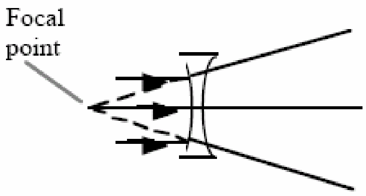


Lenses

The ray diagrams below show the effect of converging and diverging lenses on parallel rays of light.



Converging lens



Diverging lens

Image formation by a converging lens

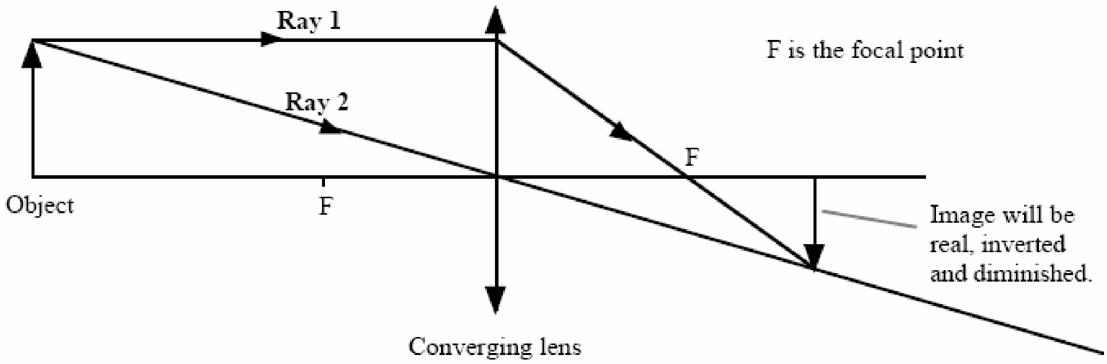
Images can be described as:

- **real or virtual**
- **inverted or upright**
- **magnified, same size or diminished.**

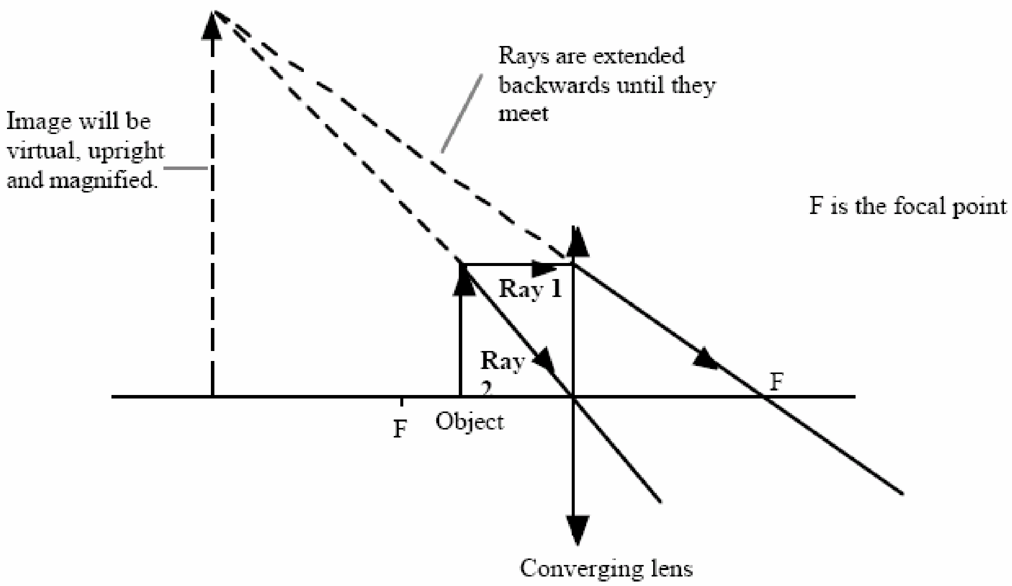
Ray Diagrams

- Choose an appropriate scale (better done on graph paper).
- Draw ray 1 from the tip of the object parallel to the axis, passing through the focal point of the lens.
- Draw ray 2 from the tip of the object, passing through the centre of the lens.
- Where the two rays meet will be the image of the tip of the object.

Object distance greater than twice the focal length



Object distance less than the focal length



The type of image formed is dependent on the object distance from the lens.

OBJECT POSITION FROM LENS	TYPE OF IMAGE
More than two focal lengths	Real, inverted and diminished
Between one and two focal lengths	Real, inverted and magnified
Less than one focal length	Virtual, upright and magnified

Power of a Lens

This is given by

$$\boxed{P = \frac{1}{f}}$$

focal length measured in metres

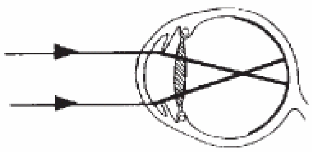
The power is measured in **dioptres (D)**.
A converging lens has a positive power.
A diverging lens has a negative power.

Example
Calculate the power of a converging lens with a focal length of 20 cm.

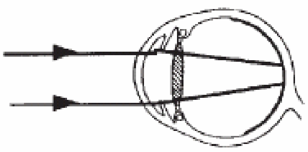
$f = 0.2\ m \qquad P = \frac{1}{f} = \frac{1}{0.2} = 5D$

Short and Long Sight

People who are short sighted have difficulty seeing distant objects. The image is formed short of the retina of the eye.

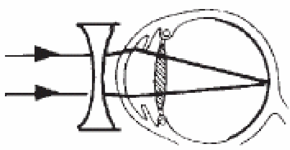


Long sighted people can see distant objects but have difficulty seeing near objects. The image would be formed behind the retina of the eye.



To rectify these:

- a diverging lens is used for short sight.



- a converging lens is used for long sight.