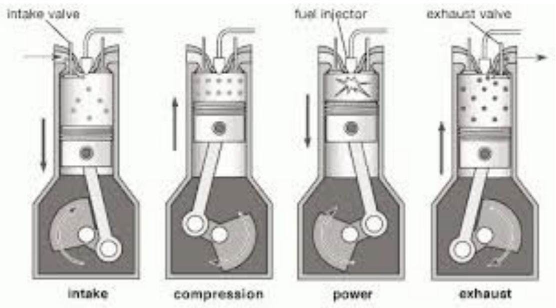
Applied Science Unit 1 Physics Knowledge Organiser

Working with waves

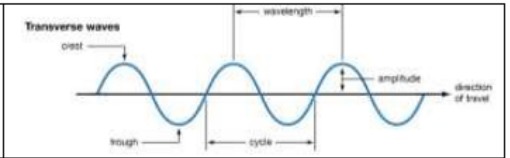
Oscillation: A regular repeating motion about a central value.
Frequency: The number of whole cycles occurring in one second. Symbol : f ; SI units: Hertz, Hz.
Period: The time taken for one whole cycle of an oscillation, i.e. before the motion starts to repeat itself. Symbol: T; SI units: s.
Displacement: How far the quantity that is in oscillation has moved from its mean (rest) value at any given time. Symbol and units: various according to what the quantity is that is oscillating.
Amplitude: The maximum value of displacement in the oscillation cycle – always measured from the mean position.

Calculating magnification

One example of an oscillating system is a piston in a motor car engine. One complete oscillation of the piston corresponds to one whole turn of the crankshaft.



Types of wave

	
Longitudinal waves move by oscillations that are <u>parallel</u> to the direction of energy transfer as <u>compressions</u> & <u>rarefactions</u>.	Transverse waves have oscillations that are <u>perpendicular</u> to the direction of energy transfer as <u>crests</u> & <u>troughs</u>.
Sound, seismic P waves.	Light, EM, water & waves on a string.
Sound: low frequency & energy, long wavelength, cannot be polarised, needs a medium to travel, mechanical wave.	Light: high frequency & energy, short wavelength, can be polarised, can travel through a vacuum, electromagnetic wave.

The Wave Equation

Wave Speed = Frequency x Wavelength

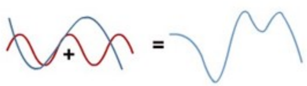
$$V = f \times \lambda$$

(m/s) (Hz) (m)

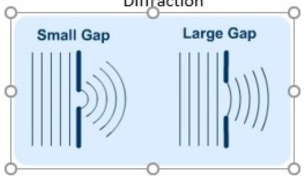
$$V = f \times \lambda$$

Wave behaviour

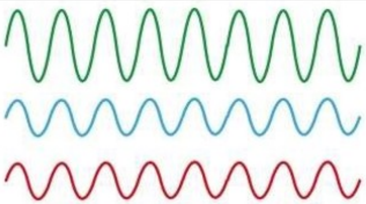
<u>SUPERPOSITION / INTERFERENCE:</u> The adding together of wave displacements that occurs when waves from two or more separate sources overlap at any given location in space.



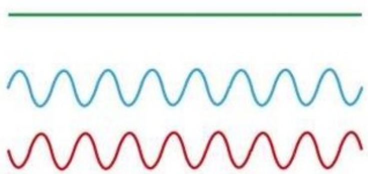
Diffraction



<u>CONSTRUCTIVE INTERFERENCE:</u> When the waves add together to make a bigger resultant wave.



<u>DESTRUCTIVE INTERFERENCE:</u> When the waves cancel each other out to make no resultant wave.



Diffraction grating

Diffraction is a key characteristic of all waves. It means the tendency of a wave to spread out in all directions, transferring **energy** to its surroundings as it does so.

A **diffraction grating** is a flat plane object. It has a series of regular lines formed on it that block parts of an advancing wave-front.

- For **microwaves** – these lines could be a series of regularly spaced metal bars or wires
- For **light** – would usually use a piece of glass with a series of fine and regularly spaced scratches on its surface.

Transmission: wave energy passing through an object e.g. diffraction grating, and mostly continuing forward in the original direction, though some energy will be diffracted through angles of less than 90°.
Reflection: wave energy that bounces off a surface and has its direction of travel altered by more than 180°.
Interference pattern: a stationary pattern that can result from the superposition of waves travelling in a different directions, provided they are **coherent**.
Coherent: "sticking together" and is used to describe waves whose superposition gives a visible interference pattern. To be coherent, waves must share the same frequency and same wavelength and have a constant phase difference.
Superposition: the adding together of wave displacements that occur when waves from two or more separate sources overlap at any given location in space. The displacements simply add mathematically.
Path difference: the difference in length between two rays e.g. one from a particular grating gap to a given point in space and the ray from the next-door grating gap to the same point.

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Emission spectre

The **quantum theory** of light and other electromagnetic radiations is based on the experimental observation that there is a simple relationship between **frequency** and the **energy** carried by each photon.

$$E = hf$$

Where h is the Planck constant, -6.626 070 x 10^{-34}Js

If a chemical element or compound is vaporised by heating in a flame, or if you pass an electric current at high voltage through a gas, you typically see light emitted of a characteristic colour, according to the chemical nature of the material you are testing.

Musical instruments

Both stringed and wind instruments depend on resonance to produce their musical notes.

In a stretched string, the oscillations are **transverse**, and the speed, v, at which waves travel down its length, L, depend on the string tension, T, and on the string's mass, m, per unit length, $\mu\ (= \frac{m}{L})$ The wave speed can be calculated:

calculation of speed $v = \sqrt{\dfrac{T}{\mu}}$

Stationary wave residence

Stationary waves: wave motion that store energy rather than transferring energy to other locations.

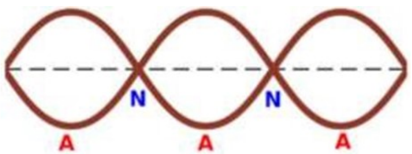
Nodes: points along a stationary wave where the displacement amplitude is at a minimum.

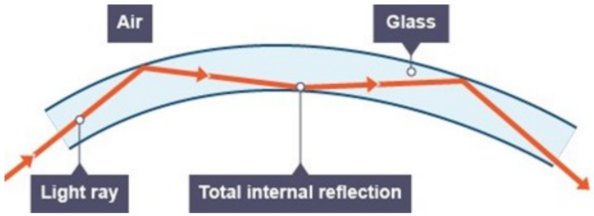
Antinodes: points of maximum amplitude that occur halfway between each pair of nodes.

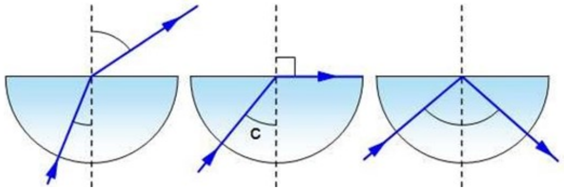
Resonance: the storing of energy in an oscillation or a stationary wave, the energy coming from an external source of appropriately matched frequency. R

Forcing frequency: the frequency of wave energy from an external source that is coupled to a resonator. Efficient energy transfer into the resonator only occurs when this is close to one of the natural frequencies.

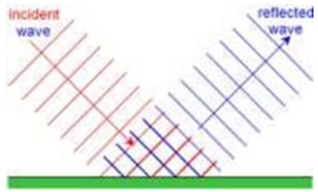
Natural frequency: a resonator has a series of natural frequencies, each of which corresponds to an exact number of half wavelengths fitting within its boundaries.







Law of reflection



In transparent materials, like water, glass and many plastics, the waves are not stopped or absorbed, but they are slowed **down**. The ratio of the speed of light in vacuum, c, to its speed in the material medium, v, is called the **refractive index**, n, of the medium.

Waves travel more directly into the glass block, that is, closer to an imaginary line drawn at right-angles to the surface of the block, which is called the **normal line.**

Normal line: a line at right angles to the surface of a transparent medium that passes through the point where a ray enters or exits that medium. The direction of rays is always described by measuring the angle between the ray and the normal line.

Incidence: the direction of the incoming ray.

Refraction: bending of the direction of travel, so it describes the direction of an outgoing ray after bending.

You can label and measure two important angles: the angle of **incidence**, i, and the angle of **refraction**, r.

refractive index $n = \dfrac{c}{v} = \dfrac{\sin i}{\sin r}$

Internal reflection: when a wave that is already in an optically dense medium hit the boundary with a less dense medium and energy is reflected back into the denser medium.

The larger the angles involved, the more light is reflected and the less energy gets through in the refracted beam to escape from the glass into the air.

When the angle in the glass between the ray and the normal line is increased to a **critical angle**, C, the refracted ray is bent so far it would need to run at 90° which is not possible. From that incident angle upwards all the wave energy is reflected internally and there is no refracted beam at all. This effect is called **total internal reflection:**

$$\sin c = \frac{1}{n}$$

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Application of fibre optics in medicine

Fibre optics are widely used in endoscopes. Endoscopes are optical instruments with long tubes that can be inserted into a body organ through an opening such as the throat, nose and ear canal. These allow to see inside a body organ. They can be used during a keyhole surgery.

Each fibre in the bundle is as thin as a human hair and consists of:

- A core
- Cladding
- A Protective plastic buffer coating

Bluetooth is named after a Danish king. Data is sent by radio & micro waves over short distances. You can connect any device using Bluetooth such as wireless speakers. It doesn't interfere with Wi-Fi as it uses frequency & channel hopping.	Mobile phones transmit & receive using radio & micro waves. The signals can be affected by reflection and the weather. Higher frequencies have more data capacity but travel less far through air. To save power low energy signals are used.
Satellites use radio & micro waves to send & receive data. A signal is sent using one frequency and returned using another to prevent interference. Signals are amplified as they can be weak. Multiple satellites are used as a line of sight is needed.	Wi-Fi stands for Wireless Fidelity and provides internet. A radio & micro wave is sent from a transmitter to receiving device. Radio signals are weak so you can only connect within your home. The closer to the hub the better the signal.

Applications of fibre optics in communication

The information transferred by each fibre of an endoscope is an **analogue signal** (a signal with strength proportional to the quantity it is representing.) An optical fibre could convey much more information than just one pixel of coloured light. The light travelling down the fibre is a very high frequency wave. However, provided that you operate at significantly below that frequency, you can chop the light signal into on/off bursts and use it to transmit **digital signal** (conveys in binary code a number that represents the size of the measured quantity).

Analogue signal to digital signal

1 Select a transducer, a device that produces an analogue electrical voltage signal proportional to the quantity you want to measure, for example, a pressure sensor, a thermocouple or thermistor for temperature, a microphone for sound.

2 Connect the output of the transducer to the input of an A to D converter, using a screened cable. To avoid picking up electrical interference the screening must be well earthed.

3 Set up the A to D converter to sample the analogue signal. This is equivalent to taking measurements to plot results out on a voltage-time graph.

4 Select an appropriate sampling rate, which is your sensitivity on the time axis.

5 Select an appropriate sensitivity for the conversion of the voltage signal into a number. The smallest difference you will be able to convey with the digitally converted data is one unit.

6 Connect the A to D converter output to a switch/transmitter to send the digital information: either electronically down copper cables; wirelessly using Bluetooth, WiFi or similar protocols; or by optical signals along a fibre network. Optical fibres are free from electromagnetic interference and virtually impossible to hack into.

Use of electromagnetic waves in communication

Light, and all forms of electromagnetic radiation, travel at the same speed though a vacuum. This is usually denoted by the letter ***c***.

Inverse square law for intensity of a wave

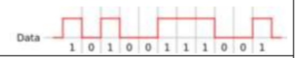
$$I = \frac{k}{r^2}$$

Where the surface area of a sphere of a radius *r* is $4\pi r^2$, *I* is intensity of wave, *k* is constant and *r* is distance from source

Frequency, sources and application

The e/m spectrum	Frequency range	Wavelengths	Produced by	Used for
Radio: Long wave Medium wave Short wave (HF) VHF UHF	30 to 300 kHz 300 kHz to 3 MHz 3 to 30 MHz 30 to 300 MHz 300 MHz to 3 GHz	10 to 1 km 1 km to 100 m 100 to 10 m 10 to 1 m 1 m to 100 mm	Electronic oscillators coupled to broadcast antennas; Astronomical radio sources for example, neutron stars	Radio and TV broadcasting Mobile phones (UHF) Plasma heating for fusion reactors Industrial ovens
Microwaves SHF EHF	3 to 30 GHz 30 to 300 GHz	100 to 10 mm 10 to 1 mm	Klystron or magnetron tubes, or solid state diodes; Thermal emission Cold → Very hot	Domestic ovens RADAR Satellite and terrestrial communications links
Infra-red (IR): Far Mid-range Near	300 GHz to 30 THz 30 to 120 THz 120 to 400 THz	1 mm to 10 μm 10 to 2.5 μm 2500 to 740 nm	Light emitting diode (LED) or laser; Thermal emission Cold → Very hot	Night vision cameras Optical fibre comms. Movement detectors Remote controls; Spectroscopy
Visible light	400 to 800 THz	740 to 370 nm	Emission by outer electron transitions; Thermal emission Cold → Very hot	Illumination Imaging Signalling; Photosynthesis in plants; Spectroscopy
Ultra-violet (UV)	800 THz to 30 PHz (10^{15} Hz)	370 to 10 nm	Emission by outer electron transitions; Thermal emission Cold → Very hot	Insect vision Tanning; Photosynthesis in plants; Spectroscopy
X-rays	30 PHz to 30 EHz (10^{18} Hz)	0.01 to 10 nm	Inner electron excitation and decay	Medical imaging; Spectroscopy
γ-rays	generally > 30 EHz	generally < 0.01 nm	Nuclear reactions and particle decays	Radiation sterilisation Medical tracing

Application	Power and mode of transmission	Frequency band	How it is used and regulated
Satellite communications	High power signals over very long distances; concentrated by dish antennae.	1 to 40 GHz (microwaves)	Satellite transponders receive incoming upload signals, amplify them and retransmit them as a download signal on a different frequency band. *For more info search 'satellite frequency bands' on the European Space Agency website www.esa.int*
Mobile phones	High power networked system, range several km.	800 MHz to 2.6 GHz (UHF radio to microwave borderline)	5 or 10 MHz bands allocated to different operators. 2G, 3G and 4G cellular networks offering increasing speeds for data. Higher frequencies have greater data capacity but travel less distance through air and penetrate into buildings less well.
Bluetooth®	Low power device to device links, range up to about 10 m.	2.4 to 2.4835 GHz – the Industrial, Scientific, Medical (ISM) unlicensed band – borderline between UHF radio and microwave frequencies	Early Bluetooth devices interfered with Wi-Fi devices because both would use the same channel for an extended period of time. Modern Bluetooth uses frequency-hopping – i.e. broadcasting in short bursts on a number of different frequency channels across the band. This reduces the amount of data lost, and in most cases both Bluetooth and Wi-Fi can maintain service. *For more info search for 'Bluetooth and Wi-Fi' at IntelligentHospitalToday.com*
Wi-Fi	Medium power networked system, range ~10 to 100 m.		
Infrared	Low power device to device links, range only a few metres.	IR wavelength 870 nm or 930 to 950 nm (frequency about 320 THz)	Used for remote controls and for data transfer between computers, phones, etc. The longer wavelength band is better because it does not suffer from 'sunlight blinding'. Atmospheric moisture blocks that range in sunlight.



BROADBAND:
High-speed data transmission in which the bandwidth is shared by more than one simultaneous signal.

Disadvantages of Broadband

- Digital signals use a greater bandwidth than analogue signals so more channels are needed to transmit data;
- Information can be lost because of sampling errors;
- Jointing of optical fibres is difficult so needs specialist equipment;
- Optical fibres are easily damaged because they are fragile;