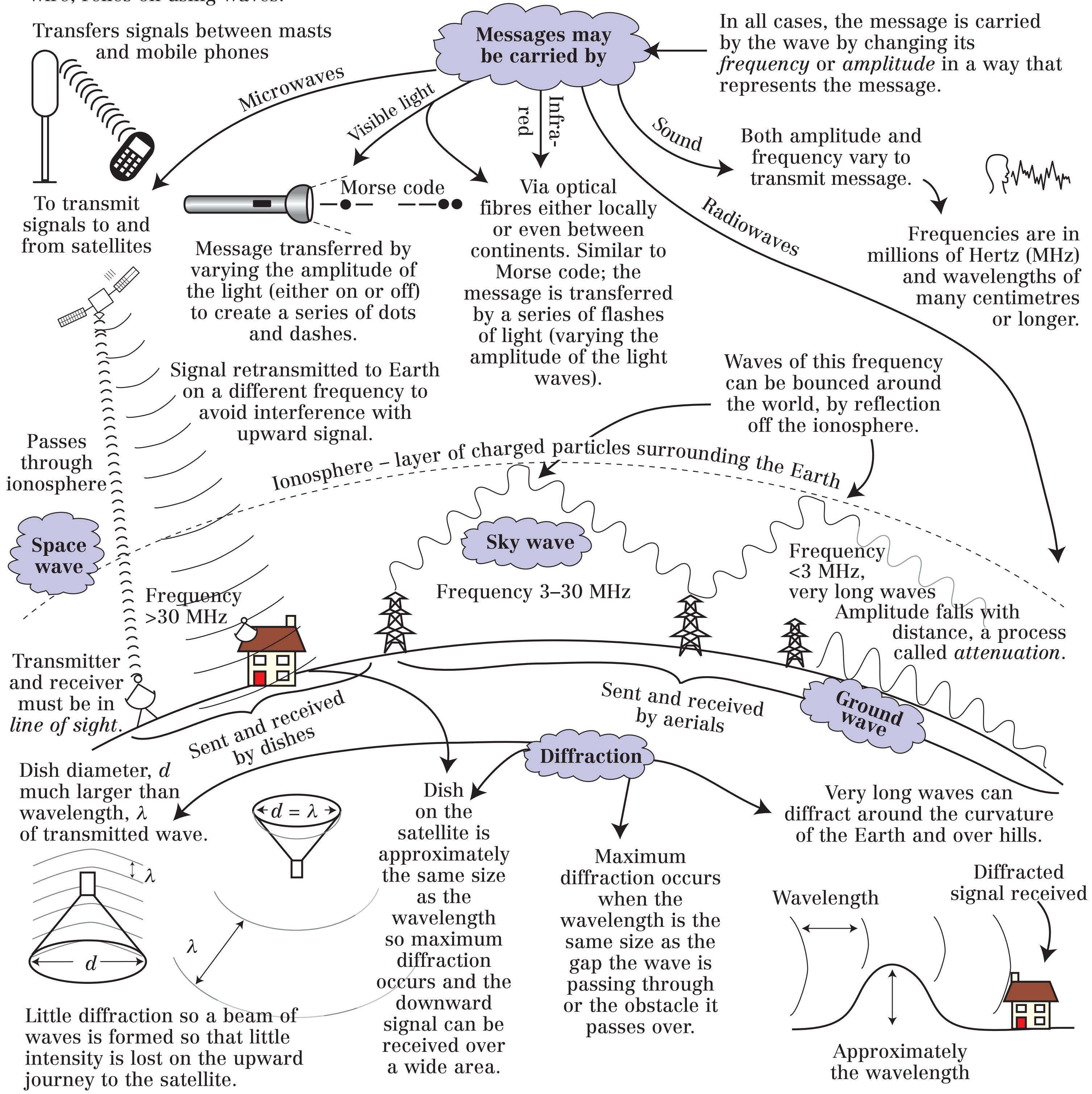
WAVES AND COMMUNICATIONS Using Waves to Communicate

The long distance transmission of information, other than by a message on paper or via an electrical signal in a wire, relies on using waves.



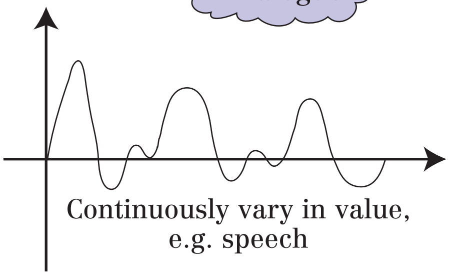
Questions

1. Name four types of electromagnetic waves used to send messages. Suggest why the other types of electromagnetic radiation are unsuitable.
2. Explain three ways radiowaves can be used to send messages over long distances. Use diagrams to help your explanation.
3. i. Use the formula wave speed = frequency × wavelength to calculate the wavelength of radiowaves of frequency:
   a. 3 MHz (3×10^6 Hz). b. 1800 MHz (1.8×10^9 Hz). c. 30 GHz (3×10^{10} Hz).
   ii. Explain which of the above frequencies would be most useful for:
   a. Diffracting around large obstacles like hills. b. Sending to a satellite using a dish.
   c. Mobile telephone communication.
4. A signal is to be sent from the UK to America across the Atlantic. Explain:
   a. Why a signal sent by a ground wave would be very weak by the time it reached America.
   b. Why the ionosphere is needed if the signal is to be sent by a sky wave.
   c. Why a satellite is needed if the signal is to be sent by a space wave.

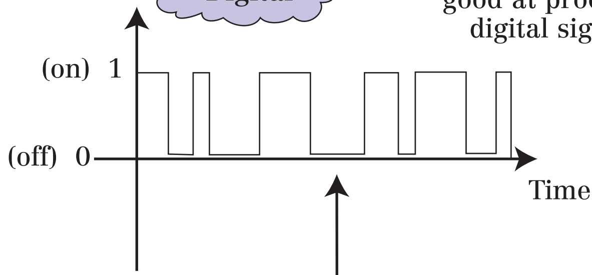
WAVES AND COMMUNICATIONS Analogue and Digital Signals

Communication signals are either

Analogue Or **Digital**



Continuously vary in value, e.g. speech



Computers work with binary code, a series high or low voltages representing 1 and 0. They are particularly good at processing digital signals.

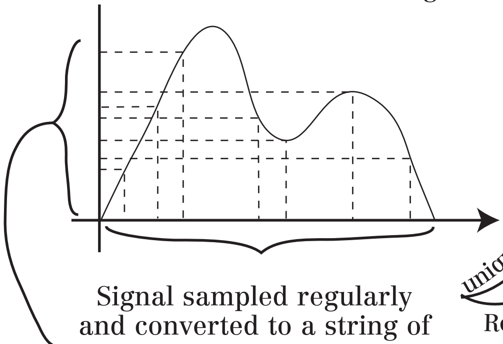
Two distinct values only. Usually on and off represented by 1 (on) and 0 (off).

Pulses of current in a wire.

Flashes of visible or infrared light in fibre-optic cables.

Pulses of radio or microwaves.

Conversion:
Sample too often and the process is too slow. Sample too few times and not enough information is available to reconstruct the original signal.



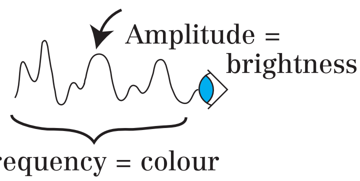
Signal sampled regularly and converted to a string of numbers.

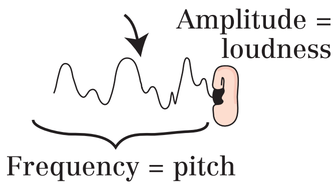
Each value represented by a unique string of 1s and 0s called binary code

Reverse of this process

When digital signals are received, they need to be converted back to analogue.

Humans cannot directly interpret digital signals. Our senses respond to analogue signals.

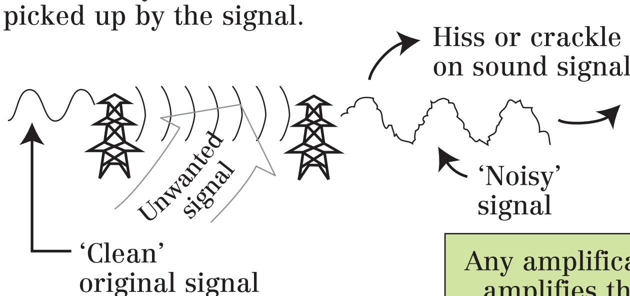




Advantages of digital signals:

1) Less noise

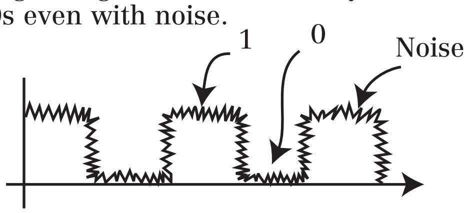
Noise is any unwanted interference picked up by the signal.



Any amplification also amplifies the noise.

With analogue signals it is hard to remove noise.

Digital signals are still clearly 1s and 0s even with noise.

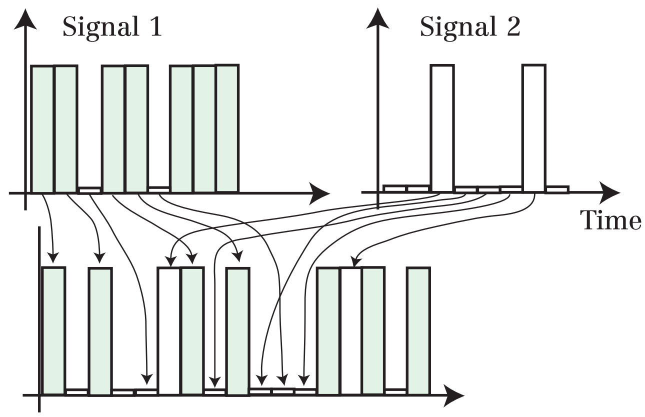


When decoded the noise is removed.

Therefore, digital radio and TV have better sound and picture quality.

2) More information can be transmitted at once.

Signals can be interleaved, (called *multiplexing*).



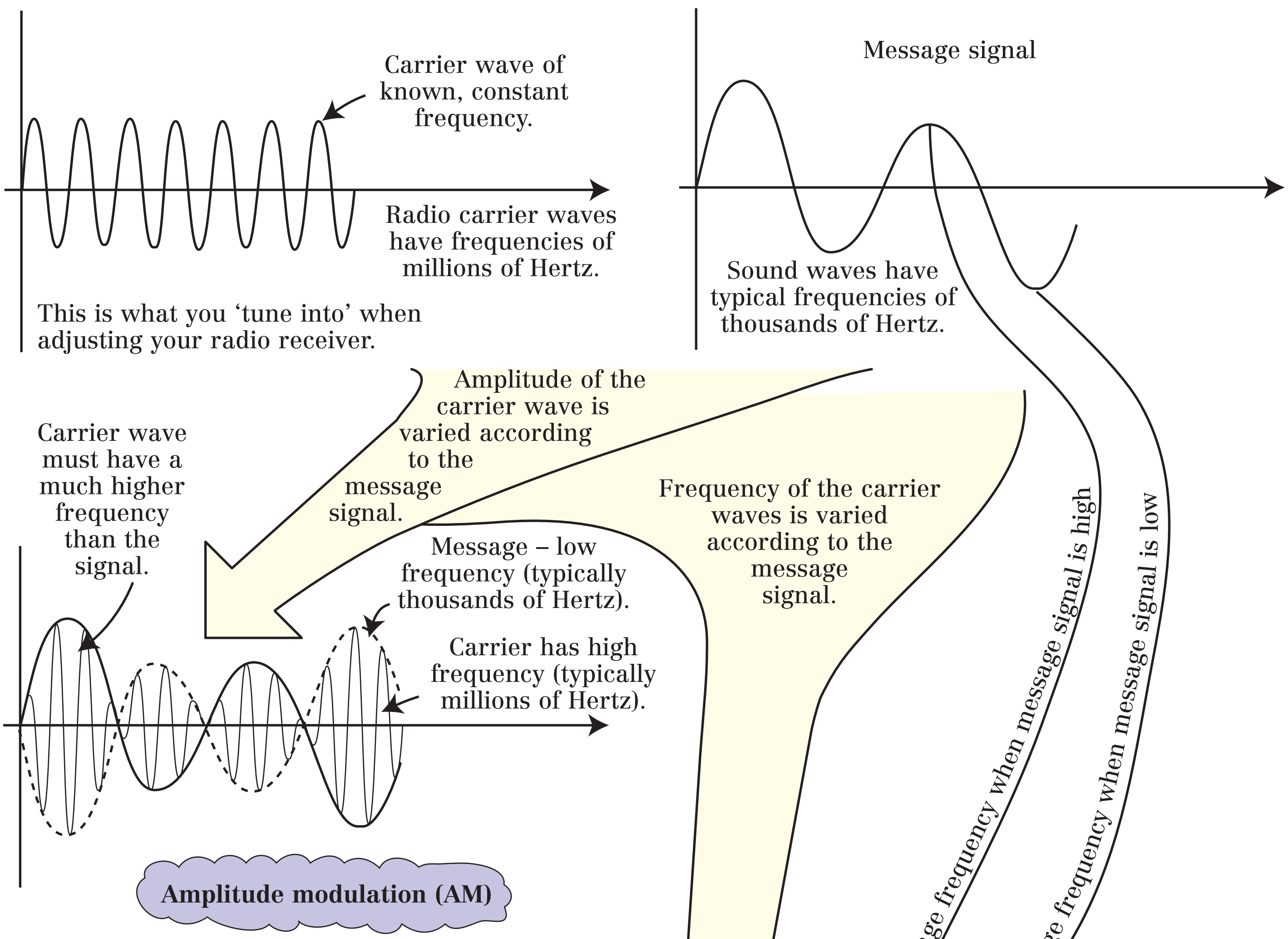
Therefore, lots of information can be sent on one signal. Hence, this is why you can have so many digital TV and radio stations but relatively few analogue ones.

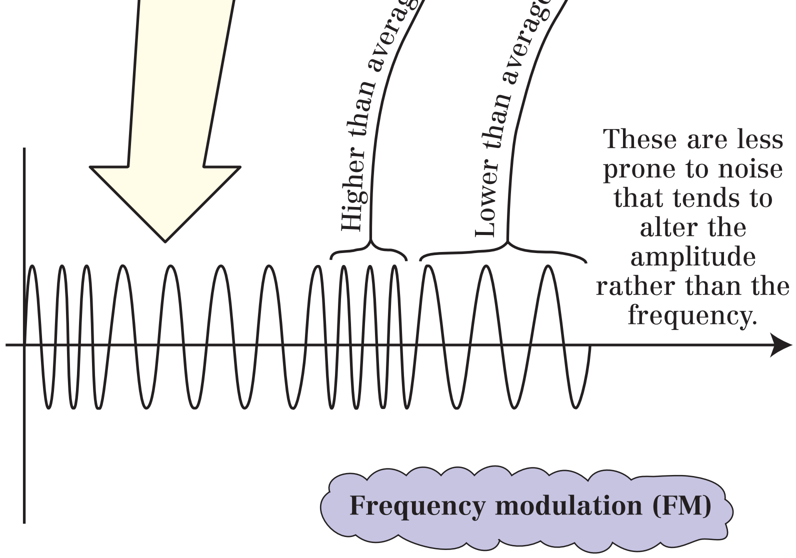
Questions

1. Use diagrams to illustrate the difference between a digital and an analogue signal.
2. When listening to a radio station a hissing sound is heard. What is likely to have caused this and is the signal most likely to have been analogue or digital?
3. Morse code is transmitted as a series of pulses of electricity in a wire or flashes of light representing dots and dashes. Explain whether it is an analogue or digital signal.
4. How are analogue signals converted to digital?
5. What is multiplexing?
6. Explain two advantages of digital signals compared to analogue.
7. When signals are amplified, noise is also amplified. Why is this less of a problem for digital signals?

WAVES AND COMMUNICATIONS AM/FM Radio Transmission

When you tune to a given radio or TV station, you select a particular frequency of radiowave to be received. This wave is called a *carrier wave*, but how is the message added to the carrier wave? There are two methods by which the carrier wave is *modulated* (or varied) by the message signal.





Both types of signal are analogue as they vary continuously.

Radio stations use different carrier frequencies so they do not interfere.

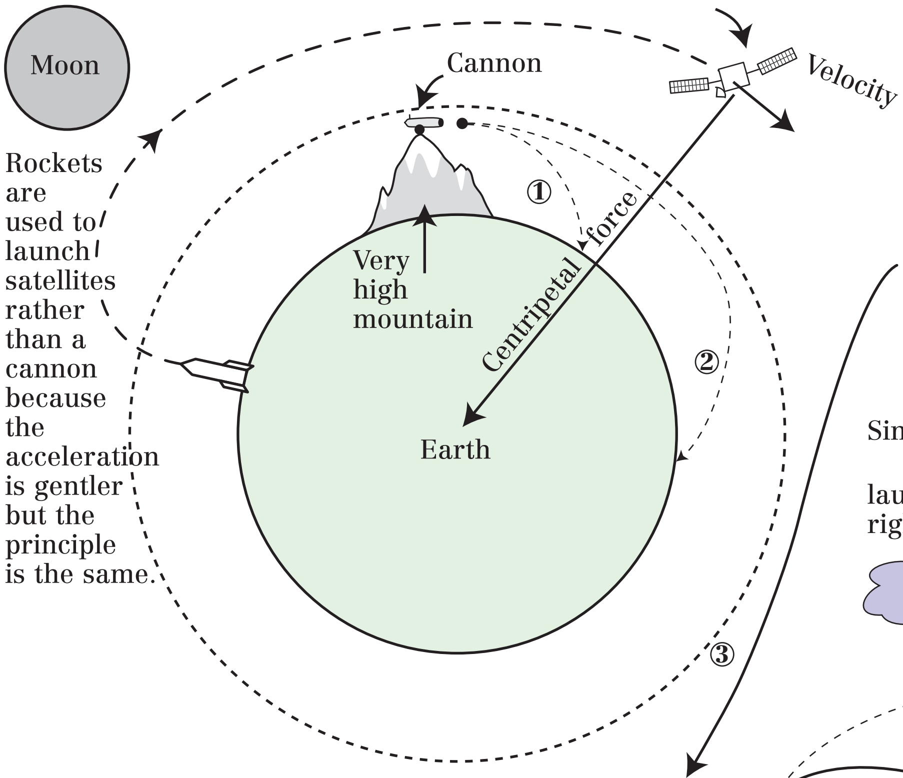
Local radio stations can use the same frequencies as long as they are located a long way apart so the signal from one is too weak to interfere with another.

Questions

1. What is a carrier wave?
2. What do you understand by the term 'modulation' in the context of radiowaves?
3. What do the abbreviations AM and FM stand for?
4. Use diagrams to explain the difference between AM and FM radio transmissions.
5. Which type of transmission, AM or FM suffers less from noise?
6. Can two different national radio stations covering the whole of the UK use the same carrier wave frequency? What about two local stations?

WAVES AND COMMUNICATIONS Satellite Orbits and Their Uses

Satellites are objects that orbit larger objects in space. They can be natural, like the moon orbiting the Earth or artificial (man-made).



Rockets are used to launch satellites rather than a cannon because the acceleration is gentler but the principle is the same.

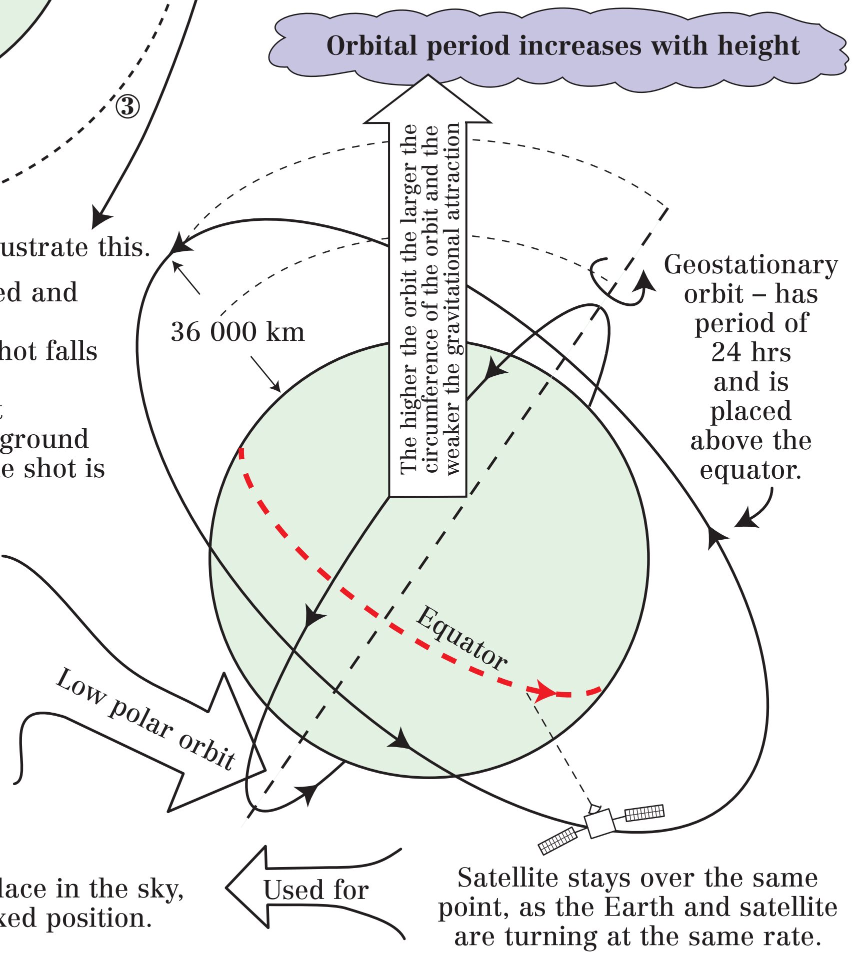
The gravitational attraction between the two objects provides the necessary centripetal force to keep the satellite moving in a circular path (see p19). Without this force, satellites would move off in a straight line into space. The gravitational attraction provides the centripetal acceleration towards the centre of the Earth that causes the satellite's direction of motion to change continuously.

Since centripetal force = $\dfrac{\text{mass} \times \text{velocity}^2}{\text{radius}}$

launching a satellite involves getting it to the right height, at the right speed.

Newton used a thought experiment to try to illustrate this.

1. Little gunpowder in cannon. Low initial speed and shot falls to Earth quickly.
2. More gunpowder. Higher initial speed and shot falls further before hitting ground.
3. Given enough gunpowder, the shot will orbit because it is travelling fast enough that the ground is 'falling' away under it at the same rate the shot is accelerating towards it.



Satellites in a low orbit make many orbits of the Earth per day. If they orbit over the poles and the Earth spins beneath them, they can observe many different parts of the Earth's surface each day.

Useful for:
- Weather forecasting.
- Imaging the Earth's surface (e.g. for spying, to monitor crops or pollution).

Communications – as they stay in the same place in the sky, satellite dishes only need to point in one fixed position.

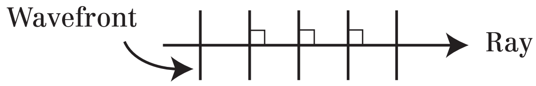
Questions

1. State and explain two reasons why satellite orbit period increases with height above the Earth.
2. Using diagrams state and explain as many differences as possible between geostationary and polar orbits.
3. For each type of orbit, geostationary and polar:
   a. State a use for a satellite in that orbit.
   b. Explain why that orbit is used.
4. A geostationary satellite orbits 36 000 km above the surface of the Earth. The radius of the Earth is 6400 km.
   a. How many hours does it take a geostationary satellite to orbit the Earth? What is this in seconds?
   b. Show that the circumference of the satellite's orbit is about 270×10^6 m.
   c. Hence show that its orbital speed is about 3080 m/s.
   d. Use the formula centripetal force = mass × velocity^2 / radius to find the resultant force on a 10 kg satellite.
   e. What provides this resultant force?

WAVES AND COMMUNICATIONS Images and Ray Diagrams

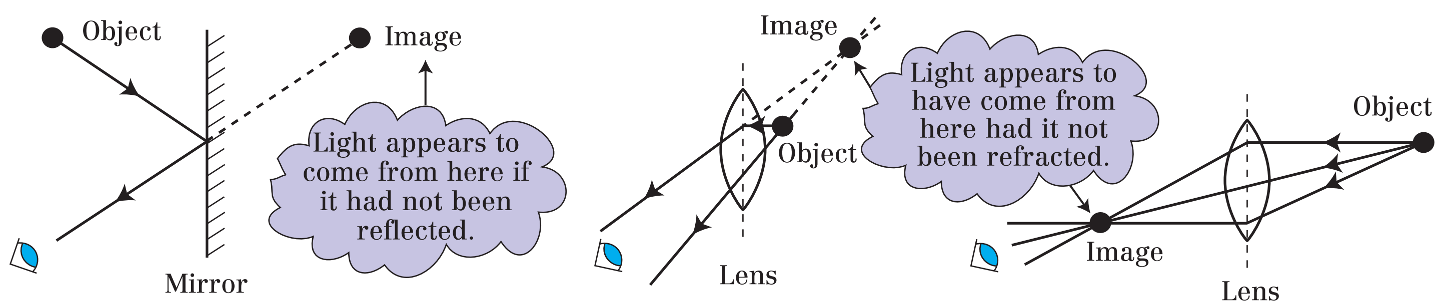
Light follows straight lines, or rays, from a source of light to an observer unless it is reflected, by a mirror, or refracted, by a lens, on route.

Mirrors and lenses come in a variety of shapes to manipulate the light rays in various useful ways. Ray diagrams help us to understand their effects.



Rays show the direction the light waves are travelling in. Light rays always travel in straight lines (as light waves travel in straight lines) except when reflected or refracted when they change direction.

An image is formed at a point where the light rays from an object appear to come from, had their direction not been changed by a mirror or lens.



Virtual images

The light rays do not pass through the image before entering the eye.

Cannot be projected onto a screen.

Always upright.

The nature of an image

Virtual or real?

Upright or inverted (upside down)?

Magnification.

Real images

The light rays pass through the image before entering the eye.

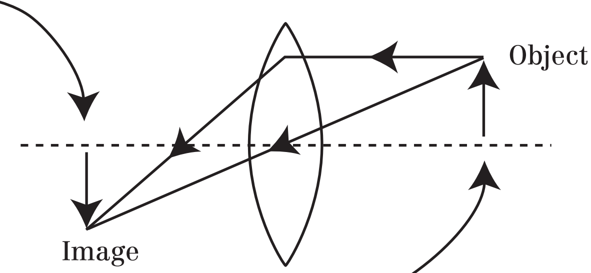
Can be projected onto a screen.

Always inverted (upside down).

Greater than 1 – *magnified* (image larger than object).

$$\text{Magnification} = \frac{\text{image height}}{\text{object height}}$$

Smaller than 1 – *diminished* (image smaller than the object).



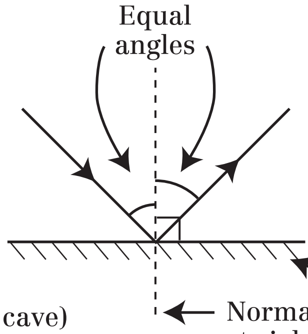
Questions

1. Make a list of three properties of an image that describe the 'nature of an image'.
2. State three differences between a real and virtual image.
3. Is the image in a plane (flat) mirror real or virtual?
4. What is a light ray?
5. What is the formula for magnification? If the magnification of a lens is less than 1, would the image be larger or smaller than the object?
6. A tree has a height of 20 m. In a photograph, it has a height of 20 cm. What is the magnification?
7. A letter 'I' in a book has a height of 5 mm. When viewed through a magnifying glass with a magnification of 1.9, how high will it appear?

Mirrors

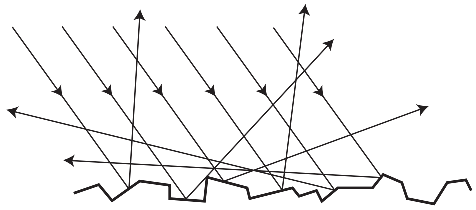
(1) Plane (flat)

Nature of image
Virtual
Upright
Same size as object



Law of reflection (applies to all mirrors):

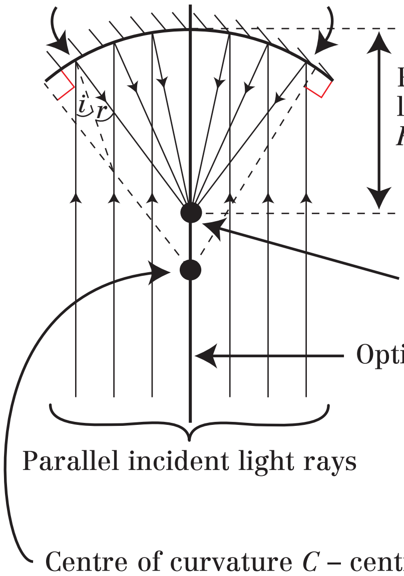
Angle of incidence, i = angle of reflection, r



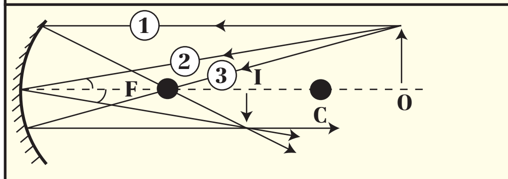
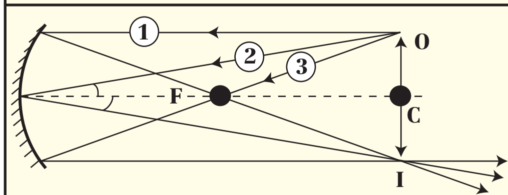
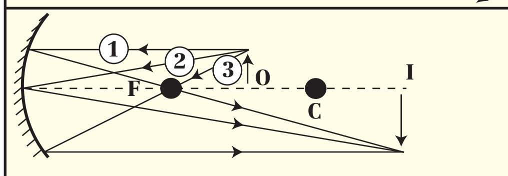
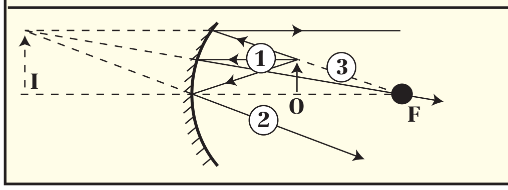
Diffuse reflection from a rough surface – no image formed.

(2) Concave – curving in (like a cave)

Brings light to a focus so is a *converging* mirror.



Nature of images

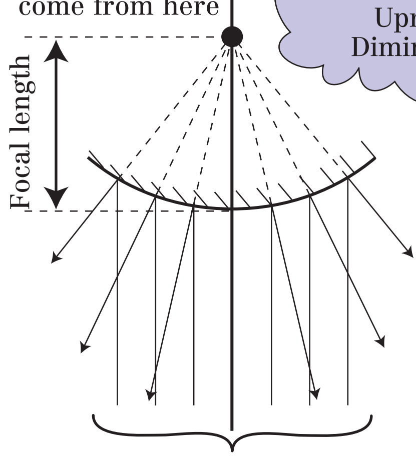
	Object	Image
	Beyond C	Between C and F Real Inverted Diminished
	At C	At C Real Inverted Same size
	Between C and F	Beyond C Real Inverted Magnified
	Closer than F	Virtual Upright Magnified

Rules for drawing ray diagrams for concave mirrors
Ray from the object
1. Parallel to optic axis – reflects through F.
2. To centre of mirror is reflected, forming equal angles with optic axis.
3. Through F is reflected parallel to the optic axis.

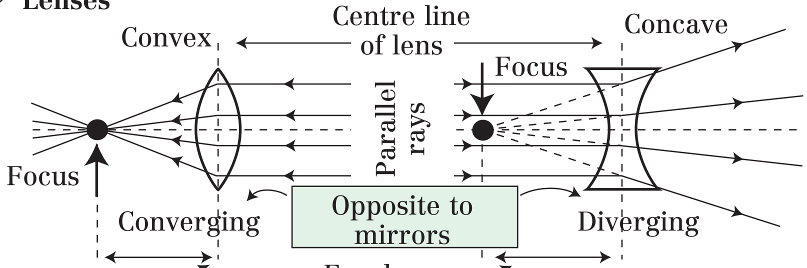
(3) Convex – bulges out

Spreads light rays out so is a *diverging* mirror.

Nature of image
Virtual
Upright
Diminished



Lenses

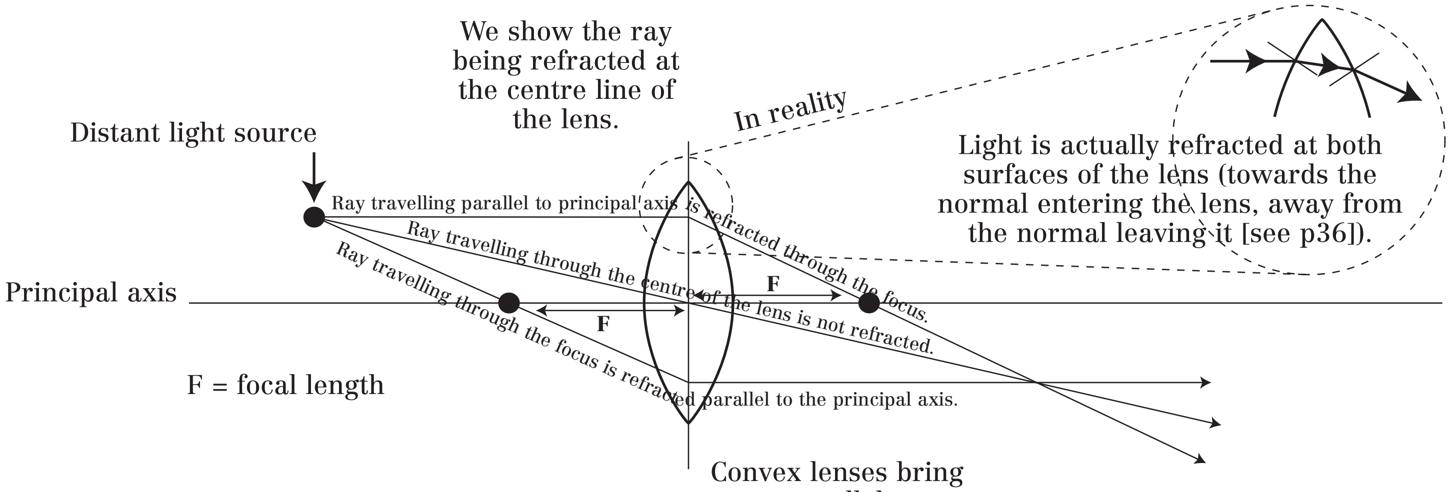


The more powerful a lens, the greater the change in direction of the light rays, and therefore the closer the focus is to the centre line of the lens.

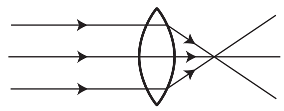
Power of lens (dioptre) = 1/focal length (m)

The more curved the surface the greater the refraction of the light. Therefore, fat lenses have short focal lengths and are more powerful.

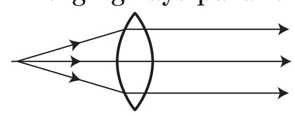
1. Convex (converging) lens



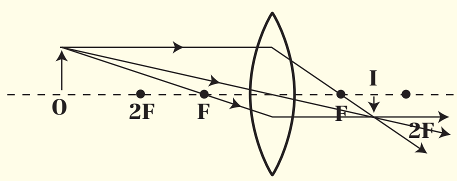
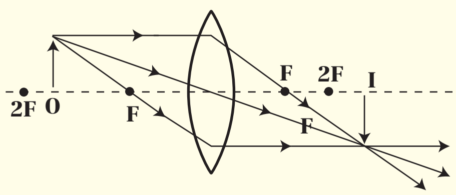
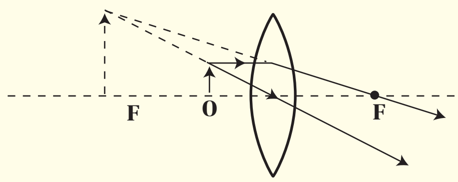
The nature of the image formed by a convex lens depends on how far the object is from the lens.



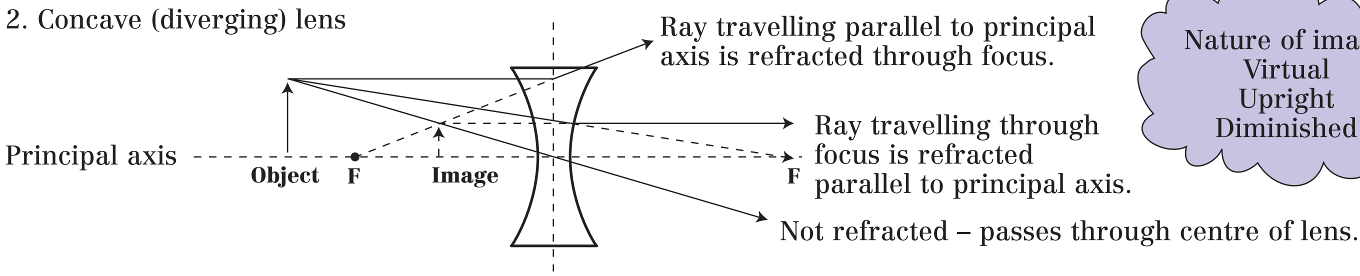
Convex lenses bring parallel rays to a focus.



Diverging rays parallel

	Object	Image	Uses
	Further than 2F	Between F and 2F Real Inverted Diminished	Camera: convex lens focuses light from a distant object to form a diminished image on the film close to the lens
	Between F and 2F	Further than 2F Real Inverted Magnified	Projector: convex lens focuses light from a nearby object to form an enlarged image on a distant screen
	Closer than F	Upright Virtual Magnified	Magnifying glass

2. Concave (diverging) lens



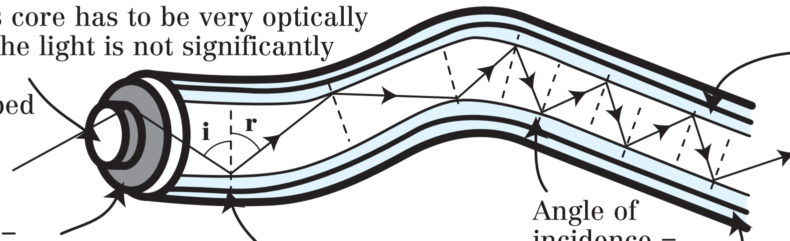
Nature of image
Virtual
Upright
Diminished

Questions

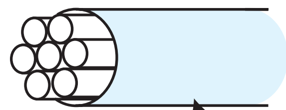
1. Describe what we mean by the term ‘focal point’.
2. Draw the shapes of convex and concave mirrors and lenses. Show with ray diagrams which will bring parallel light waves to a focus, and which will diverge them.
3. What three rays are drawn in a ray diagram for:
   a. A convex lens? b. A concave mirror?
4. Does a powerful lens have a short or long focal length? What unit is the power of a lens measured in?
5. A lens has a focal length of 0.1 m. What is its power?
6. Draw a ray diagram for an object placed at 2F from a convex lens and at F from a convex lens.
7. Draw a ray diagram for a camera and a projector; include the object, image, and lens.

WAVES AND COMMUNICATIONS Optical Fibres

An optical fibre is a thin strand of very clear glass through which visible light or infrared radiation can be guided.



Light passes down fibre by repeated *total internal reflection*.



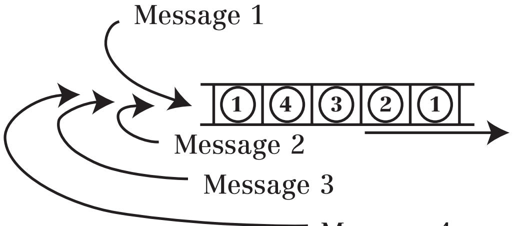
Cladding layer ensures no light transfers between fibres as it is all internally reflected.

Uses and advantages of optical fibres

Messages sent as pulses of light. Ideal for digital communications.

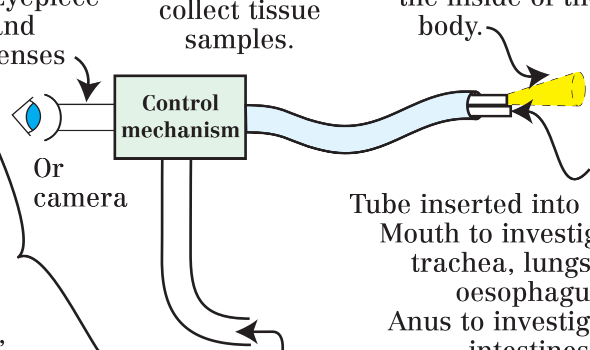
Replacing copper wires to send messages

- Light and thinner so more cables will fit in the same space. More messages can be sent.
- It is very difficult to split a fibre optic and join another cable so it is very hard to intercept messages.
- No electrical interference.
  - Light in cables cannot escape and interfere with light in an adjacent cable. Therefore, there is no interference between messages.
- The loss of signal is less than in copper wire so lower power transmitters can be used.
- Signals can be 'multiplexed'. Many messages are sent at once by breaking them up and sending the parts in turn.



Viewing inaccessible places

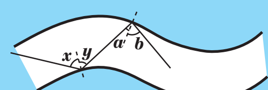
Endoscope



Similar instruments are used in industry to examine the insides of machines, engines, plumbing etc. without dismantling them.

Tube inserted into an orifice. Mouth to investigate the trachea, lungs, and oesophagus. Anus to investigate the intestines. Through the wall of the abdomen to investigate the internal organs.

Questions

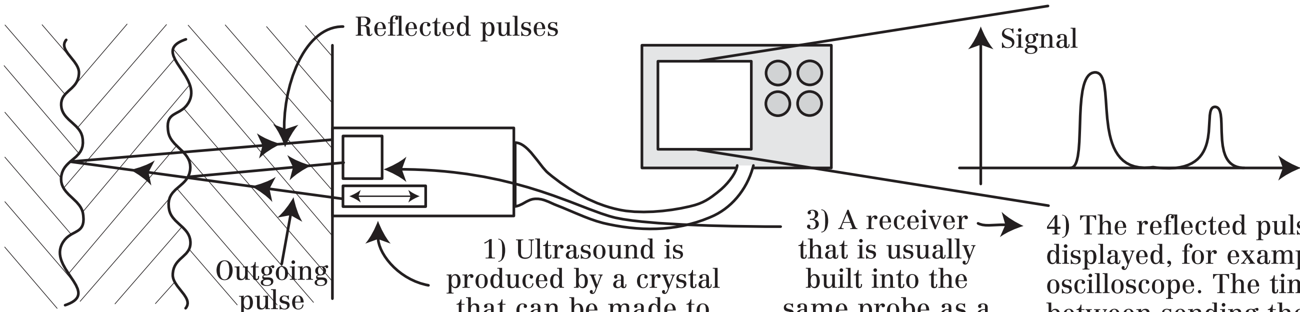


1. Copy and complete the following diagram as accurately as possible showing the path of the light along the fibre-optic cable. What can you say about the size of the pairs of angles a and b, and x and y?
2. What types of electromagnetic radiation are commonly used with fibre optics?
3. Outline some benefits of using fibre optics rather than copper wires for sending messages.
4. The light in a fibre optic gradually gets less intense as it travels along the fibre due to impurities in the glass absorbing some of the light energy. What is the electrical equivalent of this?
5. What is an endoscope? Suggest two possible uses for one.
6. Suggest why doctors often prefer to see inside people using an endoscope rather than carrying out an operation to open up the patient.

WAVES AND COMMUNICATIONS Ultrasound and its Applications

Ultrasound is a sound wave with a frequency of greater than 20 000 Hz. This is above the upper limit of hearing for humans, so we cannot hear it, although in all other respects it behaves in exactly the same manner as normal sound.

Ultrasound can be used to detect the distance between the boundaries of two objects.



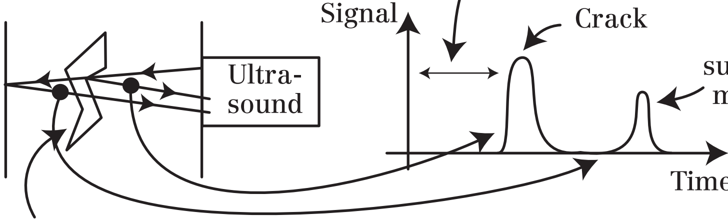
1) Ultrasound is produced by a crystal that can be made to oscillate electrically at a very high frequency.

2) Ultrasound travels through a material. If the density of the material changes the speed of the sound changes and some (usually a small fraction) of the ultrasound is reflected from the boundary to

3) A receiver that is usually built into the same probe as a transmitter.

4) The reflected pulse can be displayed, for example on an oscilloscope. The time delay between sending the signal and its echo can be used to measure the distance to the boundary, especially if the speed of the ultrasound in the material is known.

In industry

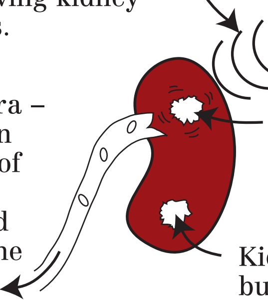


Crack in casting – for example in the turbine blade of a jet aircraft. If undetected the crack could grow until the part breaks.

Cleaning delicate mechanisms by shaking dirt free.

Mechanical effect

Removing kidney stones.



High intensity ultrasound focussed on the stone. The resulting rapid vibrations cause the stone to shatter.

Urethra – broken parts of stone passed in urine

Kidney stone – build up of mineral deposits

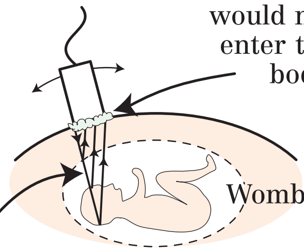
Advantages of ultrasound vs. X-rays
Ultrasound is not ionizing like X-rays so causes less cell damage. X-rays pass straight through soft tissues without reflection so cannot image them.

In medicine

Pre-natal scanning (frequencies of 1–10 MHz).

Gel to ensure that the ultrasound gets into the body (any air/tissue boundaries provide very strong reflections so the ultrasound would not enter the body.

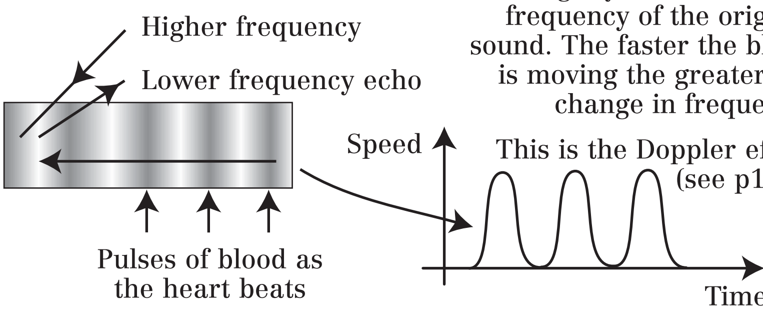

Courtesy of Teaching Medical Physics



Reflections from each boundary take different times to reach the receiver. An image of the foetus is built up.

This can be used to monitor the foetus' heart, and to check for growth abnormalities and positioning in the womb before birth.

Monitor the speed of blood flow.

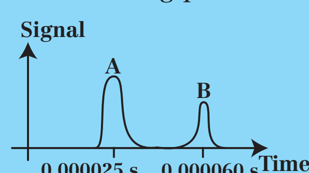


Because the blood is moving, the frequency of the returning echo is slightly different to the frequency of the original sound. The faster the blood is moving the greater the change in frequency.

This is the Doppler effect (see p125).

Questions

1. Is ultrasound a longitudinal or transverse wave? How is ultrasound different to normal sound?
2. The speed of ultrasound in soft tissue is 1540 m/s. The oscilloscope trace shows the returning pulses. How far below the surface of the body was pulse A and pulse B reflected?
3. Suggest two reasons why ultrasound may be preferable to X-rays for medical examinations.
4. Explain how ultrasound could be used to locate the depth below the skin of a cyst (fluid filled pocket) in an organ.
5. Suggest one use of ultrasound in medicine and one in industry other than for making images of hidden objects.



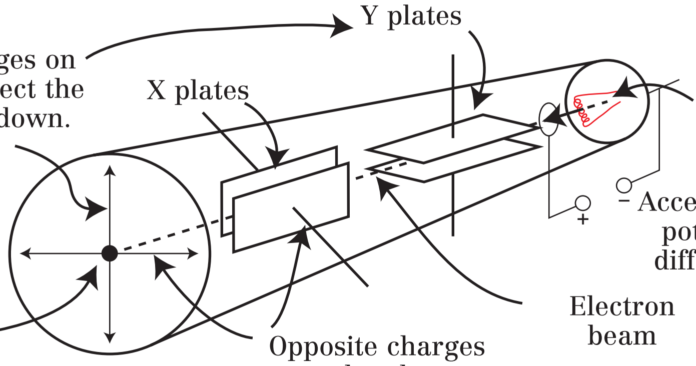
WAVES AND COMMUNICATIONS Uses of Electron Beams

Review p57. Particularly note . . .

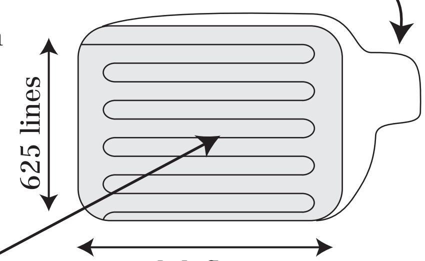
1. Electron beams are produced by 'boiling' electrons off a heated filament (thermionic emission). The hotter the filament the more electrons are produced.
2. The electrons are accelerated across a potential difference to increase their kinetic energy.

Kinetic energy = electronic charge (1.6×10^{-19} C) × accelerating voltage

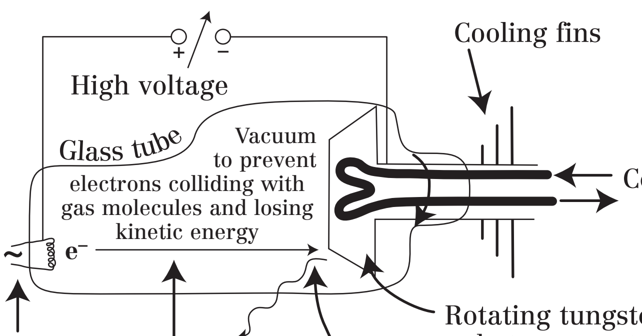
Cathode ray tubes – used in computer monitors, TVs, and oscilloscopes.



In **TVs** and computer monitors, magnetic fields from coils rather than plates deflect the beam.



X-ray tubes:



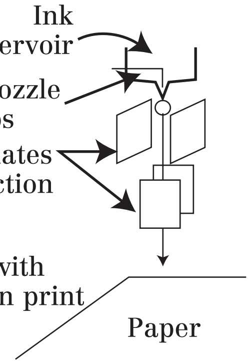
Electrons gain kinetic energy as they accelerate towards the anode. Increasing the potential difference between filament and anode gives electrons more kinetic energy on impact, so higher energy (or 'harder') more penetrating X-rays are produced.

Kinetic energy of electrons on impact

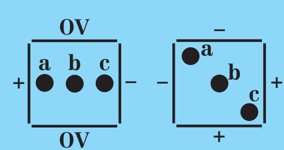
↙ 1% X-ray energy

↘ 99% thermal energy

Inkjet printing:



Questions

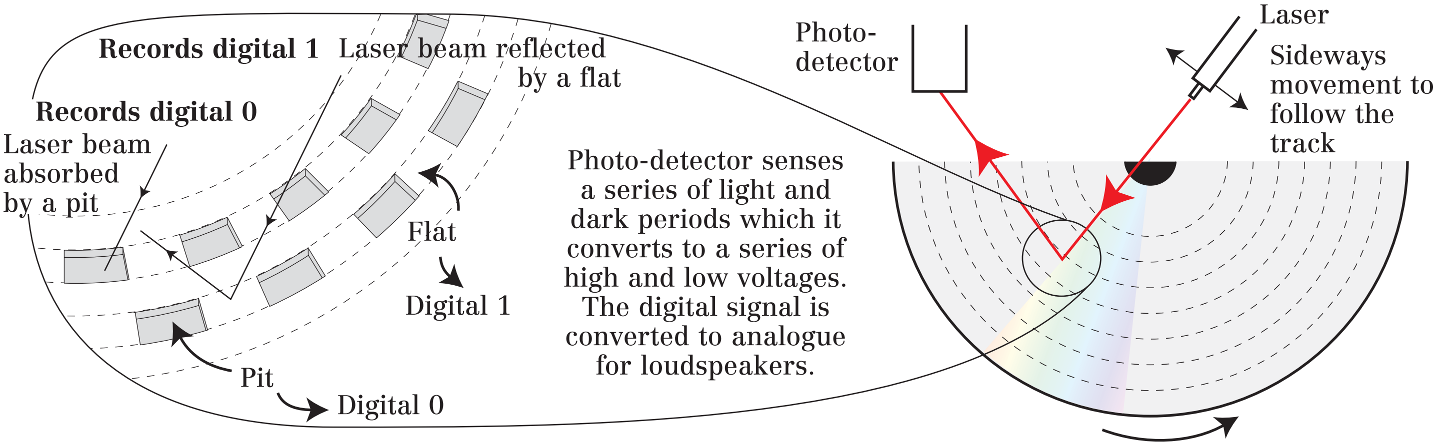


1. The diagram shows the X and Y plates in an oscilloscope viewed end on. In each case which of the dots shown (a, b, or c) correctly shows the position of the beam falling on the screen?
2. How many lines are there on a TV screen? Explain how the electron beam is made to move across the screen.
3. Describe three ways that the tungsten anode in an X-ray tube is kept cool.
4. What adjustment to an X-ray tube produces X-rays that are more penetrating?
5. An X-ray tube accelerates an electron through a potential difference of 40 000 000 V. (Charge on the electron = 1.6×10^{-19}C.)
   a. Show that its kinetic energy when it hits the anode is about 6.4×10^{-12} J.
   b. If 1.6×10^{15} electrons hit the anode, show the total energy they deliver is about 10 kJ.
   c. If this energy is delivered in about 0.2 s what is the power of the tube?
   d. What percentage of the energy above is converted to X-ray energy and hence explain why the tungsten anode needs to be cooled?
   e. Explain what effect increasing the filament temperature would have on the number of X-rays produced in an X-ray tube.

WAVES AND COMMUNICATIONS Beams of Light – CDs and Relativity

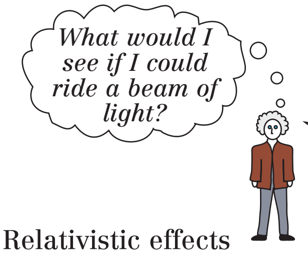
Einstein's theory of relativity is one of the most creative and challenging ideas in physics, while reading the information from a CD is a very straightforward application of physics. Yet they both involve ideas about beams of light.

A beam of laser light reads the information stored on a CD (or DVD).



Relativity

This theory makes some weird predictions about how we measure length and time when moving very fast relative to another object.



Assumptions:

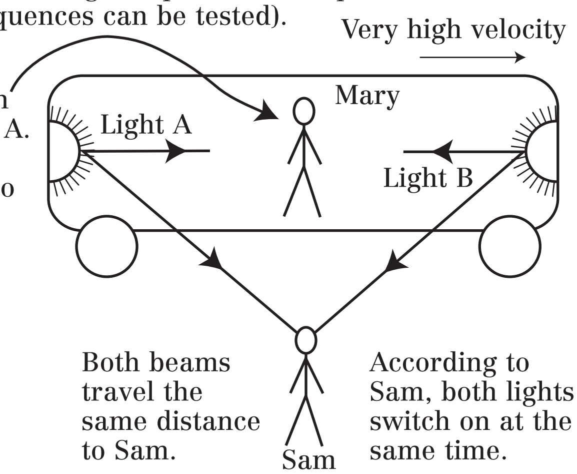
1. The Laws of Physics are the same for all observers regardless of their speed relative to each other.
2. The speed of light is always the same whatever your speed – nothing can travel faster than the speed of light.

Einstein arrived at his ideas mainly through thought experiments (experiments that are too impractical to do but whose consequences can be tested).

Relativistic effects only show up if you are moving very close to the speed of light. One consequence is that observers can only agree on when events occurred if they are stationary relative to each other.

E.g. In the train, Mary catches up with light from B but moves away from light A.

Therefore, she sees light from B first so thinks B was switched on first.



Other results of relativity

- Moving objects appear shortened.
- Moving clocks appear to run slow.
- The mass of an object appears to increase the faster it travels. This leads to the famous equation $\Delta E = \Delta mc^2$.

Some scientists did not like Einstein's ideas because they suggested Newton's Laws were not exactly right.

Other scientists → **Tested the predictions of relativity**

- Atomic clocks flown around the world on a jet aircraft record slightly less time than a stationary clock left on Earth.
- Cosmic rays create short-lived particles in the atmosphere. These travel towards the Earth's surface and should decay before reaching it, but do not as the distance appears much shorter to them. Therefore, they can easily cover it in their lifetime.
- The extraction of energy by nuclear fission and fusion relies on $\Delta E = \Delta mc^2$ being correct.

Questions

1. Laser beams can be made very narrow and do not spread out much. Why is this necessary for reading a CD as described above?
2. If you shake a CD player while playing a disc the music can be interrupted or skip a section. Using the above description try to explain why.
3. What is a thought experiment?
4. What predictions did Einstein make from his thought experiments?
5. Suggest three ways Einstein's predictions have been tested.