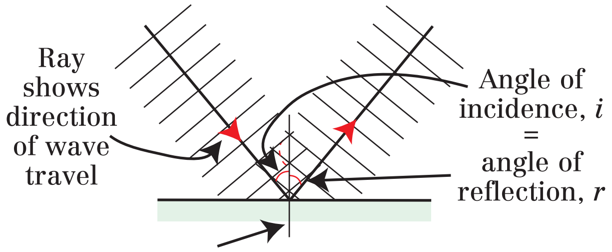
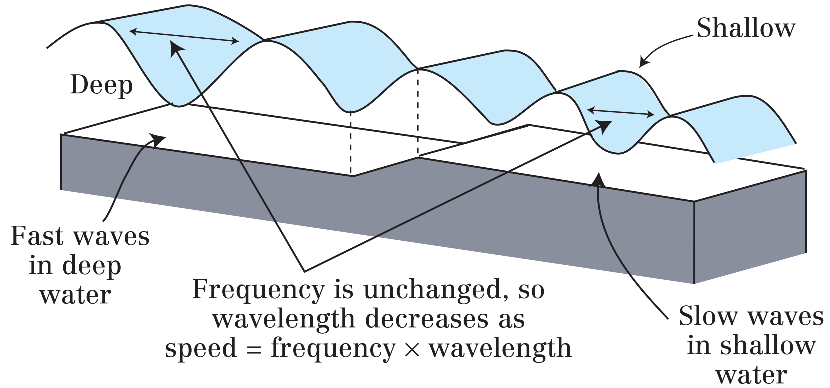
WAVES Reflection, Refraction and Total Internal Reflection

Waves *reflect* off a plane surface.

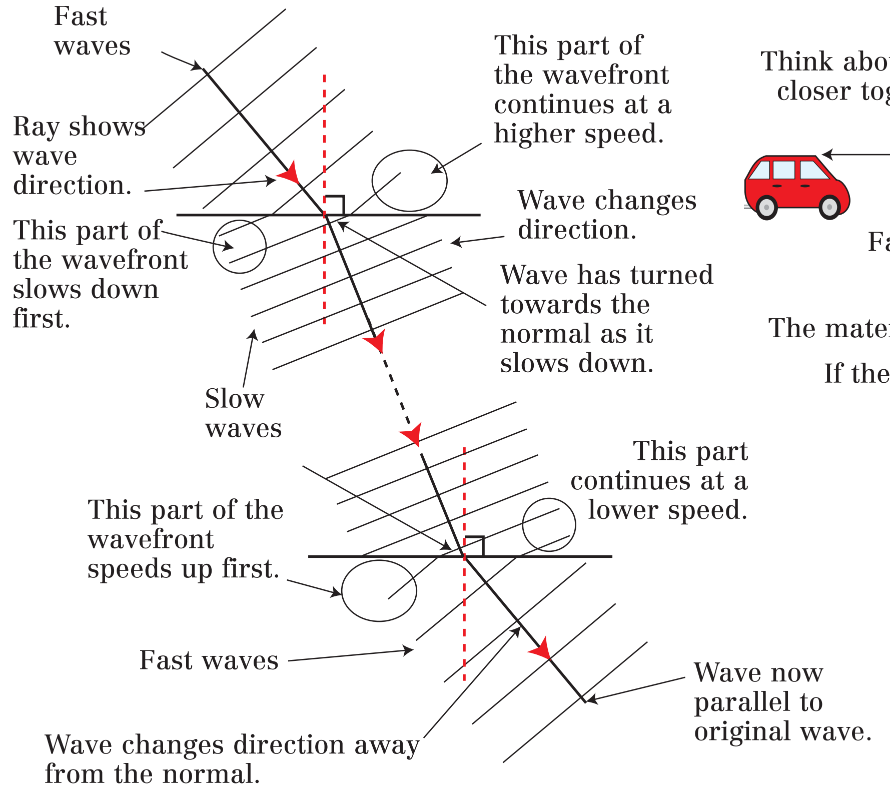


Normal – a construction line perpendicular to the reflecting / refracting surface at the point of incidence

Waves travel at different speeds depending on the media they are travelling in.

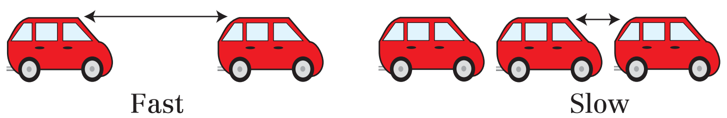


If the waves meet the boundary at an angle . . .



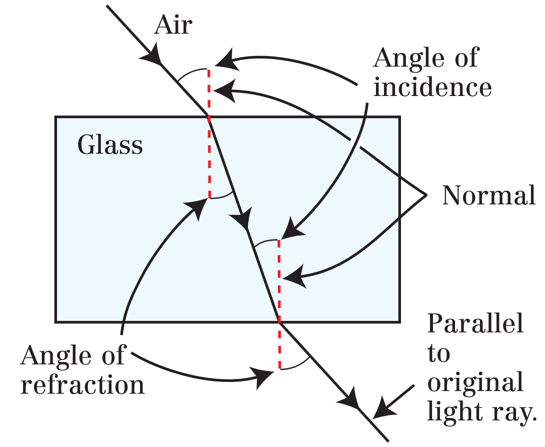
This process is called *refraction*.

Think about cars on a road, if they slow down they get closer together but the number of cars passing each second stays the same.



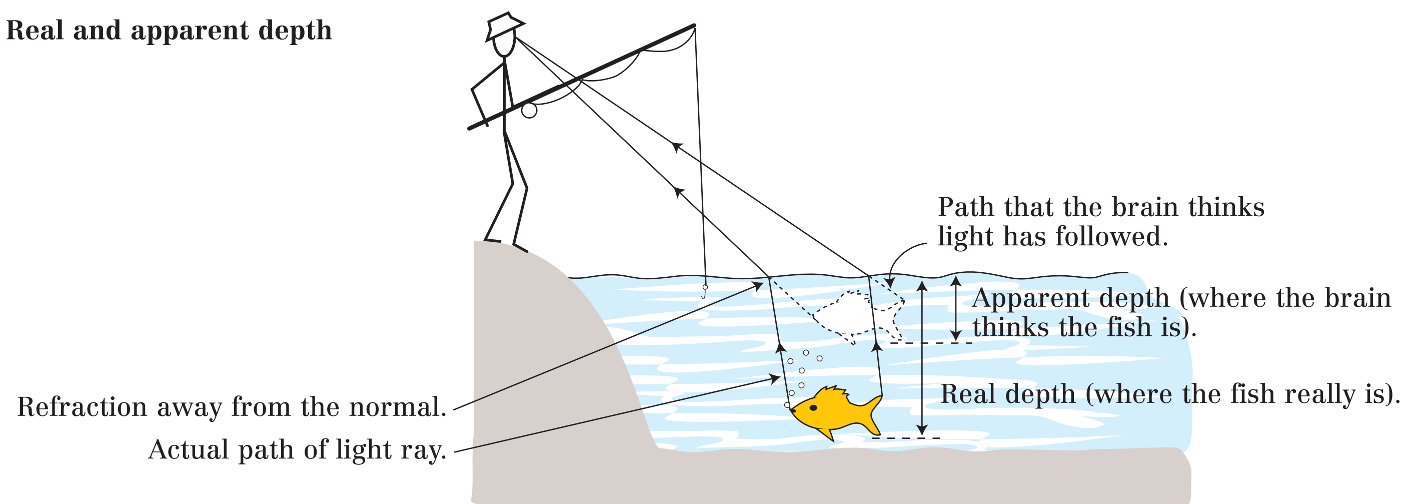
The material light passes through is called the *medium*.

If the speed of light is different in two different media, it also refracts.

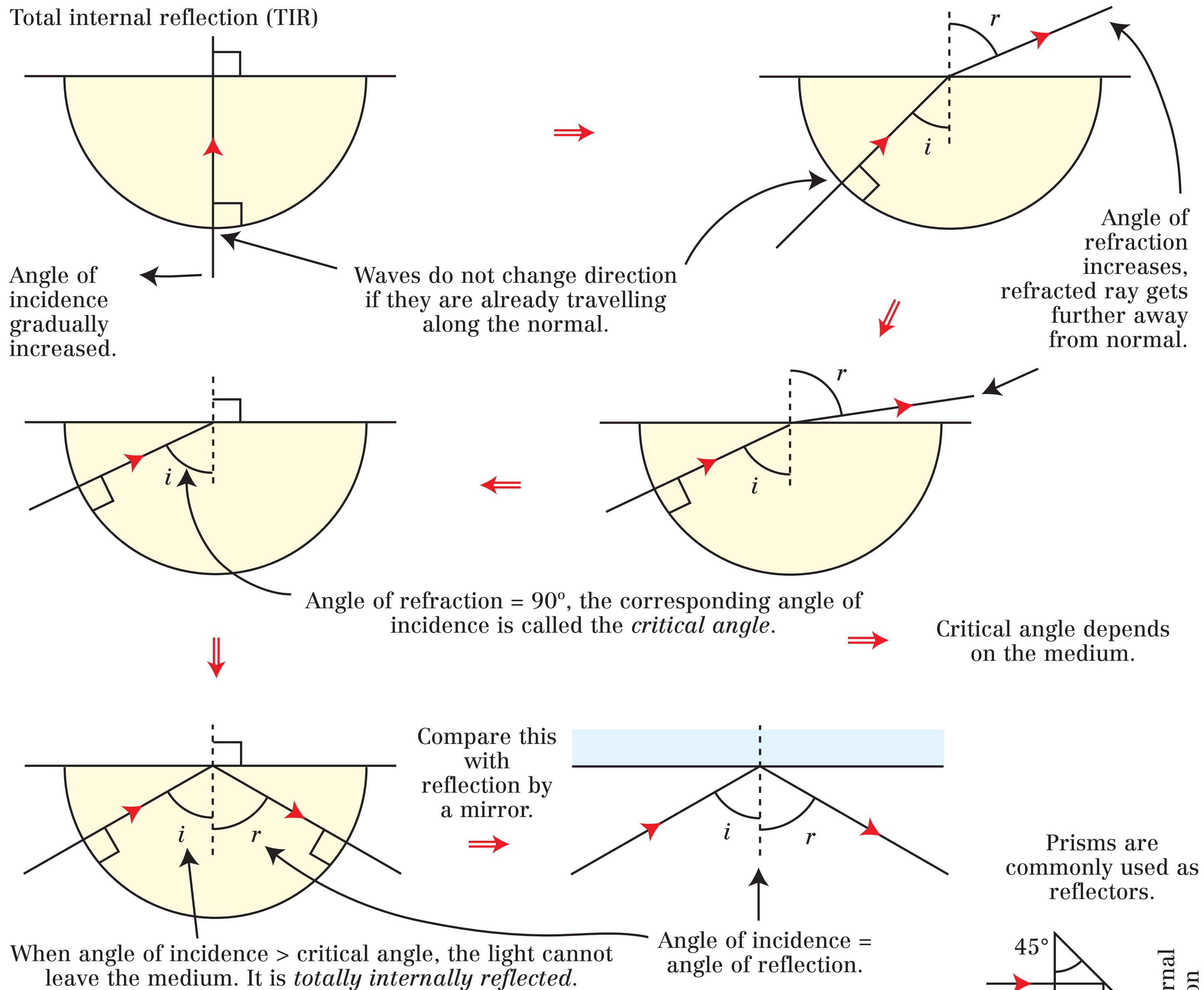


As light slows down it changes direction towards the normal (angle of incidence, i, > angle of refraction, r)
As light speeds up it changes direction away from the normal (angle of incidence, i, < angle of refraction, r).

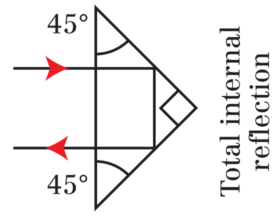
Real and apparent depth



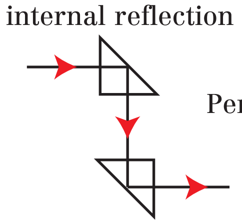
Total internal reflection (TIR)



Prisms are commonly used as reflectors.



Total internal reflection can be used to manipulate the path of light.



Periscope

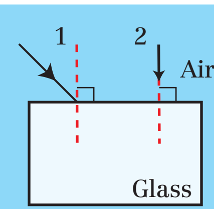
Other uses:
- Binoculars
- Bicycle reflectors

E.g. 'Cat's eyes' in roads.

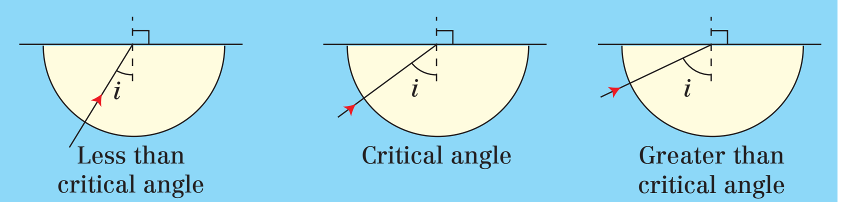
Prisms are more robust than mirrors.

Questions

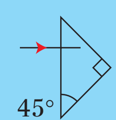
1. Explain how to decide whether a wave changes direction towards or away from the normal. In what special situation is there no change in direction?



2. Copy and complete the diagram right to show the paths of the two rays through and out the bottom of the glass block.
3. Copy and complete the diagrams right to show what happens to light incident on a glass/air surface when the angle of incidence is less than, equal to, or above the critical angle.



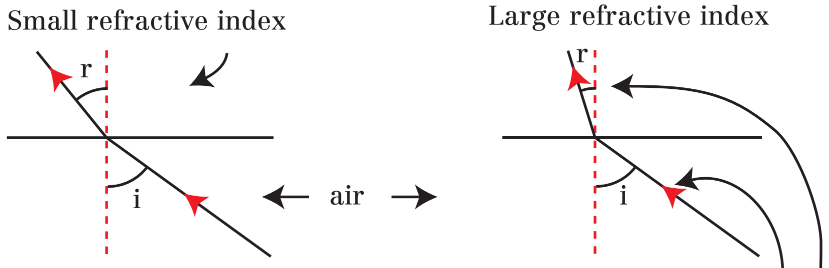
4. Explain, with the aid of a diagram, why waves meeting a boundary where they slow down at an angle change direction.
5. Complete the path of the light ray through this prism and suggest a use for such a prism.

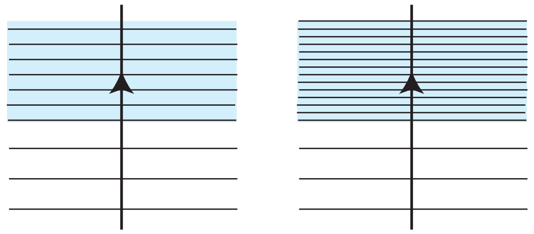


WAVES Refractive index and dispersion

When light travels from a vacuum (or air since it makes very little difference to the speed) into another medium, it is slowed down. The amount of slowing is expressed by the ratio:

$$\frac{\text{Speed of light in vacuum (m/s)}}{\text{Speed of light in medium (m/s)}} = \text{refractive index, } n$$

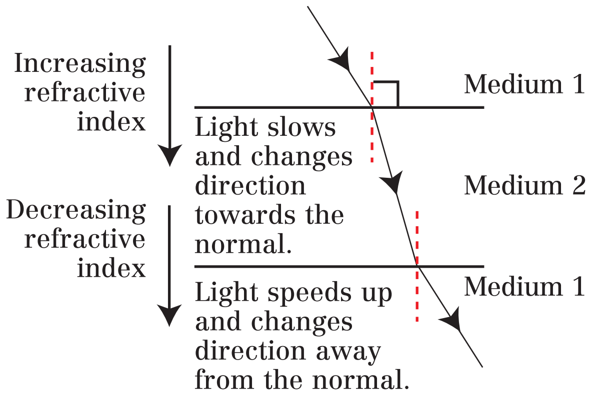




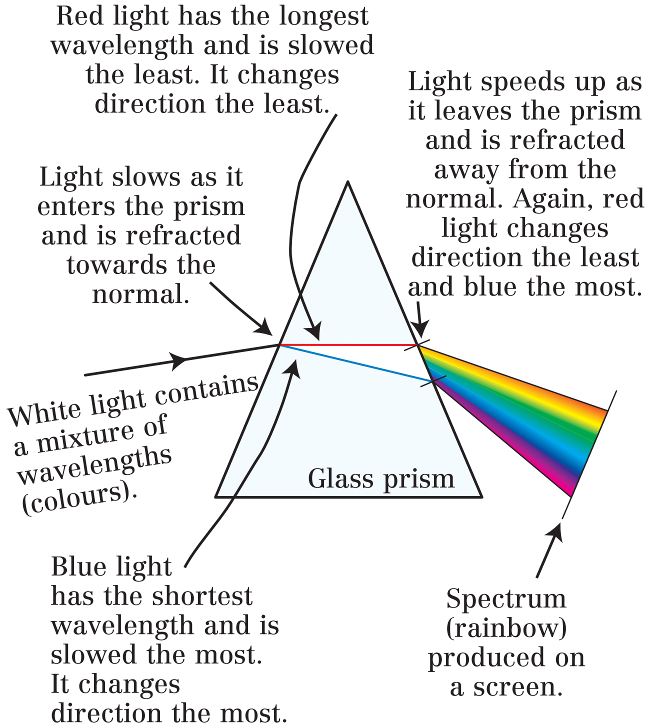
The bigger the refractive index the more the light is slowed as it passes into the medium.

Therefore, the bigger the refractive index the greater the change in direction of the light wave as it passes into the medium.

Hence Snell's Law $\quad$ Refractive index n, $= \dfrac{\sin i}{\sin r}$

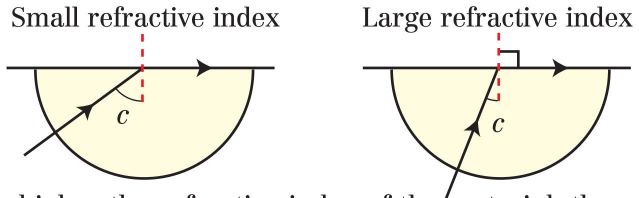


Dispersion



Total internal reflection

1. Light must change direction away from the normal so must be going from high to low refractive index.
2. Angle of incidence must be greater than the critical angle.



The higher the refractive index of the material, the greater the change of direction away from the normal and therefore, the lower its critical angle.

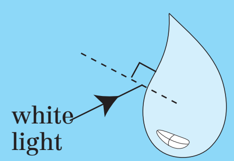
The critical angle, c, can be calculated from the ratio of the refractive indices either side of the boundary.

$$\text{Sin (critical angle)} = \frac{\text{refractive index of second material}}{\text{refractive index of first material}}$$

$$\text{Sin } c = \frac{n_r}{n_i}$$

Questions

1. Which colour, blue or red, is slowed most as it enters a glass prism?
2. Copy the water droplet and complete the diagram to show how the drop splits the white light into colours. Show the order of these colours on your diagram.
3. The speed of light in a vacuum is 3×10^8 m/s. Show that:
   a. The refractive index of water is about 1.3 given the speed of light in water is 2.256×10^8 m/s.
   b. The speed of light in diamond is about 1.2×10^8 m/s given its refractive index is 2.42.

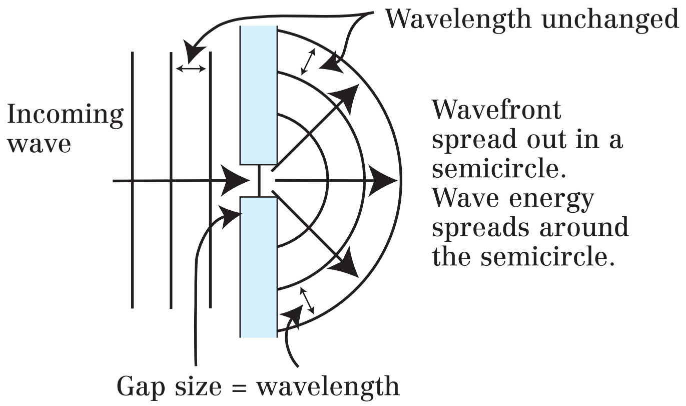


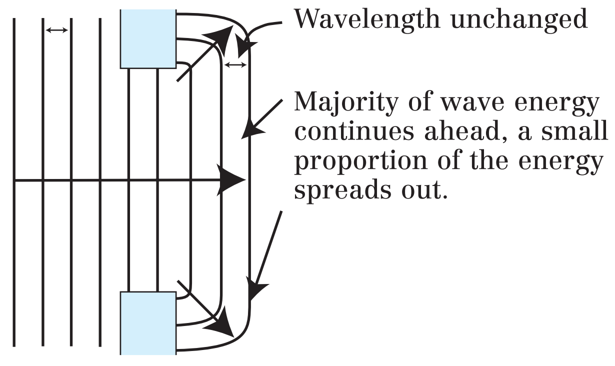
4. The refractive index of glass is about 1.52. A ray of light enters a glass block at 25° to the normal. Show that it continues through the block at about 16°.
5. What is the critical angle for light travelling from water, refractive index 1.33, to air, refractive index 1.00? Why is it not possible to calculate a critical angle for light travelling from air into water?

WAVES Diffraction and Interference

Both diffraction and interference are properties of waves. The fact that all electromagnetic waves display both effects is strong evidence for them having a wave nature.

Diffraction – the spreading out of wave energy as it passes through a gap or past an obstacle.



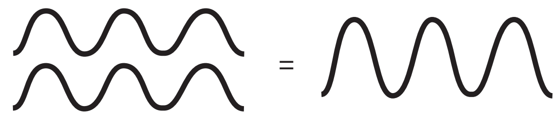


Gap size much wider than wavelength – diffraction effect is not very noticeable.

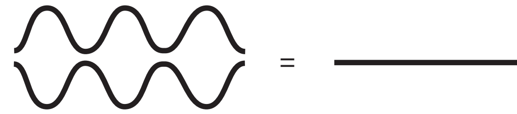
Light has a very short wavelength (about 5×10^{-7} m), so needs very small gap sizes for diffraction to be noticeable.

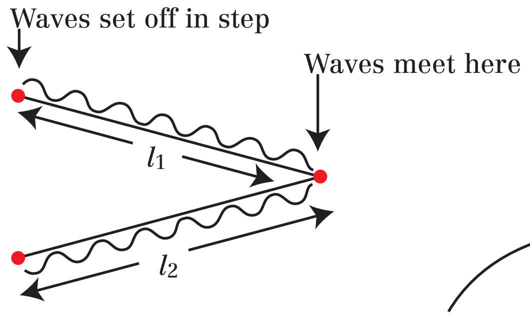
Interference – when two waves meet, their effects add.

When two waves arrive in step, they reinforce each other and this is called *constructive interference*. For light the result would be bright and for sound, loud.



When two waves arrive out of step they cancel out and this is called *destructive interference*. For light this would be dark and for sound, quiet.

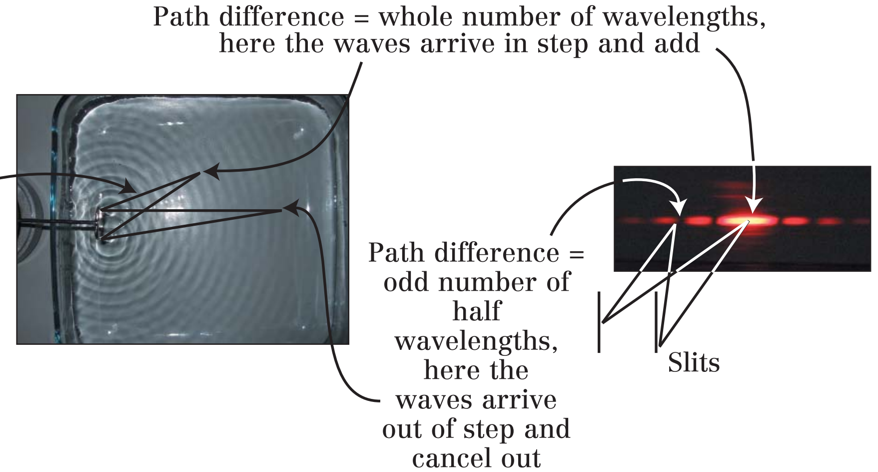




If the difference in path length ($l_1 - l_2$) is:

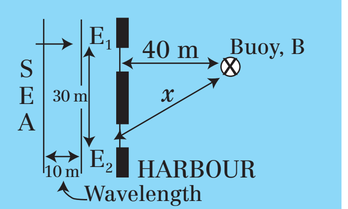
- A whole number of wavelengths the waves arrive in step and we have constructive interference.
- An odd number of half wavelengths, the waves arrive out of step and we have destructive interference.

Interference patterns

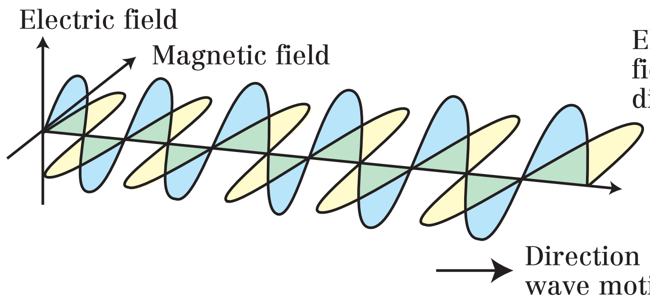


Questions

1. The speed of sound in air is about 340 m/s. Calculate wavelength of the note 'middle C', frequency = 256 Hz. Hence, explain why a piano can be heard through an open doorway, even if the piano itself cannot be seen.
2. A satellite dish behaves like a gap with electromagnetic waves passing through. Explain why the dish sending the signal to a satellite should have a much wider diameter than the wavelength of the waves, whereas a dish broadcasting a signal from a satellite over a wide area should have the same diameter as the wavelength of the waves.
3. The diagram shows a plan view of a harbour. The wavelength of the waves arriving from the sea is 10 m.
   a. How long is length x?
   b. How many waves fit in the length E_1 to B?
   c. How many waves fit in the length E_2 to B?
   d. Therefore, will the waves arrive in or out of step at the buoy, B? Hence, describe the motion of a boat tied to it.
   e. If the wavelength increased to 20 m how would your answers to b–d change?

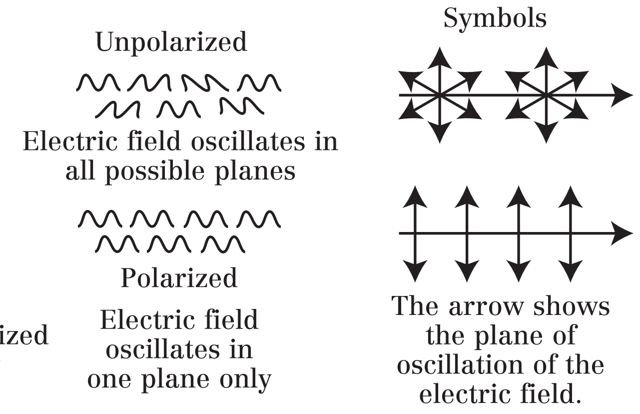


WAVES Polarization and the Photon Model of Light

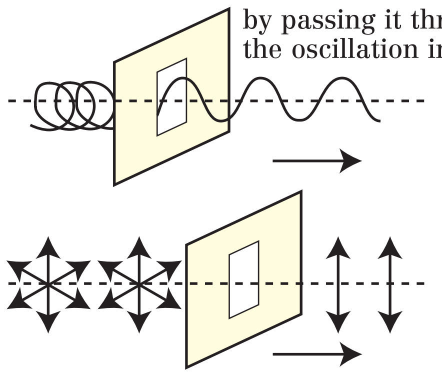


Electromagnetic waves are made from an electric and magnetic field oscillating at right angles to each other and to the direction of wave motion.

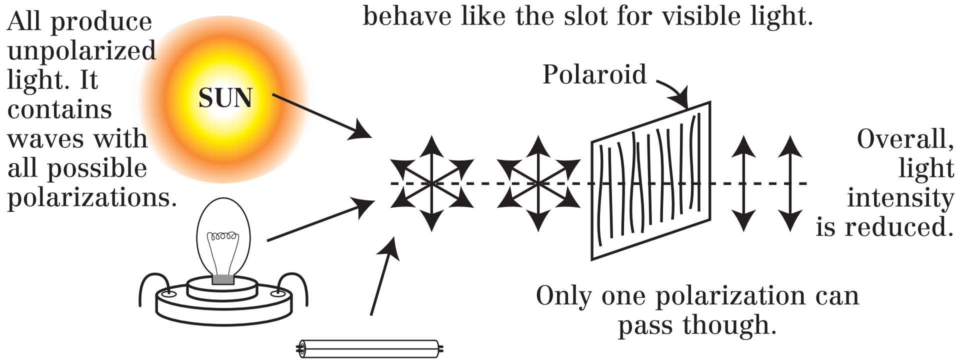
A beam of electromagnetic radiation is made up of many waves. If the electric field in all the waves only oscillates in one plane (so the magnetic field only oscillates in one plane too), the waves are said to be *polarized*.

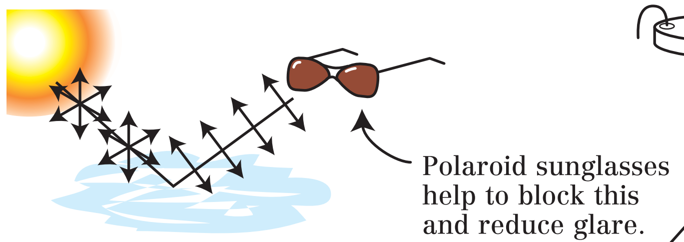


A mechanical wave on a string can be polarized by passing it through a frictionless slot; only the oscillation in one plane passes through.



Polaroid is a material that contains molecules that behave like the slot for visible light.





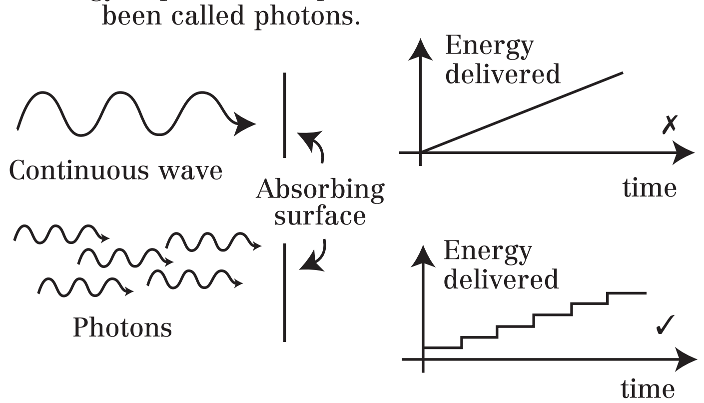
Light is polarized by reflection, e.g. from water.

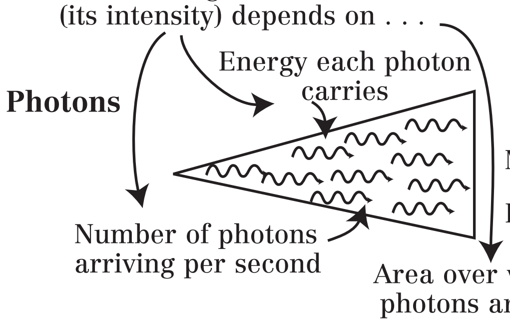
(1) Electromagnetic radiation always delivers energy in packets (or quanta). These have been called photons.

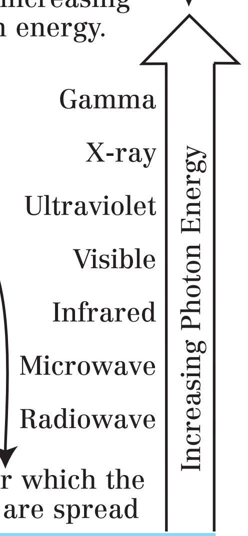
(2) The energy carried by each photon is directly proportional to the frequency of the electromagnetic wave.

(3) Hence, the electromagnetic spectrum is also a scale of increasing photon energy.

(4) The total energy delivered by a beam of electromagnetic radiation (its intensity) depends on . . .





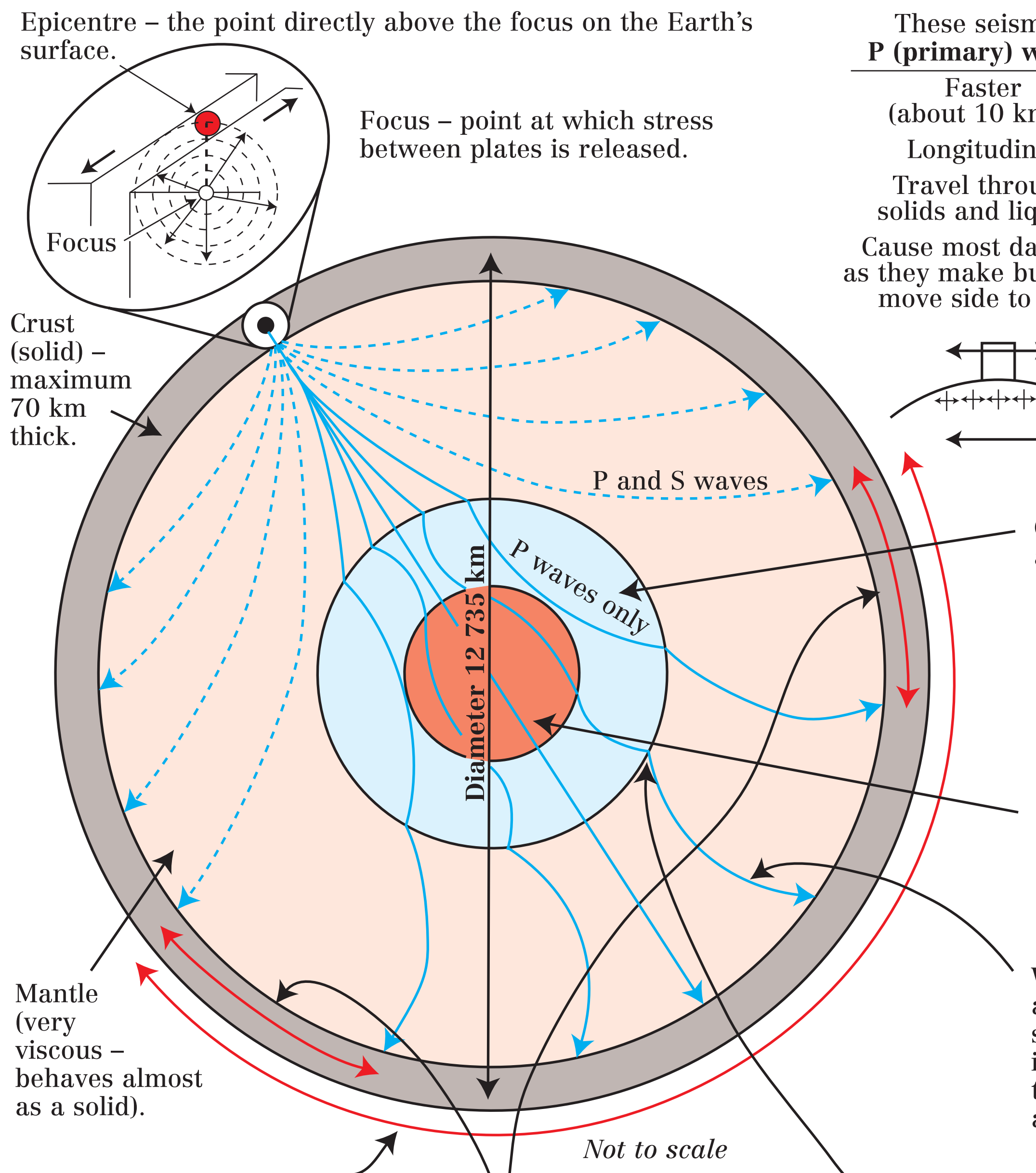


Questions

1. What do we mean by a polarized wave? Draw a diagram to illustrate your answer.
2. Reflected light from a lake in summer is horizontally polarized. Which orientation of light should the Polaroid material in sunglasses allow to pass if the glasses are to cut down glare from the lake?
3. What is a photon?
4. What type of radiation delivers more energy per photon, X-rays or radiowaves?
5. Suggest why X-rays and gamma rays can knock electrons out of atoms (ionize them) but visible light and infrared cannot. What effect might this have on the human body?
6. The photons in a beam of electromagnetic radiation carry 4×10^{-17} J each. If 1×10^{18} photons arrive each second over a 2 m^2 area what is the total energy arriving per m^2?

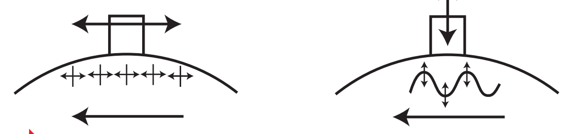
WAVES Seismic Waves and the Structure of the Earth

Earthquakes occur when stresses build up at fault lines where the Earth's tectonic plates are moving past each other. The energy stored can be suddenly released as the plates shift, sending out a shock or seismic wave.



These seismic waves come in two types

P (primary) waves	S (secondary) waves
Faster (about 10 km/s)	Slower (about 6 km/s)
Longitudinal	Transverse
Travel through solids and liquids	Travel through solids only
Cause most damage as they make buildings move side to side	Cause less damage as they make buildings move up and down



Waves follow a curved path as the density of the Earth steadily increases as you go into the Earth. Therefore, their speed changes and they are steadily refracted.

S wave shadow zone. S waves cannot travel through the molten outer core so this area forms a 'shadow' of the Earth's core. Seismometers in this region do not detect S waves.

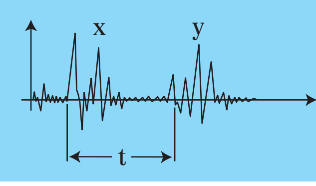
P wave shadow zone – caused by refraction as the P waves enter and leave the core. Seismometers here pick up no waves.

The distance to the epicentre can be estimated by the time lag between the P and S waves arriving.

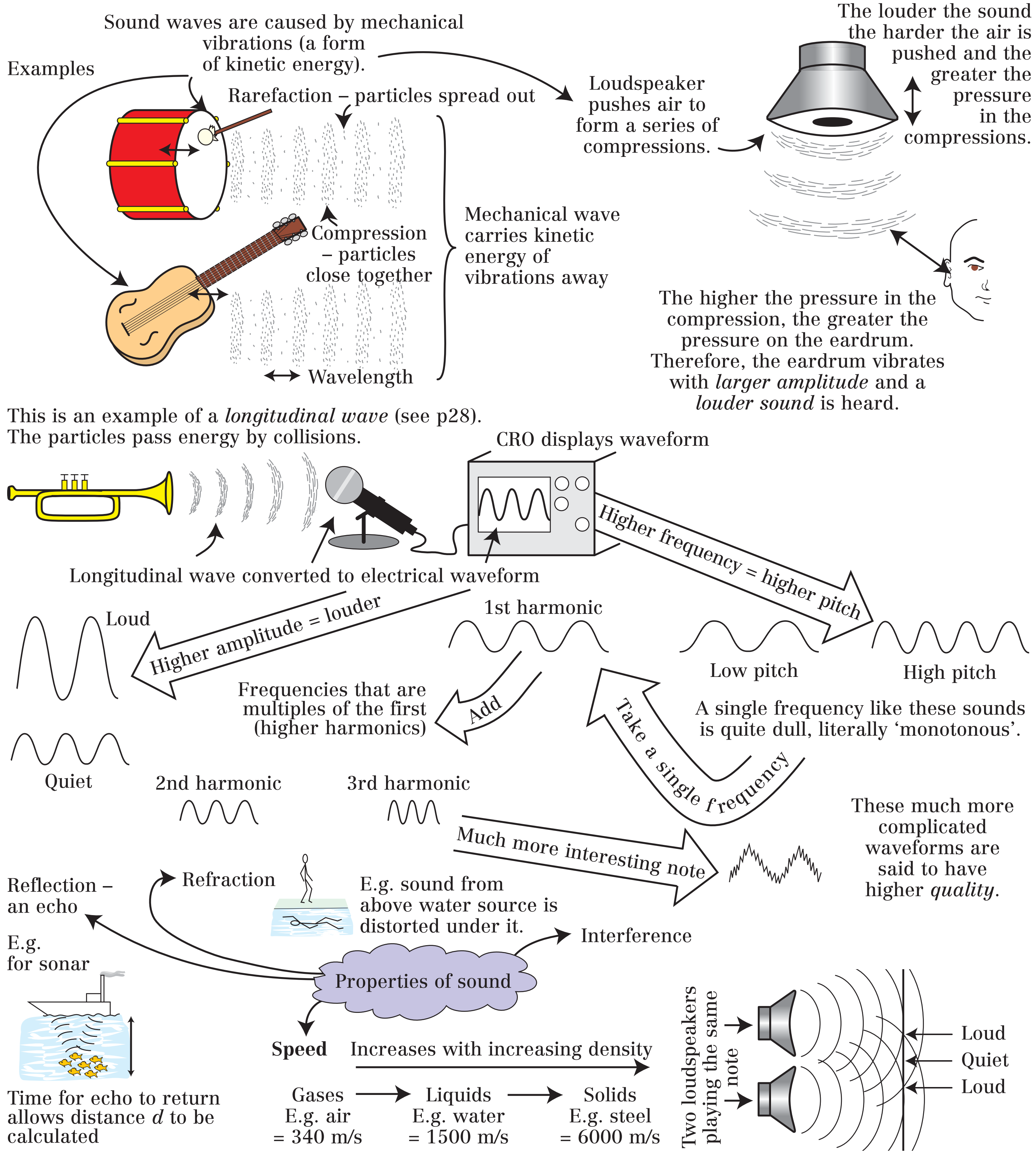
Sudden change in direction at join between layers, because the density of the material suddenly changes so there is a sudden change in wave speed and hence direction by refraction (see p36).

Questions

1. What is the difference between an Earthquake's epicentre and its focus?
2. Draw a labelled diagram of the layers in the Earth. If the crust is a maximum of 70 km thick, what percentage of the total radius of the Earth is made up of crust?
3. Write down two similarities and three differences between P and S waves.
4. Explain how scientists know that the outer core of the Earth is molten.
5. Here is a seismometer trace for an earthquake:
   a. Which trace, X or Y, shows the arrival of the S waves and which the P waves?
   b. If the speed of the P waves is 10 km/s and they took 150 s to arrive, how far away was the earthquake?
   c. If the speed of the S waves is 6 km/s, how long should they take to arrive?
   d. Hence, what is the time interval t marked on the graph?

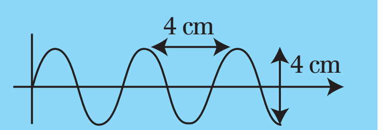


WAVES Sound Waves

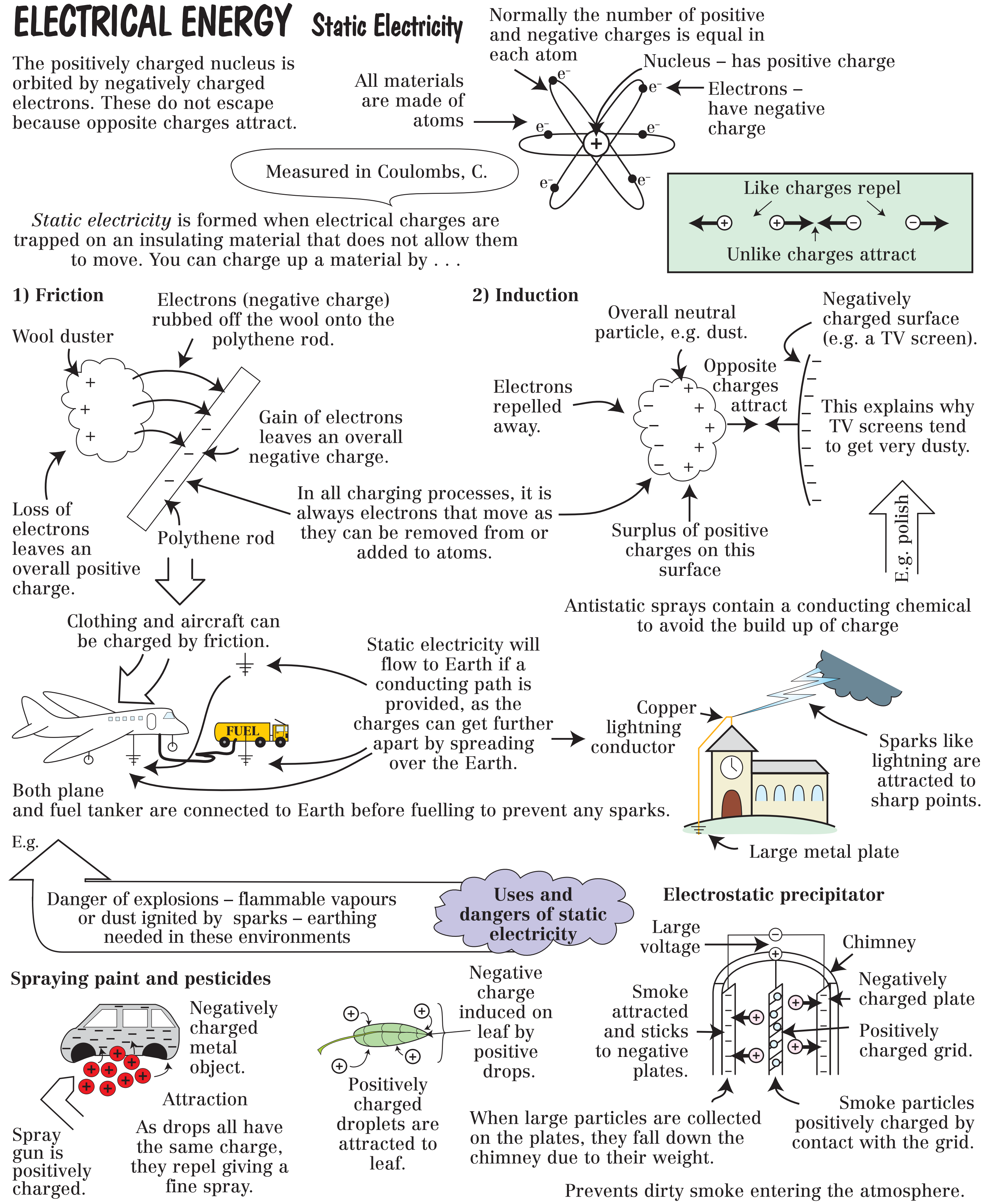


Questions

1. What causes sound? Explain how the sound from a loudspeaker reaches your ear.
2. Explain why sound cannot travel in a vacuum.
3. Use the formula speed = frequency × wavelength to calculate the range of wavelengths of sound the human ear can hear in air where the speed of sound is about 340 m/s.
4. Why does sound travel faster in solids than in gases?
5. What does the pitch of a sound wave depend on?
6. What does the loudness of a sound wave depend on?
7. What is a harmonic?
8. Copy this waveform and add:
   a. A waveform of twice the frequency but the same amplitude.
   b. A waveform of half the amplitude but the same frequency.
   c. A waveform of the same amplitude and frequency but of a higher quality.



ELECTRICAL ENERGY Static Electricity



Questions

1. Complete the following sentences. Like charges ________, unlike (opposite) charges ________.
2. What is the unit of electrical charge?
3. What is the difference between an insulator and a conductor?
4. Why would it not be possible to charge a copper rod by rubbing it, no matter how furiously you rubbed?
5. Explain in as much detail as possible how a balloon rubbed on a woolly jumper sticks to a wall.
6. Make a list of all the examples of static electricity in action mentioned in this page. Divide your list into cases where static electricity is useful, where it is a nuisance, and where it is dangerous. Try to add your own examples to the list.