Visible Light

PHYSICS • WAVES • VISIBLE LIGHT

Section 1: Properties of Light

• What is light?

The light humans can see is just one part of the electromagnetic spectrum

Light is an electromagnetic wave. All electromagnetic waves travel at the speed of light. This is significant, as it is the maximum speed at which all matter and information in the Universe can travel. Light exhibits wave properties, such as reflection, refraction, interference and diffraction. These properties can be exploited to manipulate light.

• Suggested Films

- **Manipulating Light**
- **What Is Light?**
- **Time Travel**

Extension Question

Q1. What is a photon?

Sometimes light can behave like a stream of particles instead of a wave. The energy of these particles is proportional to the frequency of the light. This is important when considering how light is absorbed. Electrons in atoms are only able to occupy certain energy levels. When light is absorbed, the electron can be raised to a higher energy level.

If light could be completely described using only wave theory, then increasing the intensity of the light would increase the amplitude of the wave. This would eventually provide enough energy to excite the electron. However, what we observe is that if the energy of each individual photon is not enough to raise the electron into the next energy level, absorption will not take place, even if the intensity of the light is increased to provide more photons. Instead the frequency of the light has to be increased. This increases the energy of each photon, and even low intensity light can then be absorbed.

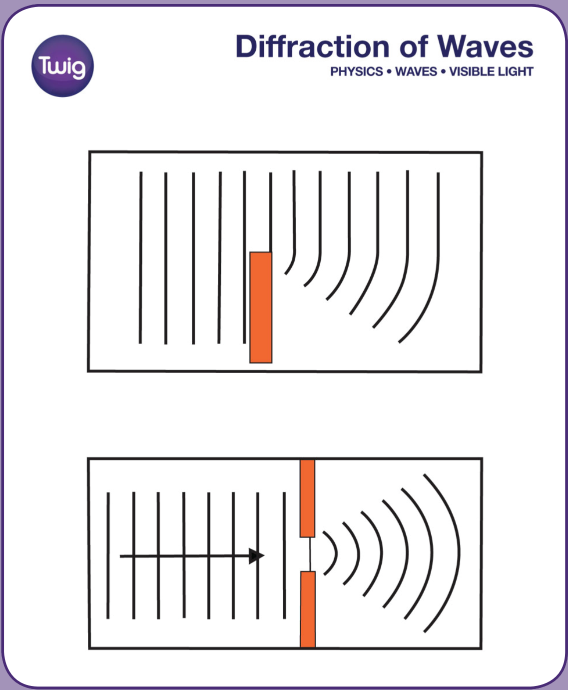
• What is diffraction?

• Suggested Film

- **Manipulating Light**

All waves exhibit diffraction. Diffraction refers to the tendency of waves to spread out when they encounter an obstacle, or pass through a gap. The diffraction of light waves is what causes the edges of shadows to appear blurred at large distances. Diffraction becomes most obvious when the gap the wave passes through is comparable to its wavelength. For visible light this requires very small gaps, as it has wavelengths that are smaller than a thousandth of a millimetre.

DIAGRAM 01:



Extension Questions

Q2. What is interference?

When two waves overlap, they can combine in a process known as interference.

When the peaks and troughs of the waves coincide, they combine to produce a wave with a greater amplitude. This is known as constructive interference.

When the peaks of one wave coincide with the troughs of another, the two waves cancel out. This is known as destructive interference. For light waves this means that light and dark areas are produced.

In practice, interference is only likely to occur when the two waves are coherent. If waves are coherent, this means that they have a fixed phase relationship – the two waves will either line up perfectly or be offset by a fixed amount. This is unlikely to happen with two separate light sources. Instead, the light from one source is often split to create more than one wave, and these are combined to produce interference.

Q3. What is a diffraction grating?

When a wave passes through a structure with series of small gaps, known as a diffraction grating, the wave spreads out as it passes through each. These waves can then interfere and produce a series of light and dark areas. This is commonly used to measure the wavelength of light, as the spacing between these areas is related to the wavelength. If many different wavelengths are present, as with white light, the different wavelengths will interfere at different points, and a spectrum can be produced. This is often used to show which wavelengths are present within a source.

This effect can be seen when light shines on a CD or a DVD, as these act as diffraction gratings. The alternating reflective and non-reflective areas on their surfaces mean that light is reflected from many different points. These light waves interfere to produce a spectrum.

• What are fibre optics?

Fibre optics are long, thin threads of glass, which can be used to transmit light using total internal reflection. They are widely used for communication. Lasers send signals along the fibres using pulses of light. Fibre optics have several advantages over copper wires: they are made of glass, which is much cheaper than copper; and they are lighter, smaller, have less signal loss, and can carry far more information than copper cables of similar size. Electrical signals can also experience interference from cables running alongside, or from electrical signals from the wider environment. Optical fibres do not experience this type of interference. In fact, several different signals can be sent down the same optical fibre without interference.

Fibre optics allow us to send light signals over long distances

• Suggested Film

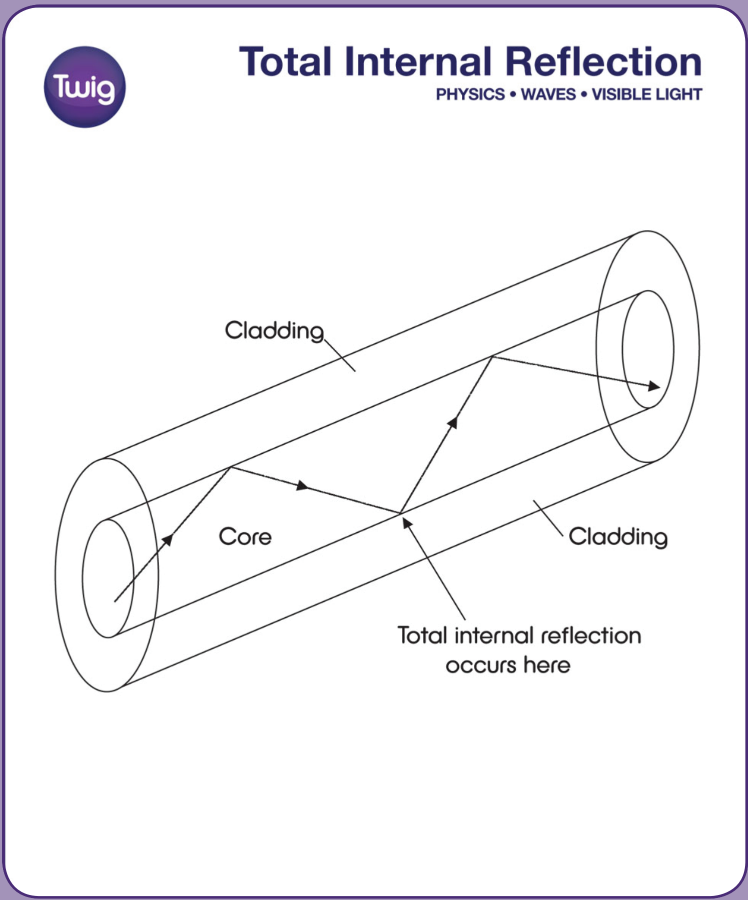
- Fibre Optics

Extension Questions

Q4. What is total internal reflection?

When light passes from one medium into another its speed changes. For example, light travels more slowly through glass than through air. If the light strikes the boundary at an angle, this causes the light to change direction: this is known as refraction. If the light is passing from a dense medium to a less dense medium, for example from glass to air, the change in direction can be so great that the light does not leave the material and the ray then reflects from the boundary. This is known as total internal reflection, and only occurs when the light ray is incident at an angle greater than a specific angle, known as the critical angle. The critical angle for a ray travelling from glass to air is around 40°. The angle from water to air is larger, as water is less dense than glass.

DIAGRAM 02:



Q5. When were fibre optics invented?

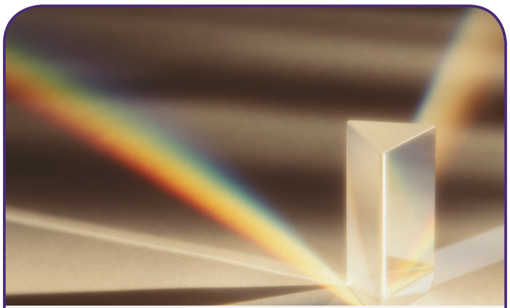
The principle behind fibre optics was understood for a long time before they were finally used for long distance communication. It was only in the 1970s that the technology was developed to solve two problems. Firstly, glass was produced which was relatively free of impurities. These impurities cause light to be absorbed before it can travel the necessary distance, therefore preventing the use of fibre optics for long distance communication. Secondly, it became possible to draw glass into strands kilometres long. The first long distance fibre optic communication systems were constructed in the late 1970s.

Q6. How do we rely on fibre optics?

Satellites only make a small contribution to international communications. Instead, the internet relies on fibre optics to carry vast amounts of data, and undersea cables running along the seabed connect every continent except Antarctica. Breaks in these cables are not uncommon, and damage can be caused by boats' fishing nets and anchors, earthquakes, or even the cable rubbing on undersea rocks, meaning dozens of repairs have to be made every year. It is unlikely that these breaks would affect communication to Europe or America as there are so many cables, but some areas have far fewer cables. For example, in 2008 a series of breaks in undersea fibre optic cables severely disrupted internet services to the Middle East and India.

Section 2: Perceiving Light

• What is colour?



The refraction of light by a prism shows all the different colours of light

As well as detecting the difference between light and dark, our eyes are equipped to distinguish between different wavelengths of light. We perceive these different wavelengths as different colours. For example, long wavelength light is seen as red, and short wavelength light is seen as blue.

The eye contains two types of cell for detecting light: rod cells, which work best at low intensities and are mainly responsible for night vision, and cone cells. There are three different types of cone cell and each responds to a different range of wavelengths. The three cones are commonly referred to as blue, green and red (or S, M and L for short, medium and long wavelengths).

The response of each cone varies with wavelength and overlaps with neighbouring cones. This means that the eye can distinguish between many different wavelengths.

• Suggested Films

- **What Is Light?**
- **Colour**

Extension Question

Q7. What happens when more than one wavelength is present?

When more than one wavelength is present, the colour which is perceived can be different to either of the colours produced by the two wavelengths on their own. For example, red and green light together are perceived as yellow.

When all three cones are stimulated at the same time, white light is perceived. White light is the result of three widely spaced wavelengths being detected at the same time. It can be demonstrated that white light is composed of many different wavelengths by passing sunlight through a prism; this splits the light into a full spectrum. The same effect is seen when light is refracted through raindrops to produce a rainbow.

• How does colour mixing work?

There are two types of colour mixing: additive and subtractive. When more than one wavelength of light is present, we determine the resultant colour using additive colour mixing. In simple terms this tells us that red and green make yellow, blue and green make cyan, and red and blue make magenta.

However, when paints are mixed, the colour mixing rules appear to work differently. For example, mixing yellow and blue paint results in green. This is known as subtractive colour mixing and results from the way pigments work.

In general, the reason that objects appear to be a particular colour is because they reflect some wavelengths of light and absorb others. Blue paint appears blue because when white light strikes the paint all wavelengths of light, except those which we perceive as blue, are absorbed, and blue light is reflected. Yellow paint is yellow because it absorbs blue light and reflects red and green light.

This means that when we mix blue and yellow paint, we are mixing two materials which each absorb different wavelengths of light. We might expect the mixture to appear black, as the blue light reflected by the blue paint will be absorbed by the yellow paint, and the red and green light reflected by the yellow paint will be absorbed by the blue; resulting in no light reaching our eyes. Mixing pigments does produce darker colours, but the mixture of paint will not appear black, instead it is likely to appear green.

This is because blue paint does not perfectly absorb all light except blue, therefore is likely that some green light will be reflected. Yellow paint also reflects green light and this is absorbed by either colour of paint.

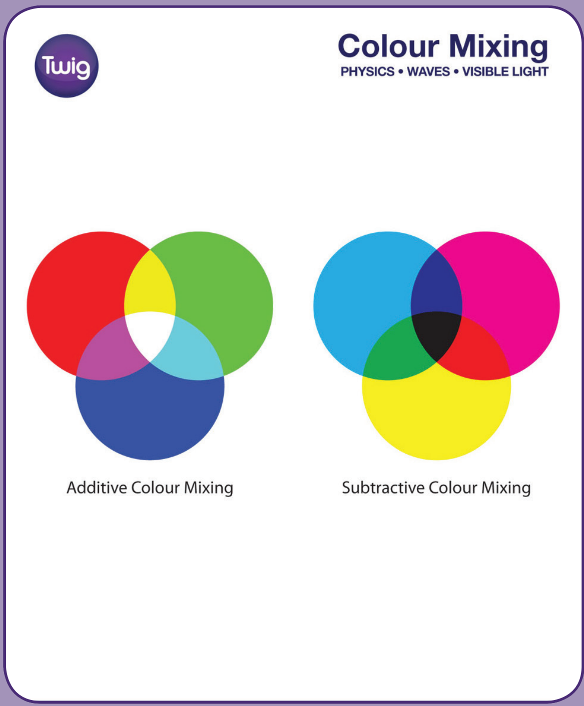
We should require cyan and yellow paint to make green, because cyan reflects blue and green light, and yellow reflects green and red. However, as blue paint usually reflects some green light, mixing blue and yellow paint usually results in green.

Because pigments work by removing wavelengths of light, and lights work by adding wavelengths, the rules for colour mixing are different.

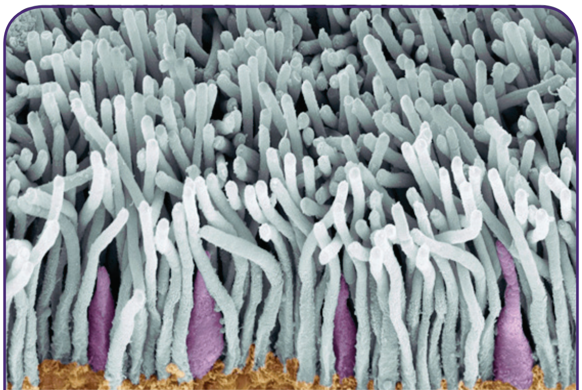
• Suggested Films

- Colour
- Animal Senses
- FactPack: Colour Mixing

DIAGRAM 03:



• Do all animals see like humans do?



The rods and cones of the human eye

• Suggested Film

- Colour

Human colour vision uses three types of cone cell; this is called trichromacy and means that humans have good colour vision. However, many other mammals, like dogs and cats, are dichromats, which means they only have two types of cone cell. This means that they are not able to distinguish the same range of colours as humans.

There are several types of animal, including birds, which are thought to have four types of cone cell. These are known as tetrachromats, and are capable of distinguishing between colours that would appear identical to humans.

Some animals, butterflies for example, have five types of cone cell, and it is thought that they are pentachromats. If these cone cells are all functional, they would be capable of making even finer distinctions between colours.

Extension Question

Q8. What is colour blindness?

It is often assumed that colour blindness refers to the complete inability to see colour; this is extremely rare. Usually, colour blindness means that one of the three types of cone cells is less effective, not functional, absent, or for some reason not able to contribute to colour vision.

This makes it more difficult to distinguish between different wavelengths of light. The exact nature of the colour blindness depends on which type of cone cell is affected. The most common type of colour blindness leads to difficulty in distinguishing green and red, and these colours will look similar.

Around 5% of males have some form of colour blindness. It is far less common among females because they inherit two copies of the genes which are involved in colour vision. This is because many of the genes are found on a structure known as the X chromosome; females have two X chromosomes, one from each parent, but males only have one. If a female inherits an X chromosome with deficiencies in the genes involved in colour vision, she will not be colour blind, as long as there are no deficiencies on the second X chromosome.

Section 3: Lasers

• What is a laser?

Laser stands for Light Amplification by Stimulated Emission of Radiation. The light produced by lasers has special properties. Laser beams can be extremely narrow, and do not spread greatly with distance. This means very intense beams of light can be achieved, even at relatively large distances from the source. Also, because of the way it is produced by stimulated emission, laser light is monochromatic, which means it only contains one wavelength (actually there will be a small range of wavelengths produced but the range is so small we can call the light monochromatic). Laser light is also coherent, which means that the waves have a fixed phase relationship. The peaks and troughs of the waves are either lined up, or they are offset by a fixed amount. These properties make lasers important for a very wide range of applications.

Lasers are used to read CDs and DVDs

• Suggested Film

- How Do Lasers Work?

Extension Question

Q9. What is stimulated emission?

When light is absorbed by an atom, an electron in the atom is raised into a higher energy level. When the electron drops back into its original state, it emits light. In addition to these two processes of absorption and spontaneous emission, there is a third, stimulated emission. It is this which makes it possible to construct lasers.

When an atom is in an excited state, and an electron has been raised to a high energy level, there will be as very short delay before the electron drops back down and emits light. However, light of exactly the same energy can cause the electron to fall to a lower state and emit light: this is known as stimulated emission. The emitted light will be exactly the same frequency as the light which stimulates the emission, and the emitted and stimulating light will be coherent.

• How are lasers constructed?

A laser can be built using an appropriate crystal as the active medium. A flashlamp is used to send light into the material, exciting the electrons within the atoms. As these electrons drop back into their ground states the atoms emit light, stimulating the emission of light from other atoms. Mirrors are placed at either end of the crystal, which reflect the light back into the medium and this causes the emission of more light. One of the mirrors is not entirely reflective and this allows some light to escape. This light is the laser beam. Unlike normal sources of light, such as light bulbs, the light heads out in a straight line. This is because any light within the laser, which was not travelling in at right angles to the two mirrors, would have been reflected away by the mirrors and would not have left the laser.

• Suggested Film

- How Do Lasers Work?

Extension Questions

Q10. Do all lasers use crystals?

There are several types of material that can be used in lasers, but in order to be suitable for use in a laser a material has to have certain properties. When electrons are excited into higher energy levels, they often drop back down and emit light almost instantly. However, for a laser to work there must be a large population of electrons sitting in an excited state, ready to be stimulated into emitting light. This is known as population inversion, and can be arranged by exciting electrons into one energy level, and having them drop into another, from which it is hard to drop back into ground state. This requires a special type of material, or combination of materials, which have the appropriate arrangement of energy levels.

Solid state lasers commonly use crystals, but lasers can also use gases, liquids or semiconductors. As well as atomic energy levels, the vibrational energy levels of molecules can also be used in lasers.

Q11. Do lasers only work with visible light?

Lasers can also be constructed which operate in the infrared or the ultraviolet. Microwave lasers (masers) were actually built before visible lasers, and even occur naturally in space, particularly around stars. Lasers can also be produced which work at X-ray wavelengths, although these are constructed using slightly different principles.

Not all wavelengths in the spectrum are available as lasers usually only emit at one specific wavelength. However, there are some lasers, particularly dye lasers, which can be tuned and allow the wavelength to be varied.

Q12. What is a free electron laser?

Although most lasers use electrons moving between energy levels in atoms or molecules to cause the emission of light, a free electron laser uses a high speed beam of electrons.

The beam is passed between magnets which pull it one way then the other, and as they move back and forth they emit light. This setup is known as a wiggler and can be adjusted to change the frequency and wavelength of the light produced. Because of this, free electron lasers can be tuned to a wide range of wavelengths, and can be used to generate X-rays.

• How directional is a laser?

A light bulb emits far more energy than a laser, but it is spread out over a far greater area

Although it is usually said that laser beams travel in straight lines, and do not spread out with distance, this is not entirely correct. The beam spreads slightly after it comes out of the laser. The angle at which this happens will be very small, perhaps a few tenths of a degree, but this means that the diameter of the beam increases with distance. This angle is known as the divergence of the laser, and means that even over a distance of a hundred metres a laser beam can be tens of centimetres in diameter. This significantly reduces the intensity of the light.

• Suggested Film

- **How Do Lasers Work?**

Extension Questions

Q13. Are lasers dangerous?

Lasers are generally more dangerous than other sources of light, as their irradiance (the amount of energy delivered to an area each second) does not decrease strongly with distance. A 100 watt light bulb emits far more energy every second than a 10 milliwatt laser, but at a distance of a few metres the laser beam will be far more intense, because the energy from the light bulb will have spread out over a far greater area. If lasers are intense enough they can cause eye damage, and even burn tissue.

The danger from a laser depends both on the power of the laser and its wavelength. There are four main classes of laser: class 1 lasers are considered safe under all circumstances; class 2 lasers are safe as long as the eye's blink reflex is able to limit exposure time; class 3 lasers are dangerous if viewed directly; and class 4 lasers can burn skin, and reflections from any surface can cause eye damage.

• Quizzes

Colour

Basic

• When light waves bounce back from a surface what is this called?

A – reflection

B – refraction

C – diffraction

D – radiation

• When light waves change direction as they interact with a medium what is this called?

A – diffraction

B – reflection

C – radiation

D – refraction

• Why are some objects red?

A – they absorb red light

B – they reflect only red and blue light

C – they reflect only red light

D – they reflect only red and green light

• What makes some objects black?

A – they reflect all visible light

B – they have surfaces which are rough and so reflect light in all directions.

C – they reflect red and green light

D – they absorb all visible light

Advanced

• What is the shortest wavelength of visible light?

A – about 400 nanometres

B – about 650 nanometres

C – about 800 nanometres

D – about 540 nanometres

• What colour of light has the shortest wavelength?

A – red

B – green

C – violet

D – yellow

• What colour of light has the longest wavelength?

A – blue

B – red

C – violet

D – orange

• What colour of light travels fastest through a medium like glass?

A – green

B – red

C – orange

D – violet

Colour

• Why do different wavelengths refract differently when entering glass?

A – they travel at different speeds in glass

B – some wavelengths are more easily absorbed than others

C – some wavelengths are more intense than others

D – the temperature of the glass will vary across its surface

• What colour of light travels slowest through a medium like glass?

A – blue

B – violet

C – red

D – orange

What Is Light?

Basic

• Where does most of our light come from?

A – fossil fuels

B – the Sun

C – the Moon

D – the stars

• What do we mean by visible light?

A – the small part of the electromagnetic spectrum we are able to see

B – it is another name for the electromagnetic spectrum

C – any electromagnetic radiation that is emitted by atoms

D – any electromagnetic radiation that is reflected

• What is meant by luminance?

A – the frequency of the light being emitted

B – the wavelength of the light being emitted

C – the brightness of a source

D – the length of time for which light is emitted

• How does light reach us from the Sun?

A – it travels as heat and changes into visible light when it hits our atmosphere

B – it can travel through a vacuum

C – because the Sun has a thick atmosphere which extends out to Earth

D – space is not a perfect vacuum so the light can travel through it

Advanced

• How long does it take light to reach us from the Sun?

A – 5 seconds

B – 1 week

C – 2 years

D – 8 minutes

• How far away is the Sun?

A – 300,000 km

B – 90 million km

C – 150 million km

D – 1 million km

• What is the speed of light?

A – 340 m/s

B – 300,000,000 m/s

C – 186,000 m/s

D – 1500 m/s

• Why are some objects visible to us?

A – all visible objects emit light

B – all visible objects reflect light

C – some visible objects reflect light and some emit light

D – our eyes emit light

• Answers

Colour

Basic

• When light waves bounce back from a surface what is this called?

A – reflection

B – refraction

C – diffraction

D – radiation

• When light waves change direction as they interact with a medium what is this called?

A – diffraction

B – reflection

C – radiation

D – refraction

• Why are some objects red?

A – they absorb red light

B – they reflect only red and blue light

C – they reflect only red light

D – they reflect only red and green light

• What makes some objects black?

A – they reflect all visible light

B – they have surfaces which are rough and so reflect light in all directions.

C – they reflect red and green light

D – they absorb all visible light

Advanced

• What is the shortest wavelength of visible light?

A – about 400 nanometres

B – about 650 nanometres

C – about 800 nanometres

D – about 540 nanometres

• What colour of light has the shortest wavelength?

A – red

B – green

C – violet

D – yellow

• What colour of light has the longest wavelength?

A – blue

B – red

C – violet

D – orange

• What colour of light travels fastest through a medium like glass?

A – green

B – red

C – orange

D – violet

Colour

• Why do different wavelengths refract differently when entering glass?

A – they travel at different speeds in glass

B – some wavelengths are more easily absorbed than others

C – some wavelengths are more intense than others

D – the temperature of the glass will vary across its surface

• What colour of light travels slowest through a medium like glass?

A – blue

B – violet

C – red

D – orange

What Is Light?

Basic

• Where does most of our light come from?

A – fossil fuels

B – the Sun

C – the Moon

D – the stars

• What do we mean by visible light?

A – the small part of the electromagnetic spectrum we are able to see

B – it is another name for the electromagnetic spectrum

C – any electromagnetic radiation that is emitted by atoms

D – any electromagnetic radiation that is reflected

• What is meant by luminance?

A – the frequency of the light being emitted

B – the wavelength of the light being emitted

C – the brightness of a source

D – the length of time for which light is emitted

• How does light reach us from the Sun?

A – it travels as heat and changes into visible light when it hits our atmosphere

B – it can travel through a vacuum

C – because the Sun has a thick atmosphere which extends out to Earth

D – space is not a perfect vacuum so the light can travel through it

Advanced

• How long does it take light to reach us from the Sun?

A – 5 seconds

B – 1 week

C – 2 years

D – 8 minutes

• How far away is the Sun?

A – 300,000 km

B – 90 million km

C – 150 million km

D – 1 million km

• What is the speed of light?

A – 340 m/s

B – 300,000,000 m/s

C – 186,000 m/s

D – 1500 m/s

• Why are some objects visible to us?

A – all visible objects emit light

B – all visible objects reflect light

C – some visible objects reflect light and some emit light

D – our eyes emit light