PHYSICS

Waves and Energy Transfer

Ideas you have met before

Energy stores and transfers

An object stores energy depending on how high it has been raised. This is because it is affected by the Earth's gravitational force.

When elastic materials are stretched or squashed they have more energy stored in them.

Energy is transferred when changes happen, and this transfer can happen in many different ways. It may be transferred from place to place in a material or from one form of storage to another.

Fuels are energy stores

Fuels are energy stored chemically. They include wood, fossil fuels and hydrogen.

Fuels only burn if oxygen is present. The products of combustion also store energy, but less than that in the fuel and oxygen together.

When a fuel is burned in oxygen, energy is transferred to the surroundings and to the combustion products.

Sound waves

Energy is transferred by sound in the form of waves.

Sound waves are longitudinal waves transmitted by vibrating air particles.

They may be reflected by hard materials and absorbed by soft materials.

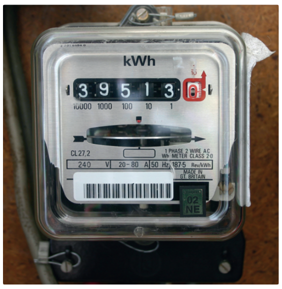
In this chapter you will find out

Energy transfers

- Conduction and radiation are important ways of moving energy from place to place.
- The quantity of energy transferred in a change can be measured.
- How quickly energy is transferred is important and this can also be measured.

Energy in the home

- Fuel bills show how much energy is used and its cost.
- Knowing the quantity of energy transferred is useful and can be calculated.
- Similarly, knowing the rate of energy transfer is also useful and can be calculated.



Water waves

- Waves in water are transverse waves that carry energy.
- Water waves, like sound waves, need a medium to travel through.
- Water waves can be reflected.

Light waves

- Light travels as transverse waves that carry energy.
- Light waves can travel through a vacuum.
- Light can be reflected, absorbed and refracted.
- White light can be split into a spectrum of colours.

Making waves

We are learning how to:

- Describe the movement of waves in water.
- Understand reflection of waves.
- Understand superposition of waves.

When you watch the waves at the seashore, it seems as if the water is coming towards you. However, watching boats and seabirds floating on the sea, you can see that they bob up and down as the waves pass by. We need to try to explain why something moving up and down seems to be carrying energy along.

FIGURE 3.6.2a: This boat bobs up and down as the waves pass by it.

Reflecting waves

You know that sound waves are reflected, or bounced back, by hard flat surfaces – this is what makes echoes. However, it is not just sound waves – all waves can undergo **reflection**.

The behaviour of waves in water can be explored using a water tank. If some single straight water ripples are generated in the tank, then blocking their path shows how the wave is reflected (Figure 3.6.2b). The wave is reflected by the barrier and the angle it is reflected at is the same as the angle it arrived at.

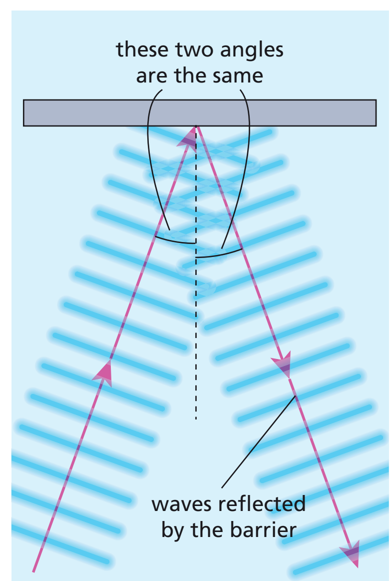


FIGURE 3.6.2b: Ripples of water bounce off the barrier.

1. Explain what we mean when we say that light has been reflected.
2. What do you notice about the direction in which a wave hits a barrier and the direction in which it is reflected?
3. Suggest why a bumpy surface does not produce a reflected wave that is the same shape as the wave that arrived.

Ripples in a pond

Previously, we explored sound waves, which are **longitudinal waves**. A longitudinal wave moves backwards and forwards in the same direction that it is travelling in.

Water waves, however, are **transverse waves**. Unlike longitudinal waves, they move up and down rather than

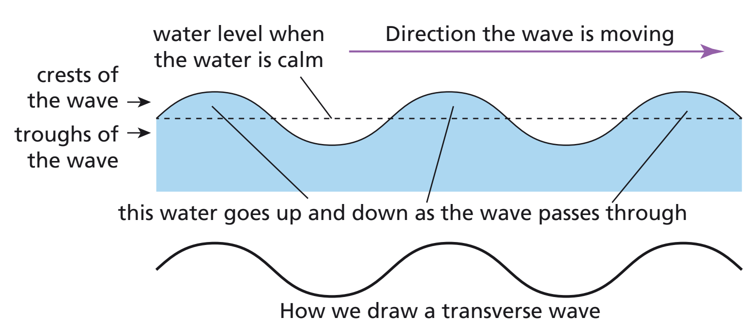


FIGURE 3.6.2c: Cross-sections through a ripple on water; volumes of water oscillate up and down as the wave passes.

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backwards and forwards. Transverse means 'across' – the water is moving across the direction the wave is travelling in.

All waves **oscillate**, moving either up and down or forwards or backwards in a regular rhythm – rather like the rhythm of a swinging pendulum.

4. Describe the movement of water in a wave.
5. Describe the difference between a crest and a trough.
6. Explain the difference between a transverse wave and a longitudinal wave.

Superposition

When two pebbles are thrown into water, the ripples produced meet one another (Figure 3.6.2d). You can see what happens when the ripples meet.

When two waves from different starting places meet, they either combine to make a bigger wave or cancel each other out. This is called **superposition**.

If the crests coincide, the waves add together and make a bigger wave.

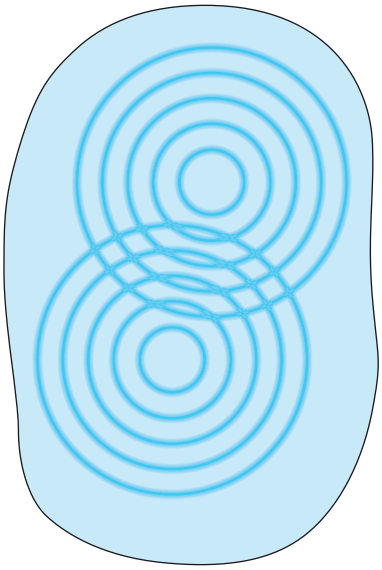

FIGURE 3.6.2d: The circles show the crests of the waves produced when two pebbles are thrown into water. They spread outwards.

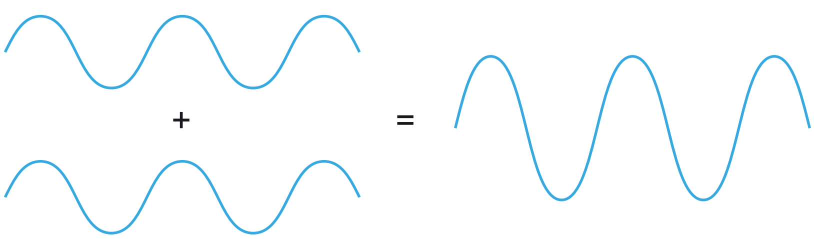

FIGURE 3.6.2e: Superposition produces bigger waves.

If the crests of one wave coincide with the troughs of the other, the waves cancel out, resulting in no wave.

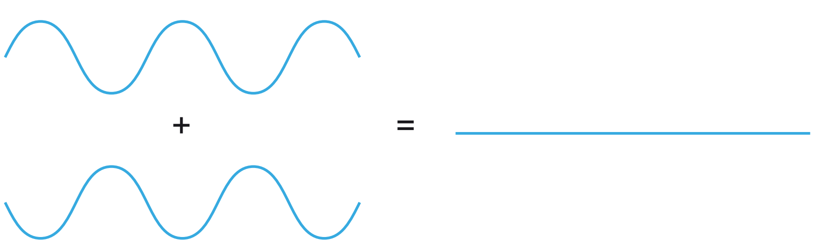

FIGURE 3.6.2f: Superposition can lead to waves cancelling one another out.

7. Describe the idea of superposition.
8. Explain the effect of combining two waves when the crests of one coincide with the troughs of the other.

Did you know...?

The largest water wave recorded was in Lituya Bay, Alaska in 1958. It was 524 metres high.

Key vocabulary

reflection

longitudinal wave

transverse wave

oscillate

superposition

Exploring light waves

We are learning how to:

- Describe light as travelling in waves.
- Understand the similarities and differences between water waves and light waves.
- Explain the frequency of a wave.

Light from the Sun travels 149 600 000 km through empty space before entering the Earth's atmosphere and finally reaching the Earth's surface. Most importantly, it transfers energy released in the Sun to Earth.

FIGURE 3.6.3a: Even on a cloudy day, light from the Sun still reaches Earth.

Sight and light

Light is emitted from sources such as the Sun, electric lamps and burning candles. It enters the eye (see Topic 6.5) and the optic nerve sends messages to the brain, which is how we see.

However, most of the light that enters the eye does not come directly from a light source. It is light that has been reflected by objects all around us.

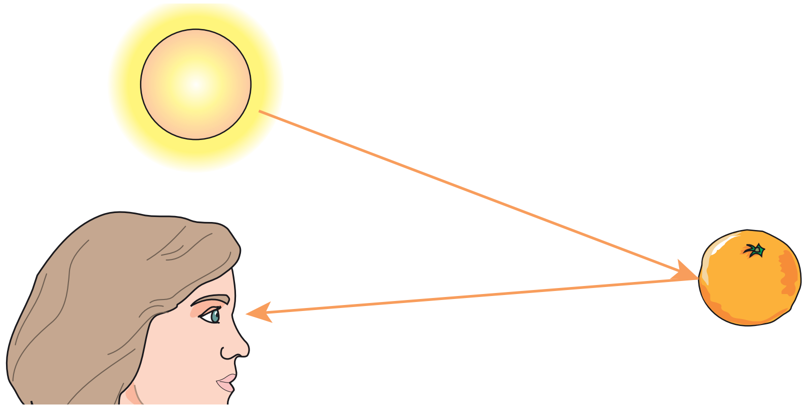

FIGURE 3.6.3b: Light from the Sun is reflected from the orange into the eye.

1. Describe, with the help of a sketch, how light from:

   a) a candle flame reaches the eye

   b) a person's face reaches another person's eye.

2. Explain why it is more difficult to see things at night.

Comparing water and light waves

Waves in water and sound waves are examples of mechanical waves. Mechanical waves need a medium (material), such as water or air, to travel through.

Light waves are examples of electromagnetic waves. Electromagnetic waves do not need a medium. They can travel through empty space (a vacuum). This is why light from the Sun can reach the Earth.

Waves in water and light waves are transverse waves – they oscillate up and down, forming **crests** and **troughs**.

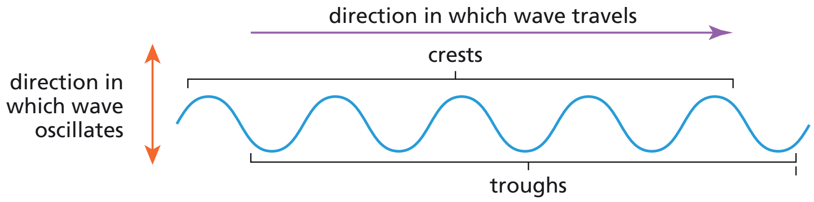

FIGURE 3.6.3c: Light is transverse waves that can travel through empty space.

3. Give two examples of mechanical waves.
4. Describe how the oscillation of a transverse wave differs from the direction that the wave travels.
5. Explain why an MP3 player will not make a noise in a vacuum.

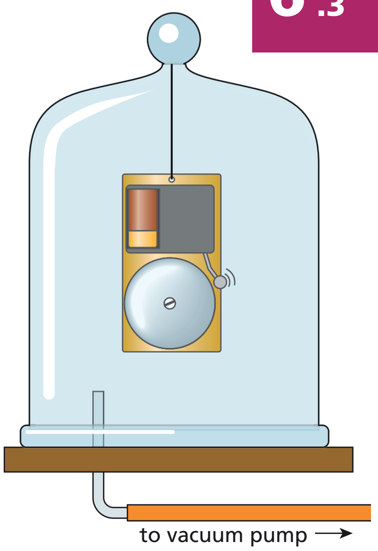

FIGURE 3.6.3d: When the air is sucked out of the jar, the bell cannot be heard, but it can be seen. This is because sound waves need a medium (air), but light waves do not.

Frequency and wavelength

If water waves were being studied, the number of crests or troughs that pass a certain place every minute could be counted. From this the number per second could be calculated – this is the **frequency**, measured in **hertz (Hz)**. One hertz is the frequency of one wave per second.

The distance between the crests is the **wavelength**.

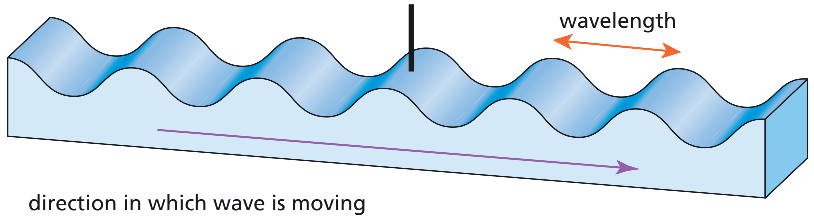

FIGURE 3.6.3e: The frequency is the number of crests that pass a fixed point every second. The distance between crests is the wavelength.

6. Explain what is meant by the frequency of a light wave.
7. The hertz is the unit of frequency. Explain what its value tells us about a wave.
8. If water waves are travelling at a steady speed, but their frequency is increased, what will have changed about their wavelength?

Did you know...?

The Sun is close enough to the Earth to provide enough energy to support life. However, the Earth is far enough away that it is not damaged by too much energy from the Sun.

Key vocabulary

crest
trough
frequency
hertz (Hz)
wavelength

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Physics

Explaining properties of light waves

We are learning how to:

- Describe how light passes through different materials.
- Understand how light can be absorbed by materials.
- Explain the difference between diffuse scattering and specular reflection.

Simple sundials can be made easily. The pointer is made of an opaque material that blocks light and produces a shadow. The position of the shadow can be used to tell the time.

FIGURE 3.6.4a: A sundial

See-through?

Light passes through gases, some liquids and some solids. Materials that light waves can pass through freely are said to be **transparent**. They do not produce shadows.

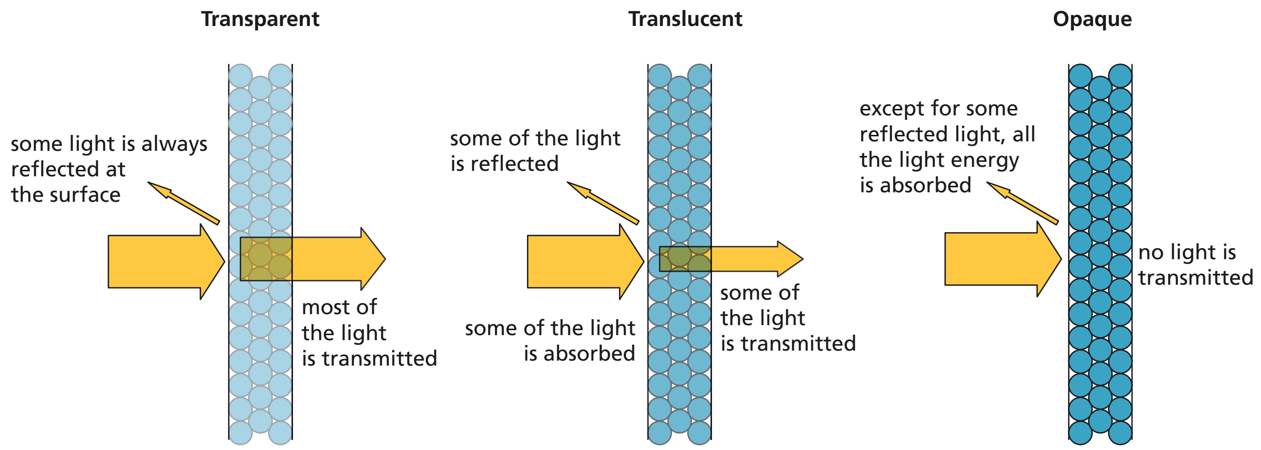

FIGURE 3.6.4b: This shows what happens to light when it falls on transparent, translucent and opaque materials.

Other materials cast shadows by either completely or partially blocking the passage of light. **Opaque** materials block the passage of light waves completely, producing a dark shadow, whereas **translucent** materials only allow some of the light to pass through, casting weak shadows.

1. Give three examples of transparent materials.
2. Compare the shadows produced by an opaque material and those by a translucent material.
3. Explain why an opaque object casts a shadow.

FIGURE 3.6.4c: Frosted glass provides some privacy because it does not allow all the light to pass through it.

Specular and diffuse reflection

When light hits a surface or a boundary, some or all of it is reflected – it bounces back in a direction away from the surface. The reflection produced by a flat, smooth surface is called **specular reflection**. All the light is reflected in the same direction. It allows us to see an **image**.

A rough reflective surface bounces light back in many directions. We can think of the surface as being a mixture of small flat surfaces at different angles. The effect is called diffuse reflection, or **diffuse scattering**.

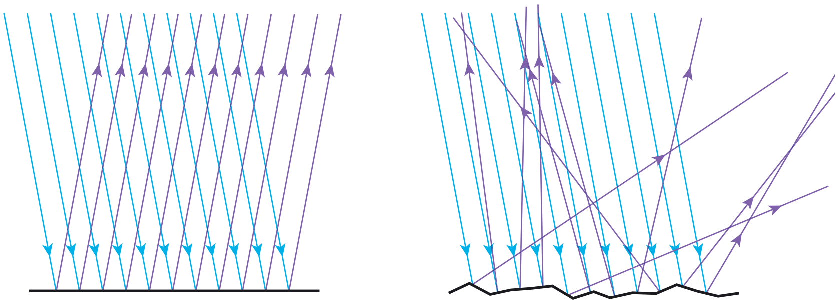

FIGURE 3.6.4e: The diagram on the left shows specular reflection. The one on the right shows diffuse reflection.

4. Describe the difference between specular reflection and diffuse reflection.
5. Explain why diffuse scattering happens on rough surfaces.
6. Explain why reflections in lakes or ponds cannot be seen if the water is choppy.

Absorption of light

Translucent and opaque materials **absorb** some or all of the light that falls on them. The energy of the light waves is transferred to the particles of the material.

Transparent materials do not absorb light. The light passes straight through and comes out on the opposite side, where it is transmitted.

All surfaces reflect some of the light that falls on them – that is how we see them.

7. Describe what happens when light waves strike a block of ice.
8. Explain what happens when light waves strike a flat steel panel.

FIGURE 3.6.4d: The result of specular reflection in a calm lake

Did you know...?

You can see through a piece of frosted glass (make it 'see-through') simply by putting a piece of clear sticky tape on it.

Key vocabulary

transparent
opaque
translucent
specular reflection
image
diffuse scattering
absorb

Using the ray model

We are learning how to:

- Describe the ray model of light.
- Explain how the direction of light rays can be changed.
- Explain how a pinhole camera and the eye work.

If you look at a swimming pool from above, it looks shallower than it really is. If a spoon is placed at an angle in a glass of water, it appears to have bent or broken at the water surface. Both of these effects are caused by refraction. To explain refraction, and reflection, we need to use the ray model.

FIGURE 3.6.5a: Refraction causes the spoon to look as if it has broken into two parts.

FIGURE 3.6.5c: The specular reflection of light from a mirror allows you to see an image.

Explaining reflection

Light travels as waves, but a **ray model** allows us to show clearly in a diagram the direction of light and how it can change its direction when it meets a surface.

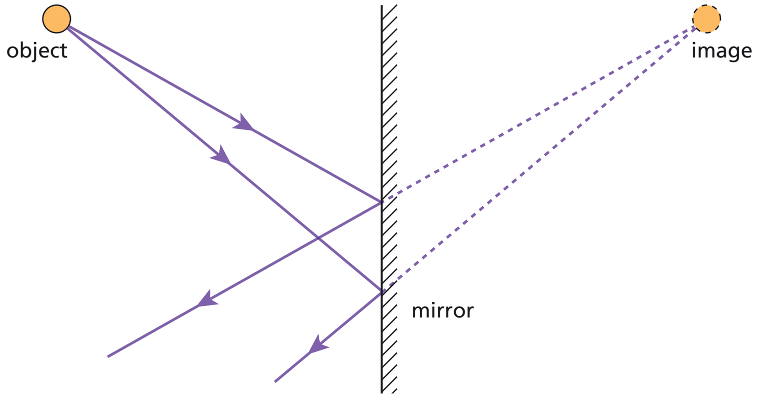

FIGURE 3.6.5b: The solid lines represent light rays. The dashed lines show where the light rays appear to be coming from – the image. This is the same distance from the mirror as from the object to the mirror.

1. Describe what Figure 3.6.5b shows.

2. Describe how the ray diagram showing image formation in a mirror needs to be changed if the object is:

a) further away **b)** closer

Refraction

Light travels through transparent materials, such as glass and air. However, its speed depends on the density of the material. The denser the transparent material, the slower light travels through it. Glass is denser than air, so light travels through it slower than it travels through air.

When the light slows down, the wavelength of its waves becomes shorter. Each of the crests catches up with the one in front. If the light then emerges into a less-dense medium it will speed up again. This effect is called **refraction**, and can cause the direction of the light to change.

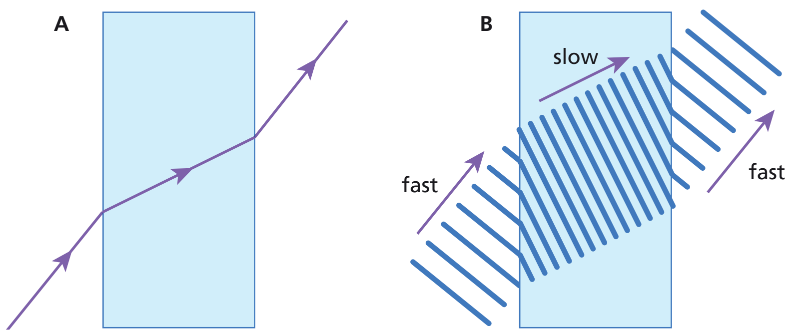

FIGURE 3.6.5d: A: ray model to show refraction of light; B: the wavelength shortens in a denser material.

3. Describe what happens to light waves when they travel into a dense material.
4. Sketch a diagram to suggest what would happen if a light ray was to hit a glass rod as shown in Figure 3.6.5e.

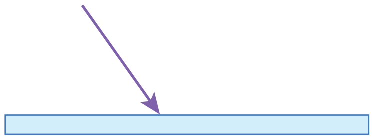

FIGURE 3.6.5e: A light ray hitting a glass rod – what happens?

The human eye

Light enters an eye through the **cornea** and then travels through the **lens**. These both refract light rays, focusing them on a common point. An image forms on the **retina**. The optic nerve sends information to the brain, which interprets it.

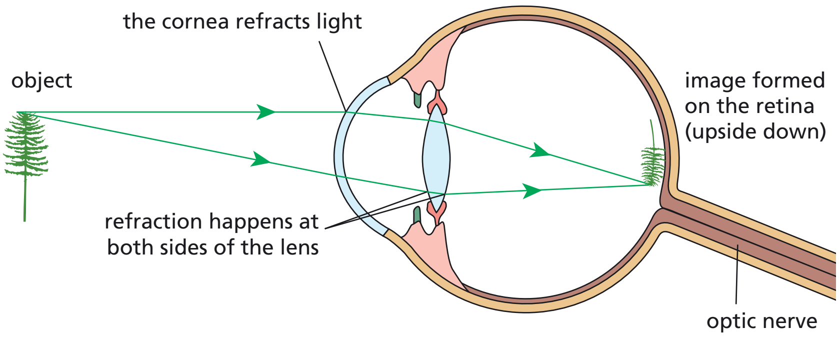

FIGURE 3.6.5f: How the eye works

5. Name the parts of an eye that refract light.
6. Explain what the lens does to the rays of light.
7. Explain why the image formed on the retina is upside down.

Did you know...?

You can make a working pinhole camera from a cardboard box, greaseproof paper and sticky tape using nothing more than a pin and a pair of scissors.

Key vocabulary

ray model
refraction
cornea
lens
retina

Understanding energy transfer by light

We are learning how to:

- Describe light as a way of transferring energy.
- Give examples of chemical and electrical effects when materials absorb light.
- Explain changes that happen when materials absorb light.

Curtains, carpets and other fabrics are often affected by strong sunlight. Colours fade and fabrics do not look as bright as when they were new. The sunlight is causing chemical changes to the pigments used to put colour into the fabrics.

FIGURE 3.6.6a: Some coloured fabrics fade in sunlight.

Light carries energy

Light waves carry energy and transfer it from place to place. They may come from a light source, such as the Sun, flames and electric lamps, or the light waves may be reflected from objects. The waves travel in straight lines until they are reflected, refracted or absorbed by a material.

When light is absorbed, there is **energy transfer** to the particles that make up the material. Sometimes this leads to chemical reactions or to a flow of electric current.

1. Describe the difference between a source of light, such as a bulb, and reflected light, such as from a mirror.
2. Describe what happens when a material absorbs energy carried by light.
3. Name two possible changes that might happen when a material absorbs light.

Photosynthesis and photovoltaic cells

Energy absorbed from light can be put to good use. In **photosynthesis**, energy carried by sunlight is transferred to chlorophyll in the cells of green leaves. The transferred energy is involved in a chemical change that produces glucose in plant leaves. The other product is oxygen.

carbon dioxide + water → glucose + oxygen

Scientists have also developed ways of harnessing energy from absorbed light. Some manufactured materials absorb light and produce an electric current. An example

Did you know...?

Before digital cameras, images were captured on photographic film. The film had a surface made from compounds that changed colour when exposed to light.

is highly purified silicon. Such materials are used to make photovoltaic (PV) cells. These have a number of applications, such as powering calculators.

A PV material absorbs sunlight, which releases electrons from the material's particles. This is called the **photovoltaic effect**. The movement of the freed electrons results in an electric current (a flow of electrons). So a PV cell is similar to the cells in a battery, except that electrons are freed by sunlight rather than by a chemical change.

FIGURE 3.6.6b: Solar panels consist of banks of PV cells.

4. Explain what is meant by the 'photovoltaic effect'.
5. Give an example of a material that exhibits the photovoltaic effect.
6. Explain why a solar panel consists of large numbers of PV cells.

Photochemical smog

Absorbing energy from light can also cause problems. Photochemical smog forms when pollutants in the atmosphere react in the presence of sunlight (see Figure 3.4.3b in Topic 4.3). One of the initial **photochemical reactions** is the breaking down of nitrogen dioxide to give nitrogen monoxide, as shown in Figure 3.6.6c.

7. Describe what can happen to air pollution on a sunny day.
8. Explain what can happen when nitrogen dioxide particles absorb sunlight.

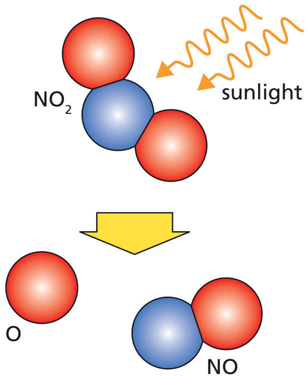

FIGURE 3.6.6c: Energy absorbed from sunlight makes nitrogen dioxide molecules vibrate faster and split into an oxygen atom and a nitrogen monoxide molecule.

Key vocabulary

energy transfer
photosynthesis
photovoltaic effect
photochemical reaction

Exploring coloured light

We are learning how to:

- Describe how a spectrum can be produced from white light.
- Compare the properties of light of different frequencies.
- Explain how light of different wavelengths can be split and recombined.

Some days it can be raining and, at the same time, the Sun can be shining. This is when a rainbow can often be seen. To make a rainbow, sunlight and droplets of water are needed.

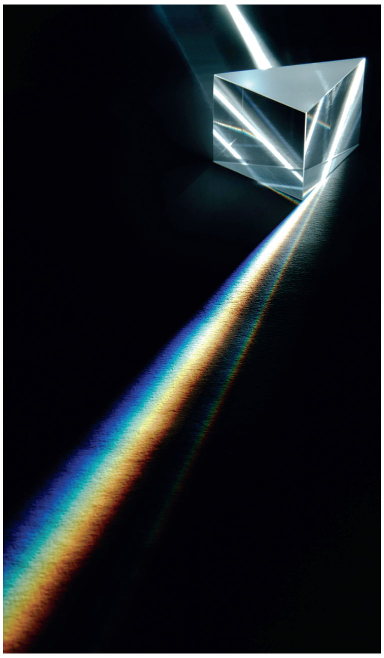

FIGURE 3.6.7a: A prism produces a spectrum from white light.

Spectrum from white light

Sunlight is made up of light waves of different **wavelengths**. The range of wavelengths that the human eye can detect as different colours is called the visible **spectrum**. Seen together they make what is called white light. This white light can be split up to produce the colours of the spectrum. For example, if sunlight is shone through a prism (triangular-shaped block of glass), it is refracted into different colours.

1. Describe the shape of a prism.
2. Describe the spectrum obtained when white light passes through a prism.
3. Which colours appear at each edge of a rainbow?

Different wavelengths

Light waves travel at the same speed in the same medium. The longer the wavelength, the fewer the crests that pass a fixed point every second and, therefore, the lower the **frequency**.

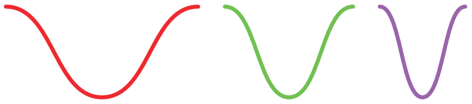

FIGURE 3.6.7b: In the visible spectrum, waves of red light have the longest wavelengths and waves of violet light, the shortest.

When a light wave passes into and out of a glass prism, the wave is refracted. The shorter its wavelength, the more it is refracted – so violet light is refracted more than red light. The 'white light' is split up and spreads out to form a spectrum.

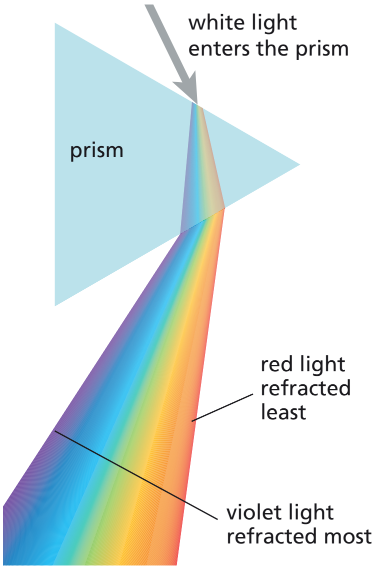

FIGURE 3.6.7c: The white light is split up by refraction.

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Waves with different wavelengths can be combined – this is additive colour mixing. It is different to mixing paints. Mixing red, blue and green light produces white light. Mixing red, blue and green paint produces muddy brown paint.

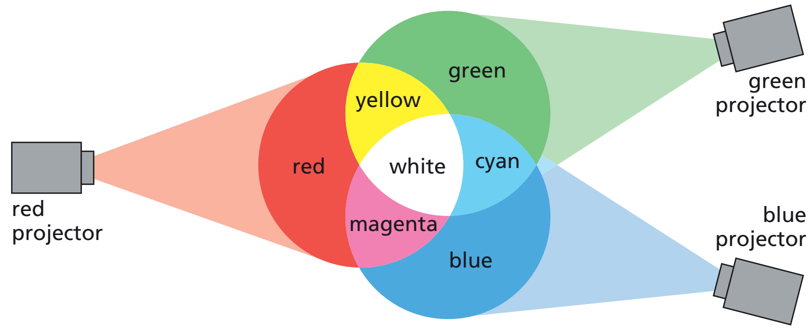

FIGURE 3.6.7d: Recombining waves to make white light

4. Explain the relationship between the wavelength and the frequency of a wave.
5. Which has the longest wavelength – red light or blue light?
6. Explain why white light spreads out to produce a visible spectrum when it passes through a prism.

Frequency and behaviour

Some materials are coloured, but can still be seen through, such as coloured plastic sheets and solutions of food dyes. They only absorb light waves of certain frequencies. The light that passes through consists of light with frequencies that were not absorbed.

Some opaque materials are coloured. This is because light waves of certain frequencies are absorbed by the material, but the light with other frequencies is reflected.

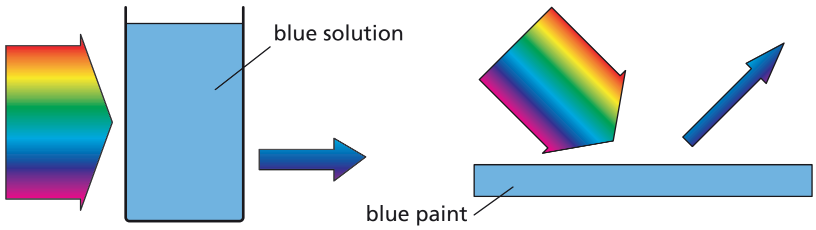

FIGURE 3.6.7e: A blue solution absorbs wavelengths of light other than blue. Only blue light passes through. Blue paint absorbs wavelengths of light other than blue. Blue light is reflected. No light passes through.

7. Explain why a solution of red food colouring is red, but also transparent.
8. Explain why green paint appears green.

Did you know...?

Light with frequencies lower and higher than those at the extremes of the visible spectrum cannot be seen by the human eye. Infrared radiation has frequencies lower than that of red light. Ultraviolet radiation has frequencies higher than that of violet light.

Key vocabulary

wavelength

spectrum

frequency

Applying key ideas

You have now met a number of important ideas in this chapter. This activity gives an opportunity for you to apply them, just as scientists do. Read the text and study the diagrams first, then have a go at the tasks. The first few are fairly easy – then they become a bit more challenging.

Rainbows

Imagine that the Sun is shining and, at the same time, it is raining. If you were to look in the direction of the Sun (not straight at it – that could harm your eyes) you would just see rain and sunshine. However, if you were to turn round so that the Sun was behind you, the chances are that you would see a rainbow. Sometimes you might even see a double rainbow.

If it is sunny, but not raining, you can still make a rainbow. You need a hose pipe or some other way of producing a spray of water. Turn the water on, adjust the hose to produce a fine spray and direct it upwards and away from you. You may need to play around a little to find the ideal direction of the spray to produce the clearest rainbow.

Rain consists of very small droplets of water. Each behaves in a similar way to a prism – it splits white light into a continuous spectrum, from red to violet. The combined effect of all the water droplets is to produce a rainbow.

In Figure 3.6.8a, the ray diagram shows what happens to sunlight when it meets a raindrop. A beam of light meets the surface of the raindrop and starts to pass through. It is split into a spectrum, which reflects back from the inside of the raindrop before passing out and back into the air. It is impossible to represent a continuous spectrum using a ray diagram, so the two lines shown represent the extreme ends of the spectrum – red and violet.

A double rainbow has two bows – an inner one and an outer one (this is sometimes called a secondary rainbow). The inner bow is produced just as for a single rainbow. Formation of the outer bow, however, involves an extra change within the raindrop.

In Figure 3.6.8c, the ray diagram shows how the outer bow of a double rainbow (a secondary rainbow) forms. The process is similar to the inner-bow formation except that light reflects back twice on the inside of the raindrop before passing out into the air.

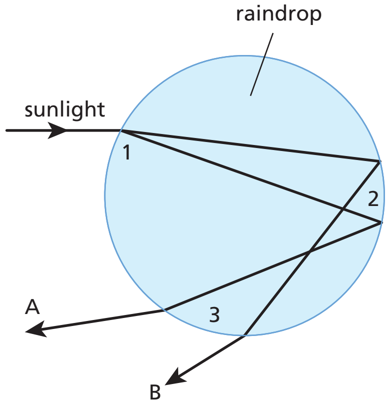

FIGURE 3.6.8a: Sunlight entering and leaving a raindrop to form a rainbow.

FIGURE 3.6.8b: A double rainbow

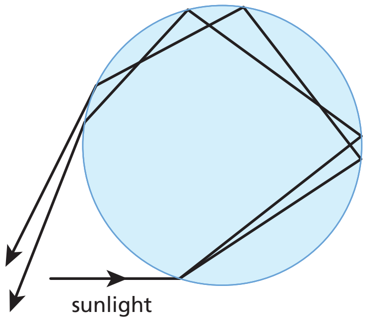

FIGURE 3.6.8c: Sunlight entering and leaving a raindrop to form a secondary rainbow.

Task 1: Making a rainbow

Read the text and describe the conditions needed for a rainbow to be formed.

Task 2: Colours of the rainbow

Look at Figure 3.6.8a. Describe what happens to rays of light when they:

a) pass from the air into a raindrop (point 1 on the ray diagram)

b) reach the far side of the raindrop (point 2 on the ray diagram)

c) pass from the raindrop back into the air (point 3 on the ray diagram).

You should use the words 'refraction' and 'reflection' in your answer.

Identify the colours of light waves A and B emerging from the raindrop.

Task 3: Explaining direction changes

Use what you have learned about the properties of light to explain what happens to sunlight in a raindrop from when it enters until when it has passed out again.

Task 4: Double rainbows

Describe the difference between the colours of the inner bow and the colours of the outer bow.

Look at Figures 3.6.8b and 3.6.8c. Explain the formation of a secondary rainbow.

Task 5: CDs, DVDs and rainbows

If you move a CD or DVD in the light, you will find positions in which you can see the colours of a rainbow. The discs have a thin layer of transparent material on top of a material that has a highly reflective surface. Using your knowledge of refraction and reflection, draw a ray diagram to explain how the colours form.

Understanding energy transfer and change

We are learning how to:

- Describe the ways in which energy is stored.
- Describe the ways that energy can be transferred from one store to another.
- Explain that any change – physical or chemical – results in a transfer of energy.

All changes, chemical and physical, involve transfer of energy. But which comes first – the change or the energy transfer? Energy transfers do not make things happen. Energy is transferred when a change happens.

FIGURE 3.6.9a: Apples on a tree store energy in many ways. One is gravitational. When an apple is ripe, its stem breaks. Energy is transferred as the apple falls.

Storing energy

Energy is stored in several ways – we could say that there are different types of **energy store**.

- All materials store energy because of their warmth (thermal store) and the interactions between their particles (chemical store).
- All objects store energy when they are pulled by gravity (gravitational store), when they are moving (kinetic store) and when they are stretched or squashed (elastic store).
- Magnetic materials store energy (magnetic store) because of the attraction of unlike poles and the repulsion of like poles.

Later in your science work you will also learn about electrical charge stores (capacitors) and nuclear stores.

1. Identify three ways in which an apple on a tree stores energy.
2. Identify one way in which an apple on a tree does not store energy.
3. Name six ways in which energy is stored.

Types of energy transfer

When change happens, there is **energy transfer** from one store to another.

The transfer can happen in a number of ways. For example it could be done electrically when energy is transferred by electric current, or it could be done by heating when energy is transferred by thermal conduction through a material or between two touching materials. It could be done mechanically, when energy is transferred by a moving object or material – for example by releasing a stretched spring or rubber band. It could be transferred by radiation – when energy is transferred by light waves for example.

4. Name four ways in which energy is transferred.

5. Describe how energy is transferred when a metal rod is heated at one end.

6. Explain how sound waves transfer energy mechanically.

FIGURE 3.6.9b: When a guitar string is plucked, energy stored elastically in the stretched string is transferred to air particles, which then move faster and store the transferred energy kinetically.

Explaining change and energy transfer

Transferring energy does not 'make things happen'. Energy is transferred because a change takes place. The change might be chemical or physical.

When a fuel burns in oxygen, energy stored in the reactants is transferred to energy stored in the products (often carbon dioxide and water). When the products cannot store all the energy released, the excess is transferred to the surroundings, which warms them.

When a battery-powered electric car moves, energy stored chemically in the battery is transferred to an electric motor by an electric current. The motor transfers energy mechanically, which makes the car move. Moving parts cause friction and some of the energy is transferred by heating, which warms the surroundings.

Did you know...?

When a candle burns, 40 per cent of its stored energy is transferred by radiation (light) and 60 per cent is transferred by heating the surroundings.

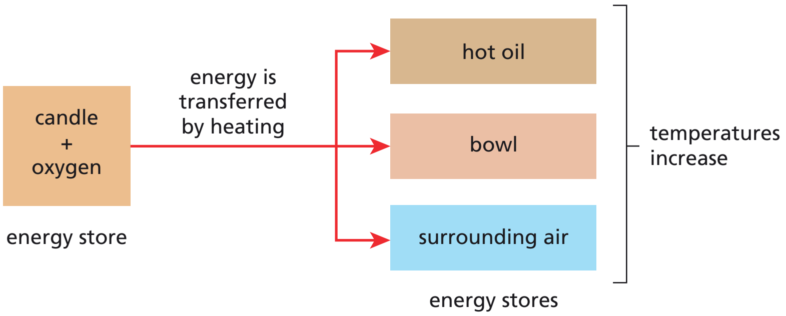

FIGURE 3.6.9c: Energy is stored in the candle and oxygen in the air. When these burn, this stored energy is transferred and stored in the hot oil, bowl and surroundings.

7. Describe how energy is transferred when an electric lamp (light bulb) is switched on.

8. Explain why it is not correct to say that energy is needed to cause a change.

Key vocabulary

energy store

energy transfer

Physics

Explaining thermal conduction and radiation

We are learning how to:

- Describe the warming and cooling of objects.
- Explain the relationship between energy transfer and temperature change.
- Compare the transfer of energy by thermal conduction and by radiation.

If you want to keep a drink hot or cold you can use an insulated flask or a vacuum flask (often called a thermos flask), which is more efficient but more expensive. What are the differences between the two? Which one would be the best value for money?

FIGURE 3.6.10a: An insulated flask is useful for slowing down temperature changes.

Cooling and warming

The warmer something is, the higher its **temperature**. Monitoring temperature changes is a useful way to measure how quickly energy is being transferred. The rate of cooling of a material may be investigated by measuring how its temperature changes over time and plotting a graph of temperature against time. This is often called a cooling curve.

1. Describe the relationship between how hot something is and its temperature.
2. Look at the graph in Figure 3.6.10b. Describe what is happening.

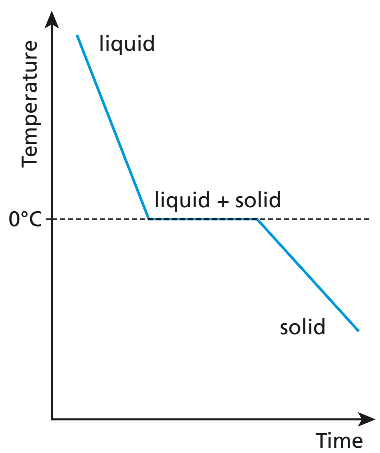

FIGURE 3.6.10b: A cooling curve for a test tube of water put in a mixture of ice and salt and cooled to –20 °C.

Energy transfer and temperature change

Energy will transfer from a warm object (higher temperature) to a colder one (lower temperature).

If you pour hot water into a cold saucepan, the temperature of the water decreases and the temperature of the saucepan increases. Energy is transferred from the water to the saucepan.

If nothing else interfered, the temperature of the water and the saucepan would become the same. However, the saucepan is standing on something and is surrounded by air. Energy is transferred to its surroundings until the saucepan and the surroundings, including the water, reach the same temperature. We say that **thermal equilibrium** has been reached.

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Materials that transfer energy well (quickly) are called **thermal conductors**. Materials that do not are called **thermal insulators**.

3. Describe what happens to the temperature of cold water if it is put into a hot metal can.
4. Describe the direction of energy transfer when a metal worker plunges a red hot piece of metal into cold water.
5. Think about the situation shown in Figure 3.6.10c and try to explain the meaning of 'open system'.

FIGURE 3.6.10c: The water, saucepan and surroundings are an 'open system'. Energy transfers happen in all parts of it.

Conduction and radiation

Energy is transferred through a material, or through two materials that are touching, by thermal conduction. This is the method of energy transfer in a solid. If a solid is heated, energy is transferred to its particles. They vibrate faster and transfer energy as they continually collide with their neighbours. Some materials are not as good as others at transferring the energy from particle to particle.

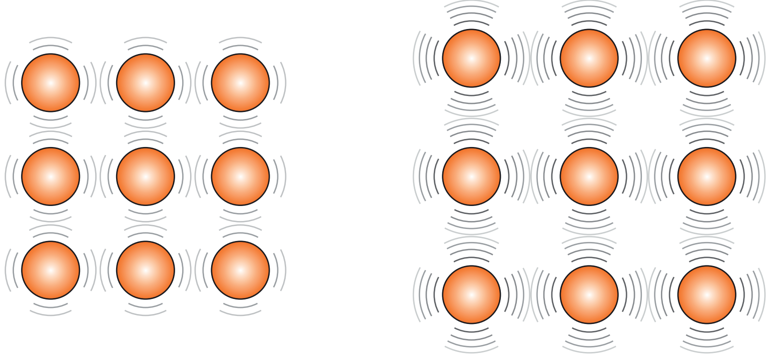

FIGURE 3.6.10d: The hotter a solid, the more its particles vibrate and collide.

Energy may also be transferred by radiation, such as light waves. As we have seen, light waves have a range of frequencies and wavelengths. **Infrared radiation** has frequencies lower than that of red light and cannot be seen by the eye. However, it transfers energy by heating – the infrared waves are emitted and absorbed. A hot object in a cool room will emit more radiation than it absorbs. It cools down until thermal equilibrium is reached.

6. Describe the difference between a conductor and an insulator.
7. Explain why gases are poor thermal conductors.
8. Explain what happens to the particles of a solid when it is heated.

Did you know...?

Double glazing works because a gas is sandwiched between two panels of glass. Originally it was air, but nowadays argon is often used because it is a better insulator than air.

Key vocabulary

temperature
thermal equilibrium
thermal conductor
thermal insulator
infrared radiation

Understanding energy transfer by fuels and food

We are learning how to:

- Describe the use of fuels in the home.
- Explain that foods are energy stores and that the amount stored can be measured.
- Explain that energy is not a material and can be neither created nor destroyed.

Natural gas and electricity are used in homes to supply energy. Our bodies, too, need supplies of energy. But is energy for the body the same as energy for the home?

Fuels and energy in the home

The National Grid supplies homes in the UK with electricity and with gas. Many homes use both, but some do not use gas – they may use oil, coal or wood. Energy stores that undergo combustion (burning) to provide us with energy by heating are called **fuels**.

FIGURE 3.6.11a: Gas pipelines and electricity cables supply us with energy.

FIGURE 3.6.11b: The use of electricity and gas is metered.

The amount of electricity used in a home is measured in a unit called **kilowatt-hours (kWh)** by an electricity meter. Gas is also metered and the amount used is measured in cubic metres.

1. Name four fuels that might be used in homes.
2. Name the instrument used to measure how much electricity is used in a home.
3. In a home, what units are used for the amounts of the following?

   a) electricity

   b) gas

Did you know…?

Conservation of energy and conservation of mass are fundamental laws of physics. However, energy can be converted into mass and vice versa. When 25 kWh of energy are transferred to any object its mass increases by 0.000 001 g. This is summarised by Einstein's famous equation $E = mc^2$, where E = energy, m = mass and c = the speed of light.

Food and energy

Food is fuel for our bodies. Energy stored in food is often called its 'energy content', sometimes measured in **calories** – 1000 joules (J) = 240 calories [1000 J is 1 kilojoule (kJ)]. During digestion food is changed into chemicals that store energy in the body's cells.

Metabolism is the name given to the chemical reactions that happen in the body. They enable growth and reproduction, responses to the environment and keeping healthy. All rely on energy being transferred from chemical stores in the body's cells which, in turn, depends on the food eaten.

4. Explain how the body builds up stores of energy.
5. Explain why information about energy stored in food is useful.
6. Calculate the energy content of 100 g of the food product shown in Figure 3.6.11c.

Nutrition Facts

Serving Size 5 oz. (144g)
Servings Per Container 4

Amount Per Serving

Calories 310 **Calories** from Fat 100

	% Daily Value*
Total Fat 15g	**21%**
Saturated Fat 2.6g	**17%**
Trans Fat 1g	
Cholesterol 118mg	**39%**
Sodium 560mg	**28%**
Total Carbohydrate 12g	**4%**
Dietary Fibre 1g	**4%**
Sugars 1g	
Protein 24g	

Vitamin A 1% • **Vitamin C** 2%
Calcium 2% • **Iron** 5%

*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:

		2,000	2,500
	Calories	2,000	2,500
Total Fat	Less Than	65g	80g
Saturated Fat	Less Than	20g	25g
Cholesterol	Less Than	300mg	300mg
Sodium	Less Than	2,400mg	2,400mg
Total Carbohydrate		300g	375g
Dietary Fibre		25g	30g

Calories per gram:
Fat 9 • Carbohydrate 4 • Protein 4

FIGURE 3.6.11c: Energy content is given as part of the nutritional data on a food label.

Conservation of energy

Whenever change happens, energy is transferred. However, no energy is ever 'lost' or 'used up'. The quantity of energy stored before the change is the same as the quantity stored after the change. This fundamental law of physics is called the **Law of Conservation of Energy**.

For example, when a fuel burns in air, energy stored in the fuel and in oxygen is transferred to the surroundings, which warm up. The energy stored in the products of combustion and the warmer surroundings equals the energy stored in the fuel and oxygen.

Similarly, warming a room with an electric heater causes a change that results in energy being transferred to the surroundings (air, walls, ceiling, furniture and so on). The total amount of energy remains the same, even though it is more spread out.

When we eat food, changes happen. Energy stored in food is transferred to energy stored in our bodies. This stored energy is transferred further during metabolism. However, whenever these changes happen, energy is not used up but is simply transferred to different places.

7. Give two other examples of changes taking place that involve energy being transferred and explain where you think the energy has been transferred to.
8. Describe, in your own words, the Law of Conservation of Energy.

Key vocabulary

fuel

kilowatt-hour (kWh)

calorie

metabolism

Law of Conservation of Energy

Physics

Comparing rates of energy transfer

We are learning how to:

- Describe what is meant by 'rate of energy transfer'.
- Recall and use the correct units for rate of energy transfer.
- Calculate quantities of energy transferred when change happens.

Chinese food is often cooked in a wok. Using a frying pan instead never seems to produce the same flavours. The reason is speed of cooking – woks are thinner than frying pans (about one-third the thickness). Energy is transferred much more quickly through them and the food is cooked more quickly – essential to create that authentic Chinese taste. How do we measure how quickly energy is transferred?

FIGURE 3.6.12a: Warm clothes slow the rate of energy transfer from the children's bodies to the cold air, helping to keep them warm.

Rates of energy transfers

When materials change, energy is transferred from one energy store to another. How quickly this happens is called the rate of energy transfer, or **power**:

$$\text{power (rate of energy transfer)} = \frac{\text{quantity of energy transferred}}{\text{time taken for the transfer}}$$

If the change can be controlled, so can the rate at which energy is transferred. For example, to make a lamp transfer energy more quickly it would need a more powerful light bulb.

1. Describe what is meant by rate of energy transfer.
2. Explain how rate of change and rate of energy transfer are linked.
3. Give an example of how controlling the rate of change is important.

Comparing rates of energy transfer

Power is a measure of how quickly energy is transferred. It is measured in **watts** (W), 1 W = 1 J/s. A thousand watts is a **kilowatt** (kW). The power rating of electrical appliances varies. For example, microwave ovens vary from 600 W to 1000 W; toasters vary from 800 W to 1500 W.

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FIGURE 3.6.12b: Some typical power ratings

4. What is the rate of energy transfer in joules per second for a 20 W laptop?

5. Based on Figure 3.6.12b, put the following in order from lowest to highest power: electric oven, microwave oven, toaster.

6. Calculate how many laptop computers could be run by the power needed for a 2150 W electric oven.

Quantities of energy transferred

When a change happens and energy is transferred, the quantity of energy transferred can be calculated in joules (J) and kilojoules (kJ) using:

energy transferred = power × time

- A 20 W laptop computer transfers 20 J/s.
  So if it is used for one hour (1 × 60 × 60 = 360 s), it transfers 20 × 360 = 7200 J = 7.2 kJ.
- A 2.15 kW electric oven transfers 2.15 kJ of energy per second.
  So if it is used for one hour (1 × 60 × 60 = 360 s), it transfers 2.15 × 1000 × 360 = 774 000 J = 774 kJ.

7. How much energy is transferred when a 1.2 kW toaster runs for three minutes?

8. Calculate the energy transferred when one store transfers energy to another store by heating it for five minutes at a rate of 15 J/s.

9. a) Calculate the energy transferred when a 10 W bulb is left on for three days.

b) Calculate the energy saved if the same light bulb is turned off every day for eight hours.

Did you know...?

The unit of energy, the joule, is named after James Joule, a Salford brewer who discovered the link between heat and work. He spent part of his honeymoon in Switzerland making measurements to show that the water at the bottom of a waterfall was slightly warmer than the water at the top.

Key vocabulary

power

watt

kilowatt

Looking at the cost of energy use in the home

We are learning how to:

- Describe the information a typical fuel bill provides.
- Explain and use the units used on a fuel bill.
- Explain how the cost of energy used can be calculated.

When you look at your gas or electricity bill there are two charges. One is for the amount used, and the other is a fixed charge. Why do energy providers make a fixed charge on top of the cost of the electricity or gas used?

Meter readings (E = estimate, C = customer, A = actual)

Electricity readings

Period	Meter no.	Previous	Present	Rate	kilowatt-hours
4 Sept 14 to 12 Nov 14	S08B 06654	12549 E	12757 C	Normal	208

Gas readings

Period	Meter no.	Previous	Present	Units	kilowatt-hours
30 Aug 14 to 12 Nov 14	674215	02938 A	02954 C	16 m^3	converts to 178

Charges

Electricity charges

4 Sept 14 to 12 Nov 14		£43.69
208 kilowatt-hours (kWh) used at 12.66p each	£26.33	
Standing charge – 69 days at 25.16p per day	£17.36	

Gas charges

30 Aug 14 to 12 Nov 14		£26.33
Gas 178 kilowatt-hours (kWh) used at 3.981p each	£7.09	
Standing charge – 69 days at 27.89p per day	£19.24	

Total charges

Total electricity and gas charges (excluding VAT)	£70.02

FIGURE 3.6.13a: This energy bill shows the quantities and charges for electricity and gas used in a home.

Fuel bills

Electricity and gas for the home is bought from energy suppliers. Users receive energy bills that show:

- the 'standing charge' – a fixed amount regardless of how much energy is used
- the price of each unit of energy and the number of units used.

Each **unit of electricity** is 1 kWh = 3 600 000 J or 3600 kJ.

A typical home might use several hundred **kilowatt-hours (kWh)** of energy every month (see Figure 3.6.13a) – in other words, hundreds of millions of joules.

1. Describe how energy use in a home is measured.
2. The energy content of a food can be measured in joules. Why do electricity meters not use joules?
3. What are the standing charges shown in the energy bill in Figure 3.6.13a for the following?

   a) electricity **b)** gas
4. Explain the difference between a standing charge and the cost of energy used. (Hint: As well as the fuel used, what else needs to be paid for?)

Did you know...?

In 2013, the average household cost of electricity and gas was £1400. About half of this is for heating the home. Double glazing can reduce heating bills, but it is expensive to install. It has been estimated that it can take 80 years before the savings are more than the cost of the double glazing.

Power of domestic appliances

Remember that the rate at which energy is transferred is called power, measured in watts (W) – 1 watt = 1 joule per second (1 W = 1 J/s). Electrical appliances have a power rating, usually shown on the label.

The amount of energy used by an appliance is calculated by multiplying its power by the time for which it was used (see Topic 6.12). Electricity supply companies use the electricity unit kilowatt-hour (kWh), so we need to use hours, not seconds, in the calculation. An appliance with a power rating of 500 W running for five hours transfers $0.5 \times 5 = 2.5$ kWh.

Choosing an electrical appliance with the optimum power rating for the intended purpose is important. A more powerful electric kettle will use more energy per second but it will take less time to do the job.

5. Which transfers energy faster – a 1600 W hair dryer or a 120 W computer?

6. Explain the difference between 'energy' and 'power'.

Calculating the cost of energy used

The quantity of electricity used in a home is shown on an electricity meter in kilowatt-hours (kWh). The quantity of gas is shown on a gas meter in cubic metres (m^3). This will probably be converted into kilowatt-hours (kWh) on an energy bill.

The typical price of 1 kWh of electricity is about 13p, and the typical price of 1 kWh of gas is about 4p. If you used 900 kWh of electricity and 700 kWh of gas, the cost would be:

electricity: $900 \times 13 = 11\,700$ p = £117.00

gas: $700 \times 4 = 2800$ p = £28.00

So the total energy cost = £117.00 + £28.00 = £145.00

7. a) 4.2 J of energy must be transferred to raise the temperature of 1 cm^3 of water by 1 °C. How much energy is needed to raise the temperature of 1 litre of water from 20 °C to 100 °C?

b) Convert this to kilowatt-hours and calculate the cost of electricity needed to heat this water, if 1 kWh costs 13p.

8. Calculate the annual cost of energy for a home that uses, on average, 700 kWh of electricity (at 13p per kWh) and 700 kWh of gas (at 4p per kWh) each month.

FIGURE 3.6.13b: The power rating of the electric fan heater is shown on the label. It is 2000 W.

FIGURE 3.6.13c: The cost of 1 kWh of energy from electricity is more than three times that of 1 kWh of energy from gas.

Key vocabulary

unit of electricity

kilowatt-hour (kWh)

Check your progress

To make good progress in understanding science you need to focus on these ideas and skills.

☐ Recognise that energy may be transferred by different types of waves, and know the difference between longitudinal and transverse waves.	☐ Explain wave oscillation, the reflection and superposition of waves, and the terms frequency and wavelength.	☐ Compare the properties of sound waves, waves in water and light waves.
☐ Recognise that light can be reflected by some materials and absorbed by others.	☐ Explain how some materials absorb energy, and the differences between transparent, translucent and opaque materials.	☐ Use diagrams to explain the difference between diffuse and specular reflection.
☐ Describe the ray model of light, using the idea that light travels in straight lines.	☐ Explain the difference between reflection and refraction, and describe what happens when light waves are refracted.	☐ Use ray diagrams to explain how a pinhole camera and the eye work.
☐ Recognise that various effects can occur when materials absorb light, for example chemical reactions or a flow of electric current.	☐ Explain how the transfer of energy carried by light happens during photosynthesis in plants and by electron release in photovoltaic cells.	☐ Explain the formation of photochemical smog.
☐ Describe the formation of a spectrum from white light.	☐ Explain how white light can be split into a continuous spectrum of colours, called the visible spectrum.	☐ Use the concepts of reflection and absorption of light to explain why some materials (transparent, translucent and opaque) are coloured.

☐ Describe different ways in which energy can be stored and different ways in which energy can be transferred.	☐ Explain that energy is transferred from one type of energy store to another when change happens, and understand that energy transfer does not cause change.	☐ Explain that all changes, physical or chemical, result in a transfer of energy.
☐ Describe the transfer of energy by heating and cooling.	☐ Explain the relationship between energy transfer and temperature difference.	☐ Compare the transfer of energy by conduction and by radiation.
☐ Recall the units used to measure quantities of energy, including joules, calories and kilowatt hours.	☐ Explain that energy can be neither created nor destroyed (the Law of Conservation of Energy).	☐ Carry out calculations of quantities of stored and transferred energy.
☐ Describe what is meant by rate of energy transfer.	☐ Identify the rate at which electrical appliances transfer energy (their power rating), using the correct units (watts or kilowatts).	☐ Compare rates of energy transferred when electrical appliances are used.
☐ Explain the data given on an energy bill, including the units used for energy 'consumed' (transferred to appliances in the home) and the meaning of 'standing charge'.	☐ Use the power rating of an appliance to calculate the amount of energy transferred.	☐ Calculate the cost of energy used in different scenarios.

Questions

Questions 1–7

See how well you have understood the ideas in the chapter.

1. Which of the following describes what happens when a water wave hits a barrier? [1]

a) it is absorbed **b)** it is reflected **c)** it is refracted **d)** it passes through

2. Which of the following is true of light waves, but not of waves in water? [1]

a) they travel through empty space **b)** they are transverse waves
c) they can be reflected **d)** they are not longitudinal waves

3. Which of the pairs of waves in Figure 3.6.15a would cancel each other out? [1]

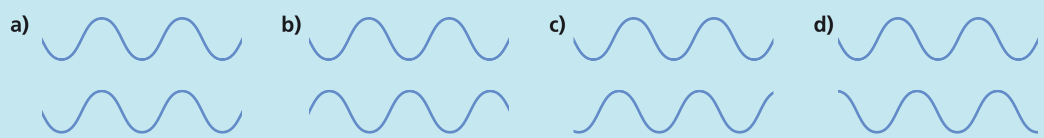

FIGURE 3.6.15a

4. In which of the following materials does light travel the fastest? [1]

a) water **b)** glass **c)** air **d)** transparent plastic

5. Describe two effects that may happen when materials absorb light. [2]

6. Give an example of two energy stores and describe how energy is transferred from one to the other. [2]

7. List the information found on an energy bill, including the units used. [4]

Questions 8–14

See how well you can apply the ideas in this chapter to new situations.

8. Imagine looking at a small object through a block of glass. Complete a copy of Figure 3.6.15b to show where the object appears to be (its image). [1]

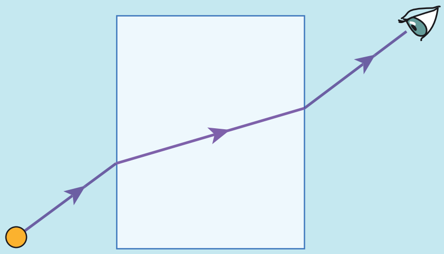

FIGURE 3.6.15b

9. Think about what happens to sunlight when it passes through transparent materials, and then explain why we see different colours in stained glass windows. [1]

10. Explain why an electric kettle has a power rating of 2000 W, but a small TV has a power rating of 65 W. [1]

11. When the temperature of 1 cm^3 of water increases by 1 °C, 4.2 J of energy are transferred. Calculate the energy transferred when 50 cm^3 of water at 20 °C is heated to its boiling point. [1]

12. Describe the energy transfers that happen when an archer pulls back and then releases a bow to shoot an arrow. [2]

13. Figure 3.6.15c shows a graph of water temperature as the water cools in a beaker. Describe:

a) what happens to the rate of energy transfer as the water cools.

b) how the graph might be different if the water had been kept in an insulated flask. [2]

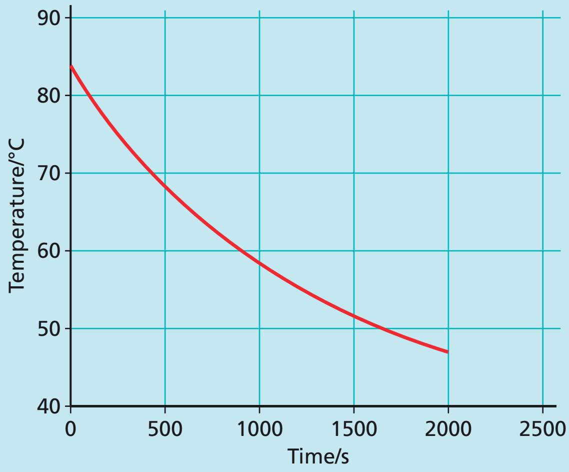

FIGURE 3.6.15c

14. A car covered in dirt and dust does not shine. Washing it and then polishing it makes it shine. Explain why. [4]

Questions 15–17

See how well you can understand and explain new ideas and evidence.

15. Explain why the presence of chlorophyll in leaves makes them green. [1]

16. Describe and explain what you would see if transparent red sticky tape were put on a piece of frosted glass. [1]

17. Nutritional information about food products is shown on their labels. It includes 'energy', which means energy stored. Table 3.6.15 shows some information about different types of milk.

What does this tell you about the differences between whole, semi-skimmed and skimmed milk? [4]

TABLE 3.6.15

	Amounts in 100 cm³ of milk			
	Unit	**Whole (full cream)**	**Semi-skimmed**	**Skimmed**
energy stored	kilojoule (kJ)	282	201	148
protein	gram (g)	3.4	3.6	3.6
carbohydrate	gram (g)	4.7	4.8	4.9
fat	gram (g)	4.0	1.8	0.3