PEARSON

Science

STUDENT BOOK | 3RD EDITION

9

TOPIC 3

Wave and particle models of energy transfer

When you turn on a television, electrical energy is transformed into sound and light, as well as some heat energy. The ways in which these forms of energy are transferred can be explained using particles and waves.

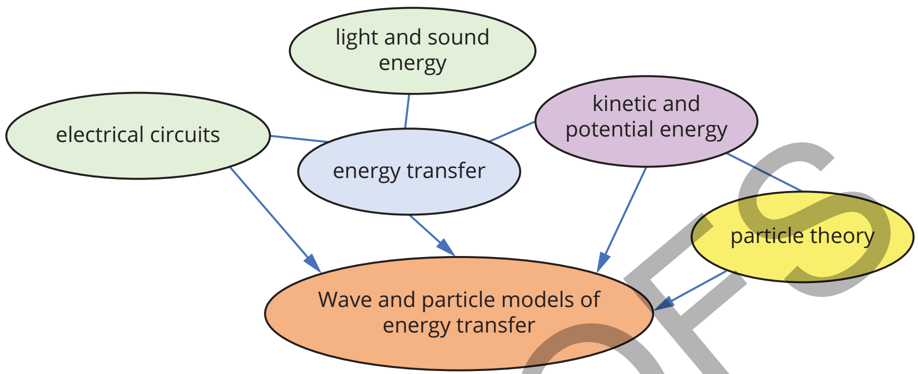
In this topic, you will learn about the transfer of energy by waves and particles.

Learning intentions

- ☐ To understand ways heat energy is conducted from particle to particle in solids, liquids and gases **xx**
- ☐ To be able to develop and test a hypothesis and prediction related to heat transfer **xx**
- ☐ To understand that heat energy can move through fluids (gases and liquids) by convection **xx**
- ☐ To understand how electrical energy is transferred around a circuit **xx**
- ☐ To be able to use a variation of resistance to change the current in an electrical circuit **xx**
- ☐ To understand how waves can transfer energy from one place to another **xx**
- ☐ To be able to investigate the behaviour of sound as a type of energy transferred via longitudinal waves **xx**
- ☐ To be able to model transverse and longitudinal waves **xx**
- ☐ To understand the nature of electromagnetic waves, including visible light **xx**
- ☐ To be able to explore advances in energy transfer technologies such as CSIRO's invention of wi-fi **xx**
- ☐ To be able to design a way to compare the effectiveness of ultraviolet (UV) radiation blockers **xx**
- ☐ To be able to design a way to compare the ability of materials to radiate heat **xx**

3 Wave and particle models of energy transfer

The key concepts that you will use in this topic:



The following prior knowledge questions will help to support your learning in the topic and can be attempted before the first lesson.

Wave and particle models

1 What term is used to describe the average kinetic energy of particles in a substance?

2 State two different ways of modelling a soundwave, providing an example of each.

Energy transfer

3 Explain why a dropped ball does not return to its original height.

Kinetic and potential energy

4 Consider the kinetic energy and potential energy of an object.

- **a** State one way the kinetic energy of an object could be increased.
- **b** State one way the gravitational potential energy of an object could be increased.

Light and sound energy

5 State the key difference between sound energy and light energy.

Electrical circuits

6 State the energy transformations involved in powering a lightbulb with a battery.

3.1 Energy of particles and heat conduction

Lesson overview

All matter is made up of particles. It is the motion of these particles that is responsible for how hot an object feels. The faster the particles move or vibrate, the greater their kinetic energy and the hotter the object will be.

In this lesson, you will learn about how heat energy is transferred and the process of conduction.

SC 1 I can explain that all matter is made up of particles

All **matter** is made up of **atoms**. You can imagine that all atoms are modelled as tiny balls, called **particles**, that are constantly in motion. This is known as the **particle model** (Figure 3.1.1).

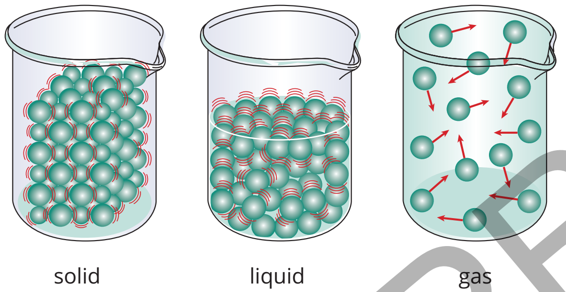


FIGURE 3.1.1 In all states of matter, the particles are constantly in motion, even in solids

In a solid, the particles are all tightly packed together so that they can only vibrate or jiggle around in their positions.

In a liquid, the particles are still packed closely together, but they can move about, and flow over one another.

In a gas, the particles are further apart and are free to move. They may bump into each other or into the walls of their container.

SC 1 CHECK YOUR UNDERSTANDING

Describe the arrangement of particles in solids, liquids and gases.

SC 2 I can explain how particles can pass on heat energy to nearby particles when they collide

Heat is a form of energy that moves from warmer to cooler substances. When a substance is heating up, the molecules it is made up of start to move faster (Figure 3.1.2). It is the motion of the particles that gives them **kinetic energy**, which is observed as the temperature of the substance.

Learning intention

To understand ways heat energy is conducted from particle to particle in solids, liquids and gases

Success criteria

SC 1: I can explain that all matter is made up of particles.

SC 2: I can explain how particles can pass on heat energy to nearby particles when they collide.

SC 3: I can evaluate the usefulness of describing the conduction of heat in terms of particles.

KEY TERMS

matter a physical substance; anything that has mass and volume

atom the smallest piece of individual matter that can exist by itself

particle tiny parts of matter; includes atoms and molecules

particle model model used to describe and explain the behaviour of particles in solids, liquids and gases

heat energy that is transferred from a warmer object or substance to a cooler object or substance

kinetic energy energy possessed by a moving object

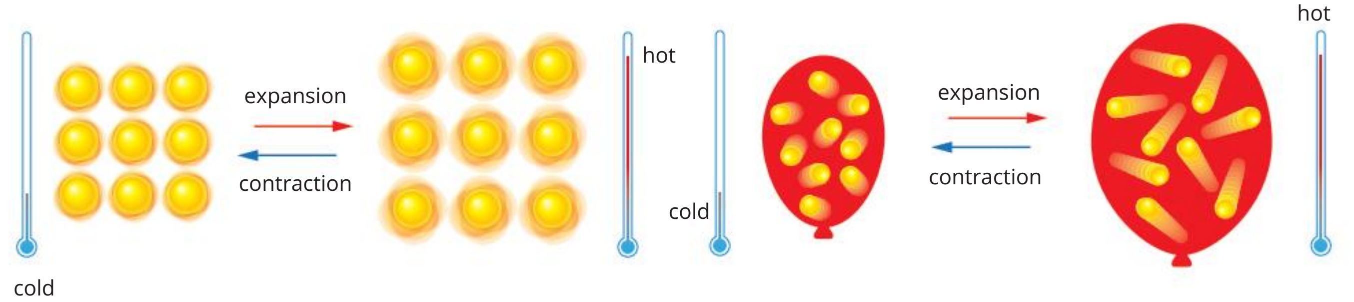


FIGURE 3.1.2 As heat is added to a substance, the kinetic energy of the particles increases

As heat is added to a material, it will add kinetic energy to the particles and they will speed up and spread out. When particles collide, kinetic energy is transferred between them, transferring heat energy.

SC 2 CHECK YOUR UNDERSTANDING

Describe how heat energy is transferred between particles.

SC 3 I can evaluate the usefulness of describing the conduction of heat in terms of particles

Conduction

When heat is transferred via **conduction**, it travels through a material or between two objects in contact with each other. By using the particle model to explain conduction, it is possible to show how heat is transferred within and between substances (Figure 3.1.3).

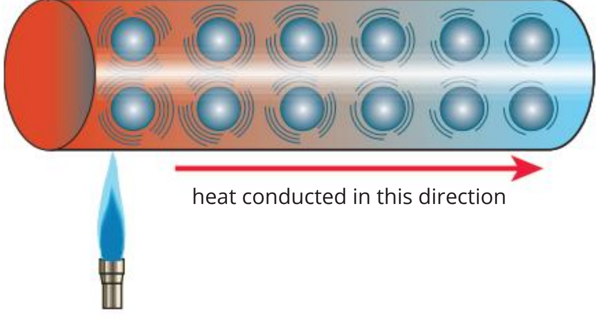


FIGURE 3.1.3 In conduction, particles transfer heat via vibrations

At the point where heat is added to the system, the particles begin to vibrate faster. This vibration is passed along to neighbouring particles as a transfer of kinetic energy. This is how the energy is transferred throughout the whole substance, heating it up.

KEY TERM

conduction a method of heat transfer in which heat travels through a material or between two objects in contact with each other

Scifile

Insulating materials

Some materials, such as wool and foam, are poor conductors of heat. Their particles are not as tightly packed, making it harder for energy (heat) to travel through them—which is why poor conductors are used for insulation in clothing and homes.

Model limitations

Like all models, the particle model has its limitations. For example, the particles are modelled as solid balls. But, in reality, the particles (atoms) are not solid spheres. The collisions between atoms can also be modelled in a similar way to billiard balls colliding in a game of pool, but the collisions and forces involved at this microscopic scale do not completely match up with this model either.

With all its limitations, though, the particle model can demonstrate methods of heat transfer, such as conduction, and helps analyse situations where conduction may be occurring.

SC 3 CHECK YOUR UNDERSTANDING

Identify a limitation of the particle model in explaining heat transfer via conduction.

Lesson review

Use these questions to check whether you have met the learning intention for this lesson.

1 State two forms of energy involved in energy transfer via conduction.

2 Matter can exist in different states—solid, liquid and gas—each with unique particle arrangements.
- **a** Describe the arrangement of particles in a solid.
- **b** Explain how the arrangement of particles in a solid differs to that in liquids and gases.

3 Recall the basic principle of heat conduction. Outline how useful the particle model is in explaining how conduction occurs.

4 Consider how heat is transferred by conduction within a substance or between substances. Determine which state of matter—solid, liquid or gas—is likely to be the best conductor. Justify your answer.

3.2 Heat conduction in materials

Learning intention

To be able to develop and test a hypothesis and prediction related to heat transfer

Success criteria

SC 1: I can identify the dependent and independent variables of an investigation.

SC 2: I can develop a hypothesis and write a prediction that can be tested.

SC 3: I can use data to evaluate whether a hypothesis is supported.

Introduction

Heat is the transfer of energy from a warmer substance to a cooler substance via the process of conduction, which involves energy moving through a material.

When a substance is heated, its particles move faster, gaining kinetic energy (Figure 3.2.1). This increase in kinetic energy is transferred to nearby particles, allowing thermal energy (heat) to spread throughout the material.

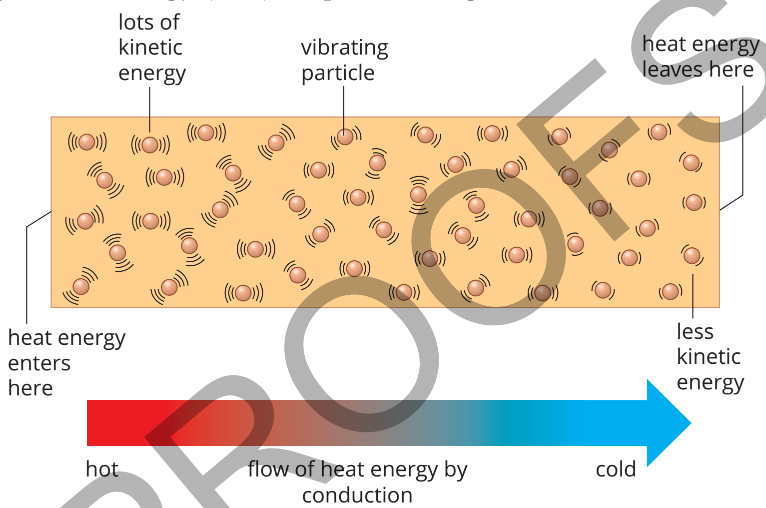


FIGURE 3.2.1 The conduction of heat energy involves the transfer of kinetic energy from particle to particle

In this practical investigation, you will test a hypothesis about which of three materials will conduct heat energy the fastest.

Background

The way a material behaves in the presence of heat is determined by its internal properties. This includes how quickly a substance can heat up or cool down, and the rate at which heat can travel through the material. This last aspect—the rate of heat transfer—is what you will investigate in this practical investigation.

A substance that transfers heat quickly is described as a good **conductor** of heat. A material that transfers heat slowly is described as a poor conductor of heat. Another name for a poor conductor of heat is an **insulator**.

KEY TERMS

conductor material through which heat, sound or electrical energy can be transferred

insulator a material which does not readily allow the transfer of heat, sound or electricity – the opposite of a conductor

Aim

To compare how well plastic, wood and metal conduct heat

Hypothesis

Write a hypothesis for your investigation by ordering the three substances according to how quickly you think they conduct heat, from fastest to slowest.

Materials

- butter or low melting point wax
- very hot water (from a kettle)
- plastic teaspoon
- metal teaspoon
- wooden teaspoon
- 250 mL beaker
- 3 small beads or similar
- stopwatch
- ruler

Assessment of risk

Ensure you are aware of the risks of this practical investigation and have considered how safety can be improved before carrying out this activity.

SAFETY NOTE

- Handle hot water with care

Method

1 Construct a suitable results table to record your observations and measurements.

2 Place a small 'dob' of butter or wax near the top of the handle of the plastic spoon.

3 Push a bead onto the dob of butter/wax.

4 Repeat steps 1 and 2 for the metal spoon and the wooden spoon. Make sure the beads are placed at similar positions along the spoon's handle and that approximately the same amount of butter/wax is used each time.

5 Carefully place the three spoons into very hot water in the beaker as shown in Figure 3.2.2 and start your stopwatch at the same moment.

6 Time how long each bead takes to fall off and record your results in your table.

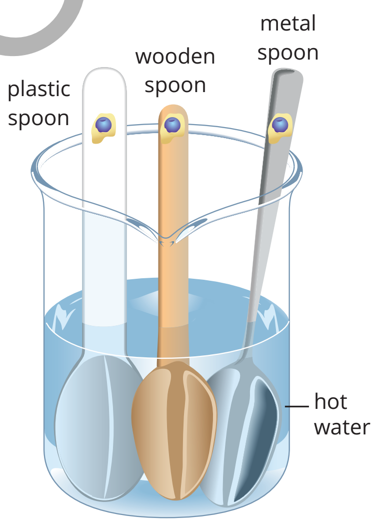


FIGURE 3.2.2 Sample experiment set up

Results

Record your results in a results table. Use the headings 'Material' and 'Time taken for bead to drop (s)'.

Conclusion

1 Identify the best conductor of heat and the best insulator of heat.

2 Comment on how well your results supported your hypothesis.

Evaluation

1 Describe at least three controlled variables in this experiment.

2 What was the independent variable in this experiment?

3 What was the dependent variable in this experiment?

4 A student decided to place each spoon in a separate beaker. They asked the teacher for a measuring cylinder and a thermometer to use. Explain why these pieces of equipment are required.

GO TO
Skills Toolkit 1.1 Dependent and independent variables

3.3 Heat convection

Learning intention

To understand that heat energy can move through fluids (gases and liquids) by convection

Success criteria

SC 1: I can explain how temperature affects the density of gases and liquids.

SC 2: I can describe how warmer fluids rise and cooler fluids sink to create convection currents.

SC 3: I can describe examples of heat convection in the environment.

KEY TERMS

density a measure of the mass per unit volume of substance

volume the amount of space that a substance or object occupies; measured in cubic units

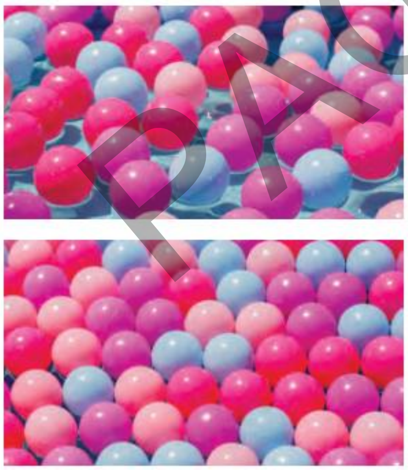


FIGURE 3.3.3 The ball pit on the bottom has more balls per area than the ball pit on the top – this is similar to density, where a denser substance will have more mass (particles) per volume

Lesson overview

Convection is a form of heat transfer that occurs in gases and liquids. Heat is transferred in gases and liquids due to differences in density and temperature throughout the substance. For example, clouds form from rising hot air in which the water vapour condenses as it cools.

In this lesson, you will learn about the changes in density to liquids and gases as heat is added to a system, and how convection currents are formed.

SC 1 I can explain how temperature affects the density of gases and liquids

As a material is heated, its particles will gain kinetic energy and they will speed up. When particles collide, kinetic energy is transferred between them, passing on heat energy through the material. As the particles speed up, they will spread out causing the material to expand (Figure 3.3.1).

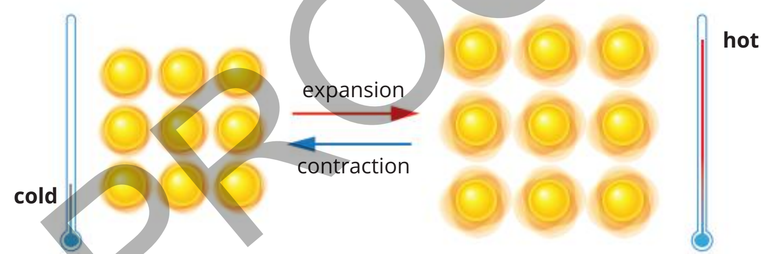


FIGURE 3.3.1 The vibration of particles, and the resulting expansion, is proportional to temperature

Density

The **density** of a substance describes how closely packed its particles are. Stated mathematically, density is equal to the mass of a substances divided by its **volume**.

The separation of particles in liquids and gases causes them to have less mass in the same volume compared to solids (Figure 3.3.2). Additionally, the separation between particles in gases and liquids allows them to expand more easily with the addition of temperature than solids.

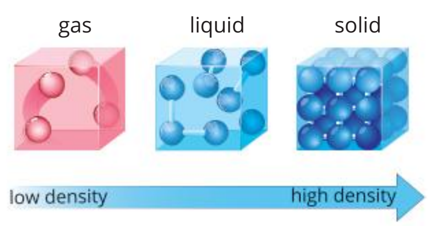


FIGURE 3.3.2 Typically, gases are less dense than liquids, which are less dense than solids

One way to visualise density in the particle model is with a ball pit (Figure 3.3.3). Imagine you have two ball pits that are the same size. In one, there are hardly any balls. The other is completely full. The full pit has a higher density than the emptier pit because it has more balls in the same amount of space, compared with the other ball pit.

SCIENCE IN SOCIETY

Why does a hot air balloon rise?

The particle model can be used to explain how density causes a hot air balloon to rise. Heat from the flame is transferred to the air (gas) inside the balloon.

The transfer of heat to the air causes the air particles to move faster. The increased movement of the particles leads to more collisions between them, and also more collisions between the particles and the balloon itself. This pushes out the size of the balloon and allows the volume of the gas to expand.

While the volume of the gas increases, the mass of the particles stays the same. This means that the density of the air inside the balloon is now less than the density of the surrounding air. This causes the balloon to rise (Figure 3.3.4).

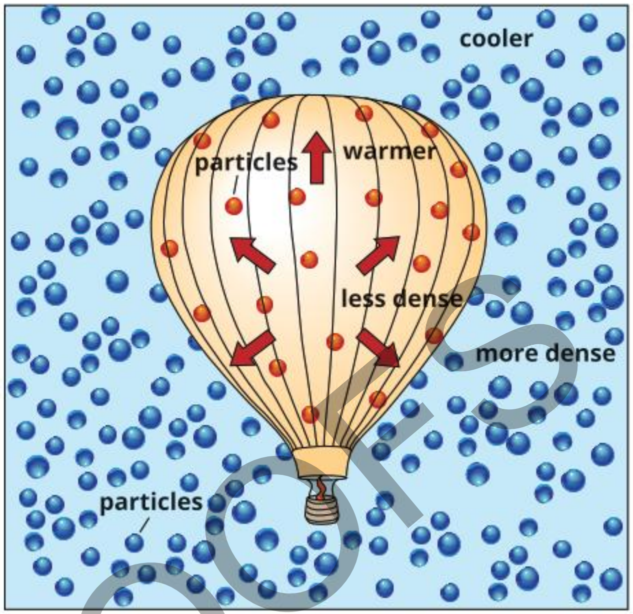


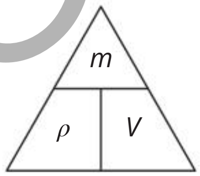
FIGURE 3.3.4 A hot air balloon rises due to changes in air density

SkillBuilder

Calculating density

The density of different states of matter can be calculated if you know the mass and volume of the substance. Mathematically, density is equal to the mass per unit volume of a substance. This can be written as:

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$



This relationship can be written using symbols: $\rho = \frac{m}{V}$

where ρ (the Greek letter rho) is used to represent density, and m and V represent mass and volume.

Consider this example: Elena wants to calculate the density of water. In a beaker of water, she finds the volume of water is equal to 250 mL, which is 0.25 L. She then measures the mass of the water using a digital scale and finds it to be 0.25 kg.

Using these values, Elena calculates the density of water to be:

$$\rho = \frac{m}{V} = \frac{0.25}{0.25} = 1.0 \text{ kg/L}$$

Worked example

Calculating density

Problem

Calculate the density of a solid piece of silver, given it has a mass of 100 g and a volume of 10 cm^3.

Solution

Thinking	Working
Write out the known variables (note their given units) and the required equation.	$m = 100$ g $V = 10\ cm^3$ $\rho = \frac{m}{V}$
Substitute the values into the equation.	$\rho = \frac{m}{V} = \frac{100}{10}$
Calculate the density. Make sure to include the units.	$\rho = 10\ g/cm^3$

Try yourself

Calculating density

Calculate the density of 250 mL of honey, which has a mass of 350 g.

SC 1 CHECK YOUR UNDERSTANDING

Explain how temperature affects the density of a liquid.

SC 2 I can describe how warmer fluids rise and cooler fluids sink to create convection currents

Convection currents

KEY TERM

convection the transfer of heat through movement in a liquid or gas

The particle model can be used to describe the **convection** of particles in a pot of water as it heats up on the stove (Figure 3.3.5).

Initially, heat energy is transferred from the flame to the particles near the bottom of the pot. These particles speed up and move faster than the particles at the top of the water, which are further away from the heat source.

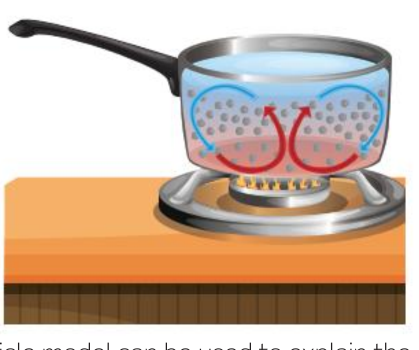


FIGURE 3.3.5 The particle model can be used to explain the convection of water in a saucepan

The increased motion of the particles near the bottom of the pot means that they spread further apart. For this reason, the hotter water at the bottom is less dense than the cooler water above it.

This causes the denser fluid at the top to fall to the bottom and the less dense fluid rises to the top. This creates what is called a **convection current**. Convection is the transfer of heat in a fluid due to these warm currents circulating with cooler, denser matter.

KEY TERM

convection current transfer of heat in a liquid or gas due to less dense, warmer matter rising and denser, cooler matter falling

SC 2 CHECK YOUR UNDERSTANDING

Explain why warmer fluids rise and cooler fluids sink.

SC 3 I can describe examples of heat convection in the environment

Convection is a key component of different environmental systems that can be observed.

Wind

The differences in temperature between the ground and the water at different times during the day produces convection currents (Figure 3.3.6).

During the day sunlight heats the surface of Earth. Land changes temperature more quickly than water. This causes the air above land to become warm and rise, starting the convection process.

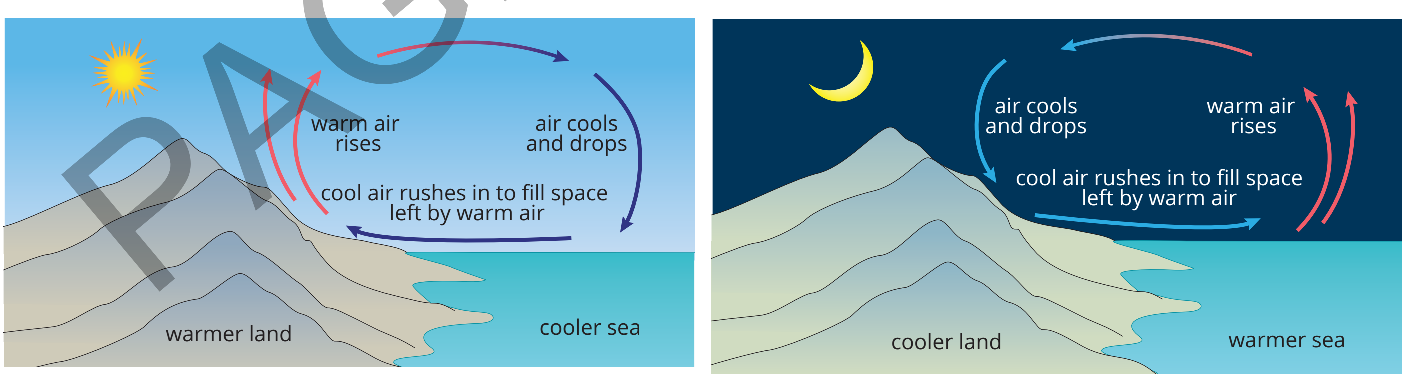
At night, land cools faster than water. This causes the air above the water to become warm and rise, reversing the process.

This process also contributes to cloud formation (Figure 3.3.7). As the warm air rises it brings water vapour with it. As the air cools, so does the water vapour causing it to condense and form clouds.

Scifile

Lava lamps

Lava lamps are a fun example of convection. The heat from the lamp's bulb warms the 'lava' (wax), making it less dense than the surrounding fluid, causing it to rise. When it cools, it becomes denser and sinks, creating a mesmerising convection current.



A sea breeze during the day

A land breeze at night

FIGURE 3.3.6 Convection currents explain the difference in coastal wind direction at night compared to during the day

FIGURE 3.3.7 The formation of clouds as rising air cools is an example of convection

FIGURE 3.3.8 The convection of air (wind) and the convection of water both play a role in the mixing of ocean water

Ocean currents

Convection currents occur deep in the oceans, as well as near the surface.

Deep ocean currents are convection currents which occur when cool, salty water sinks while warmer water rises to the surface. This convection causes mixing in the oceans which spreads heat, minerals, and nutrients around Earth (Figure 3.3.8).

Surface currents are driven by wind, which is due to convection occurring in the air above the water's surface.

SC 3 CHECK YOUR UNDERSTANDING

Explain how convection currents contribute to wind and cloud formation.

Lesson review

Use these questions to check whether you have met the learning intention for this lesson.

1 Describe the relationship between the temperature of a substance and its density.

2 Explain how convection currents form in a pot of boiling water.

3 Compare the effect of temperature on the density of solids and gases.

4 With reference to convection, predict the impact of increasing global temperatures on the climate. You may need to conduct some research to support your answer.

3.4 Transfer of electrical energy

Lesson overview

Electricity powers many aspects of daily life and makes cities visible from space (Figure 3.4.1). Its use depends on the transfer of electrical energy from a source to devices such as lightbulbs, motors, or phones.

FIGURE 3.4.1 This composite image (because night does not occur simultaneously) shows the global network of lighting which is visible from space

In this lesson, you will learn about how electrical energy is transferred and some of the fundamental concepts of electric circuits.

SC 1	I can describe an electric current through a metal wire as a flow of electrons powered by a voltage

Electric current

Electrons are negatively charged particles. An **electric current** in a circuit is the motion of electrons through a wire (Figure 3.4.2). It is the movement of the electrons that is observed as electricity. This is how electrical energy is transferred around a circuit – through the energy of the moving electrons. The overall direction of the current is determined by the overall movement of electrons.

To function properly, an electric circuit must have:

- a power source such as a battery; the power source supplies a **voltage** that pushes the electrons around the circuit
- metal wires; metal is an electrical conductor, so it allows the electrons to flow through the circuit as current
- a closed loop; if there is a break in the circuit, the electrons will no longer flow and transfer energy.

Circuits can be used to connect a range of useful components that will transform the electrical energy into other forms of energy. For example, a battery supplies a voltage to a circuit. A lamp in the circuit transforms the electrical energy into light energy (and some heat energy, too).

Learning intention

To understand how electrical energy is transferred around a circuit

Success criteria

SC 1: I can describe an electric current through a metal wire as a flow of electrons powered by a voltage.

SC 2: I can describe electric current as a measure of the flow of electrons.

SC 3: I can explain how electrical energy can travel through a circuit much faster than the drift velocity of electrons in the conductor.

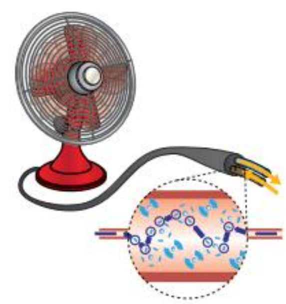


FIGURE 3.4.2 The movement of electrons in a wire can appear random but overall, they move in the same direction when current is flowing.

KEY TERMS

electron negatively charged subatomic particle, located around the nucleus of an atom
electric current the flow of charge
voltage a measure of the amount of energy provided to charges or used by them; measured in volts (V)

SCIENCE IN SOCIETY

Understanding circuit symbols

Electrical circuit symbols provide a simplified way to represent circuits, making it easier to understand their construction and the flow of current to different components (Figure 3.4.3). Each component, such as a battery, resistor, or lightbulb, has a specific symbol. Learning these symbols enables the reading and creation of circuit diagrams.

You will learn more about common circuit diagram symbols in Lesson 3.5.

Engineers and electricians use these symbols to design and troubleshoot electrical systems. They create detailed circuit diagrams, often referred to as schematics, to ensure that everything is connected correctly and safely. For example, the electrician shown in Figure 3.4.4 is consulting a schematic to diagnose a fault in the distribution board behind them. A distribution board is a more complicated version of the fuse-box found on the side of your house. They are used by businesses in factories and offices.

FIGURE 3.4.3 A circuit diagram in real life

FIGURE 3.4.4 An electrician checking connections according to the schematics

KEY TERMS

voltmeter an instrument that measures voltage

parallel when components are connected in branches adjacent to one another; voltmeters are connected in parallel

Voltage can be measured using a device called a **voltmeter**. The unit used to measure the voltage is volts (symbol V). A higher voltage increases the energy of the electrons in the circuit, giving them a bigger 'push'. Voltmeters are connected to the circuit either side of a component. This is so they can measure the energy of the electrons before passing through the component and compare it to the energy after passing through the component. This arrangement is referred to as 'being connected in **parallel**'.

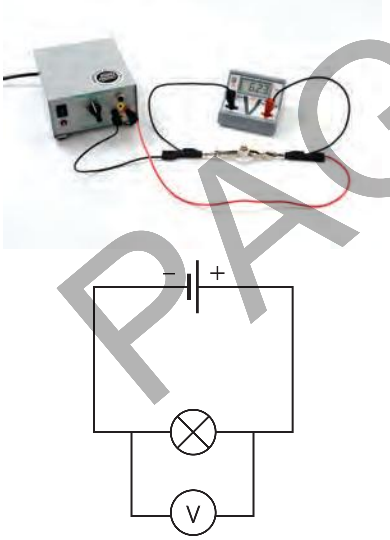


FIGURE 3.4.5 A voltmeter connected in parallel to a lightbulb – note that the positive terminal of the meter (red) is connected to the positive terminal of the power source

SkillBuilder

Connecting a voltmeter

A voltmeter compares the energy of electrons before and after they pass through a component such as a lightbulb (Figure 3.4.5). For this reason, voltmeters are connected in parallel. This means they are not part of the circuit itself, but instead, they are attached across the component being measured.

For example, Andras connects the parallel circuit shown in the photo and finds that the voltage running through the lightbulb is equal to 6.23 V (6.23 volts).

SC 1 CHECK YOUR UNDERSTANDING

Identify the form of energy which is provided to an electron by the application of a voltage.

SC 2 I can describe electric current as a measure of the flow of electrons

The number of electrons that flow past a point in a circuit each second is used to determine the electric current. The electrons flow from the negative terminal (usually black in colour) of the power source, around the circuit towards the positive terminal (usually red in colour). Current is measured in units of ampere (symbol A). This is usually shortened to 'amps'.

The direction of current is often given by **conventional current**, though. Conventional current flows in the opposite direction to electron current, that is from the positive terminal to the negative. This is because historically the phenomenon of electric current was discovered before scientists understood that it was negatively charged particles moving in the conductors to produce the effect. Hence, a 'convention' or rule was put in place that the conventional current flows from the positive terminal, around the circuit and into the negative terminal (Figure 3.4.6).

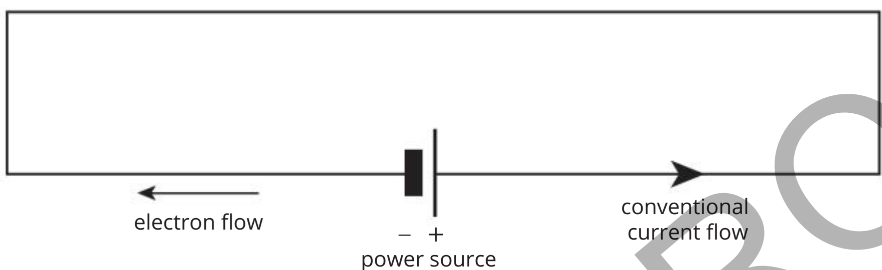


FIGURE 3.4.6 A circuit diagram containing a battery

An **ammeter** is a device that measures the amount of electric current passing through a circuit. A larger current is measured when more electrons flow through the ammeter per second compared with a small number of electrons per second. Ammeters are connected into the circuit so that the current through the ammeter is the same as the current in any part of the circuit. This way of connecting to a circuit is referred to as 'being connected in **series**'.

KEY TERMS

conventional current a way to describe electrical current as flowing through a circuit from the positive terminal to a negative terminal

ammeter an instrument for measuring current in electric circuits

series when components are connected with each other in a single line; ammeters are connected in series

SkillBuilder

Connecting an ammeter

Electrons must pass through an ammeter for the charge to be detected. Therefore, the ammeter needs to be in line with the rest of the circuit's components. This arrangement is known as being in series and is shown in Figure 3.4.7.

For example, Liu connects the series circuit shown and finds that the current in the circuit is 0.06 A (0.06 amps).

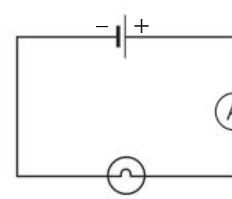


FIGURE 3.4.7 An ammeter in series with a bulb – note that the positive terminal of the ammeter (red) is connected to the positive terminal of the power source

SC 2 CHECK YOUR UNDERSTANDING

Contrast ammeters and voltmeters, with reference to electron flow.

SC 3 I can explain how electrical energy can travel through a circuit much faster than the drift velocity of electrons in the conductor

KEY TERM

drift velocity the average velocity of electrons moving (drifting) in an electric circuit

The drift velocity of electrons describes how fast the electrons are moving through the conductor (see Figure 3.4.2). It is directly proportional to the current.

As described earlier, the electrons in a conductor do not all move in the same direction. The term **drift velocity** is used to describe the overall (or average) movement of the electrons when a current is moving through the circuit. An analogy would be pieces of wood floating in a river. They might move back and forwards, and from one side of the river to the other, but overall, they drift down the river in the direction of the flow of the water.

When you turn on a light switch, though, the lights seemingly turn on immediately. How is the electrical energy transferred almost instantaneously even though the electrons are travelling slowly at a fixed speed? The bicycle chain analogy is often used to explain this phenomenon (Figure 3.4.8).

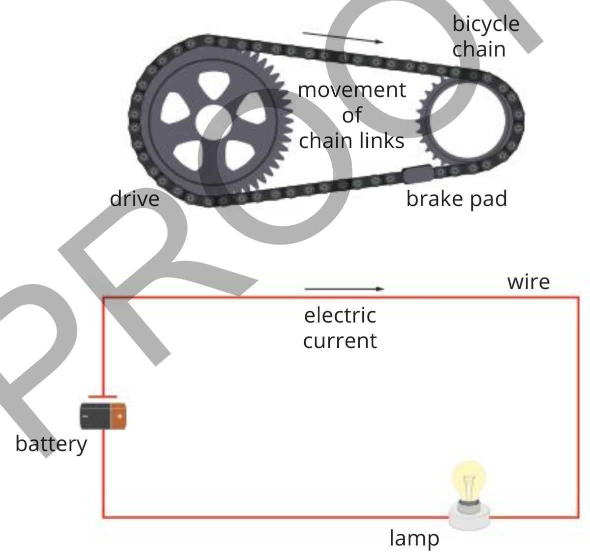


FIGURE 3.4.8 The motion of an individual chain link in the chain analogy is similar to the motion of an individual electron in an electric circuit

When the pedal is turned, each link on the chain affects the link ahead of it. Similarly, when the power is supplied to a circuit (similar to pushing the pedals), the electrons in the conductor all push the electrons ahead of them. The energy is transferred much faster than the speed of the individual electrons.

Scifile

Safe circuits

Electric currents that are too high can cause wires in a circuit to melt and fires to start. This can happen when connections are not secure, or a circuit is overloaded with too many appliances. Resistors can be used to reduce the current and fuses can stop the circuit working completely before the current gets too high.

SC 3 CHECK YOUR UNDERSTANDING

Explain why an electron does not need to travel from a power source to a lightbulb before the light turns on.

Lesson review

Use these questions to check whether you have met the learning intention for this lesson.

1 Describe the cause of electron flow in a closed circuit.

2 Explain the link between current and voltage in an electric circuit.

3 Contrast electron current and conventional current.

4 Explain why electrical energy travels faster than the drift velocity of electrons.

3.5 Using resistance to control electric current

Introduction

Resistance describes how difficult it is for electrons to pass through an electric circuit. Components that are connected to a circuit, such as a lightbulb, will have a certain resistance. As will the wires that connect the circuit.

If you have seen or used a light dimmer switch, then you have seen a variable resistor in action. By changing the resistance of components in the circuit, a different output can be observed, such as changing the brightness of the lightbulb.

In this practical investigation, you will explore the effect of changing the resistance on the measured current in an electric circuit.

Learning intention

To be able to use a variation of resistance to change the current in an electrical circuit

Success criteria

SC 1: I can set up a safe electrical circuit in which resistance can be altered.

SC 2: I can use electrical circuit symbols to represent a simple electrical circuit.

SC 3: I can explain, with evidence, how variation in resistance controls an output from the circuit.

Background

An electric circuit is made up of certain components. All circuits require a power source, such as a battery, which supplies a voltage to the circuit. The voltage provides the push which moves the electrons around the circuit.

The circuit must be a closed loop of a conducting material such as copper. Current is the flow of electrons through the conductor and around the circuit. **Resistance** describes how difficult it is for electrons to flow through the circuit.

The voltage (V), current (I) and resistance (R) in a circuit are linked together using the following equation:

$$V = IR$$

You can rearrange this equation so that resistance is the subject.

$$R = \frac{V}{I}$$

From this equation, it is possible to show that the resistance is **inversely proportional** to the current. In other words, when the resistance is increased, the current is decreased (and vice versa).

KEY TERMS

resistance a measure of how difficult it is for current to pass; measured in ohms (Ω)

inversely proportional a description of a relationship where the value of one quantity increases as another quantity decreases by the same proportion, i.e. when one doubles, the value of the other quantity halves

Electric circuit diagrams

Electric circuits can be drawn using specific symbols (Figure 3.5.1).

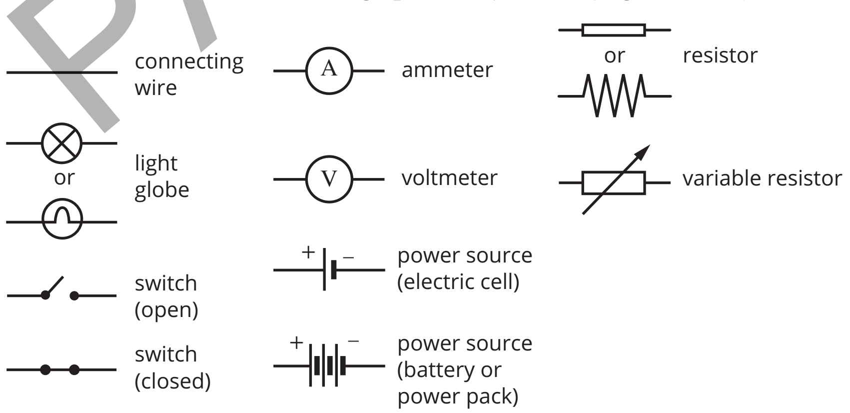


FIGURE 3.5.1 Common circuit diagram symbols

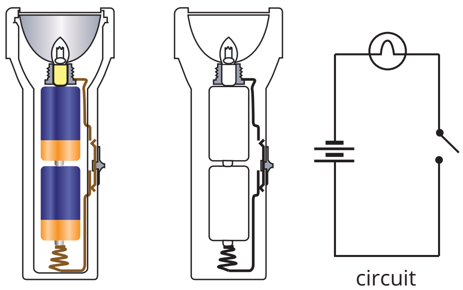


FIGURE 3.5.2 The circuit diagram for the torch is quicker to create and easier to read than a detailed diagram

For example, Figure 3.5.2 shows the circuit of a torch with two batteries, a lightbulb, connecting wires and an on–off switch.

Aim

To design a circuit containing a variable resistor which controls the current supplied to a lightbulb and hence control its brightness

Materials

- power pack
- 12V lightbulb
- connecting wires
- variable resistor (rheostat/potentiometer)
- ammeter

Assessment of risk

Ensure you are aware of the risks of this practical investigation and have considered how safety can be improved before carrying out this activity.

SAFETY NOTES

- Construct a risk assessment.
- When using electrical equipment, it is important to use them responsibly to avoid the risk of electric shock.

Method

1. Construct a diagram of the circuit you intend to build.
2. Show your teacher your planned circuit and your risk assessment.
3. Once your design is approved, collect the required materials and construct your circuit.
4. Once your circuit is connected and switched on, move the variable resistor to get a feel for the impact it has.
5. Read steps 6 and 7 and construct a suitable results table to record your observations.
6. Increase the resistance of your variable resistor.
   - Observe the brightness of the lightbulb. How does it change?
   - Check the ammeter reading. What happens to the current?
7. Decrease the resistance of your variable resistor.
   - Observe the brightness of the lightbulb. How does it change?
   - Check the ammeter reading. What happens to the current?

HINT

To measure the current through a component, an ammeter needs to be connected in series.

Results

Record your observations in your table.

Conclusion

Write a conclusion. Explain how variation in resistance controls the output from the circuit.

Evaluation

Evaluate your practical investigation.

1. What practical skills did you learn in completing this investigation?
2. Brainstorm some ideas in groups on how else a variable resistor could be useful in an appliance.

3.6 Longitudinal and transverse waves

Lesson overview

Wave motion describes the transfer of energy without the net transfer of any matter (Figure 3.6.1). Waves in the water are a great way to demonstrate this. When you drop a pebble in a pond, for example, the waves ripple outwards – the energy of the waves moves outwards but the water itself does not.

In this lesson, you will learn about different types of waves and their properties.

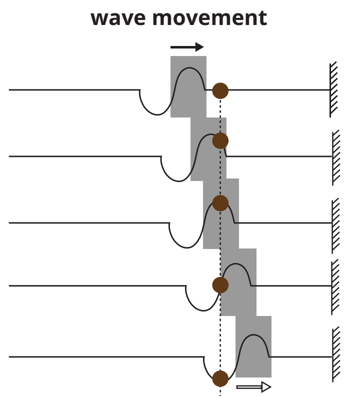


FIGURE 3.6.1 A single point on the wave, represented by the dot, moves up and down as the wave passes without moving forwards

SC 1	I can explain, using diagrams, how particles move in relation to the direction of transfer of energy in longitudinal and transverse waves

There are two types of waves: longitudinal and transverse. A slinky spring can be used to explain the differences between these two wave types.

Transverse waves

The vibration of particles in **transverse waves** is at right angles to the direction of energy transfer. In the slinky example, the energy moves away from the hand, but the motion of the slinky itself is up and down (Figure 3.6.2).

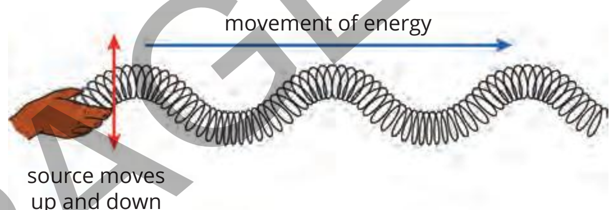


FIGURE 3.6.2 The slinky moves up and down, while the energy moves forwards

Longitudinal waves

The vibration of particles in **longitudinal waves** is in the same direction of motion as the energy. In the slinky example, the energy moves away from the hand and the slinky moves backwards and forwards (Figure 3.6.3).

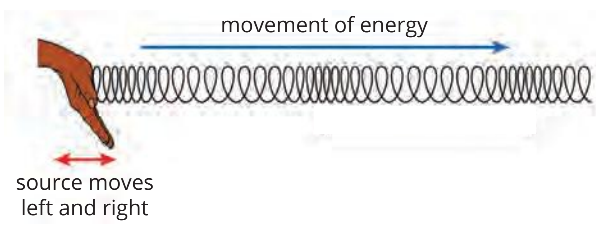


FIGURE 3.6.3 The slinky moves back and forth, while the energy moves forwards

Learning intention

To understand how waves can transfer energy from one place to another

Success criteria

SC 1: I can explain, using diagrams, how particles move in relation to the direction of transfer of energy in longitudinal and transverse waves.

SC 2: I can describe examples of longitudinal and transverse waves.

SC 3: I can use the wave equation to relate the speed, wavelength and frequency of a wave.

KEY TERMS

transverse wave a wave in which the vibration is at right angles to the direction the wave is travelling

longitudinal wave a wave in which the vibration is in the same direction as the wave is travelling

SC 1 CHECK YOUR UNDERSTANDING

Contrast the direction of particle motion and energy flow in a transverse wave.

SC 2 I can describe examples of longitudinal and transverse waves

Examples of transverse waves

Stringed instruments

FIGURE 3.6.4 The vibration of a stringed instrument shows the string vibrating at right angles while the energy travels along the string

The vibration of the strings in a stringed instrument is a transverse wave. For example, consider when a guitar string is played (Figure 3.6.4). When the player's finger plucks the string, the string vibrates perpendicularly to the energy which travels along the string from the point where it was plucked. Because the guitar string is fixed at both ends, it appears to vibrate in place. The transverse motion of the string causes the surrounding air to vibrate back and forth. This converts the transverse wave of the string into the longitudinal wave of the sound through the air.

Battle ropes

Battle ropes are a common gym exercise involving vigorously shaking a rope (Figure 3.6.5). This example can be compared to the guitar string. The guitar string is vibrated in the middle, but the rope is vibrated from the end. Unlike the guitar string which appears to vibrate in place, the battle rope clearly shows the wave travelling along the rope.

Surface ripples in water

Surface ripples in water (Figure 3.6.6) also demonstrate transverse waves. The disturbance in the water travels outwards in all directions. This shows waves can occur in planes, such as the surface of the water, and not just along lines, such as a string. The vibration of the Earth's surface during an earthquake also demonstrates this property.

FIGURE 3.6.5 The rope is vibrated from the end; the rope itself travels up and down but the energy moves forwards

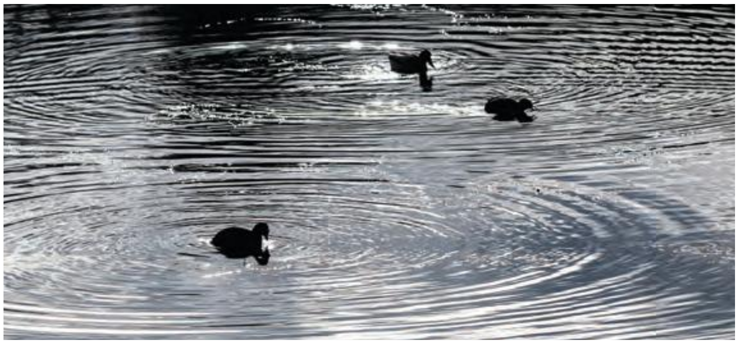


FIGURE 3.6.6 As the duckling swims the water travels up and down, even though the energy is traveling outward from the duckling

Examples of longitudinal waves

Sound waves

Sound waves are an example of longitudinal waves (Figure 3.6.7). For example, when you hear a sound, it is the vibration of air particles that transfers sound energy from the source of the vibration to your ear as a longitudinal wave. In a longitudinal wave, the particles are moving together at points called **compressions** and moving apart from each other at points called **rarefactions**.

Note that the particles are vibrating around a fixed position as the sound wave passes through. It is the energy that travels to your ears rather than a big rush of air.

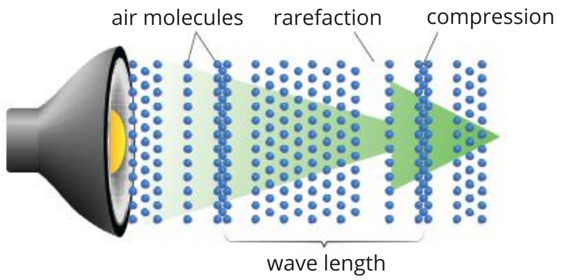


FIGURE 3.6.7 For sound waves, the vibration of particles is in the same direction as energy flow

KEY TERMS

compression a region of high pressure in which particles are close together

rarefaction a region of low pressure in which particles are far apart

SC 2 CHECK YOUR UNDERSTANDING

Provide an example of a transverse wave which has not already been used as an example in this section.

SC 3 I can use the wave equation to relate the speed, wavelength and frequency of a wave

Properties of waves

There are many key terms which relate to waves.

Wavelength

Wavelength (Figure 3.6.10) describes the length of one complete wave and is generally measured in metres (m).

The wavelength of a transverse wave is the distance between one crest (highest point) and the next or one trough (lowest point) and the next.

The wavelength of a longitudinal wave is the distance between a compression and the next closest compression, or a rarefaction and the next closest rarefaction.

KEY TERM

wavelength the length of one wave, measured between two corresponding points, measured in metres

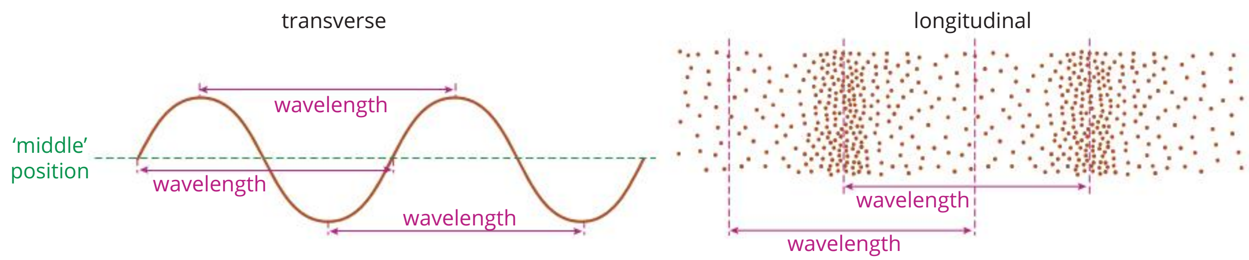


FIGURE 3.6.10 Wavelength of transverse and longitudinal waves

KEY TERM

amplitude the maximum displacement of a wave from its rest position

Amplitude

Amplitude (Figure 3.6.11) describes the distance between the central position of a wave and its maximum or minimum position.

In sound waves, amplitude is related to the loudness of the sound. Sound waves with greater amplitudes are louder. For light, waves with greater amplitude correspond to brighter light.

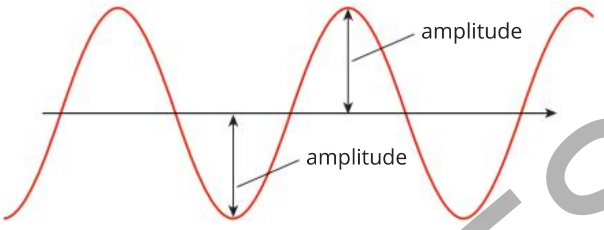


FIGURE 3.6.11 The amplitude of a transverse wave

SCIENCE IN SOCIETY

How loud is that sound?

The loudness of a sound is related to the amplitude of its wave. Amplitude is the height of the wave from its resting position. The greater the amplitude, the louder the sound. For example, when you shout, the sound waves have a bigger amplitude compared to when you whisper.

Consider a drum. When you hit it softly, the sound waves have a low amplitude, and the sound is quiet. When you hit it hard, the sound waves have a bigger amplitude, and the sound is louder.

Understanding amplitude is important for creating safe sound levels at concerts and events. Acoustical engineers use special speakers called omnidirectional noise devices (Figure 3.6.8) to generate sound to test how it performs in a space, such as a theatre.

FIGURE 3.6.8 Omnidirectional noise source for acoustic testing

By moving the omnidirectional sound source around in the space and measuring the sound with a sound level meter (Figure 3.6.9), the engineer can measure the amplitude of the sound wave in all directions. This helps to ensure sound is working effectively in a space. The engineers can determine if there are dead spots where sound is cancelling out, making it harder to enjoy a performance. Likewise, they can determine if sound is too loud in a particular position, perhaps requiring insulation.

FIGURE 3.6.9 Sound level meter measuring the level of noise in a house

Unwanted sound can make a space harder to work in, such as performers in a theatre being confused when they can hear their own sound reflected back at them.

Frequency

Frequency describes the number of waves passing a point each second and is measured in hertz (Hz). A wave with a high frequency vibrates back and forth rapidly. As you will see in the next section, frequency is inversely proportional to wavelength. This means as the wavelength decreases, frequency increases.

The frequency of sound and light waves can be observed. For sound waves, high frequency sounds will be higher in **pitch**. Low frequency waves will have a lower pitch. For light waves, frequency corresponds to different types of light. High frequency light such as ultraviolet (UV) light carries more energy compared to low frequency waves, such as radio waves.

KEY TERMS

frequency number of waves produced each second and is measured in hertz

pitch how low or high a sound is; the faster particles producing the sound vibrate, the higher the pitch

speed of light the speed that electromagnetic radiation, including light, travels. In a vacuum this is approximately 300 000 000 metres per second

Speed

Speed describes how fast the wave is travelling and is measured in metres per second (m/s).

The speed of sound depends on the substance the sound waves travel through. More dense substances contain more particles which are closer together, allowing for collisions to occur more easily, increasing the speed of the wave. The speed of sound in air at 25°C is approximately 346 m/s.

Light always travels at the **speed of light**. Like sound, the speed of light varies slightly with the substance the light is travelling through. In a vacuum, such as in outer space, light travels at approximately 300 000 000 m/s (3.0×10^8 m/s).

SkillBuilder

The wave equation

The speed, wavelength and frequency of a wave depend upon each other and are linked by a formula called the wave equation. The wave equation is:

$$v = f\lambda$$

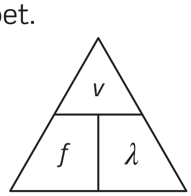
where v is the speed of the wave (in m/s)

f is the frequency of the wave (in Hz)

λ is the wavelength (in m).

The symbol for wavelength is λ, a letter from the Greek alphabet. The letter is called lambda.

The equation can be rearranged algebraically to solve for frequency or wavelength. Otherwise, you can use the triangle to the right to rearrange the equation.



For example, Ellisa wants to calculate the frequency of a wave. They place their finger over the f and the equation shows:

$$f = \frac{v}{\lambda}$$

Xani wants to rearrange the equation to calculate the wavelength. They place their finger over the λ and the equation shows:

$$\lambda = \frac{v}{f}$$

Worked example

The wave equation

Problem

Determine the frequency of a wave with wavelength 0.25 m, travelling at a speed of 340 m/s.

Solution

Thinking	Working
Recall the wave equation.	$v = f\lambda$
Determine from the question which quantity is unknown. Use algebraic techniques or the triangle to rearrange the equation to find the required quantity.	$f = \frac{v}{\lambda}$
Determine the known values and substitute them into the equation.	$f = \frac{340}{0.25}$
Solve for frequency and include the units.	$f = 1360$ Hz

Try yourself

The wave equation

Calculate the wavelength of a wave traveling at 2.5 m/s with a frequency of 0.8 Hz.

SC 3 CHECK YOUR UNDERSTANDING

Use the wave equation to identify the relationship between frequency and wavelength.

Lesson review

Use these questions to check whether you have met the learning intention for this lesson.

1 Waves transfer energy through the movement of particles in different ways.
   a Draw a diagram of a longitudinal wave and use arrows to show the direction of particle movement.
   b Draw a diagram of a transverse wave, using arrows to show the direction of the particle movement.
   c Explain how the direction of particle movement differs between the two types of waves.

2 A child is jumping with a skipping rope. Categorise the motion of the rope as either a transverse wave or a longitudinal wave.

3 Use the wave equation to calculate the:
   a velocity of a wave with wavelength 1.5 m and frequency 120 Hz
   b wavelength of a wave with frequency 6000 Hz and velocity 340 m/s
   c frequency of a wave if its velocity is 12 m/s and its wavelength is 3.2 m.

4 Describe what happens to the wavelength of a wave if its frequency is doubled, assuming the speed remains constant.

Practical investigation

3.7 Investigating sound waves

Introduction

An oscilloscope (Figure 3.7.1) is an instrument that transforms an energy input into electrical energy. For example, it can take the energy from a sound wave and transform it into electrical energy.

When connected to an audio (sound) source, it will display the sound wave as a transverse wave, rather than a longitudinal one. This makes it a great tool to study sound waves and their properties as you can more easily see the amplitude and frequency of the wave.

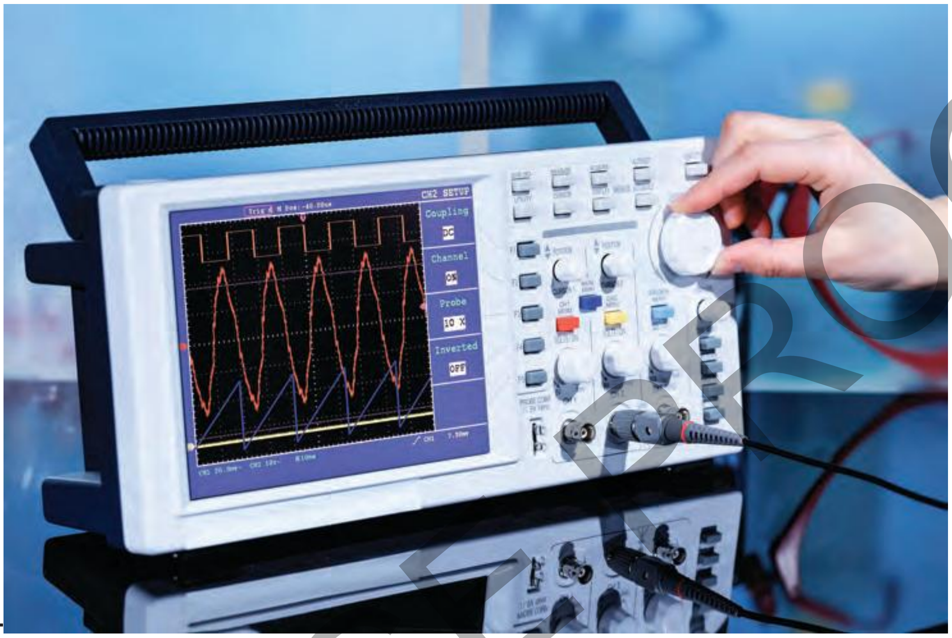


FIGURE 3.7.1 An oscilloscope is a useful tool for visualising waves

In this practical investigation, you will explore the relationships between loudness, amplitude, pitch and frequency by experimenting with a sound source connected to an oscilloscope app on a smartphone.

Learning intention

To be able to investigate the behaviour of sound as a type of energy transferred via longitudinal waves

Success criteria

SC 1: I can use an oscilloscope or oscilloscope app to convert an audible sound wave to a visual transverse wave.

SC 2: I can describe the relationship between loudness and the amplitude of the sound wave.

SC 3: I can describe the relationship between pitch and the frequency of the sound wave.

Aim

To explore the relationship between loudness and amplitude, and pitch and frequency in sound waves

Prediction

Make predictions about the relationship between:

- the loudness of the sound and the appearance of the wave on the oscilloscope
- the pitch of the sound and the appearance of the wave on the oscilloscope.

Materials

- oscilloscope or an oscilloscope app
- signal generator or signal generator app

Method

1. Turn on the oscilloscope or open the oscilloscope app.
2. If using an oscilloscope, make sure the output is positioned evenly on the x-axis and the y-axis using the 'position' horizontal and vertical dials and the 'trace rotation' dial as required. Once the signal generator is connected, adjust the voltage and time base so that a sine wave is clearly visible. Your teacher will be able to help you with this.
3. Turn on the signal generator. Have a quick 30 s exploration with the controls to see how this affects what you can hear.
4. If not using the app, connect the signal generator to the oscilloscope.
5. Read steps 6 and 7 and construct a suitable results table to record your observations.
6. Turn up the dial labelled dB or volume on the signal generator.
   - What does this do to the sound?
   - What does this do to the wave on the oscilloscope?
7. Adjust the dial labelled Hz or frequency on the signal generator.
   - What does this do to the sound?
   - What does this do to the wave on the oscilloscope?

Results

Record your observations in your table.

Conclusion

1. What type of wave is a sound wave?
2. What type of wave does an oscilloscope display?
3. Describe the relationship between loudness and the amplitude of a sound wave.
4. Describe the relationship between pitch and the frequency of a sound wave.

Evaluation

1. What have you learnt about sound waves today?
2. What skills did you use in this investigation?
3. If you were to continue your investigation into sound waves, what would you like to learn about?

3.8 Modelling waves

Introduction

A slinky spring can be used to model longitudinal and transverse wave motion.

In this practical investigation, you will use a slinky spring to model the motion of waves to explore different wave properties.

Background

The motion of springs can be used to model the properties of waves, such as:

- modelling either longitudinal or transverse motion
- visualising the wavelength and amplitude of waves.

Aim

To use a slinky spring to model the properties of waves

Materials

- slinky spring
- video recording device
- tape measure

Method

Write a method for your investigation. Your method should include how you plan to:

- model either longitudinal or transverse motion
- visualise the wavelength and amplitude of waves.

Results

1 Describe what happened to the slinky when it was moved from left to right.

2 Describe what happened to the slinky when it was moved towards and away from you (that is, stretching and compressing the slinky).

3 Develop two questions that you would like to explore about the wave behaviour you produced.

4 Analyse the video footage of the waves you produced to answer your two questions.

Conclusion

Was the slinky an effective tool to model wave behaviour? Use your observations to justify your answer.

Evaluation

1 What are the limitations of using a slinky to model waves?

2 Propose an item, other than a slinky spring, that could be used to demonstrate wave behaviour.

Learning intention

To be able to model transverse and longitudinal waves

Success criteria

SC 1: I can describe what may occur when a spring is stretched or lifted up and down to model waves.

SC 2: I can develop investigable questions to explore using a spring to model waves.

SC 3: I can evaluate the effectiveness of a spring to model waves.

3.9 Electromagnetic radiation

Learning intention

To understand the nature of electromagnetic waves, including visible light

Success criteria

SC 1: I can describe the properties of electromagnetic waves, including speed, wavelength and frequency.

SC 2: I can describe how the concept of photons can be useful for explaining the properties of electromagnetic radiation.

SC 3: I can compare different forms of electromagnetic waves in terms of wavelength, frequency or energy of photons.

KEY TERMS

electromagnetism the phenomenon of electric and magnetic fields interacting with each other

electromagnetic wave transverse electric and magnetic fields positioned at right angles to each other and travelling through empty space at the speed of light

Lesson overview

What do you think of when you think of light? Visible light, or the visible spectrum, describes light you can see with your eyes. Visible light includes the bands of colours that are produced from splitting white light, such as through a prism.

The visible spectrum is just one part of the full electromagnetic spectrum. The electromagnetic spectrum includes gamma rays, X-rays, ultraviolet (UV) rays, visible light, infrared rays, microwaves and radio waves.

In this lesson, you will learn about the full electromagnetic spectrum and its properties.

SC 1 I can describe the properties of electromagnetic waves, including speed, wavelength and frequency

Electromagnetic waves

Electromagnetism describes the phenomenon of electric and magnetic fields interacting with each other. When an electric current runs through a wire, it produces a magnetic field around the wire. Similarly, an electric field can be generated inside a wire by moving a magnet nearby.

An **electromagnetic wave** (or electromagnetic radiation) consists of electric and magnetic fields vibrating transversely and at right angles to each other and to the direction of motion (Figure 3.9.1). The waves travel at the speed of light.

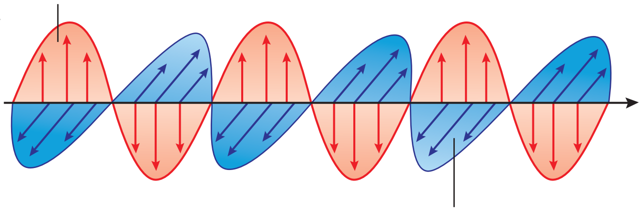


FIGURE 3.9.1 An electromagnetic wave is a transverse wave consisting of electric and magnetic fields oscillating perpendicularly to each other.

Properties of electromagnetic waves

The properties of electromagnetic waves are like the properties of the transverse waves described in lesson 3.6. They are characterised by their wavelength and frequency. Recall that wavelength and frequency are inversely proportional. So, electromagnetic waves with longer wavelengths have lower frequencies. Waves with shorter wavelengths have higher frequencies.

Because light is formed from electromagnetic waves, it does not require particles to travel. This allows light to travel through a vacuum, such as outer space.

The speed of light is a constant for all wavelengths of the electromagnetic (EM) spectrum. The speed of light can be represented by the symbol c. It is equal to 300 000 000 m/s (3.0×10^8 m/s) in a vacuum and very similar to that in air.

SC 1 CHECK YOUR UNDERSTANDING

Identify the two fields electromagnetic radiation is comprised of.

SC 2 I can describe how the concept of photons can be useful for explaining the properties of electromagnetic radiation

Wave properties of light

Some phenomena involved with light show its wave behaviour.

Dispersion

Dispersion is the process where white light, such as the light emitted by the Sun, is split into its component colours. It occurs in prisms and can be seen when light is dispersed through raindrops producing a rainbow (Figure 3.9.2).

Scattering

Scattering occurs where waves of light interact with the atmosphere. As the Sun's light passes through the atmosphere, it scatters, producing a generally blue sky (Figure 3.9.3).

Diffraction

Diffraction is the bending of a wave around an obstacle. When a wave passes through a slit, it bends around the edges of the opening, producing diffraction and interference patterns. These patterns can be created with both light waves (Figure 3.9.4) and water waves (Figure 3.9.5).

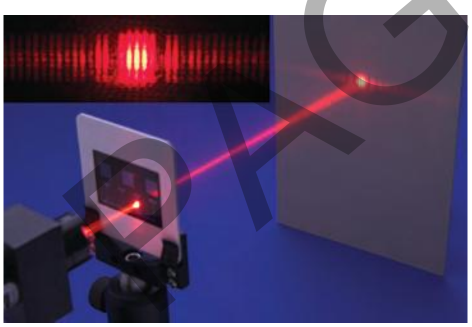


FIGURE 3.9.4 A laser shines through a set of slits producing an interference pattern

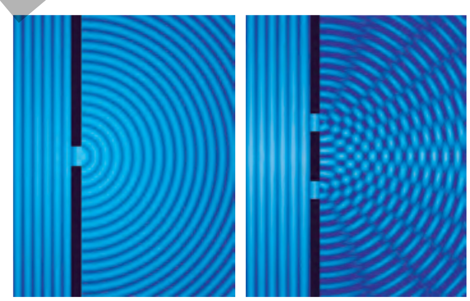


FIGURE 3.9.5 Water waves demonstrating diffraction as they pass through gaps between obstacles

KEY TERMS

dispersion the splitting of white light into colours of the rainbow

scattering the interaction of light with particles in the atmosphere, depending on colour and frequency of the light

diffraction bending of a wave around an obstacle or through a small gap

FIGURE 3.9.2 Rainbows are created by the dispersion of white light as it travels through water droplets.

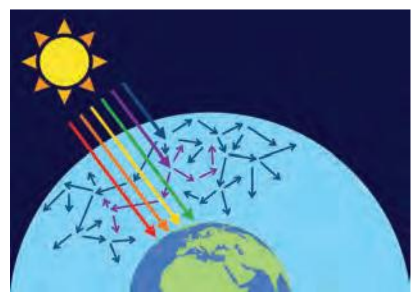


FIGURE 3.9.3 Shorter wavelengths of light are scattered more by the atmosphere than longer wavelengths; this means that blue light is scattered more than other colours, giving the sky a blue appearance

Particle properties of light

Although there is a lot of evidence to show that light is a wave, there is also evidence that shows it can behave like a particle. These particles of light are called **photons**.

The **photoelectric effect** (Figure 3.9.6) is a phenomenon of light that requires it to behave as a particle. It occurs when light above a certain frequency is shone onto a metal and causes electrons to be ejected. This can best be explained by light behaving like a particle.

KEY TERMS

photon a particle without mass that carries a specific amount of energy representing a minute quantity of light or other electromagnetic radiation

photoelectric effect the emission of electrons from a material that is exposed to electromagnetic radiation, such as light

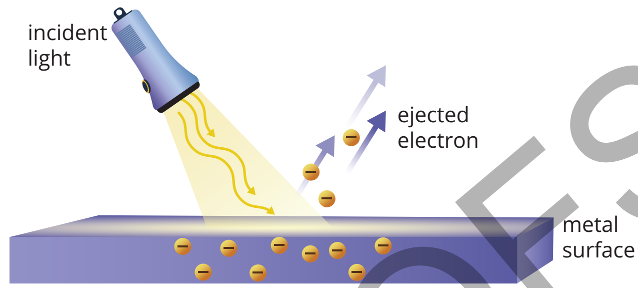


FIGURE 3.9.6 When light above a certain frequency shines on metal, electrons are ejected from the surface

Imagine a billiard ball (photon) hitting a group of balls (atom). If the billiard ball has enough energy, it can cause one of the group (electron) to break away. The energy from the light particle transforms into the kinetic energy of the electron in the photoelectric effect, in a similar way.

If, instead, light behaved only as a wave, the energy from the applied wave would build up inside the atom until an electron was ejected. This would mean that changing the amplitude of the wave would increase the kinetic energy of the photons, but this is not observed.

Solar panels utilise the physics of the photoelectric effect and the particle properties of light to produce electricity.

Wave or particle?

Waves and particles behave in very different ways. Particles travel in straight lines and their position is at a particular point at any given time. But waves can bend around corners and oscillate in their position. So, how can light be both a particle and a wave?

The answer lies in **quantum mechanics**, a field of physics that deals with the motion and interaction of **subatomic particles**. Within this branch of Physics, it can be shown that light and even matter are able to display properties of being both a wave and a particle under different conditions, a concept known as wave–particle duality.

KEY TERMS

quantum mechanics a branch of science that explores the motion and interaction of subatomic particles, including the ideas that energy exists in small 'packets' and extremely small particles can display the characteristics of particles and waves

subatomic particle the particle that atoms are made of—protons, neutrons and electrons

SC 2 CHECK YOUR UNDERSTANDING

Contrast the mass and speed of particles of matter compared to particles of light.

SC 3 I can compare different forms of electromagnetic waves in terms of wavelength, frequency or energy of photons

The electromagnetic spectrum

The range of electromagnetic waves is called the **electromagnetic spectrum** (Figure 3.9.7). This means that there are different types of electromagnetic waves that have different wavelengths/frequencies. Waves with a small wavelength have a high frequency and carry a lot of electromagnetic energy. Conversely, waves with a long wavelength have low frequencies and low energies.

KEY TERMS

electromagnetic spectrum
the range of all forms of electromagnetic radiation, from high-frequency gamma rays to low-frequency radio waves, which includes visible light

infrared radiation
electromagnetic radiation with wavelengths slightly longer than those of visible light, detected by the skin as heat

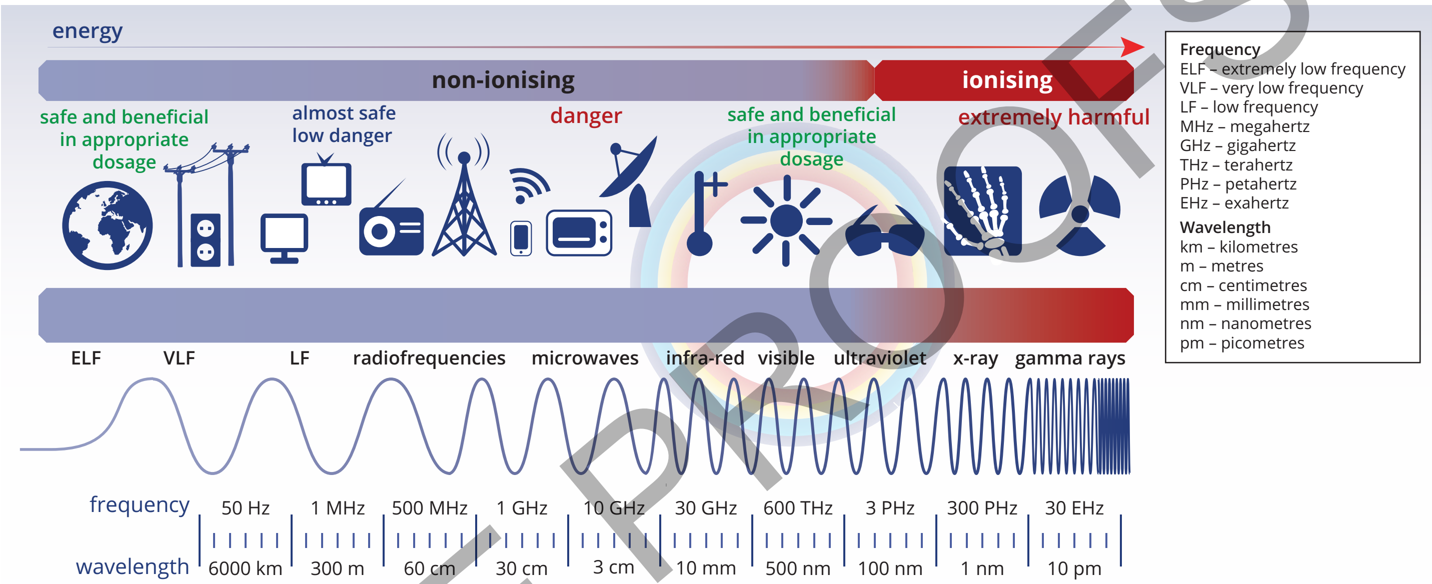


FIGURE 3.9.7 The electromagnetic spectrum

Radio waves

Radio waves have a large wavelength which allows them to easily travel long distances around the world. Due to their long wavelengths, they bounce off the atmosphere and are reflected back towards Earth. This makes them useful for communication devices (hence the name, radio).

Microwaves

Microwaves are utilised in microwave ovens to heat food. Microwaves generate heat by causing water molecules to vibrate. Unlike radio waves, microwaves can penetrate the atmosphere, allowing for communication with satellites.

Infrared radiation

The human eye cannot see infrared, but the body can detect this form of light as heat. **Infrared radiation** is seen in cooking, heating, television remotes, and infrared cameras, which convert infrared light into visible light (Figure 3.9.8).

FIGURE 3.9.8 A thermal camera uses infrared light to investigate the temperature of machinery as it operates; by analysing this data the efficiency and safety of the machinery can be evaluated

Scifile

UV shield

Sunscreen acts as a shield against UV radiation from the Sun. It contains ingredients that either absorb or reflect UV rays, protecting your skin from damage and reducing the risk of sunburn and skin cancer.

FIGURE 3.9.9 An airport security officer uses an X-ray machine to check luggage as passengers board a plane

KEY TERMS

visible spectrum the band of colours produced from the splitting of white light

ionising radiation any form of radiation that can remove electrons from atoms and molecules

Visible spectrum

The **visible spectrum** is the portion of the electromagnetic spectrum which the human eye perceives as colour. Aside from colouring the world, it is also utilised in technologies such as optical fibres to transmit information.

Ultraviolet (UV) light

UV light is the first form of light in the spectrum which carries enough energy to be considered dangerous. UV light causes sunburn and can damage cells which can lead to cancer. An example of the usefulness of UV light is in fluorescent lamps which produce UV light which is converted into visible light by a special coating on the inside of the bulb.

X-rays and gamma rays

X-rays and gamma rays are very high energy light rays capable of penetrating many objects. Fortunately, the atmosphere protects you from these rays. Because of their penetrative ability, X-rays are utilised in medical imaging and security systems, like those used at the airport (Figure 3.9.9). Gamma rays are used in medicine to destroy unwanted cells, such as cancer, and to sterilise medical equipment.

Ionising radiation

Ionising radiation is defined as any radiation that has enough energy to strip electrons from an atom. Electromagnetic waves that have large amounts of energy (that is, X-rays and gamma rays) are said to be ionising as they can cause chemical changes to atoms. This can be damaging to living tissue.

SC 3 CHECK YOUR UNDERSTANDING

Explain why ultraviolet light has higher energy than infrared radiation.

Lesson review

Use these questions to check whether you have met the learning intention for this lesson.

1 Electromagnetic waves have specific properties such as speed, wavelength and frequency.
  - **a** State the speed of electromagnetic waves in a vacuum.
  - **b** Explain how wavelength and frequency are related in electromagnetic waves.

2 Use the wave equation to solve the following problems.
  - **a** Calculate the frequency of red light with a wavelength of 7×10^{-7} m.
  - **b** Calculate the wavelength of blue light with a frequency of 6×10^{14} Hz.

3 Explain why the wave model cannot explain the results of the photoelectric effect experiment.

4 Different forms of electromagnetic waves vary in wavelength, frequency and photon energy.
  - **a** Identify the types of electromagnetic radiation which are ionising.
  - **b** Explain the relationship between energy and frequency, and how this explains the types of ionising radiation.

3.10 Energy transfer and wi-fi

Introduction

In today's rapidly evolving world, advancements in energy transfer technologies are transforming communication and connectivity. One groundbreaking development is CSIRO's invention of wi-fi (Figure 3.10.1), which has revolutionised daily life.

Wi-fi enables data transfer via radio waves, providing internet access without the need for cumbersome cables. This innovation has reshaped the way people learn, work, and interact, making seamless connectivity an essential part of modern life.

In this inquiry, you will explore advances in energy transfer technologies such as CSIRO's invention of wi-fi.

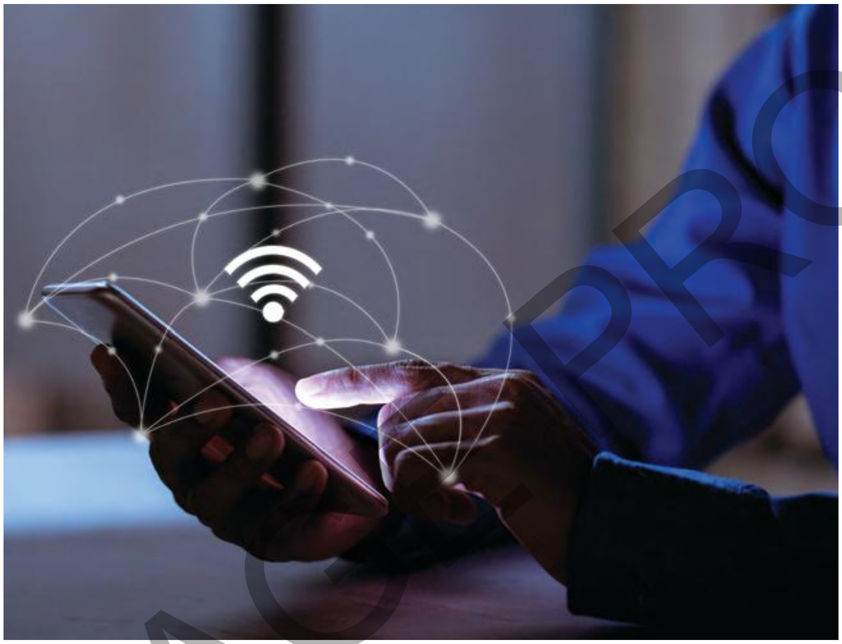


FIGURE 3.10.1 Wi-fi technology enables wireless data communication, allowing devices like smartphones to access the internet without physical cables

Learning intention

To be able to explore advances in energy transfer technologies such as CSIRO's invention of wi-fi

Success criteria

SC 1: I can explore how science has contributed to advances in wi-fi technology.

SC 2: I can examine ways that energy is transferred through wi-fi.

SC 3: I can create an infographic explaining how wi-fi has enabled advances in science.

Background

Scientific research and discoveries have been fundamental in the development of wireless communication. By applying the principles of electromagnetism and radio waves, scientists have enabled the wireless transmission of data, leading to the creation of wi-fi.

Understanding how energy is transferred through wi-fi involves exploring concepts such as modulation techniques, signal propagation, and antenna design. Informative infographics can effectively illustrate how wi-fi has driven advancements across various scientific fields, supporting researchers, educators, and innovators worldwide.

Aim

To explore advances in energy transfer technologies such as CSIRO's invention of wi-fi

Plan

1 Research the ways in which energy is transferred through wi-fi.

2 Explore how science has contributed to advancements in wi-fi technology.

HINT

Consider the type of electromagnetic radiation wi-fi uses to transmit data and the equipment required to send and receive these signals.

Design

1 Explore what makes an effective infographic.

2 Using the information gathered in your planning, identify key content to include in your infographic.

HINT

For your infographic, consider:

- simplicity
- visual appeal
- organisation
- presentation of data
- storytelling
- relevance
- reliability

Conduct

Design your infographic utilising all the information gathered from your planning and designing.

Improve

1 Which parts of your infographic worked well?

2 Were there parts of your infographic that needed improvement?

3 How could you modify your infographic to make it better?

Evaluate

1 What aspect of energy transfer were you investigating in this inquiry?

2 In this inquiry, you created an infographic explaining how wi-fi has enabled advances in science. What skills did you use in this activity?

3.11 Investigating protection from UV radiation

Introduction

Ultraviolet (UV) radiation can cause damage to your skin and even lead to skin cancer. So, it is vital that you practise sun protection (Figure 3.11.1) to block out harmful wavelengths of electromagnetic radiation. But which type of sunscreen is the most effective?

In this practical investigation, you will explore different varieties of sunscreen and evaluate their effectiveness at blocking UV radiation.

FIGURE 3.11.1 Sunscreen is used to block harmful electromagnetic radiation

Learning intention

To be able to design a way to compare the effectiveness of ultraviolet (UV) radiation blockers.

Success criteria

SC 1: I can write a conclusion from an investigation that answers questions about the effectiveness of materials in blocking UV radiation.

SC 2: I can construct arguments that support or reject claims about the effectiveness of products in blocking UV radiation.

SC 3: I can identify possible sources of error in an investigation.

Background

The Sun emits light across the electromagnetic spectrum, including **ultraviolet (UV) radiation**. UV radiation has a higher frequency than visible light and has different impacts on people depending on exposure. Short exposure can lead to sunburn while repeated exposure can cause serious health issues, such as skin cancer.

Finding effective ways to block out the Sun is, therefore, very important. One common method is to use sunscreen. Sunscreens come in different Sun Protection Factor (SPF) varieties. The SPF value is determined by scientists and measures the length of time that the sunscreen protects from sunburn.

KEY TERM

ultraviolet (UV) radiation
electromagnetic radiation with frequencies just above those of visible light, contained in sunlight

Aim

To evaluate the effectiveness of different sunscreens in blocking out UV radiation

Hypothesis

Create a hypothesis for your investigation by considering how the SPF values will affect the photosensitive paper.

Materials

- UV photosensitive paper, cut into four rectangles
- sunscreens with different SPF values, such as 15, 30 and 50
- piece of transparent plastic, cut into four rectangles
- marker pen
- timer or stopwatch
- Blu Tack
- ruler
- scissors

SAFETY NOTE

- Do not look directly into the Sun.

Assessment of risk

Ensure you are aware of the risks of this practical investigation and have considered how safety can be improved before carrying out this activity.

Method

Write a method for your investigation.

Results

Paste your exposed pieces of photosensitive paper (or a photograph of them) into your notebook.

1 Describe the differences, if any, between each piece of UV photosensitive paper.

2 Identify possible sources of error in your investigation.

Conclusion

1 Review the aim of this investigation: Has it been met?

2 Summarise your results: Was there a clear difference between the UV-sensitive paper rectangles at the end of your experiment?

3 Identify sources of error in your investigation and explain how these could be avoided in a repeat of the investigation.

4 Optional: After analysing your results, is there an area of research that you would like to continue with, related to UV protection?

Evaluation

Share your conclusion with your classmates. Note any differences between yours and theirs.

1 Were there elements of their investigation that you could incorporate into yours if you were to repeat it?

2 Were there elements of their conclusion that you could incorporate into yours?

3.12 Investigating heat radiation

Learning intention

To be able to design a way to compare the ability of materials to radiate heat

Success criteria

SC 1: I can identify variables that can impact results from an investigation.

SC 2: I can design and conduct a safe and valid investigation to compare the ability of materials to radiate heat.

SC 3: I can assess the validity of a method in an investigation.

Introduction

Heat is a form of energy that can move through space as a type of electromagnetic radiation called infrared radiation. This form of heat transfer is different from conduction because it does not require a material to pass through. It is also different from convection because it does not require the movement of a gas or liquid. Heat radiation (infrared) can, in fact, travel through a complete vacuum with no air. This is the case with all forms of electromagnetic radiation, such as sunlight and radio waves. This is how heat radiation travels from the Sun to Earth.

Objects will give off heat radiation into their surroundings. The hotter the object, the more heat radiation it emits (Figure 3.12.1).

FIGURE 3.12.1 Some heaters radiate out heat energy in the form of infrared radiation

In this practical investigation, you will test a hypothesis about whether the colour of an object will affect how much heat radiation is given off from the object.

Background

The amount of heat radiation being emitted from an object can be determined by measuring the temperature of the object. As heat is lost to the surroundings by radiation, the temperature of the object will decrease. The higher the amount of radiation emitted, the greater the temperature drop of the object.

Aim

To compare how silver, white and black cans radiate heat

Hypothesis

Write a hypothesis about which colour—silver, white or black—will radiate the most heat over a given time (Figure 3.12.2).

FIGURE 3.12.2 Cans required for the experiment

Method

Design a method to test your hypothesis. You will be provided with silver, white and black aluminium cans. You can include other required equipment in a materials list at the end of the method.

Your experiment should compare the amount of heat radiated over a given time from silver, white and black aluminium cans.

Discuss ideas in your group and come up with different ways to investigate the problem. Select the best method and write it out, including a diagram if required.

Before you start any practical work, assess all risks associated with your procedure and add your safety notes. Show your teacher your method, and if they approve, collect all the required materials and start work.

Materials

List the required materials for your experiment.

SAFETY NOTE

- List any safety notes for your experiment.

Assessment of risk

Ensure you are aware of the risks of this practical investigation and have considered how safety can be improved before carrying out this activity.

Results

Record your results in a suitable result table and/or graph. You can use a spreadsheet to create a graph.

Conclusion

1. Identify the best colour for the radiation of heat.
2. Comment on how well your results supported your hypothesis.

Evaluation

1. Describe at least three variables, other than the colour of the can, that would impact the temperature loss in the experiment.
2. Use your answer to the above question to assess the validity of your results.

Topic review

3 Wave and particle models of energy transfer

Topic summary

The key concepts included in this topic are:

- Heat energy is conducted via conduction, convection and radiation.
- Heat energy moves through fluids (gases and liquids) by convection due to density changing with temperature.
- Voltage provides energy to electrons in the form of kinetic energy, allowing them to move through a circuit.
- Resistance is a property of conductors which reduces current.
- Waves can transfer energy between two points without transferring matter.
- Transverse waves involve particles vibrating at right angles to the direction of energy.
- Longitudinal waves involve particles vibrating parallel to the direction of energy.
- Sound is a type of energy transferred via longitudinal waves.
- Light is transmitted by electromagnetic waves.
- Light may be modelled as an electromagnetic wave or as a massless particle called a photon.
- CSIRO's invention of wi-fi allows the transmission of data wirelessly via electromagnetic waves.

Review questions

The following questions will assess your success in achieving the learning intentions for this topic.

Remember

1 Describe conventional current.

2 A spring can be used to demonstrate the difference between longitudinal and transverse waves.
  a Describe longitudinal and transverse waves. Provide an example of each.
  b Describe how you can model these waves using a spring.

3 Describe the basic principle behind wi-fi technology.

Understand

4 Explain how particles transfer heat energy to nearby particles.

5 Explain how varying resistance controls the current flowing through a circuit.

6 Contrast the connection of an ammeter and the connection of a voltmeter in a circuit.

7 Compare the energy of photons in radio waves to those of visible light.

Apply

8 Develop a hypothesis for an experiment comparing the heat transfer in metals of different conductivity.

9 Sound waves and electromagnetic waves both transfer energy but in different ways.
  a Describe the difference between how sound waves and electromagnetic waves transfer energy.
  b Explain how you could experimentally test the difference between the speed of sound and the speed of light.

10 Use the wave equation to solve the following problems:
  a Calculate the frequency of microwaves, with wavelength 12 cm, which travel at the speed of light.
  b Calculate the wavelength of the musical note of B-flat, which has a frequency of 466 Hz and a speed of 346 m/s.
  c Calculate the speed of the surface waves in an earthquake which have a frequency of 0.5 Hz and a wavelength of 5 km.

11 Describe what would happen to the current in a circuit if the voltage of the power supply was increased.

Analyse

12 Compare the effectiveness of conduction and convection in transferring heat in a liquid.

13 Explain how you would evaluate a product claim that states it blocks 99% of UV radiation.

Extension: Research task

14 The two main types of waves in an earthquake are P-waves and S-waves. Research these waves to determine what types of waves they each are and how this changes their properties.

Topic reflection

The learning intentions for this topic are given in each lesson and at the beginning of the topic. Consider how well you have achieved them. Note down any particular areas that you are confident in, and others where you are not so sure.

3 Glossary

ammeter an instrument for measuring current in electric circuits

amplitude maximum displacement of a wave from its rest position

atom the smallest piece of individual matter that can exist by itself

compression a region of high pressure in which particles are close together

conduction a method of heat transfer in which heat travels through a material or between two objects in contact with each other

conductor material through which heat, sound or electrical energy can be transferred

controlled variable a variable that is kept constant throughout an experiment

convection the transfer of heat through movement in a liquid or gas

convection current transfer of heat in a liquid or gas due to less dense, warmer matter rising and denser, cooler matter falling

conventional current a way to describe electrical current as flowing through a circuit from the positive terminal to a negative terminal

density a measure of the mass per unit volume of a substance

dependent variable the variable that is being measured in an experiment; it changes as the independent variable changes

diffraction bending of a wave around an obstacle or through a small gap

dispersion the splitting of white light into colours of the rainbow

drift velocity the average velocity of electrons moving (drifting) in an electric circuit

electric current the flow of charge

electromagnetic spectrum the range of all forms of electromagnetic radiation, from high-frequency gamma rays to low-frequency radio waves, which includes visible light

electromagnetic wave transverse electric and magnetic fields positioned at right angles to each other and travelling through empty space at the speed of light

electromagnetism the phenomenon of electric and magnetic fields interacting with each other

electron negatively charged subatomic particle, located around the nucleus of an atom

frequency number of waves produced each second and is measured in hertz

heat energy that is transferred from a warmer object or substance to a cooler object or substance

independent variable the factor that is changed in an investigation to find out how it affects another factor (the dependent variable)

infrared radiation electromagnetic radiation with wavelengths slightly longer than those of visible light, detected by the skin as heat

insulator a material which does not readily allow the transfer of heat, sound or electricity - the opposite of a conductor

inversely proportional a description of a relationship where the value of one quantity increases as another quantity decreases by the same proportion, i.e. when one doubles, the value of the other quantity halves

ionising radiation any form of radiation that can remove electrons from atoms and molecules

kinetic energy energy possessed by a moving object

longitudinal a wave in which the vibration is in the same direction as the wave is travelling

longitudinal wave a wave in which the vibration is in the same direction as the wave is travelling

matter a physical substance; anything that has mass and volume

parallel when components are connected in branches adjacent to one another; voltmeters are connected in parallel

particle tiny parts of matter; includes atoms and molecules

particle model model used to describe and explain the behaviour of particles in solids, liquids and gases

photoelectric effect the emission of electrons from a material that is exposed to electromagnetic radiation, such as light

photon a particle without mass that carries a specific amount of energy representing a minute quantity of light or other electromagnetic radiation

pitch how low or high a sound is; the faster particles producing the sound vibrate, the higher the pitch

quantum mechanics a branch of science that explores the motion and interaction of subatomic particles, including the ideas that energy exists in small 'packets' and extremely small particles can display the characteristics of particles and waves

rarefaction a region of low pressure in which particles are far apart

resistance a measure of how difficult it is for current to pass; measured in ohms (Ω)

scattering the interaction of light with particles in the atmosphere, depending on colour and frequency of the light

series when components are connected with each other in a single line; ammeters are connected in series

speed the rate of change of distance

speed of light the speed that electromagnetic radiation, including light, travels. In a vacuum this is approximately 300 000 000 metres per second

subatomic particle the particle that atoms are made of—protons, neutrons and electrons

transverse wave a wave in which the vibration is at right angles to the direction the wave is travelling

ultraviolet (UV) radiation electromagnetic radiation with frequencies just above those of visible light, contained in sunlight

visible spectrum the band of colours produced from the splitting of white light

voltage a measure of the amount of energy provided to charges or used by them; measured in volts (V)

voltmeter an instrument that measures voltage

volume the amount of space that a substance or object occupies; measured in cubic units (e.g. cm^3)

wavelength the length of one complete wave, measured between two corresponding points, measured in metres

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