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SUMMARY GUIDES

Science 9

Rachael Smith

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Summary Guides – Science 9 / Rachael Smith

Rachael Smith asserts the moral right to be identified as the author of this work.

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Please be aware this book contains images of Aboriginal and Torres Strait Islander people who may be deceased.

Contents

Introduction

We have written the *Summary Guides – Science* series to create user-friendly, accessible guides that will help you learn fundamental science knowledge and skills, and understand complex scientific concepts. This book includes real-world examples, step-by-step explanations and exercises for you to complete to embed your learning.

Science is a part of life – understanding it will help you think critically and make sense of the world. The best way to use this book is to make a habit of it, regularly working through the material and questions, and comparing your answers with those provided. Whether you commit to a daily, weekly or fortnightly routine, consistent practice is the key to your success.

Rachael

About the author

Rachael Smith is a passionate educator and writer who is enthusiastic about making complex scientific concepts accessible to all learners.

With over 20 years of experience in teaching and curriculum development, Rachael has dedicated her career to inspiring curiosity and critical thinking in students.

Rachael has worked with teachers and students to develop engaging and effective learning materials that align with the Australian Curriculum. Her expertise spans multiple scientific disciplines, ensuring a well-rounded approach to science education.

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Curriculum correlation

While this book has been written to follow the Australian Curriculum: Science, its content also covers specific state curricula. Go to www.insightpublications.com.au/resources for curriculum correlation charts.

Chapter 1 – Biology

1.1 What is life?

It is surprisingly hard to come up with a precise definition of 'life'. What is it that defines life? How can we tell whether something is alive or not?

1.2 Properties of living things

Biologists have identified various traits that are common to all organisms. Non-living things may show some of these properties or characteristics, but only living things show all of them.

Organisation

Living things are highly organised. They contain specialised coordinated parts. All organisms are made up of cells, the fundamental units of life. In Year 8, you studied cells, which make up tissues, which make up organs, which make up organ systems. These carry out specific organised functions needed by the organism. Even unicellular organisms are organised. Inside each cell, atoms make up molecules, which make up cell organelles and structures.

Metabolism

Life depends on a range of chemical reactions. These chemical reactions allow an organism to sustain itself and do work – such as moving, catching prey, growing, reproducing and maintaining body structure. Living things use energy and consume nutrients to carry out chemical reactions that sustain life. The total of these biochemical reactions in an organism is called its metabolism.

Homeostasis

All organisms have optimal conditions they require to survive. Organisms regulate their internal environment to maintain the conditions needed for cell function. For example, your body temperature needs to be kept close to 37°C. Maintaining a stable internal environment even when conditions externally are changing is called homeostasis.

Growth

Organisms can grow. Individual cells can grow, and multicellular organisms accumulate many cells through cell division. You started out as a single cell and now there are tens of trillions of cells in your body.

Reproduction

Organisms can reproduce to create more living organisms. Reproduction can be:

- asexual, involving a single parent organism. For example, a bacterium can divide and become two new bacteria cells
- sexual, requiring two parents. In this process, genetic information is passed from the two parents to the offspring.

Response

Organisms can sense the environment around them and respond to stimuli or changes in their environment. For example:

- you pull your hand away from a hot flame
- some plants turn towards the Sun
- bacteria can sense and move towards a food source and can sense and move away from a toxic chemical.

Evolution

Evolution is a theory proposed by Charles Darwin in the 19th century. Populations of organisms undergo evolution, which means their genetic make-up changes over time to adapt to changing environments. The fittest individuals survive and thrive in the environment. All life can evolve over generations to adapt to environments.

Activity 1.2.1

Summarise the seven properties or characteristics that all things have. Include diagrams to help you to remember.

1.3 Eukaryotic cells versus prokaryotic cells

Recall from Year 8 that two main types of cells make up organisms: **prokaryotic** cells and **eukaryotic** cells. The main difference between the cells is their structure:

- Prokaryotic cells do not contain a **nucleus** or **membrane-bound organelles**.
- Eukaryotic cells do contain a nucleus and membrane-bound organelles.

Key terms

nucleus	in biology, the organelle in a eukaryotic cell that controls and regulates the activities of the cell and carries the genes
membrane-bound organelles	an organelle that is encased by a membrane, giving it a distinct internal environment
organelle	a small organ-like structure inside a cell that has a specific job; the word means ‘very small organs’

Eukaryotic cells

The living organisms that you see each day are most likely made up of eukaryotic cells – cells with a nucleus and membrane-bound organelles. These living organisms are mostly multicellular, but some are unicellular such as **protists** and some fungi. An example of a unicellular protist is green algae.

Key term

protist	a diverse group of eukaryotic organisms that are mostly unicellular; includes algae, amoeba and slime mould, among others

Eukaryotes are organisms that are made of eukaryotic cells and include all animals, plants, fungi and protists.

Animal and plant cells are eukaryotic cells.

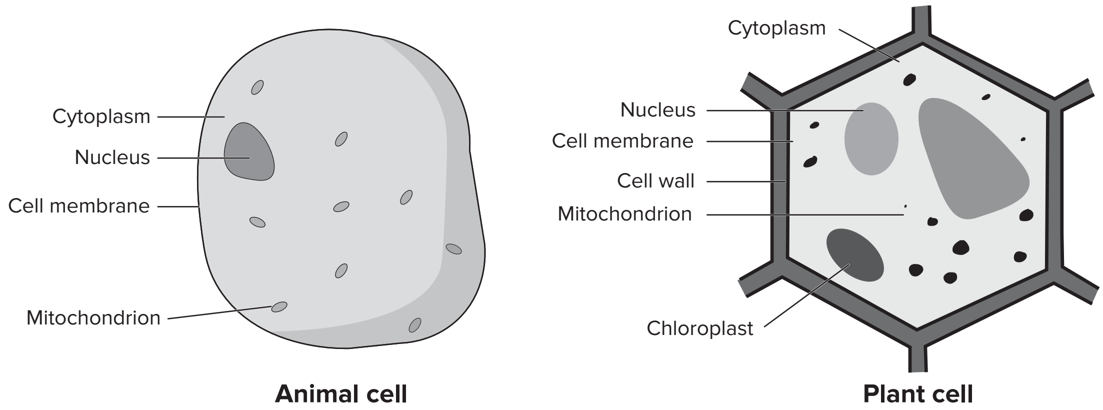


Figure 1.1: An animal and a plant cell

Eukaryotic cells are more complex and generally larger than prokaryotic cells. As well as the nucleus that contains **DNA**, eukaryotic cells have membrane-bound organelles – specialised compartments separated by membranes that act as a boundary. Examples are the nucleus, mitochondria (singular: mitochondrion), Golgi apparatus (or Golgi body), endoplasmic reticulum and vacuoles. You learned about these in Year 8.

Key term

DNA	(deoxyribonucleic acid) the molecule that carries genetic information so an organism can develop and function

Prokaryotic cells

Prokaryotic cells do not contain a nucleus or membrane-bound organelles. They have a specialised structure and their DNA is contained in the central area of the cell. Prokaryotic cells are simpler and generally smaller than eukaryotic cells.

Organisms that are made of prokaryotic cells are unicellular.

Prokaryotes are organisms that are made of prokaryotic cells. Examples are bacteria.

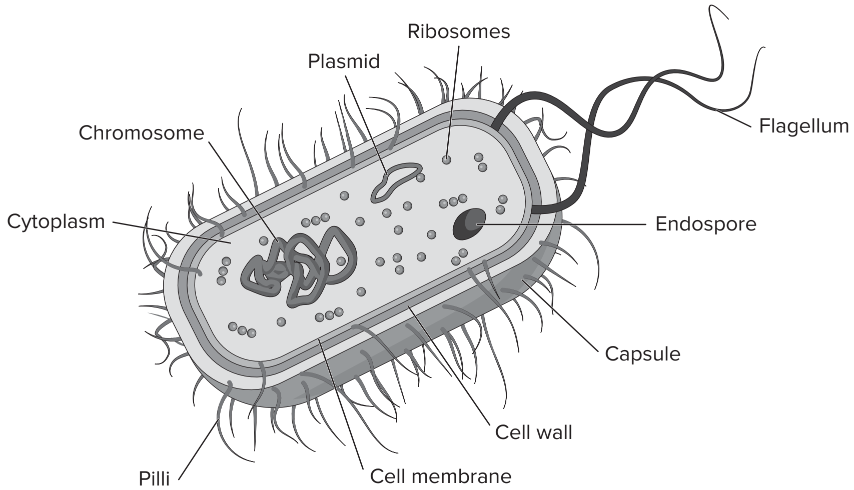
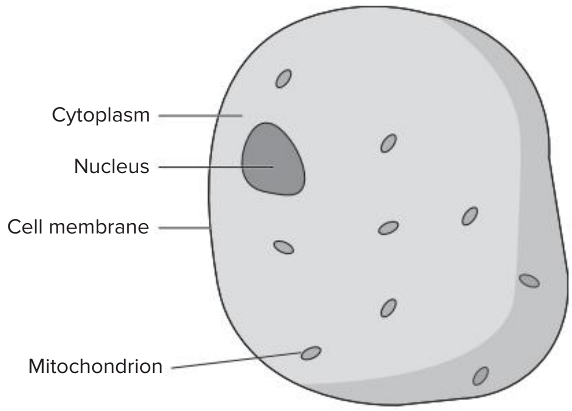


Figure 1.2: A prokaryotic cell

Activity 1.3.1

Is this cell prokaryotic or eukaryotic? Discuss why.



1.4 The levels of organisation of life

Organisms are organised from the atomic level to the macroscopic level.

- **Atom** – the smallest unit that makes up all matter.
- **Molecule** – formed when atoms bond together. Each molecule has unique properties that allow it to provide functions to a cell.
- **Organelle** – a small structure in a cell. Each organelle has an important and specific role in a cell's function and survival.
- **Cell** – the smallest living unit of life. Cells have specific structures and functions.
- **Tissue** – a group of similar cells working together to perform a specific function. Examples are muscle tissue, nervous tissue, epithelial tissue and connective tissue (Figure 1.3).

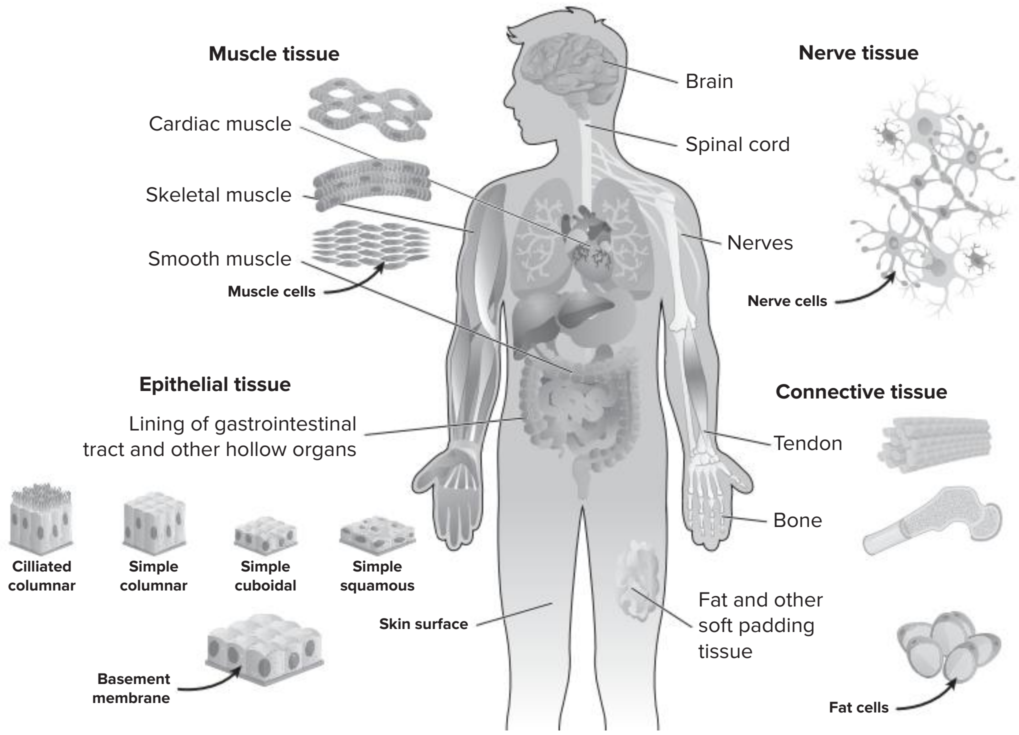


Figure 1.3: Types of tissues

- **Organ** – a structure made up of two or more types of tissue that work together to perform a specific function (Figure 1.4). For example, the:
  - **heart** is made of muscle tissue, connective tissue and nervous tissue. It pumps blood throughout the body
  - **lungs** are made of a special sponge-like tissue that stretches easily to keep its shape without being damaged; it also has epithelial tissue to enable gas exchange
  - **stomach** contains muscle tissue to churn food, epithelial tissue to secrete digestive enzymes, and nervous tissue to control its functions.

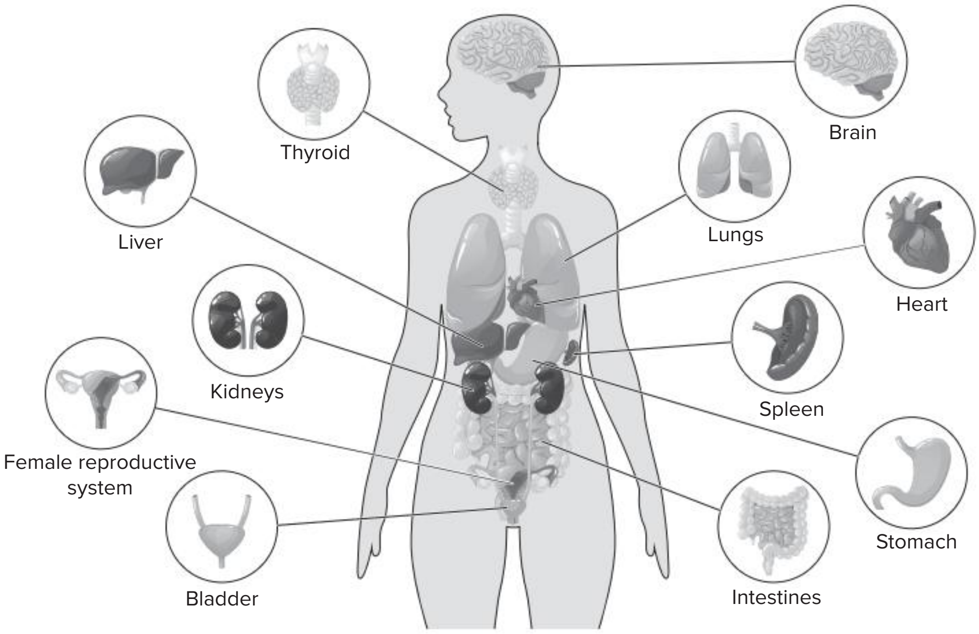


Figure 1.4: Human internal organs

- **Body/organ systems** – a group of organs working together to perform complex functions in the body (Figure 1.5). Examples are:
  - **digestive system**, which breaks down food to absorb nutrients.
  - **circulatory system**, which transports oxygen, nutrients and waste products.
  - **respiratory system**, which facilitates breathing and gas exchange.
  - **nervous system**, which sends signals and controls body functions.
- **Organism** – organisms consist of a range of different organ systems with coordinated systems being the key to their survival (more on this later!).

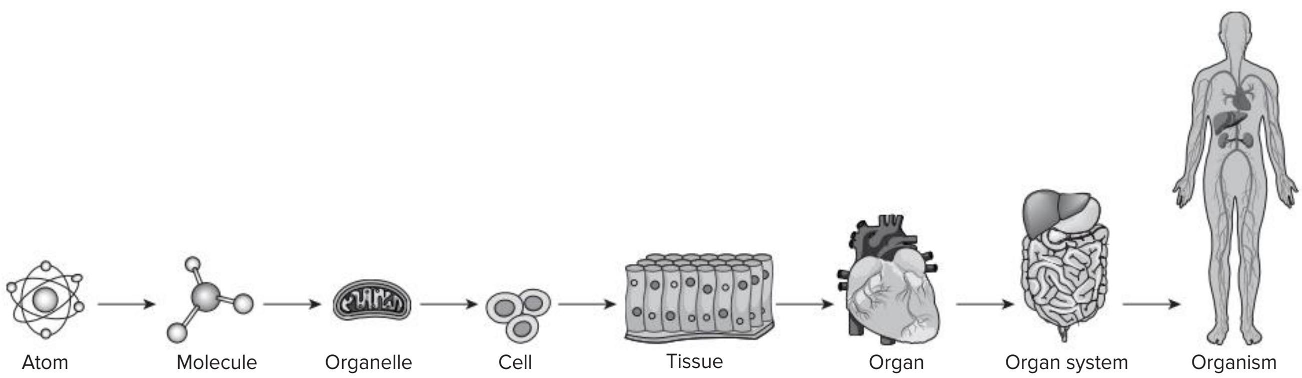


Figure 1.5: The levels of organisation in an organism

These systems are **interdependent**. They need each other to function properly. For example, the respiratory system and circulatory system work together to deliver oxygen to cells.

Activity 1.4.1

Create a flow chart to show the levels of organisation from atom to full organism. Draw diagrams to help you to remember.

All life processes are performed by one or more body system. There are 11 main body systems that can be classed into four categories (Table 1.1).

Table 1.1: The 11 main body systems

Category	System	Role
Supporting, moving and protecting the body	Skeletal	Supports and protects body, stores calcium, generates red blood cells
	Muscular	Moves skeleton, aids movement of blood and other materials
	Integumentary	Covers and protects internal organs, keeps water inside body, regulates body temperature
Maintaining the body	Respiratory	Exchanges gases between blood and external environment
	Digestive	Ingests (takes in) food, digests it (breaks down) and absorbs it into bloodstream
	Circulatory (cardiovascular system)	Transports blood and materials around body
	Excretory (urinary system)	Filters and removes metabolic waste, removes excess substances from blood
	Lymphatic (immune system)	Helps preserve fluid balance and protects body against disease
Continuing the life cycle	Reproductive	Produces sex cells, enabling reproduction of organism
Coordinating and regulating other body systems	Nervous	Detects and responds to stimuli, integrates activities of other organ systems
	Endocrine	Regulates body functions by hormones

Activity 1.4.2

Create a mind map of the 11 main body systems divided into their four categories to show their main functions. Use different colours and pictures to help you to remember.

1.5 The nervous system

The two body systems that coordinate and regulate (control) the other body systems are the nervous system and the endocrine system. They work together to regulate many body functions in different ways (Table 1.2).

Table 1.2: A comparison of the nervous system and the endocrine system

Feature	Nervous system	Endocrine system
Components	Neurons	Glands
Primary signal	Electrical signals and neurotransmitters	Hormones
Transmission of signals	Through nerve cells	Through bloodstream
Speed	Very fast	Slow
Duration of effects	Short-term effects	Long-term effects

Activity 1.5.1

Create a colourful table with words and diagrams to show the differences between the nervous system and the endocrine system.

Nervous system

The nervous system is a complex network of neurons that transmits signals between different parts of the body and the brain. It controls and coordinates all body activities, including voluntary (solving maths problems) and involuntary (breathing) actions. Think of it as the control centre of your body.

The primary function of the nervous system involves three steps:

1. **Monitor changes** to the internal and external environment, via sensory receptors (you notice that a branch is falling above you)
2. **Interpret these changes** (you decide what action to take)
3. **Effect a response** by activating muscles or glands (you move your body out of the way of the falling branch).

The nervous system is made up of nerve tissue, which is made up of nerve cells (neurons). A nerve is a bundle of nerve cells. Nerve cells transmit electrical signals called nerve impulses. The electrical signals are very fast, which means we can have very quick reactions. For example, when we touch something hot with our hand (external stimuli) and then move our hand away quickly, we can thank the sensory neurons in our skin!

Activity 1.5.2

Explain the primary function of the nervous system and the steps involved.

Neuron structure

Nerve cells are varied in structure and function and have six main components:

- **cell body** – contains the nucleus and other cell organelles
- **dendrite** – receives nerve impulses from other nerve cells

- **axon** – sends nerve impulses to other nerve cells
- **nucleus** – controls and processes information
- **axon ending** (terminal) – passes message to next neuron
- **myelin sheath** – insulates axon and protects impulse.

Many axons and some dendrites are surrounded by an insulating layer called a **myelin sheath** (Figure 1.6). This protects nerves and increases the speed of nerve signals.

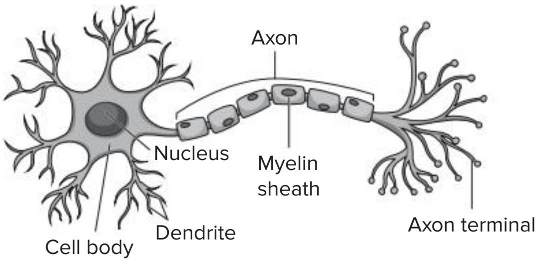


Figure 1.6: The structure of a neuron (nerve cell)

Activity 1.5.3

Explain the six main components of a nerve cell (neuron). Draw and label a diagram to show the structure of a neuron.

Types of neurons

There are three functional types of nerve cells (Figure 1.7):

- **Sensory neurons** detect changes in the environment via receptors and send messages to the brain.
- **Motor neurons** send messages from the brain to muscles or glands that carry out a response.
- **Interneurons** connect sensory neurons to motor neurons.

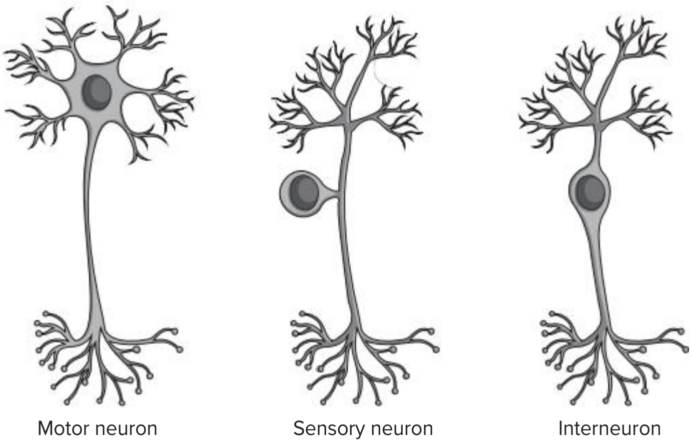


Figure 1.7: Types of neurons

Between adjacent neurons is a small gap called a **synapse**. Electrical nerve impulses cannot travel across a synapse. Instead, neurotransmitters (messenger molecules) carry a chemical signal across a synapse.

Activity 1.5.4

Explain the three functional types of nerve cells. Draw and label a diagram of each type.

Main components of the nervous system

The nervous system has two main parts: the central nervous system and the peripheral nervous system.

Central nervous system (CNS)

The **central nervous system** is the control centre of the body. It consists of the brain and the spinal cord.

The **brain** is the most complex organ in the human body. It contains approximately 100 billion neurons, which receive and process sensory information. The brain controls every process that regulates your body, both physical and mental; for example, memory, emotions, motor skills, senses, speech, breathing, sleep and hunger.

Messages are processed in the brain and redirected out to the body. The main parts of the brain are:

- **Cerebrum** – the largest part of the brain and does most of the brain's work. It has lobes, which have different functions. Each lobe has special sections called cortexes that also have specialised functions. Functions include controlling movement, language, thinking and reasoning, interpreting sense, speech and interpreting speech, memory, emotions, problem solving and judgement.
- **Thalamus** – a structure below the cerebrum in the central area of the brain. The thalamus relays sensory information to the cerebrum and is involved in controlling consciousness and alertness.
- **Hypothalamus** – a structure in front of the thalamus that regulates homeostasis. It receives sensory signals from nerves throughout the body and signals appropriate organs to act. The hypothalamus links the nervous system to other body systems.
- **Brainstem** – a structure at the bottom of the brain that connects the brain and the spinal cord. It is involved in regulating a range of involuntary actions, including breathing and heartbeat.
- **Cerebellum** – a structure located behind the brainstem. It is involved in coordination of movements and balance.

The **spinal cord** is a long, tube-like bundle of nerves that runs from the brain down the back, connecting the brain to the rest of your body, transmitting signals to and from the brain.

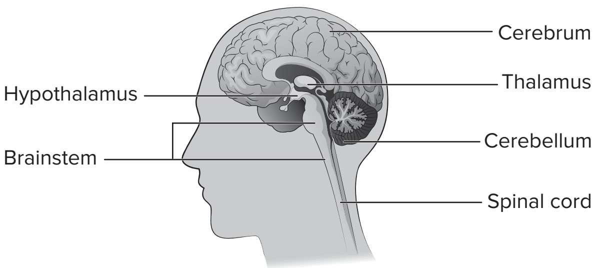


Figure 1.8: The central nervous system: the brain and spinal cord

Peripheral nervous system (PNS)

The peripheral nervous system is a long network of nerves that connects the central nervous system to the rest of the body. Messages are passed through the body to get a response or action. The PNS consists of sensory neurons, which detect changes and motor neurons, which effect a response.

The peripheral nervous system is made up of two parts (Figure 1.9):

- **Somatic nervous system** – controls voluntary actions (actions that you have control over) (e.g. deciding to move) as well as the sensory signals you get from touching objects (e.g. a hot saucepan).
- **Autonomic nervous system** – controls everything in your body that is automatic such as breathing, your heartbeat, digestion and blinking. The autonomic nervous system is made up of two more parts:
  - **Sympathetic nervous system** – prepares your body for 'fight or flight' when you encounter a stressful or scary situation. Fight or flight responses makes you either jump into action or run and hide.
  - **Parasympathetic nervous system** – promotes 'rest and digest' activities. This system helps you to return to a calm and relaxed state by reducing the heart rate and stimulating digestion, so the body gets back to normal after experiencing stress.

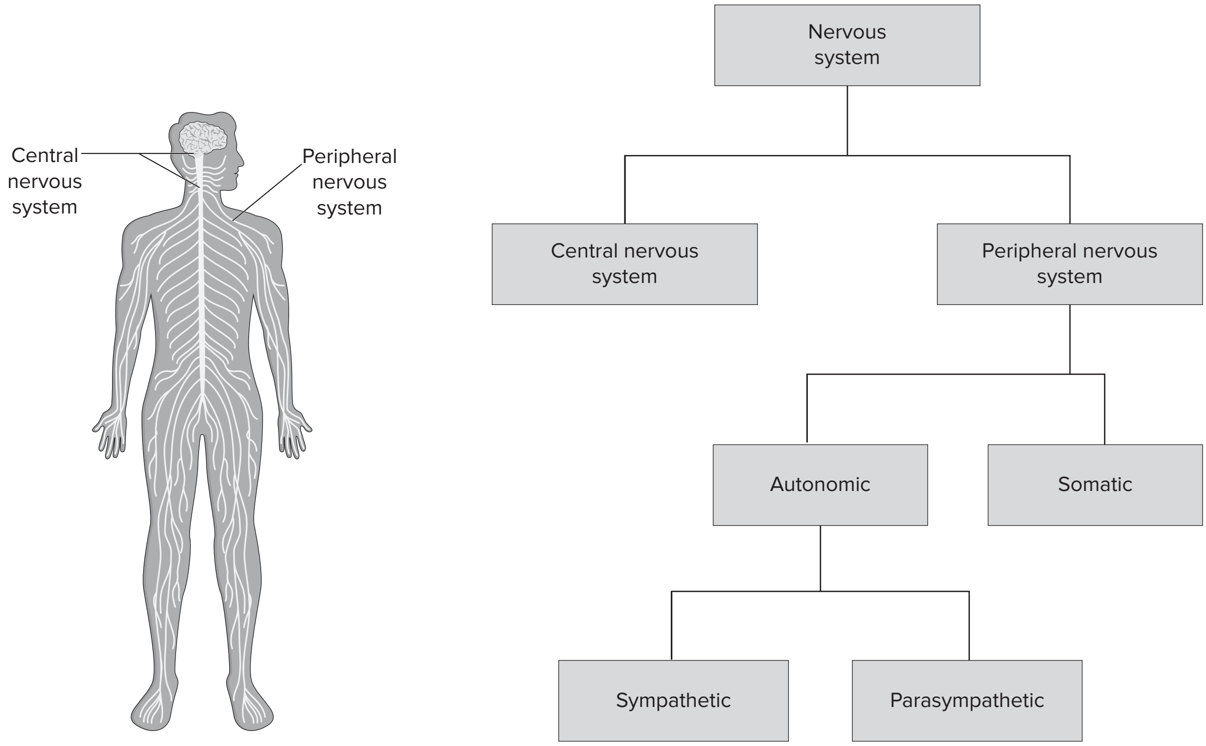


Figure 1.9: The parts of the nervous system

Responding to the environment

The body responds to external stimuli in several ways. A reflex is a rapid, automatic response. For example, if you touch a cactus and move your hand away quickly from the spike, or if you flinch.

The **reflex arc** is the neural pathway in which a reflex response is carried out. Reflex arcs are not initiated by the brain but come directly from the spinal cord. This allows for a quicker response because it bypasses the neural route between the spinal cord and brain. Another involuntary reflex is the change in the diameter of our pupils when exposed to light and sneezing.

Activity 1.5.5

1. Identify the two main parts of the nervous system.
2. Identify the main components of the central nervous system.
3. Explain the peripheral nervous system.
4. Describe the differences between the autonomic and somatic nervous systems.
5. Describe the difference between the sympathetic and parasympathetic nervous systems and their functions.
6. Describe the two parts of the autonomic nervous system and their functions.
   a. List the three key functions of the nervous system and why it is important.
   b. What makes neurons able to send signals so fast?
   c. Explain how a reflex arc differs from a normal response.

1.6 The endocrine system

The endocrine system regulates body functions through hormones. The system consists of endocrine glands that are located throughout the body. The glands secrete hormones directly into the bloodstream and are circulated throughout the body. The endocrine system is coordinated by the hypothalamus via the pituitary gland. The pituitary gland regulates the function of other endocrine glands and is considered the 'master gland'.

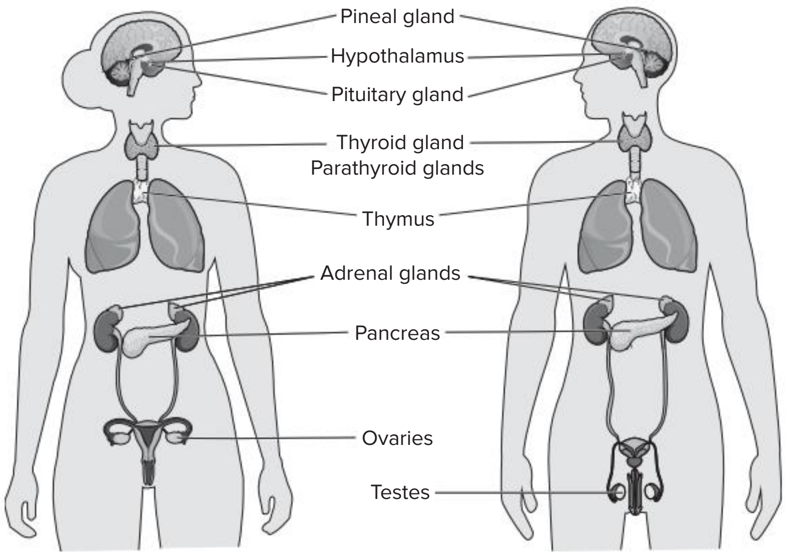


Figure 1.10: The endocrine system

In Figure 1.10, you can see that the endocrine system is a network of endocrine glands distributed throughout the body but working together to regulate body functions. Each gland produces its own hormones that target specific cells.

Table 1.3 on the next page lists the endocrine glands of the endocrine system and their main functions.

Table 1.3: The main functions of endocrine glands

Endocrine gland	Function
Hypothalamus	Regulates the endocrine system via the pituitary gland
Pituitary gland	Regulates the function of other endocrine glands
Pancreas	Regulates blood sugar levels (also functions as a digestive organ)
Thyroid gland	Regulates basal (resting) metabolism and body temperature
Parathyroid glands	Regulate calcium levels
Adrenal glands	Regulate functions such as heart rate and blood pressure
Pineal gland	Modulates sleep patterns and circadian rhythms
Thymus	Produces hormones involved in the body's immune response
Ovaries and testes	Involved in sexual maturation and reproduction

Hormones

Hormones are chemical substances that are produced in the endocrine glands. They have a specific regulatory effect on organs. Hormones are transported around the body in the bloodstream. Hormones only act on target cells, which have specific receptors that fit the shape of the hormone (Figure 1.11).

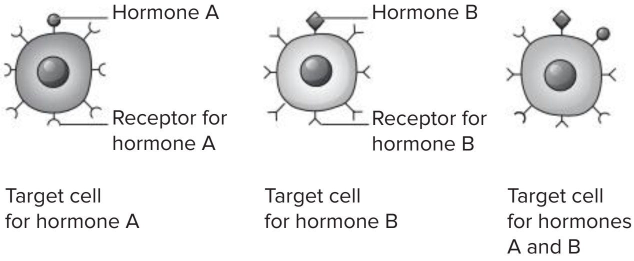


Figure 1.11: Hormones only act on target cells.

Responding to the environment

When you are scared or stressed or feeling threatened, your body releases a hormone called adrenaline. Adrenaline is produced in the adrenal medulla of the adrenal glands. This hormone increases your heart rate and breathing rate and opens the blood vessels in the lungs. It also dilates your pupils and brings blood to your muscles. This hormone is essential for survival because it allows your body to prepare itself for danger and threats.

Activity 1.6.1

1. Describe the function of the endocrine system.
2. Identify the glands of the endocrine system and describe each gland's function.
3. Explain what hormones are.
4. Describe where adrenaline is produced, what happens to the body when the hormone is released into the body and why it is important.

1.7 Regulation of body systems

The human body can only function within a narrow range of internal parameters. **Homeostasis** is the process of maintaining a constant internal environment so that the human body can function optimally. Homeostasis is coordinated by the nervous system and the endocrine system.

Substances that need to be kept within certain levels include water, sugar, carbon dioxide and urea. Body temperature also needs to be maintained at 36.5–37.5˚C.

Homeostasis involves receptors and effectors.

- Receptors are sensitive to a particular stimulus.
- Effectors enact a response that has an effect on that stimulus.

This type of stimulus response regulation is called **negative feedback**.

Activity 1.7.1

1. Explain what homeostasis is.
2. What is the difference between a receptor and an effector?
3. Define 'stimulus'.

Regulation of body temperature – thermoregulation

The human body needs to be kept at a constant temperature so that all the metabolic processes can take place. Metabolic processes are internal chemical reactions that maintain life. Stable body temperature is maintained by the nervous system and the endocrine system.

Hyperthermia occurs when the body gets so hot that body temperature rises. This can result in dizziness, weakness, nausea and headaches. In severe cases heart rate increases, and you may have heat exhaustion or heat stroke.

Hypothermia occurs when the body gets so cold that body temperature drops. This can result in shallow breathing, drowsiness and slurred speech. In severe cases, you can have a weak pulse, disorientation, loss of consciousness and organ failure.

Table 1.4 shows how the nervous system responds to changes in body temperature.

Table 1.4: Nervous system response to body temperature change

Increase in temperature	Decrease in temperature
• Vasodilation – blood vessels near the skin become wider. This allows more heat to escape the body and can make skin appear flushed (red). • Sweating – sweat (which is mostly water) is secreted from sweat glands in the skin. The water evaporates and cools the body. This is called evaporative cooling.	• Vasoconstriction – blood vessels near the skin become narrower. This allows less heat to escape the body and can make skin appear pale. • Shivering – involuntary muscle activity generates heat as a by-product. • Goose bumps – contraction of tiny muscles at the base of body hairs causes bumps, which make the hairs stand upright.

Activity 1.7.2

Create a mind map using colours and images to explain how the nervous system responds to an increase and a decrease in body temperature.

The endocrine system responds to changes in body temperature by regulating levels of thyroid-stimulating hormone (TSH). This hormone is produced by the pituitary gland under the control of the hypothalamus.

TSH regulates the production of the hormone thyroxine. Thyroxine is produced by the thyroid gland. Thyroxine affects the rate of metabolism, which then affects the amount of heat produced by the body.

Figure 1.12 shows how the endocrine system responds to changes in body temperature.

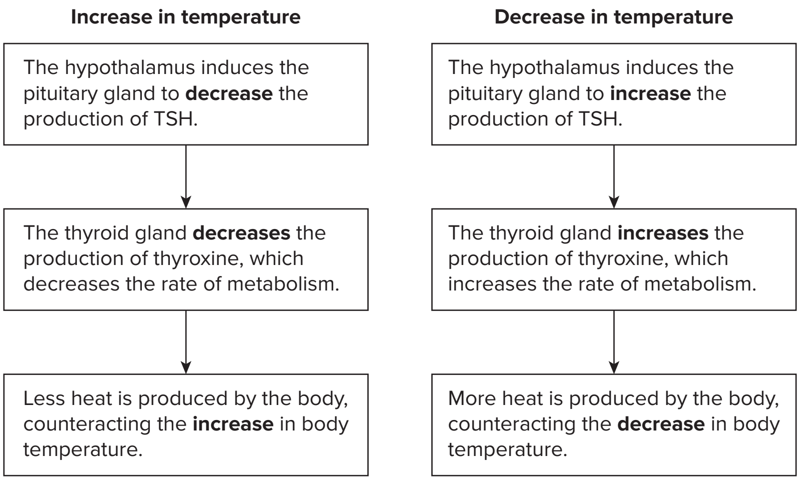


Figure 1.12: How the endocrine system responds to changes in body temperature

Activity 1.7.3

Create a mind map using different colours and diagrams to explain how the endocrine system responds to an increase and a decrease in body temperature.

Regulation of blood glucose

Our cells require a constant supply of glucose for energy. Glucose is transported around the body through the bloodstream.

- High blood glucose (**hyperglycaemia**) makes the blood thick and harder to move through blood vessels.
- Low blood glucose (**hypoglycaemia**) means the body is not getting enough energy, resulting in symptoms such as dizziness.

The endocrine system, particularly the pancreas, maintains stable blood glucose levels (Figure 1.13).

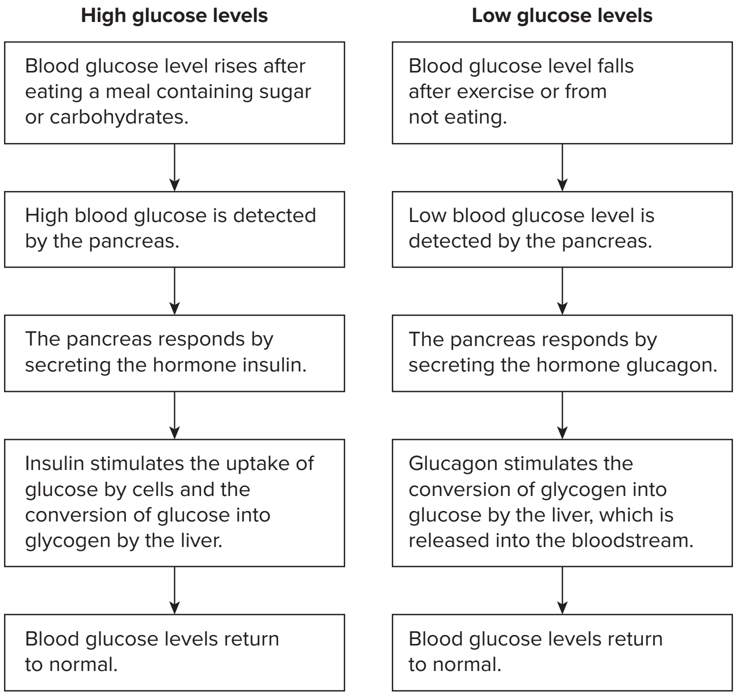


Figure 1.13: How the endocrine system responds to high and low glucose levels

Activity 1.7.4

Create a mind map using different colours and diagrams to explain how the endocrine system responds to high glucose levels and low glucose levels.

Homeostasis and negative feedback

Negative feedback is a key part of homeostasis. When there is a change in the body's internal environment, it is detected by receptors and the body's protective mechanisms work to return to the **set point** (the point at which the condition is at its optimum, otherwise known as homeostasis). The body counters the change and, hence, this is negative feedback and is shown in Figure 1.14.

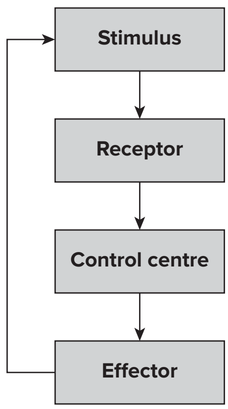


Figure 1.14: Negative feedback – a key part of homeostasis

Disruption of negative feedback in the endocrine system

Disruption of negative feedback can result in overproduction or underproduction of hormones, leading to various health problems such as diabetes, thyroid disorders and growth disorders.

Diabetes occurs when the feedback loop that controls blood sugar levels malfunctions. This results in abnormally high blood glucose levels because cells cannot take up glucose and store it as glycogen or convert it to fuel.

In a healthy body, the hormones insulin and glucagon work together to regulate blood sugar levels:

- Insulin is secreted by the pancreas after a meal. Insulin signals cells to take up glucose and convert it to glycogen.
- Glucagon is released when blood sugar levels are low. Glucagon causes cells to release glucose.

When the feedback loop is broken or disrupted, the body can't lower blood sugar levels to a healthy level.

Diabetes can lead to many long-term health problems, including:

- nerve damage
- eye damage
- kidney damage
- foot complications
- skin and mouth conditions
- hearing impairment
- Alzheimer's disease
- depression.

It is important to note that negative feedback can be restored in the endocrine system through medication or lifestyle changes that help to regulate hormone levels and promote balance in the body.

Activity 1.7.5

Explain how diabetes is caused by a malfunctioning feedback loop that controls blood sugar levels. How can it be restored?

Science and a human endeavour: Imaging technologies

Imaging technologies are tools and techniques that allow scientists and doctors to see inside the body without invasive surgery. These advancements have greatly improved our understanding of how body systems function and interact.

Imaging technologies include X-rays, ultrasound, magnetic resonance imaging (MRI), computed tomography (CT and CAT) scans, positron emission tomography (PET) scans and endoscopies.

There are many benefits to imaging technologies. They are non-invasive and they allow medical professionals to understand organ function, study disease progression and develop effective treatment plans for patients.

Table 1.5 shows how imaging technologies have improved our understanding of some body systems.

Table 1.5: How imaging technologies have increased our understanding of some body systems

Body system	Improvement through imaging
Skeletal system	Better understanding of bone fractures, joint function and skeletal diseases such as arthritis
Nervous system	Insights into brain function, neural pathways and conditions such as strokes and epilepsy
Cardiovascular system	Better understanding of heart and blood vessel structures Detection of blockages and heart defects
Respiratory system	Observation of lung function Detection of diseases such as pneumonia and lung cancer
Digestive system	Ability to study organ interactions and detect disorders such as ulcers and digestive blockages
Reproductive system	Monitoring of foetal development and diagnosing reproductive issues

1.8 Pathogens, disease and the immune system

Any medical condition with specific symptoms is called a **disease**. Microbes (organisms that can only be seen with a microscope) and other microscopic agents that cause disease are known as **pathogens**.

Diseases that are caused by pathogens and can be passed on to another person or living thing are known as **infectious diseases**.

Key terms

disease	a negative interruption to the normal functioning of a living thing, leading to pain and weakness
pathogen	a specific thing, usually a virus or bacteria, that causes disease

Types of pathogens

Pathogens are usually divided into three main types: bacteria, viruses or fungi. (Other types include parasites and protists.)

Table 1.6: Characteristics of common pathogens

Type of pathogen	Number of cells	Structure	How it causes disease
Bacteria	Unicellular	Small, simple cells without a nucleus	Attaches to cells and takes their nutrients
Viruses	None – non-living	Not cells – genetic material in a layer of protein or fat	Enters cells to reproduce, causing them to burst and die
Fungi	Unicellular or multicellular	Complex cells but cannot photosynthesise	Feeds off the host

Infectious diseases

When pathogens enter the body and multiply, we call this an infection. Many infectious diseases can spread from person to person. When an infectious disease can pass from one person to another, it is described as **contagious**. Diseases can pass via different channels – some from people shaking hands or sharing drinks, others from breathing in saliva droplets among many other examples.

A medical condition that cannot spread from person to person is non-contagious. Diseases that are not caused by pathogens are known as non-infectious diseases. They can be caused by lifestyle, environmental or genetic factors.

The immune system's three lines of defence

The body system that prevents and fights disease is called the **immune system**. It is made up of many organs, tissues and cells working together. The immune system uses three lines of defence.

The first line of defence – barriers

The body uses a combination of physical and chemical barriers to provide the first line of defence against diseases. Pathogens must make it past this before they can cause an infection. The main barrier is the skin – it is difficult for pathogens to pass through this physical barrier. In addition, the skin can produce acidic sweat and antimicrobial oils to try to kill pathogens.

While they are a much less effective barrier than the skin, the mouth and nose also have ways to prevent infection. The saliva in the mouth and mucous in the nose have antimicrobial properties, and the nose has specialised cells containing micro hairs (cilia) to filter out pathogens.

If you swallow a pathogen in something you eat or drink, your body can also try to kill it with the acid in your stomach, which has a pH of 1–3. The tears in your eyes also have some antimicrobial properties to prevent eye infections.

The second line of defence – innate protections

An infection occurs when pathogens make it past the first line of defence and enter the body. When this happens, the immune system responds in some general ways that treat all pathogens equally.

One way is for your immune system to trigger an increase in core body temperature to produce a **fever**. This helps to fight pathogens by making it too hot for them to survive.

Another defence is **inflammation**. This is where the body sends blood to the site of the infection, which causes heat and swelling. This blood contains white blood cells that attack the infection.

The third line of defence – adaptive protections

The third line of defence against diseases involves the body rallying specialised white blood cells called **lymphocytes**. Mounting this defence takes time, but it is highly effective because it is targeted. Lymphocytes include T cells and B cells:

- T cells identify and destroy specific pathogens
- B cells build long-lasting immunity against the pathogens in case they infect the body again.

Key term

lymphocytes	specialised white blood cells within the immune system

Activity 1.8.1

1. Name three barriers your immune system uses as its first line of defence. How does each stop pathogens?
2. What is the difference between T cells and B cells?

1.9 Reproduction

Biologists think that the purpose or meaning of life is to **reproduce** to ensure the continuation of the species. The ability to reproduce is one of the key indicators of life and is essential to the survival of species.

Reproduction is a biological process in which new individuals – **offspring** – are produced from existing individuals – **parents**.

- Offspring are the **hereditary** products of parents, meaning that the new life carries the parents' DNA.
- Some offspring are genetically similar to their parents.
- Some offspring are genetically identical to their parents.

Key term

hereditary	the passing of genetic information from parent to child through genes in sperm and egg cells

Although there are many ways that species reproduce, there are two main methods – asexually and sexually (Table 1.7 on the next page). Some species reproduce by both asexual reproduction and sexual reproduction.

Table 1.7: Comparing asexual and sexual reproduction

Feature	Asexual reproduction	Sexual reproduction
Parent	The production of offspring from one parent	The production of offspring from two parents
Offspring	Genetically identical	Unique and carry DNA from two parents
Organisms	All unicellular and many multicellular organisms	Most multicellular organisms (most animals and plants produce by sexual reproduction)

Activity 1.9.1

1. Why is reproduction important?
2. Create a table to summarise the differences between asexual reproduction and sexual reproduction.

1.10 Asexual reproduction

Asexual reproduction produces offspring that are genetically identical to the parents. In other words, the parent is cloning itself. Asexual reproduction is common in fungi. They do this by producing spores through mitosis, which eventually grow into a whole organism.

There are many methods of asexual reproduction, but we will look at two major types: binary fission and budding.

Binary fission

Binary fission occurs when a parent cell divides into two identical daughter cells (Figure 1.15). The two daughter cells are genetically identical. Organisms that reproduce by binary fission are anemones, flatworms and bacteria.

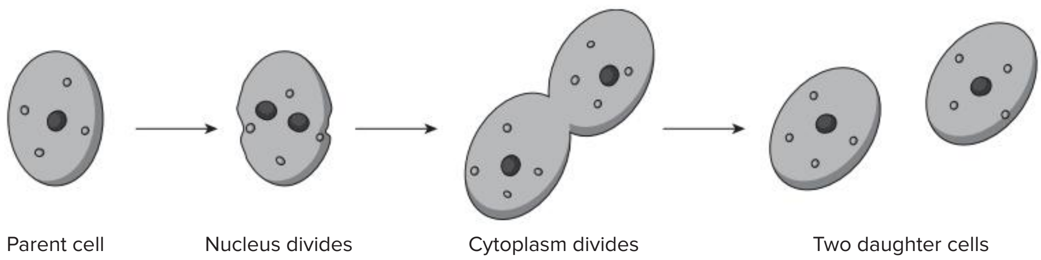


Figure 1.15: Binary fission produces two identical daughter cells from one parent cell.

Budding

Budding occurs when a new organism grows as an outgrowth (bud) on the parent and eventually detaches, growing into a complete and independent organism (Figure 1.16). Organisms that reproduce by budding are hydra (multicellular microscopic animals that live in fresh water) and yeast.

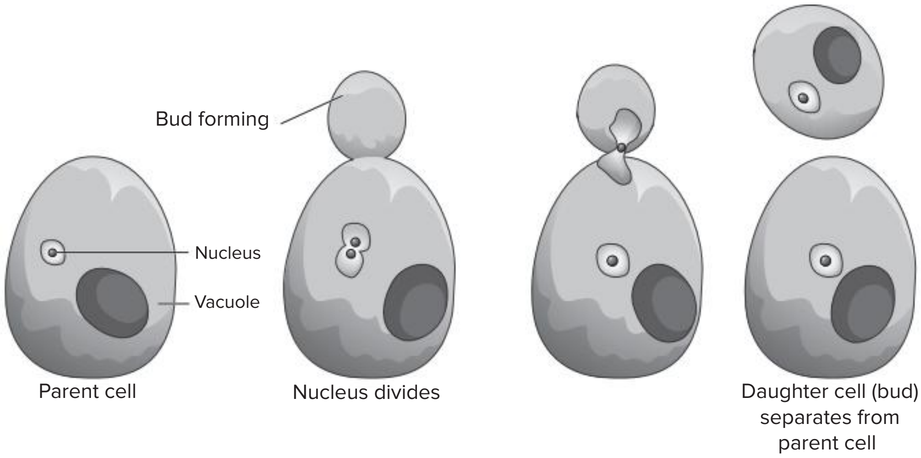


Figure 1.16: Budding in yeast

There are disadvantages and advantages to producing offspring through asexual reproduction (Table 1.8).

Table 1.8: Disadvantages and advantages of asexual reproduction

Advantages	Disadvantages
Efficiency – no need to find a mate, which saves time and energy	Lack of genetic diversity – makes the species vulnerable to diseases and environmental changes
Rapid reproduction – can produce more offspring	Limited evolution – slower adaptation to changing environments

Activity 1.10.1

1. Describe two ways that new organisms can produce asexually. Draw a labelled diagram for both.
2. What are the advantages of asexual reproduction?

1.11 Sexual reproduction

Sexual reproduction involves specialised reproductive cells called sex cells, or gametes. It results in offspring that are genetically different from the parents.

In animals, the male sex cells (gametes) are sperm cells (sometimes called spermatozoa), and the female sex cells are egg cells (also called ova, singular ovum).

In plants, the male sex cells are pollen grains and the female sex cells are ovules.

Gametes contain half the genetic information of body cells, so when a male and female gamete combine, they produce a full set of DNA for the formation of offspring.

Sex cells are produced in specialised reproductive tissues called gonads. Gonads in animals and plants have different names:

- In animals, the male gonads are the testes and the female gonads are ovaries.
- In plants, the male gonads are anthers and the female gonads are ovaries.

Sexual reproduction involves fertilisation – the fusion of male and female gametes to form a zygote. Zygotes grow into embryos, which result in new individual organisms that are separate from the parent.

There are disadvantages and advantages to producing offspring through sexual reproduction (Table 1.9).

Table 1.9: Disadvantages and advantages of sexual reproduction

Advantages	Disadvantages
Genetic diversity – offspring have unique genetic combinations, improving adaptability	Time consuming – finding a mate and producing offspring takes time
Disease resistance – genetic variation reduces susceptibility to disease	Limited reproduction – few offspring are produced compared to asexual reproduction

Most species reproduce sexually, even though there are some major disadvantages. However, the two advantages are extremely beneficial for survival and continuation of the species.

Activity 1.11.1

1. Define 'sexual reproduction'.
2. State the names of the sex cells in animals and plants (male and female).
3. Explain why gametes contain only half the genetic information of body cells.
4. Explain where sex cells are produced in animals and plants (male and females).
5. What are the disadvantages of sexual reproduction?

1.12 Animal reproductive systems

Reproduction in animals varies widely between different animal groups. Factors that differ include:

- where fertilisation occurs
- where development of the embryo occurs
- the length of the **gestation period**
- the number of offspring produced
- the time and effort involved in raising offspring.

Key term

gestation period	the period of time between conception and birth

Fertilisation can take place internally or externally:

- **Internal fertilisation** involves the fusion of eggs and sperm inside the body. Internal fertilisation occurs in terrestrial animals such as mammals, birds and reptiles.
- **External fertilisation** involves the fusion of eggs and sperm outside the body. This mainly occurs in aquatic animals such as fish, amphibians and crustaceans.

The embryo can develop internally or externally:

- **Internal development** of embryos occurs inside the body.
- **External development** of embryos occurs outside the body – external fertilisation is followed by external development.

Internal fertilisation is followed by internal or external development or a combination of both.

Most mammals and some reptiles fertilise and develop internally, followed by birth when the offspring separates from the mother.

Marsupials such as kangaroos and koalas develop internally and externally. They are born in early development. The newborn attaches to the mother's teat and stays there for several weeks before detaching.

Birds and most reptiles fertilise internally and develop externally. After fertilisation, these animals lay eggs and the young develop inside the eggs before hatching.

Generally, the more complex the organism is, the longer the gestation period, the more parental care is required and the fewer offspring they have because of the time and energy required to raise them.

The human reproductive system

The human reproductive system produces gametes. Gametes have half the amount of genetic material of body cells. In humans, these gametes are ova (eggs) and spermatozoa (sperm). Sperm is produced in the testes. Eggs are produced in the ovaries. Figure 1.17 shows the male and female reproductive systems.

A female with a **uterus** produces eggs in her **ovaries**. The eggs are released roughly once a month, from the age of menstruation to the age of menopause.

For offspring to develop, the egg must combine with spermatozoa. This happens in the **fallopian tubes**. If the egg is fertilised, it moves along the fallopian tube and into the uterus. The fertilised egg then implants into the **uterine wall** where it develops from a foetus to a baby over about nine months.

The mother's body forms a large organ called a **placenta**. This is attached to the uterus and the mother's blood supply. It provides oxygen and nutrients to the growing baby and removes waste.

If the egg is not fertilised, it will not implant into the uterus. The egg and the uterine lining will be expelled from the **vagina**, which is what happens when a woman has a period.

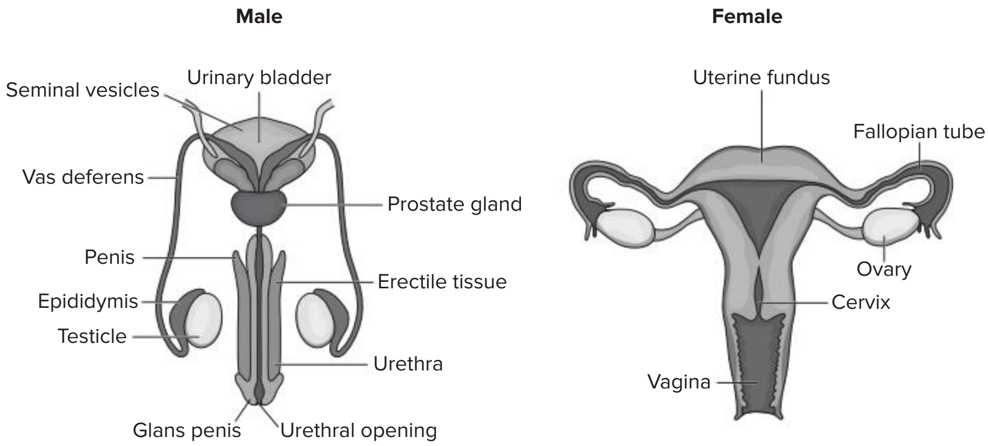


Figure 1.17: The male and female reproductive organs

A male with a penis will produce spermatozoa (sperm) in the testes. The sperm travels through the epididymis to mature and then continues through to the vas deferens. The sperm combines with fluid from the seminal vesicles before exiting the penis via the urethra. The mature sperm can then fertilise an egg.

Activity 1.12.1

1. Summarise the process of human reproduction and the parts of the reproductive system involved. Complete separate summaries for male and female reproductive systems.
2. Draw and label diagrams of the female and male reproductive systems.

1.13 Plant reproductive systems

Most plants reproduce sexually. This includes flowering plants, conifers (cones for reproduction), ferns and mosses (spores for reproduction). There are also plants that produce asexually, by self-fertilisation or vegetative means.

Sexual reproduction in flowering plants

Flowering plants, also known as angiosperms, have their reproductive components in their flowers (Figure 1.18). Flowering plants are a very large and diverse group, so there is an enormous range of flower structures.

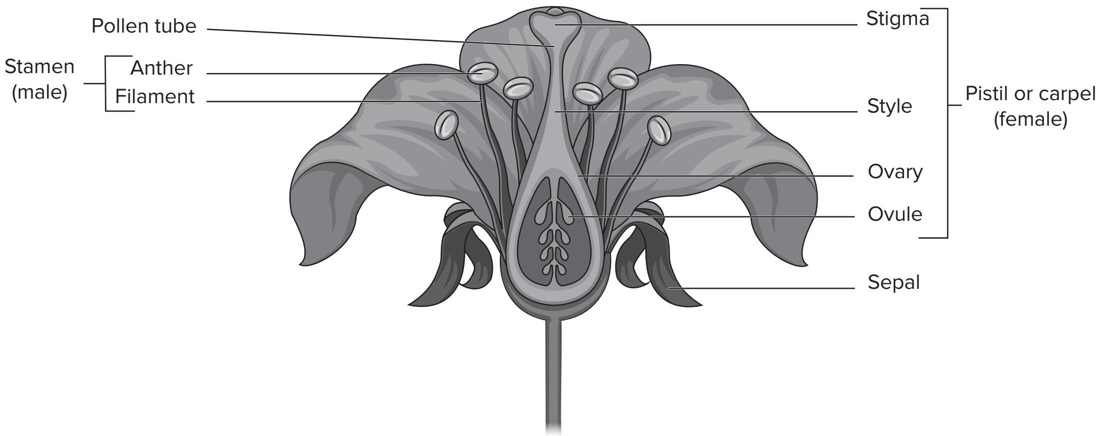


Figure 1.18: Parts of a flower

Male reproductive part (stamen)

The stamen produces pollen (male gametes). It consists of the:

- **anther** – produces and stores pollen; contains pollen sacs where male gametes are formed
- **filament** – a stalk that supports the anther; positions the anther for efficient pollen dispersal.

Female reproductive part (carpel or pistil)

The carpel, or pistil, produces eggs and houses the seeds. It consists of the:

- **stigma** – the sticky top where pollen grains land during pollination
- **style** – a tube-like structure that connects the stigma to the ovary; allows pollen to travel to the ovary

- **ovary** – contains ovules (female gametes); develops into a fruit after fertilisation
- **ovule** – located inside the ovary; contains the egg cell; develops into seeds after fertilisation.

Pollination and fertilisation

The steps involved in the fertilisation of flowering plants are shown in Figure 1.19. These steps are:

- A pollen grain is transferred from the anther to the stigma by wind, bees, insects and other animals.
- The pollen grain develops a long tube called a pollen tube that extends down through the style into the ovary.
- Fertilisation of an ovule occurs.
- The fertilised ovule develops into a seed. The seed contains the embryo of the new plant as well as stored food.
- At the same time, the surrounding ovary develops into a fruit.

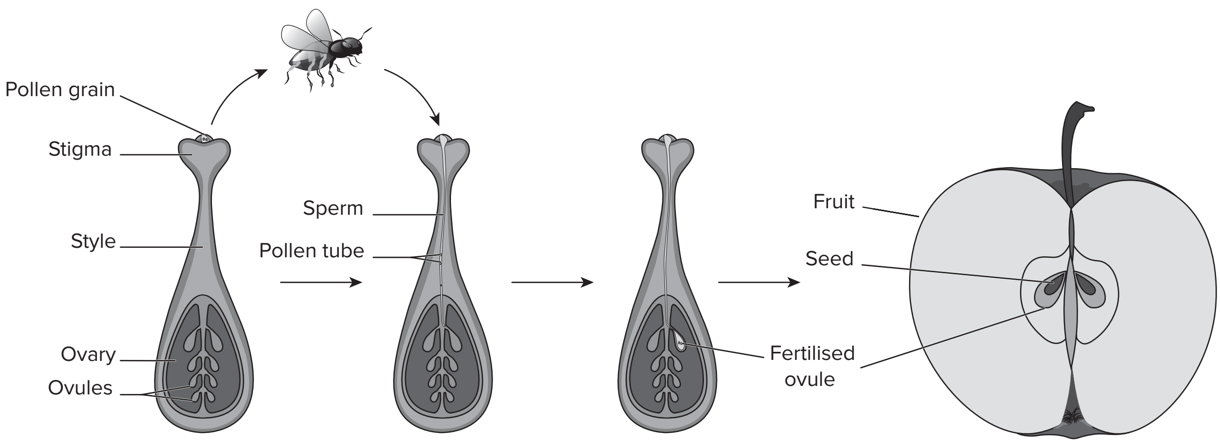


Figure 1.19: The steps in the fertilisation of flowering plants

Some plants self-pollinate, but most rely on birds, bees and other insects to transport pollen from nearby flowers to fertilise the eggs. Bees are very important because they play a vital role in plant reproduction, including the production of fruits and vegetables for us and other animals to eat.

Activity 1.13.1

1. Summarise the process of reproduction in flowering plants, including naming the parts of the reproductive system.
2. Draw and label the parts of a flowering plant. Colour code the male and female parts.
3. Draw and label a diagram of the process of pollination and fertilisation of a flowering plant.

Science as a human endeavour: Reproductive technologies for humans

Reproductive technologies are medical procedures that help individuals and couples conceive children when natural conception is not possible or very difficult. These technologies work by handling eggs, sperm or embryos to aid reproduction.

In 1978, the birth of the first baby conceived by in-vitro fertilisation (IVF) occurred. The birth of Louise Brown in the UK was a major milestone in reproductive medicine.

Advancements and the development of techniques such as embryo freezing, egg freezing and intracytoplasmic sperm injection has made reproductive technologies more accessible.

Reproductive technologies include:

- IVF – eggs are fertilised with sperm outside the body in a laboratory; a fertilised egg (embryo) is implanted into the uterus
- intracytoplasmic sperm injection – a single sperm is injected into an egg
- egg and sperm freezing (cryopreservation) – eggs and sperm are frozen and stored for future use.

Reproductive technologies have become more widely used because of:

- rising infertility rates due to lifestyle factors, delayed parenthood and health conditions
- social changes such as acceptance of diverse family structures (e.g. single parents, same-sex couples)
- advancements in science – improved success rates because of advances in medical technology.

The benefits include:

- overcoming infertility – providing solutions for couples unable to conceive naturally
- genetic screening – preimplantation genetic testing to identify potential genetic disorders
- options for diverse families – helping single parents and LGBTIQA+ couples have biological children
- postponing parenthood – egg or sperm freezing allows individuals to delay having children.

Science as a human endeavour: Reproductive technologies in farming

In farming, reproductive technologies are used to enhance animal and plant reproduction. These technologies help increase productivity, improve genetic quality and meet the growing demand for food.

Table 1.10: Reproductive technologies in farming

Reproductive technology	Description	Applications	Advantages and disadvantages
Artificial insemination (AI)	Semen from a selected male animal is collected and manually inserted into a female's reproductive tract.	Widely used in cattle, pigs, sheep and poultry farming	Advantages: • allows farmers to use semen from males with desirable genes across a large population • cost-effective compared to natural breeding • reduces disease transmission • increases genetic diversity.

Table 1.10: Reproductive technologies in farming (continued)

Reproductive technology	Description	Applications	Advantages and disadvantages
Embryo transfer	Fertilised embryos from a female with desired genes are transferred into surrogate females.	Widely used in cattle and sheep farming	Advantages: • allows high-value females to produce more offspring than they could naturally • accelerates genetic improvement • maximises the reproductive potential of animals with favoured traits.
Cloning	Genetically identical copies of an animal or a plant are produced.	Used to replicate high-yield livestock or disease-resistant crops Dolly the sheep was the first cloned mammal.	Advantages: • preserves desirable traits • produces consistent quality in livestock and crops. Disadvantages: • ethical concerns and high costs • reduces genetic diversity.
In-vitro fertilisation (IVF)	Eggs are fertilised by sperm outside the body, and the embryos are implanted into females.	Used in cattle farming to produce offspring from high-value animals	Advantages: • increases the chances of successful reproduction • can be used with cryopreserved (frozen) embryos.
Genetic engineering	The genetic material of an organism is altered to introduce desirable traits.	Used to produce genetically modified organisms (GMOs); e.g. pest-resistant and drought-resistant crops Used to create livestock with faster growth or better disease resistance	Advantages: • improves productivity and sustainability • reduces the need for chemical pesticides or antibiotics.
Sex-sorting technology	Sperm cells are separated according to whether they carry X or Y chromosomes to produce male or female offspring as desired.	Used in dairy farming to produce more female cows (for milk production)	Advantages: • helps target specific production goals (e.g. milk or meat) • reduces the production of unwanted offspring.

Reproductive technologies have revolutionised agriculture by improving productivity, genetic quality and efficiency. However, they must be used responsibly.

Chapter 2 – Earth and space

2.1 Earth's spheres

Imagine you are an astronaut looking down at Earth from space. What do you see? What do you feel? Earth is an amazing place with millions of diverse living and non-living things interacting with each other.

Earth can be thought of as being made up of four interconnected systems, known as Earth's spheres (Figure 2.1). In the same way that the human body is made up of systems that work together, all Earth's spheres are linked, and each one is necessary to keep Earth in balance.

The spheres interact continuously and play a critical role in supporting life and shaping the planet's environment. They are dynamic (changing) and interdependent, meaning a change within one sphere causes a change in another.

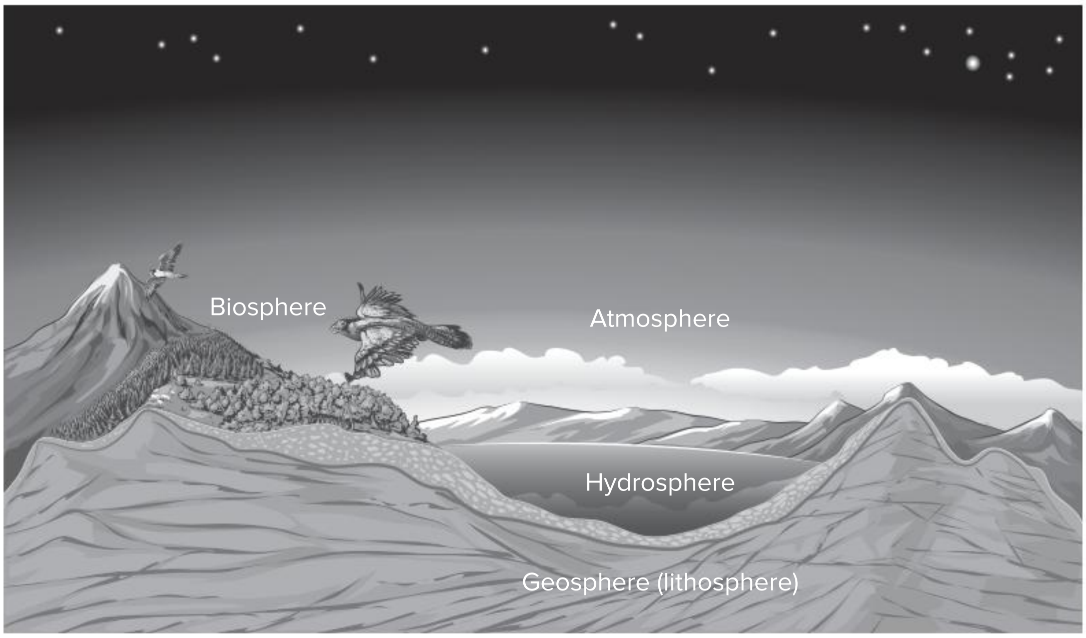


Figure 2.1: Earth's spheres are interconnected.

Activity 2.1.1

List Earth's spheres and explain why we can compare them to the systems of the human body.

Geosphere (lithosphere)

The geosphere, sometimes called the lithosphere, consists of Earth's crust, mantle and core. All of Earth's landforms – mountains, valleys, plains, plateaus and canyons – are part of the geosphere as well as the ocean floor. The geosphere includes molten rock (magma) and molten metals under Earth's surface and all the rocks, soil, sand and sediments on the crust.

Recall from Year 8 that the following processes occur in the geosphere:

- Plate tectonics – movement of Earth's plates causes earthquakes, volcanoes and mountain building.
- The rock cycle – the process through which the three main types of rocks (igneous, metamorphic and sedimentary) transform from one type into another.
- Erosion and weathering – rocks and minerals break down into smaller pieces by chemical and physical interactions with air, water and organisms.

Hydrosphere

The hydrosphere consists of all the water on Earth in all its different forms (solids, liquids and gases). Water exists as oceans, seas, rivers, lakes, glaciers and the polar ice caps and underground as groundwater, in wells and in aquifers.

Salt water makes up 97.5 per cent of Earth's water. Of the 2.5 per cent that is fresh water, most of it is frozen in the polar caps. The frozen part of the hydrosphere has its own name, the cryosphere. Less than 0.5 per cent of Earth's fresh water is available for human consumption.

Water is essential for life. We need water for drinking, for agriculture and for ecosystems to thrive. The hydrosphere regulates climate through heat distribution (e.g. in ocean currents).

Water moves through the hydrosphere in a cycle. The **water cycle** moves water between the different parts of the hydrosphere such as the atmosphere, oceans and land (Figure 2.2). It includes the processes of evaporation, condensation, precipitation and run-off. Water collects in clouds, then falls to Earth in the form of rain or snow. This water collects in rivers, lakes and oceans, then evaporates into the atmosphere to start the cycle all over again. The global water cycle is driven by sunlight and gravity.

Water also circulates in oceans – 71 per cent of Earth's surface is ocean. Oceans are constantly in motion. When large masses of water move together (ocean currents), they transport heat, nutrients, dissolved gases (including carbon dioxide and oxygen), marine organisms and pollutants all over the world. Climate and ecosystems are affected by ocean circulation even far away from the ocean.

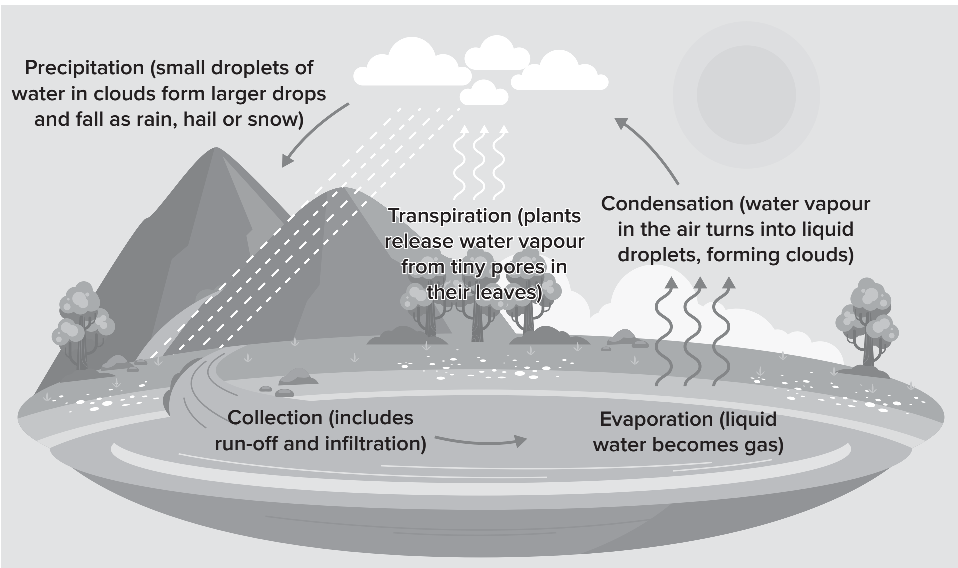


Figure 2.2: The water cycle is driven by sunlight and gravity.

Biosphere

The biosphere includes all organisms on Earth – all animals (e.g. humans), plants, fungi and microorganisms (e.g. bacteria). It is the collection of all Earth's lifeforms, distributed in major life zones called biomes. These include tundra, rainforests, deserts, marine, fresh water, grassland and temperate forest.

The biosphere relies on the atmosphere, hydrosphere and geosphere. It provides food and materials for life while supporting biodiversity and ecological balance.

The following processes occur in the biosphere:

- Photosynthesis – the process of using sunlight to convert carbon dioxide (a greenhouse gas) from the atmosphere and water into food. Photosynthesising organisms such as plants, algae and bacteria provide most of the chemical energy that flows through the biosphere. They also produced most of the **biomass** that led to the **fossil fuels** that power much of our modern world.
- Respiration (cellular respiration) – the process organisms use to release energy from food. As you learned in Year 8, cellular respiration is chemically the reverse of photosynthesis because it releases energy.
- Evolution – the change in characteristics of a population of organisms over time.

Key terms

biomass	the organic materials from living or recently living organisms such as plants, animals and microorganisms
fossil fuels	fuels formed from the burial of photosynthetic organisms, including plants on land (which form coal) and plankton in the oceans (which form oil and natural gas)

Atmosphere

The atmosphere is the layer of gases surrounding Earth. The gases include nitrogen (78 per cent of the atmosphere), oxygen, which is essential for all life (a little less than 21 per cent), argon (almost 1 per cent), tiny amounts of carbon dioxide, water vapour and trace amounts of other gases.

The atmosphere stretches from the surface of Earth up to as far as 10 000 km into space. Most of Earth's atmosphere is in the first 10 km.

Table 2.1 lists the layers of the atmosphere.

Table 2.1: The layers of the atmosphere

Height (km)	Layer	Description
0–20	Troposphere	Weather occurs here; temperature decreases with altitude
20–50	Stratosphere	Contains the ozone layer; temperature increases with altitude
50–85	Mesosphere	Meteors burn up here; the coldest layer
85–600	Thermosphere	Satellites orbit here; auroras occur in this layer
600–10 000	Exosphere	Outer edge where the atmosphere merges into space

The following processes occur in the atmosphere:

- Atmospheric circulation – from the gentlest breeze to a category 5 cyclone, the atmosphere is constantly in motion. Atmospheric circulation, along with ocean circulation, distributes heat across the entire surface of Earth, bringing us our daily weather and shaping regional climates.
- The greenhouse effect – the natural warming of Earth that results when gases in the atmosphere trap heat from the Sun that would otherwise escape into space. Without greenhouse gases, much of Earth's heat would be lost to outer space. Life would not be possible without the greenhouse effect.

The function of the atmosphere is to:

- protect life from harmful solar radiation (e.g. ultraviolet rays)
- regulate Earth's temperature
- provide oxygen for cellular respiration and carbon dioxide for photosynthesis.

Fun facts

- The names of the four spheres are derived from the Greek words for earth (*geo*), air (*atmo*), water (*hydro*) and life (*bio*).
- The prefix 'cryo' – means 'icy cold' or 'frost'. It comes from a Greek word, *kryos*. Other words that have the prefix 'cryo' are cryogenics and cryobiology.

The four spheres interconnect and influence each other. For example, a cyclonic weather event (atmosphere) causes flooding (hydrosphere); this erodes land (geosphere) and displaces and/or damages animals and humans (biosphere).

Other examples of interactions between Earth's spheres include:

- Hydrosphere and atmosphere – water evaporates from the hydrosphere, forming clouds and rain in the atmosphere.
- Biosphere and atmosphere – plants in the biosphere use carbon dioxide from the atmosphere for photosynthesis, and release oxygen.
- Hydrosphere and geosphere – water from the hydrosphere shapes the geosphere when it forms rivers, oceans and streams.
- Atmosphere and geosphere – wind from the atmosphere erodes rocks in the geosphere.
- Biosphere and hydrosphere – animals in the biosphere drink water from bodies of water that are formed by rainfall from the hydrosphere.
- Hydrosphere and geosphere – plants absorb water from the biosphere and minerals from the soil (geosphere).

Humans have a huge impact on Earth's spheres. People are often responsible for events that have a negative effect on the spheres. Think about an oil spill or air pollution that is caused by humans. Which of Earth's spheres do these events affect?

Activity 2.1.2

1. Draw four large circles and label each as a different Earth sphere. Within each circle, draw and label processes and functions of that sphere.

2. List four interactions between Earth's spheres that are different from the examples you included in question 1.

2.2 The carbon cycle

Carbon is an essential element for all life on Earth. It is a key component of molecules such as carbohydrates, proteins and DNA. Carbon compounds regulate Earth's temperature, make up our food and provide energy that fuels our global economy.

The carbon cycle describes the movement of carbon through Earth's spheres. It ensures that carbon is recycled and available for all organisms.

The carbon cycle is important for the following reasons:

- Climate regulation – the carbon cycle balances carbon dioxide (CO_2) levels, helping to regulate Earth's temperature.
- Ecosystem support – the carbon cycle provides carbon for photosynthesis, which is the foundation of most food chains.
- Carbon storage – the carbon cycle prevents excessive carbon dioxide (CO_2) in the atmosphere by **sequestering** carbon by storing it in **carbon sinks** such as oceans, rocks and fossil fuels. A carbon sink is a system that absorbs more carbon than it releases.

Key terms

carbon sequestering	the process of storing carbon in carbon sinks
carbon sink	a natural reservoir that absorbs and stores carbon; e.g. forests and oceans

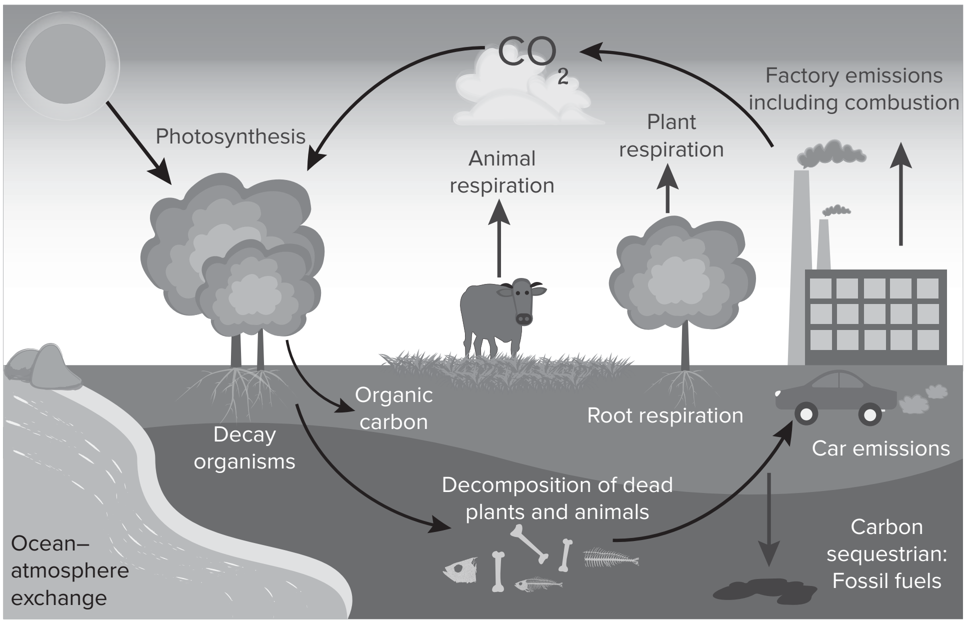


Figure 2.3: The carbon cycle

In Figure 2.3, you can see the car and factory emissions. Humans have had a huge impact on the carbon cycle through:

- burning fossil fuels for electricity, industry and car use (combustion). This adds large amounts of CO_2 into the atmosphere, contributing to the greenhouse effect and global warming.
- deforestation, which reduces the number of trees available to absorb CO_2 during photosynthesis.

Table 2.2 lists the key processes of the carbon cycle.

Table 2.2: Key processes of the carbon cycle

Process	Description
Photosynthesis	• Plants, algae and some bacteria absorb carbon dioxide (CO_2) from the atmosphere. • They use sunlight, water and CO_2 to produce glucose ($C_6H_{12}O_6$) and oxygen (O_2). • Equation: $6CO_2 + 6H_2O \xrightarrow{\text{sunlight}} C_6H_{12}O_6 + 6O_2$
Respiration	• All organisms (plants, animals, microorganisms) release CO_2 back into the atmosphere by breaking down glucose for energy. • Equation: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy
Decomposition	• When plants and animals die, decomposers (bacteria and fungi) break down their remains. • This releases carbon into the soil as organic matter or as CO_2 into the atmosphere.
Combustion	• Burning fossil fuels (coal, oil, natural gas) releases stored carbon into the atmosphere as CO_2. Fossil fuels are often burned to power human activities, such as driving cars and manufacturing goods.
Carbon sequestration	• Over millions of years, dead organisms can be compressed under layers of sediment to form fossil fuels. • Carbon can also be stored in limestone and other sedimentary rocks.
Ocean–atmosphere exchange	• Oceans absorb CO_2 from the atmosphere and re-release it in a balanced exchange. • CO_2 dissolves in seawater to form carbonic acid (H_2CO_3), affecting ocean pH levels.

Activity 2.2.1

1. Define the 'carbon cycle' and list its key processes.
2. Draw a diagram of the carbon cycle and label the following:
   - CO_2 into the atmosphere (combustion)
   - arrows pointing to plants (photosynthesis)
   - arrows from plants and animals to the atmosphere (respiration)
   - arrows from fossil fuels to the atmosphere (combustion)
   - arrows from dead organisms to the soil (decomposition)
   - arrows to and from the ocean (ocean–atmosphere exchange).

2.3 Combustion reactions

Combustion is an exothermic (releases energy) chemical reaction that occurs when fuel, oxygen and heat combine.

The burning of fossil fuels is a combustion reaction. Burning fossil fuels has dramatically increased the exchange of carbon from the ground back into the atmosphere and oceans. This return of carbon to the atmosphere as CO_2 is occurring at a rate that is hundreds to thousands of times faster than it took to bury it (decompose through the process of decomposition), and much faster than it can be removed by photosynthesis and other natural methods such as weathering.

The CO_2 released from the burning of fossil fuels is accumulating in the atmosphere, increasing average temperatures and causing ocean acidification.

Greenhouse effect

The natural greenhouse effect is a good thing! Without it, Earth would not be habitable. The greenhouse effect warms Earth to temperatures that make life possible.

However, burning fossils fuels for energy is artificially increasing the natural greenhouse effect. This results in an increase in global warming. This alters Earth's climate system and affects Earth's spheres.

The greenhouse effect occurs in the following steps:

- The Sun emits energy in the form of sunlight that reaches Earth (solar radiation).
- Earth's surface absorbs some of this energy and radiates it back as heat (infrared radiation).
- Greenhouse gases in the atmosphere trap some of this heat, preventing it from escaping into space, keeping Earth warm.

Table 2.3 lists some key greenhouse gases.

Table 2.3: Greenhouse gases and where they come from

Greenhouse gas	Source
Carbon dioxide (CO_2)	Released from burning fossil fuels (coal, oil, gas) and deforestation
Methane (CH_4)	Released from agricultural activities (e.g. cattle farming), rice paddies and decaying organic waste
Nitrous oxide (N_2O)	Emitted from agricultural and industrial activities, as well as the combustion of fossil fuels
Water vapour	Evaporates from water bodies, the most abundant greenhouse gas, which amplifies the effect of other gases
Fluorinated gases	Emitted by industry, includes synthetic gases such as chlorofluorocarbons (CFCs)

Higher concentrations of greenhouse gases, in particular CO_2, are causing Earth's average surface temperature to rise. This is called global warming.

Activity 2.3.1

1. Define 'combustion reaction' and explain how it is linked to greenhouse gases.
2. Explain how the greenhouse effect works.
3. List the key greenhouse gases.
4. Describe why higher concentrations of greenhouse gases is an issue.

2.4 Global warming

Global warming refers to the increase in Earth's average surface temperature due to the enhanced greenhouse effect caused by human activities.

Global warming is caused by:

- burning fossil fuels for electricity generation and transportation – releases large amounts of CO_2
- deforestation – reduces the number of trees that absorb CO_2
- agriculture – produces methane and nitrous oxide
- industrial processes – emit greenhouse gases such as chlorofluorocarbons (CFCs) and fluorinated gases.

For much of the past 800 000 years, the concentration of CO_2 in the atmosphere was about 200–280 parts per million. Put simply, there were 200–280 molecules of CO_2 per million molecules of air.

In the past century, the concentration of CO_2 has increased. In 2022, measurements at the Mauna Loa Atmospheric Baseline Observatory in Hawaii showed that CO_2 concentrations peaked at 421 parts per million.

Global warming causes:

- climate change – changes in weather patterns lead to more extreme weather events including cyclones, droughts, bushfires and floods
- rising sea levels – melting ice caps and glaciers contribute to higher sea levels, threatening coastal areas
- ecosystem disruption – changes in habitats affect wildlife, potentially causing species to become extinct
- impacts on human health – through heatwaves, and food and water insecurity
- ocean acidification – excess CO_2 dissolves in oceans, harming marine life such as coral reefs.

As a society, we can help mitigate global warming. Some ways in which we can do this are outlined in Table 2.4 on the next page.

Table 2.4: How we can mitigate global warming

Strategy	Description
Reduction of greenhouse gas emissions	• Use renewable energy sources (solar, wind, hydroelectric) • Improve energy efficiency in buildings and transportation • Transition to electric vehicles and public transport
Reforestation and **afforestation**	• Plant trees to absorb CO_2 from the atmosphere
Carbon capture and storage/ sequestration (CCS)	• Capture CO_2 emissions and store them underground
Use sustainable practices	• Consume less • Reduce waste and recycle materials • Support sustainable agriculture and dietary changes, such as reduced meat consumption
International agreements	• For example, the Paris Agreement is a global pact to limit global warming to well below 2°C above pre-industrial levels, with efforts to limit it to 1.5°C.

Key term

afforestation	the process of planting trees in an area that was previously not forested

Activity 2.4.1

1. Define 'global warming' and explain how it has occurred.
2. List the effects on Earth of global warming.
3. Create a mind map of all the ways we can mitigate global warming.

2.5 Carbon sequestration

Carbon sequestration is the process of capturing, securing and storing CO_2 from the atmosphere. The goal is to reduce the amount of CO_2 in the atmosphere and slow climate change. The process shows tremendous promise for reducing the human 'carbon footprint'.

There are two main types of carbon sequestration: biological and geological.

Biological carbon sequestration

Biological carbon sequestration is the storage of CO_2 within ecosystems: in vegetation such as grasslands and forests, as well as in soils and oceans. It is a natural process that helps regulate the carbon cycle and mitigate the effects of global warming. Some examples are shown in Table 2.5.

Table 2.5: Examples of biological carbon sequestration

Process	Description
Photosynthesis	Plants absorb CO_2 from the atmosphere during photosynthesis and convert it into glucose ($C_6H_{12}O_6$), which is used for growth.
Carbon storage in biomass	Trees absorb CO_2 from the air and store it in their biomass (branches, trucks, leaves, roots etc.).
Soil carbon sequestration	Organic matter from decayed plants and animals increases carbon storage in soils.
Marine carbon sequestration	Oceans absorb CO_2 directly from the atmosphere. Marine organisms, such as plankton, also play a role in sequestering carbon.

Biological carbon sequestration is affected by:

- the type of ecosystem because different ecosystems (e.g. forests, wetlands and grasslands) store carbon differently
- the type of plant species because fast-growing species (e.g. bamboo) sequester carbon quickly
- human activities because land use can reduce sequestration capacity.

Carbon storage in biomass

We can mitigate climate change by reducing greenhouse gases, reforestation and afforestation. By planting more trees, we can reduce greenhouse gases in the atmosphere.

Scientists use formulas to calculate the approximate carbon storage of trees. The formulas use the terms:

- above-ground biomass (AGB) – biomass stored in the parts of the plant above the ground (e.g. trunk, branches, leaves)
- diameter at breast height (DBH) (cm), usually at 1.3 m above the ground

  $AGB (kg) = 0.0673 \times (DBH)^{2.6}$
- below-ground biomass (BGB) – biomass stored in roots

  $BGB = 0.2 \times AGB$
- carbon content in biomass – about 50 per cent of the biomass is carbon.

  $Carbon\ storage\ (kg) = (AGB + BGB) \times 0.5$

Geological carbon sequestration

Geological carbon sequestration is the process of storing CO_2 in underground geologic formations or rocks. Typically, CO_2 is captured from an industrial source – such as steel or cement production, a power plant or natural gas processing facility – and injected into porous rocks for long-term storage.

Geological carbon sequestration can occur at:

- power plants, which use equipment to capture and store CO_2 to prevent it from being released into the atmosphere
- factories, which capture CO_2 at the source, such as in steel or cement production and then inject it into porous rocks for long-term storage.

Carbon sequestration is important for reducing atmospheric CO_2 and helps to enhance biodiversity and soil fertility.

Activity 2.5.1

1. Define 'biological carbon sequestration' and provide examples. You can add diagrams to help you to remember.
2. Define 'geological carbon sequestration' and provide examples. You can add diagrams to help you to remember.

2.6 First Nations peoples and climate change

Reducing Australia's greenhouse emissions through traditional fire-management regimes

As climate change continues to exacerbate natural disasters such as bushfires, the value of First Nations peoples' knowledge and practice of using fire to manage the Australian bush is becoming increasingly recognised. First Nations peoples set small, low-intensity fires (called 'cool burns') early in the dry season to clear the underbrush that provides much of the fuel for bushfires.

Cool burn fires are set by people on foot, using matches or fire sticks. The fires are closely monitored to ensure that only the underbrush is burned. Cool burns ensure that seeds and nutrients in the soil are not destroyed.

When this traditional knowledge and practice is not applied, bushfires in Australia tend to be larger and more destructive. Bushfires have devastating effects on ecosystems and release huge volumes of greenhouse gases into the atmosphere.

The benefits of cool burns include:

- reducing greenhouse gas emissions – smaller bushfires mean less greenhouse gases
- sequestering carbon – more carbon is stored in the soil
- supporting First Nations communities – First Nations cultures and communities are strengthened and jobs are created for First Nations land managers.

2.7 Carbon footprint and reducing emissions

The carbon footprint measures the total greenhouse gases (mainly CO_2) emitted by an activity, product or individual, expressed as CO_2 equivalent (CO_2e):

$$\text{Carbon footprint} = \text{activity level} \times \text{emission factor}$$

where activity level could be kilometres driven, electricity used or food consumed, and emission factor is the amount of CO_2e released per unit of activity (e.g. kg CO_2e per kWh of electricity).

Example calculation

A car emits 0.2 kg of CO_2 per kilometre. If you drive 500 km:

Carbon footprint = 500 km × 0.2 kg CO_2/km = 100 kg CO_2

Human activities that release carbon emissions include:

- burning fossil fuels for electricity and heat – the largest source of carbon dioxide emissions
- using cars, planes and ships, which burn fossil fuels
- cutting down trees, which releases absorbed carbon in the form of CO_2
- farming livestock, which produce methane, a potent greenhouse gas
- producing cement and steel, which releases significant amounts of CO_2.

Table 2.6 lists some strategies for reducing CO_2 emissions.

Table 2.6: Strategies to reduce CO_2 emissions

Strategy	Description
Switch to renewable energy	• Use solar, wind, hydro and geothermal energy instead of coal and gas • Install solar panels if possible
Energy efficiency	• Use energy-efficient appliances and LED lighting • Improve insulation to reduce heating and cooling needs
Transportation changes	• Drive less by carpooling, walking, cycling or using public transport • Transition to electric or hybrid vehicles
Reforestation and conservation	• Plant trees to absorb CO_2 from the atmosphere • Protect forests to maintain their carbon storage capacity
Waste reduction	• Reduce, reuse and recycle to minimise waste sent to landfills, which emit methane • Compost organic waste
Dietary changes	• Reduce meat and dairy consumption because livestock farming is a major source of greenhouse gases • Choose locally grown and seasonal food to reduce transport emissions
Carbon capture technology (CCS)	• Support research and deployment of CCS technologies • Encourage companies to adopt CCS in industrial processes

Understanding how CO_2 is captured, stored and reduced helps combat global warming. Reducing individual and collective carbon footprints through lifestyle changes, technological innovation and international cooperation is essential for a sustainable future.

Activity 2.7.1

1. Define 'carbon footprint'.
2. Create a mind map showing the human activities that release carbon emissions.
3. Create a small poster with words and diagrams, showing strategies to reduce CO_2 emissions.

Science as a human endeavour: Government initiatives supporting land restoration practices

Case study – Landcare Australia

Landcare is an Australian community-based not-for-profit organisation that was established 35 years ago. It encourages individuals, groups and organisations to take action to improve the health of the environment. It focuses on sustainable land management, conservation and the restoration of ecosystems.

Landcare's vision is 'All Australians actively caring for the land and water that sustains us'.

Landcare supports:

- educating landowners and farmers about sustainable land management and the management of water resources
- protecting native plants, animals and habitats to enhance biodiversity
- practices that increase soil fertility and reduce erosion
- practices that store more carbon in soil and vegetation, reducing greenhouse gases in the atmosphere through carbon sequestration.

Landcare supports the restoration of land by providing financial support through funding and grants to help landowners restore their land. Landcare conducts workshops and training sessions on sustainable farming techniques and soil health, bringing the community together to work in collaboration with farmers, scientists, volunteers and researchers.

Land restoration practices include the following:

- Reforestation and afforestation – planting trees and shrubs to stabilise soil, reduce erosion and increase carbon storage. Trees absorb CO_2 during photosynthesis, storing it in biomass.
- Improved pasture management – rotational grazing to prevent overgrazing and allow vegetation to recover. Healthy pastures increase organic matter in the soil, improving carbon storage.
- No-till farming – reduces soil disturbance, preserving soil structure and organic matter. Prevents CO_2 release from soil during ploughing.
- Cover cropping – planting crops such as clover and rye grass between harvests to prevent soil erosion and increase organic matter. Cover crops add nutrients to the soil and capture carbon.
- Soil amendments – adding organic materials such as compost, manure and biochar to improve soil fertility and increase carbon storage.
- Erosion control – techniques such as contour ploughing and constructing windbreaks reduce soil loss.

Landcare supports more than 6000 groups and 140 000 volunteers with land-care projects.

Chapter 3 – Physics

3.1 Energy review

Energy is all around us. Your computer works because of electrical energy, your food gets hot because of thermal energy, and you get energy from the food you eat so your body can move and function.

Energy is the ability to do work or cause change. 'To do work' means to perform an action.

Activity 3.1.1

Define 'energy'.

3.2 The law of conservation of energy

Energy exists in many forms and can be transferred or transformed but never created or destroyed. This is the **law of conservation of energy**. Keep this law in your mind as you read this chapter. It underpins how we understand energy in every aspect of science.

When you toast bread, you put the piece of bread into the toaster and the electrical energy is changed into heat energy, which cooks the bread. This shows the law in action. The energy was not created or destroyed, just transformed (or converted or changed).

Activity 3.2.1

Write the law of conservation of energy and add diagrams to help you to remember it.

3.3 Kinetic energy and potential energy

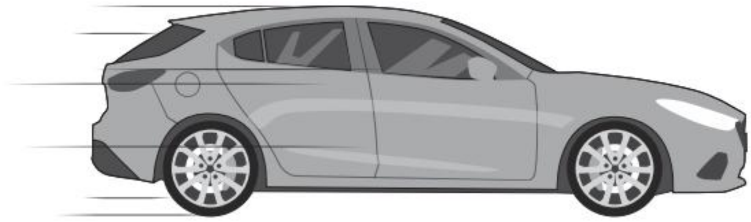
There are two main types of energy: kinetic energy and potential energy.

Kinetic energy

Kinetic energy is active energy. It includes any form of energy where work is being done. Kinetic energy involves movement, which could be the movement of whole objects or the movement of particles within objects or waves.

It is a form of energy that can be **directly used** and **measured**. Figure 3.1 shows some examples of kinetic energy.

Walking is a form of kinetic energy.



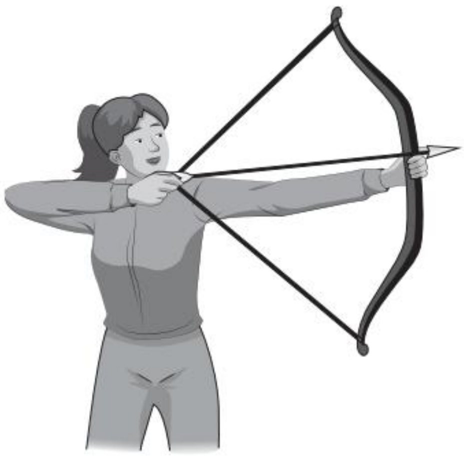
A moving car is kinetic energy.

Figure 3.1: Forms of kinetic energy

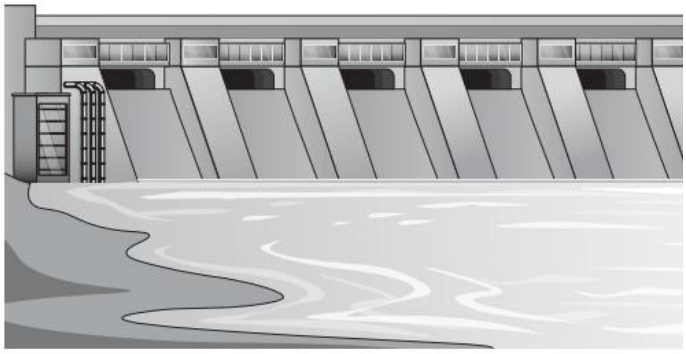
Potential energy

Potential energy is **inactive energy**. It includes any form of energy where work is not being done but the capacity to do work exists. Potential energy involves energy storage (Figure 3.2). It is a form of energy that is **not directly usable** or **measurable**.

Potential energy can only be used and measured when it is converted into kinetic energy.



A stretched bow and arrow is potential energy.



A dam wall holding back water is potential energy.

Figure 3.2: Forms of potential energy

Activity 3.3.1

Create a Venn diagram to compare kinetic energy and potential energy. You can add diagrams to help you to remember.

3.4 Types of energy

Some types of energy are more complicated than others to understand, so read the information in Table 3.1 a few times.

Table 3.1: Different types of energy

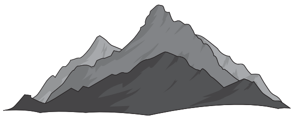
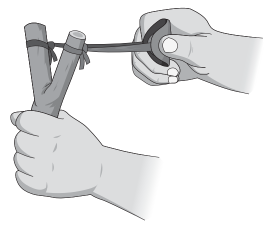
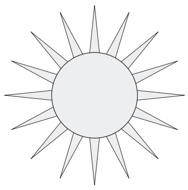
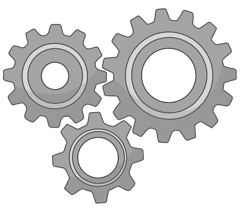
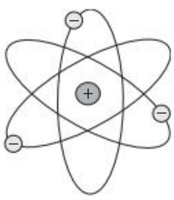
Energy	Description	Potential and/or kinetic	Example
Gravitational 	Gravitational energy is associated with gravity. It is the potential energy stored by an object because of its higher position compared to a lower position.	Potential	A ball sitting on top of a mountain has a higher gravitational potential energy than a ball sitting at sea level.
Elastic 	Elastic energy is energy stored in an object when there is a temporary strain on it, such as a stretched elastic band.	Potential	Stretching a rubber band gives it elastic potential energy as its shape temporarily changes and is strained.
Light 	Light energy is the energy of electromagnetic waves. These waves can travel through space.	Kinetic	Light energy can be visible waves such as light rays or invisible waves such as X-rays and radio waves.
Thermal 	Thermal energy (also called heat energy) is energy that comes from a substance whose molecules and atoms are vibrating faster because of a rise in temperature.	Kinetic	When you boil a pot of hot water, the flame makes the particles in the metal pot move faster. This makes the particles in the water move faster, heating it up to boiling point.
Mechanical 	Mechanical energy (sometimes called motion energy) is energy stored in moving objects.	Potential and kinetic	A moving car has mechanical energy due to its motion (kinetic energy).

Table 3.1: Different types of energy (continued)

Energy	Description	Potential and/or kinetic	Example
Electrical 	Electrical energy is caused by moving electric charges called electrons.	Potential and kinetic	Electricity is a type of energy that comes from electrical energy.
Chemical 	Chemical energy is energy that is stored in the bonds in chemical compounds, such as between atoms and molecules.	Potential and kinetic	Dry wood contains chemical energy. When the wood is burnt, the chemical energy is released and converted into thermal (heat) energy.
Sound 	Sound energy is the movement of energy through a substance such as air and is caused by vibrations. It moves through a substance in waves.	Potential and kinetic	Music is a form of sound energy. When the strings on a guitar are plucked, the strings vibrate and transmit energy.
Nuclear 	Nuclear energy is the energy released when an atomic nucleus splits apart (fission) or fuses with another nucleus (fusion). This process releases a huge amount of energy.	Potential and kinetic	An atomic bomb releases huge amounts of energy in the form of damaging electromagnetic radiation (gamma rays, X-rays). Nuclear energy has beneficial applications in medicine for cancer treatment and body scanning technologies.

The mind map in Figure 3.3 may help you to remember the different types of energy.

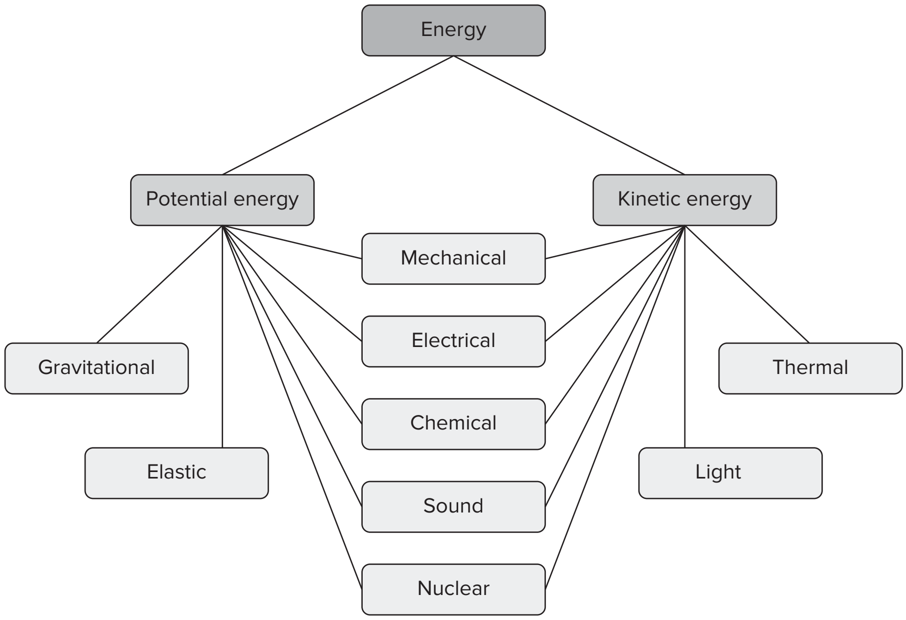


Figure 3.3: Types of energy

Activity 3.4.1

Using coloured markers, create a mind map of the different types of energy and their examples. You can add diagrams to help you remember.

Key point

Kinetic energy refers to the movement of something and this includes the movement of electrons in a circuit (electrical) and the movement of sound and light from one place to another.

3.5 Waves

Energy can travel from one place to another. Think about the heat and light that travels from the Sun to Earth or sounds from a distant road. This is due to energy travelling from a source (the Sun, the car on the road) and continues to travel forever unless there are objects or obstacles in the way. Different energy travels in different ways.

Waves are vibrations or **oscillations** that transfer energy from one place to another without transferring matter. They can travel through various **mediums** (air, water, solids) or even through a **vacuum** (space).

Key terms

oscillation	repeated movement back and forth
medium	a substance or material that energy travels through; can be solids, liquids, gases or vacuums
vacuum	a volume where no particles are present

There are two types of waves: mechanical waves and electromagnetic waves.

Mechanical waves

Mechanical waves are oscillations (vibrations) that require a medium to travel through. The oscillations involve movement of **particles** within the medium. Mechanical waves can travel through solids, liquids and gases, but cannot travel through a vacuum (where there are no particles, e.g. space).

Examples of mechanical waves are sound waves, seismic waves and water waves.

Mechanical waves need a disturbance of a medium. For example, striking a cymbal causes it to oscillate, which disturbs the surrounding air, transmitting a sound wave.

Electromagnetic waves

Electromagnetic waves are oscillations (vibrations) that do not require a medium to travel. The oscillations involve fluctuations in an **electromagnetic field**. Electromagnetic waves can travel through solids, liquids, gases and a vacuum (space).

Examples of electromagnetic waves are radio waves, microwaves, infrared radiation, visible light, UV (ultraviolet) radiation, X-rays and gamma rays.

Electromagnetic waves need a source that generates electromagnetic oscillations such as a radio transmitter, which is an electric device that produces radio waves by oscillating electrons in an antenna.

Activity 3.5.1

Create a Venn diagram to compare mechanical waves and electromagnetic waves. Include wave examples and diagrams.

3.6 Wave categories – types of wave motion

Waves can oscillate in different ways. There are three main types of wave motion – transverse waves, longitudinal waves and surface waves – and they have different ways of oscillating.

- In transverse waves, the particles oscillate up and down, which creates crests (high points) and troughs (low points) (Figure 3.4). Examples are all electromagnetic waves, seismic S waves and waves created by moving a rope up and down.

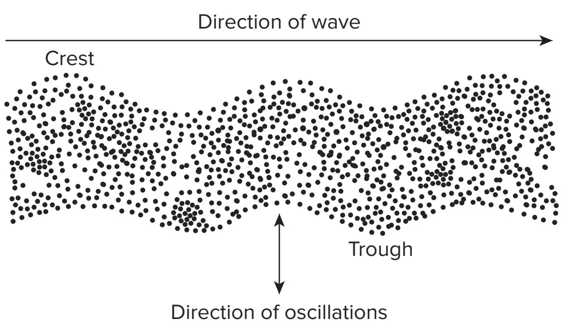


Figure 3.4: A transverse wave

- In longitudinal waves, the particles oscillate back and forth (Figure 3.5). There are areas where particles are very close to each other (compressions) and areas where particles are far apart from each other (rarefactions or expansions). Examples are sound waves and seismic P waves.

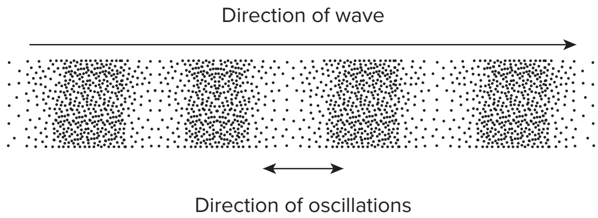


Figure 3.5: A longitudinal wave

- In surface waves, the particles oscillate in a circular motion (Figure 3.6). Surface waves are considered a hybrid of transverse and longitudinal waves. Surface waves occur at the interface of two different mediums. When you throw a stone into water, the ripples occur because you cause a disturbance on the water's surface, which travels from one point to another. Examples are waves in water and seismic surface waves.

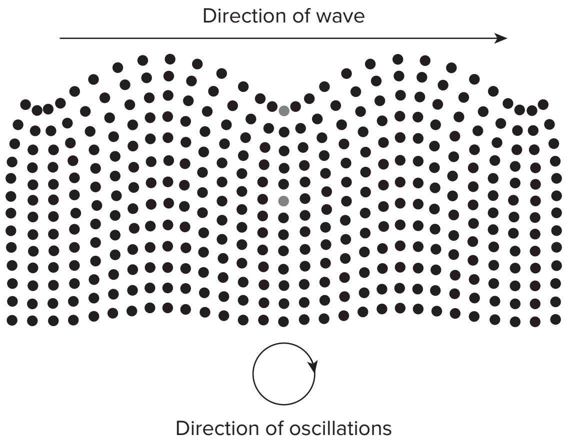


Figure 3.6: A surface wave

Fun facts

- Seismic waves are vibrations that occur during seismic activity such as earthquakes, volcanic eruptions and human-made explosives.
- Seismic P waves are also known as primary, or pressure, waves. P waves are the first waves to arrive after an earthquake and travel the fastest.
- Seismic S waves are also known as secondary, or shear, waves. S waves are the next waves to arrive after P waves and travel more slowly.

Activity 3.6.1

Explain each type of wave motion. Draw diagrams and include examples.

3.7 Properties of waves

Waves have the properties listed in Table 3.2; we use these properties to help us measure and understand waves.

Table 3.2: Properties of waves

Property	Description
Wavelength (λ)	• The distance between two corresponding points on a wave (e.g. crest to crest), i.e. the distance a wave travels during one cycle • Measured in metres (m)
Frequency (f)	• The number of wave cycles per second • Measured in hertz (Hz). 1 Hz = 1 cycle per second
Amplitude	• The height of a wave from the rest position, i.e. the distance between the central starting position and the maximum point of oscillation (crest or trough) • Indicates the energy of the wave (higher amplitude = more energy)
Velocity (v)	• How fast the wave travels • The velocity of both mechanical waves and electromagnetic waves depends on the medium they are travelling through. For example, sound waves travel through the air at 340 m s^{-1} and through water at 1500 m s^{-1}. Light waves travel through the air at 300 000 km s^{-1} and through water at 225 000 km s^{-1}. • $v = f \times \lambda$ (wave speed = frequency × wavelength) • Measured in metres per second (m s^{-1}) or km s^{-1}

Activity 3.7.1

Explain each property of waves that we can use to help us to measure and understand them.

Waves can be represented graphically as waveforms (Figure 3.7).

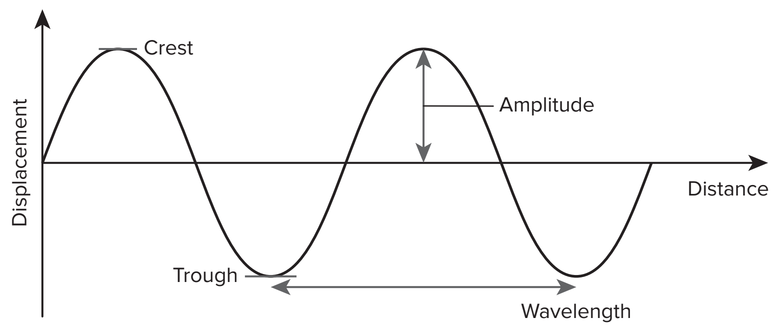


Figure 3.7: A waveform

Frequency and wavelength are inversely proportional. This means:

- the higher the frequency, the shorter the wavelength
- the lower the frequency, the longer the wavelength.

Amplitude does not affect frequency, wavelength or velocity.

Frequency (f), wavelength (λ) and velocity (v) are mathematically related: $v = f \times \lambda$

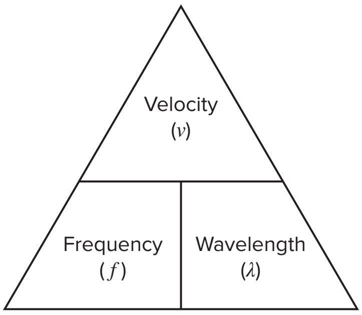


Figure 3.8: A formula triangle for the wave velocity equation. To use the triangle, cover the variable you want to find, and the remaining variables will give you the equation. For example, to find velocity (v), cover it and you'll see $f\lambda$. To find frequency (f), cover it and you'll see $\frac{v}{\lambda}$.

Activity 3.7.2

Describe how frequency, wavelength and velocity are mathematically related. Write the formula to help you to remember.

3.8 The particle and wave models

There are two models that explain how energy travels in waves through a medium: the particle model and the wave model.

The particle model explains how energy moves through different forms of matter by the movement and interactions of particles. The model uses concepts such as kinetic energy and thermal conductivity to explain how energy is transferred by mechanisms such as conduction, convection and radiation.

Different types of energy travel in different ways. Some forms of energy can be understood by applying the particle model, while others can be understood by using the wave model.

Particle model

Energy travels because the particles in solids, liquids and gases (air) vibrate and transfer energy from one particle to another. When one particle vibrates, it causes adjacent particles to vibrate, allowing energy to travel.

Examples are sound and heat energies. At a loud concert, you may have noticed the ground vibrating due to the music. This shows how the sound is travelling through the solid ground. When heating up a metal pan on the stove, you may have noticed that the sides of the pan also get hot. This is because the heat source causes the particles in the pan to vibrate and the heat quickly transfers to all parts of the pan.

The vibration of the particles in this model occurs in a pattern. Particles vibrate either side to side (**longitudinal waves**) or up and down (**transverse waves**). This is illustrated in Figure 3.9 on the next page.

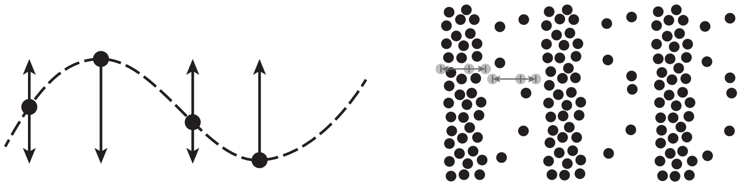


Figure 3.9: The vibrations of particles in transverse and longitudinal waves

Wave model

All forms of energy in the electromagnetic spectrum travel as waves. These forms of energy do not require particles to vibrate to allow energy to travel.

Electromagnetic waves can travel through a vacuum where particles are not present (e.g. space).

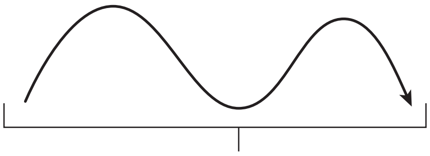


Figure 3.10: The wave model: electromagnetic waves do not have particles.

Key point

The main difference between the particle and wave models is that the particle model says that energy cannot travel through a vacuum, whereas the wave model permits energy to travel through a vacuum.

Activity 3.8.1

Explain the particle and wave models of how energy travels through a medium. Draw diagrams to help you remember.

Electromagnetic waves

Electromagnetic waves are transverse waves that can travel though matter as well as through a vacuum. An electromagnetic wave has an electric field and a magnetic field oscillating together on planes that are **perpendicular** to each other (Figure 3.11). The two oscillations are **synchronised**; therefore, they have the same frequency and wavelength.

Key terms

perpendicular	at 90° to a given line, plane or the ground
synchronised	occurring at the same time or rate

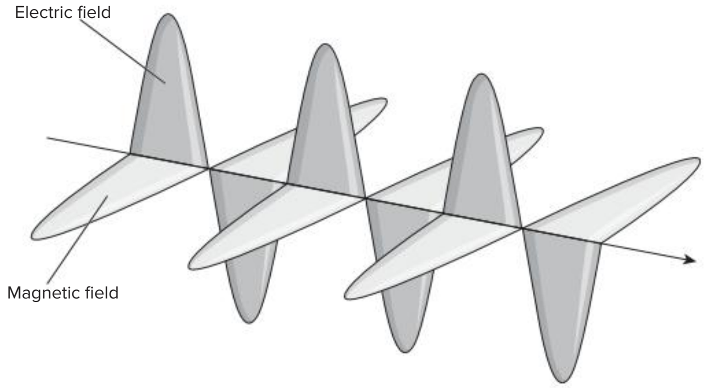


Figure 3.11: An electromagnetic wave

Activity 3.8.2

Describe electromagnetic waves. Draw a diagram to help you remember.

Electromagnetic spectrum

The different electromagnetic waves make up the electromagnetic spectrum. Electromagnetic waves have a range of frequencies and wavelengths. The higher the frequency of the radiation, the more energy it has.

From Figure 3.12, you can see why gamma rays are so dangerous: the radiation has a very high frequency, so very high energy. This type of radiation is said to be ionising. This means that it can result in changes to a cell's DNA, causing mutations such as cancer.

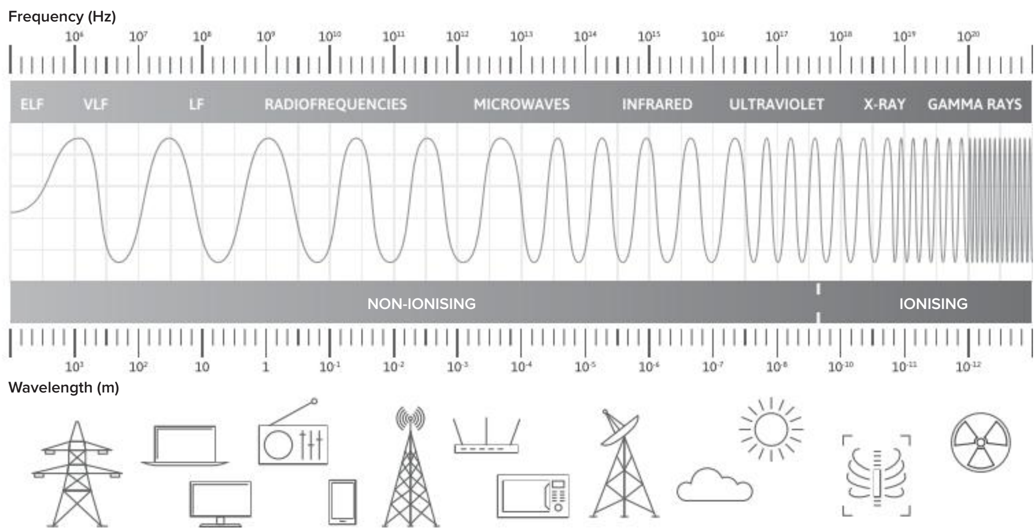


Figure 3.12: The electromagnetic spectrum

Frequency and wavelength are inversely proportional. Therefore:

- radio waves have the lowest frequency and the longest wavelengths
- gamma rays have the highest frequency and the shortest wavelengths.

Different types of electromagnetic waves, from lowest frequency to highest are:

radio waves < microwaves < infrared light < visible light < UV light < X-rays < gamma rays

Activity 3.8.3

1. Explain what the electromagnetic spectrum is. Draw diagrams to help you remember.
2. List the electromagnetic waves in order from lowest frequency to highest frequency. Draw diagrams to help you remember.

Electromagnetic radiation

Electromagnetic waves are also referred to as electromagnetic radiation because they radiate energy outwards from their source.

The higher the energy of a wave, the more it penetrates matter. This means that low-frequency electromagnetic radiation (e.g. radio waves and microwaves) are not harmful to living things. However, high-frequency electromagnetic radiation (e.g. gamma rays, X-rays and UV light) are harmful to living things.

Fun fact

Two very important forms of electromagnetic radiation are infrared and visible light. This type of radiation sustains life on Earth. The light travels as a wave from the Sun through space to arrive at Earth in eight minutes. Infrared radiation provides us with warmth.

Table 3.3 outlines the electromagnetic waves in the electromagnetic spectrum.

Table 3.3: Types of electromagnetic radiation

Electromagnetic wave	Examples
Radio wave	Radio, television, mobile phones, medical imaging with magnetic resonance imaging (MRI)
Microwave	Microwave ovens, mobile phones, Wi-Fi, satellites, radar
Infrared light	Heat detection, thermal-imaging cameras
Visible light	Sunlight, light bulbs, fire
Ultraviolet light	Emitted from very hot objects such as the Sun
X-ray	Used in radiography and radiotherapy
Gamma ray	Used in radiography and radiotherapy

Activity 3.8.4

Using coloured markers, draw examples of electromagnetic radiation.

Science as a human endeavour: Real-life application of the electromagnetic spectrum

Electromagnetic radiation has a range of uses in our everyday lives, as shown in Table 3.4.

Table 3.4: Applications of electromagnetic radiation

Application	Examples
Communication	• Radio waves and microwaves are essential for modern communication systems, including television, radio, mobile phones and satellites.
Medicine	• X-rays and gamma rays are used for diagnostic imaging and cancer treatment. • Infrared radiation is used for thermal therapy and detecting inflammation.
Safety and security	• Infrared cameras are used for night vision and detecting heat. • X-rays are used in airport security to scan luggage.
Daily life	• Visible light is used for seeing, lighting, photography and art. • Microwaves are used for cooking food quickly and evenly.
Scientific research	• Gamma rays and X-rays help astronomers study distant celestial objects. • Infrared and UV light are used in chemical analysis and studying biological structures.
Industry	• UV light is used in water purification systems. • Infrared radiation is used in heating systems and industrial inspection.

3.9 Light

Light waves – electromagnetic waves

Light is a form of energy that is transferred as a wave and is visible to the human eye. Light waves are electromagnetic waves, which means they involve oscillating electric and magnetic fields. Light waves are transverse waves – their oscillations are perpendicular to the direction of the wave.

Light waves can travel through solids, liquids, gases and a vacuum. Light waves are produced by hot objects, including the Sun, light bulbs and some chemical reactions.

Activity 3.9.1

Explain, in one sentence, what light is, and draw and explain a light wave.

The visible light spectrum is made up of different colours, which have different wavelengths. It is important to remember that the human eye cannot see ultraviolet light (UV) or infrared light.

When light encounters matter, it can be:

- transmitted – passes through the substance. Regular transmission occurs when light passes directly through. Diffuse transmission occurs when light scatters as it passes through.
- reflected – bounces off the substance. Regular reflection occurs when light is reflected directly. Diffuse reflection occurs when light is scattered as it is reflected.
- absorbed – is trapped by the substance and energy is transformed into heat.

Activity 3.9.2

Describe what happens when light encounters matter.

3.10 Sound

Sound waves – mechanical waves

Sound is a form of energy that is transferred as a wave. Sound waves are mechanical waves involving the vibration of particles. Sound waves are longitudinal waves; the sound is the result of particles vibrating back and forth, in line with the direction the sound wave is travelling.

Sound can travel through solids, liquids and gases but not through a vacuum.

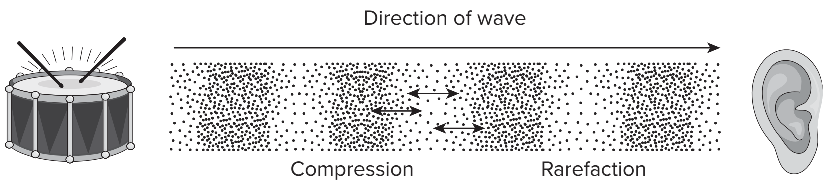


Figure 3.13: Like all longitudinal waves, sound waves have areas where particles are closer together (compressions) and areas where particles are further apart (rarefaction).

Remember that mechanical waves require a source of vibration that disturbs the surrounding medium.

Examples of sound waves:

- A drum is struck, causing the drum skin to vibrate, which generates sound (Figure 3.13).
- A speaker receives an electrical signal, causing it to vibrate back and forth, which generates sound.
- Your vocal cords vibrate, which produces your voice – sound.

Activity 3.10.1

Draw and explain a sound wave and list some examples.

First Nations peoples' understanding of sound

Musicians understand the way sound energy works to produce different sounds with their instruments.

A didgeridoo is a hollow tube made from wood from a variety of trees. Didgeridoos are blown with the mouth, while vibrating the lips and cheeks. This causes the air to travel through the didgeridoo, creating vibrations that we hear as sound.

Skilled players can create unique and interesting sounds. Didgeridoos are used in First Nations peoples' ceremonies, storytelling and cultural rituals and the sound of the didgeridoo is deeply connected to the natural environment and spiritual beliefs.

3.11 Light and colour, reflection and refraction

Light

For us to see an object, light particles must reflect off it and into our eyes. How light interacts with an object depends on the object itself. However, not all the parts of light are reflected by every object. In fact, the darker an object appears, the less light is reflected off it.

When light strikes an object, some of it is taken in by the object. The transfer of light energy into an object is called **absorption**. The light energy is transformed into heat energy. This is one reason why you are encouraged to wear lighter-coloured clothes on a hot day. Black clothes absorb more light and therefore more heat energy, making you hotter.

An object's material determines which wavelengths of light are reflected and which are absorbed. An object that only transmits some types of light is called a **filter**.

Key fact

A particle of light is called a photon.

Colour

In the case of sound, amplitude relates to loudness. In the case of light, amplitude relates to brightness.

The splitting of white light through a prism shows an important principle. It demonstrates that white light, like that from the Sun, is composed of all wavelengths of visible light. When this light enters a prism, different wavelengths of light refract in different ways.

Waves that have a longer wavelength and lower frequency are refracted less. Waves with a shorter wavelength and higher frequency are refracted more. These properties allow scientists to define colours by one of their fundamental properties: their wavelength.

Each colour of the rainbow has a measurable wavelength. Their wavelengths are so small that we use nanometres to measure them.

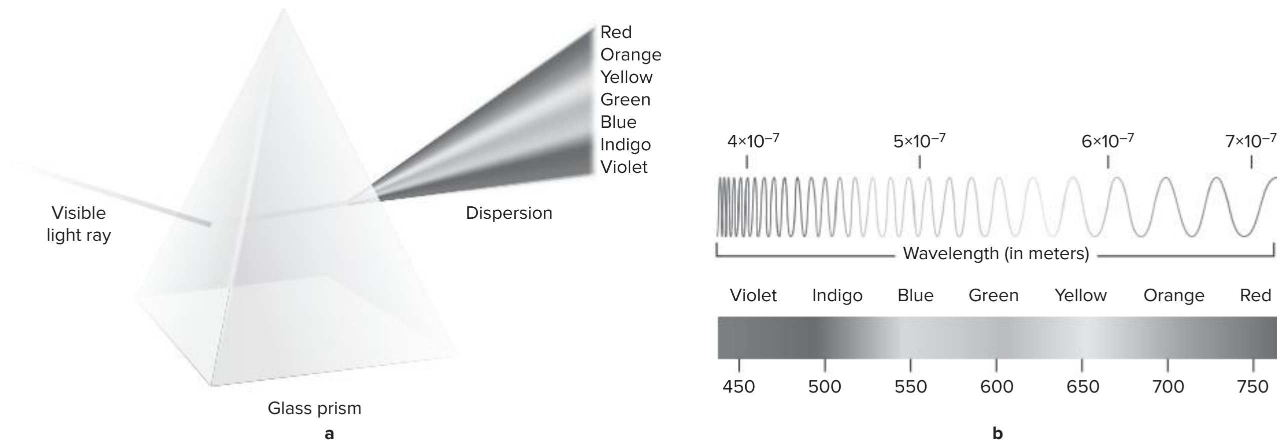


Figure 3.14: (a) The dispersion of light through a prism and **(b)** The different wavelengths of the visible spectrum

Reflection

Reflection occurs when light changes direction as it bounces off a surface, as shown in Figure 3.15a.

To create a diagram showing reflection, draw a line at right angles to the surface. This line is called the normal. The angle that the light is incoming and the angle that it is reflected should be measured in reference to the normal line.

Refraction

The change in direction of light as it passes from one transparent material to another is called refraction. For example, light passes through the lens of a camera before it reaches the sensor. Any transparent object with a curved surface can be a lens.

The angle of refraction should always be measured from the normal line, just like the angle of incidence.

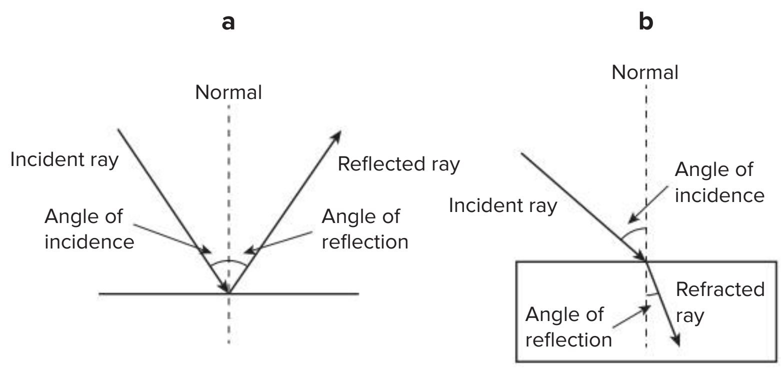


Figure 3.15: (a) Reflection and **(b)** Refraction

Activity 3.11.1

Do some research to find out about infrared and ultraviolet light. Where do they appear on the light spectrum? Can humans see them?

3.12 Energy conversion – transfer and transformation

Recall that the law of conservation of energy states that energy cannot be created or destroyed; it can only be transferred and transformed.

The following provides a quick review of what you learned about transfer and transformation in Year 8.

Energy transfer

Energy transfer is the movement of energy from one place to another. For example, when you charge your phone, electrical energy moves from a power point, through a charger, to the phone battery. The energy is moving from one place to another but not changing form or type (Figure 3.16).

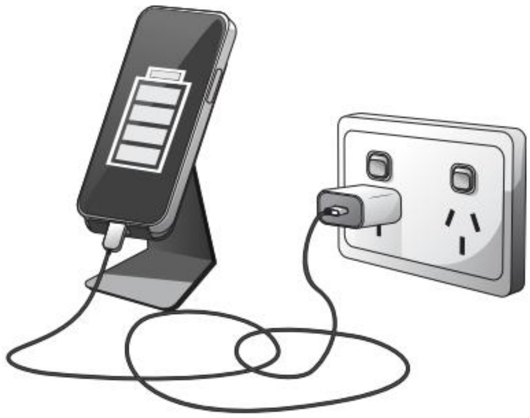


Figure 3.16: Charging a mobile phone involves the transfer of energy from the power point, through the charger and into the phone battery.

Energy transformation

Energy transformation is when energy changes from one form to another. For example, when electrical energy is converted to light (and heat) energy in a lamp, the energy is being changed or converted into another form of energy (Figure 3.17).

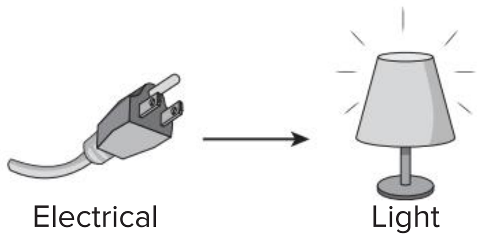


Figure 3.17: Electrical energy is transformed to light energy.

These examples demonstrate the law of conservation of energy. Remember that although energy can be transferred and transformed, the total amount of energy does not change. This is called energy conservation.

In Figure 3.18, you can see more examples of energy transformation.

- The chemical energy in the apple is transformed into mechanical energy when riding the bicycle.
- The light energy from the Sun is transformed into chemical energy for the plant to use as food through the process of photosynthesis.

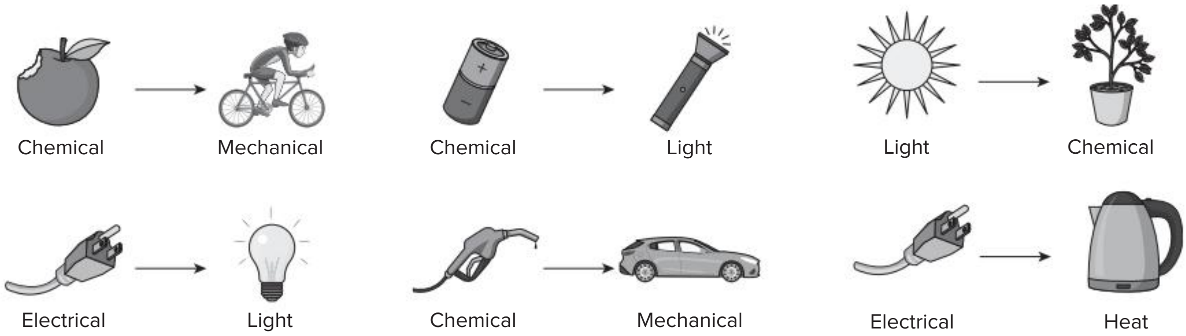


Figure 3.18: Energy transformations

Activity 3.12.1

1. Define the 'law of conservation of energy'.
2. Define 'energy transfer' and 'energy transformation'. Draw diagrams to help you to remember.

3.13 Thermal (heat) energy

Thermal energy, or heat energy, is the energy resulting from the movement of particles (molecules and atoms) in a substance. The particle model describes the arrangement and movement of particles in a substance.

When a substance heats up, this causes the particles to move faster and bump into each other. The hotter the substance, the more the particles move, and the higher the thermal energy (Figure 3.19).

Examples of thermal energy are the:

- warmth of the Sun
- heat from a heater or fire.

Thermal energy is produced when the particles (atoms and molecules) in a substance vibrate faster because of an increase in temperature.

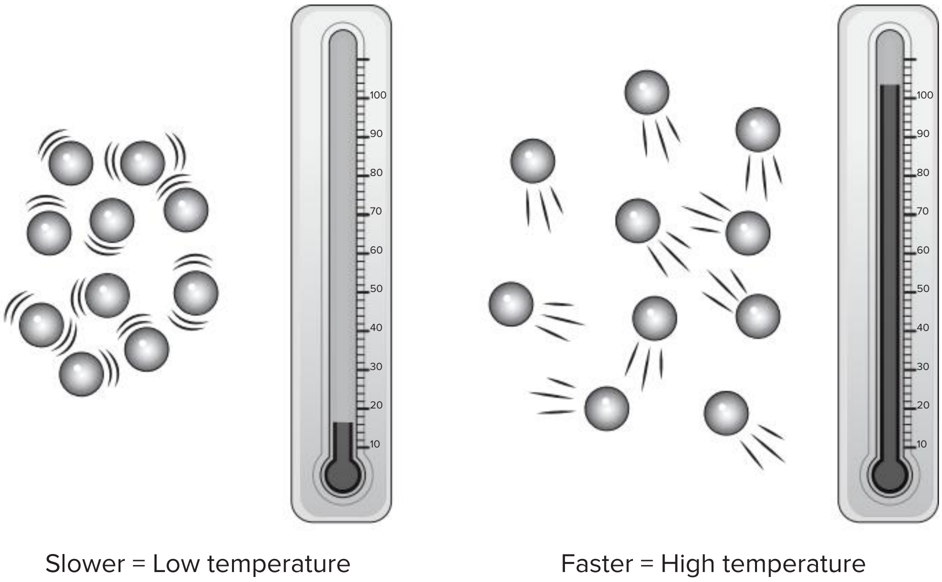


Figure 3.19: The speed of particles depends on their thermal energy.

Activity 3.13.1

Define 'thermal energy'. Draw diagrams and write key words to help you remember.

Transferring heat energy

Heat or thermal energy can be transferred (moved from one place to another) in three main ways: conduction, convection and radiation.

Conduction

Conduction is the movement of heat energy in a substance through direct contact between particles. The particles collide, forcing energy along an object. Conduction usually only happens in solids and liquids because their particles are closer together than in gases.

A piece of metal can conduct heat from another piece of metal if the two are touching. For example, a saucepan on a stove heats up as heat is conducted from one particle to the next from the base to the handle.

Some materials are better at conducting heat than others. These materials are called thermal conductors and include metals such as iron and copper, ceramics and glass. Thermal conductors are essential for effective heat transfer in cooking and heating.

Other materials are thermal insulators. These are materials that do not easily conduct heat and include rubber, plastic such as Styrofoam, gases such as air, and fibres such as wool. Thermal insulators are essential for preventing heat transfer. They are commonly used in clothing to retain warmth and in building insulation to improve energy efficiency.

Convection

Convection is the transfer of heat energy through indirect means. Heat transfer occurs in fluids when particles start to move faster as they heat up. Convection only happens in liquids and gases.

When you heat water in a saucepan on a stove, the water at the bottom of the saucepan, which is closer to the heat source, heats first. As this layer of water heats, it expands slightly, becomes less dense and rises. As the warmer water rises, cooler water above it sinks to take its place and is then also heated. The cyclic process of rising warm water and sinking cooler water creates **convection currents** that distribute the heat throughout the saucepan.

Convection also takes place in gases. As hot air rises, it cools and falls back to Earth. This helps to drive our weather patterns on Earth. When you heat a room in winter, the warm air rises so the air is warmer near the ceiling than near the floor.

Radiation

Radiation is different from the other types of heat transfer. Radiation does not require particles to be transferred; instead, it is transferred through electromagnetic waves. Heat waves radiate out from a hot object in every direction. Any energy that can travel through space (a vacuum) is radiant energy.

When you feel the warmth of the Sun or a campfire, you don't need to be touching them to feel their warmth! The Sun and campfires radiate heat in all directions.

Figure 3.20 shows the three types of heat transfer occurring when you boil water on the stove.

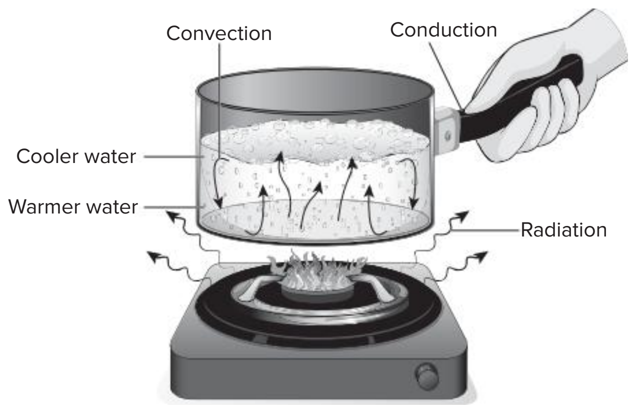


Figure 3.20: Heat transfer by conduction, convection and radiation

Activity 3.13.2

1. Write key points and key words and draw diagrams to show your understanding of the three main types of heat transfer. Include examples to help you to remember.
2. Describe the difference between thermal conductors and thermal insulators with examples. Draw diagrams to help you to remember.
3. Explain how the particle and wave models are related to the different types of waves involved in the transferring of heat.

First Nations peoples' use of materials for insulation

First Nations peoples of Australia have been using materials to keep warm for thousands of years. They use an extensive array of natural materials for insulation in their clothing, shelters, and everyday life.

Examples of insulating materials used by First Nations peoples are:

- animal skins: possum fur, kangaroo pelts and other animal hides for warmth and protection
- plant-based materials: woven grasses, bark and leaves for insulation of shelters and to make sleeping mats
- earth and clay: used in shelters and ground ovens to trap and retain heat.

Insulating materials are selected based on the local environment:

- In cooler climates (e.g. southern regions of Australia), thick animal furs such as possum skins are common.
- In hotter regions, materials with breathable properties, like woven grass, are preferred.

Possum cloaks

Possum cloaks are garments made from the pelts of possums, sewn together with kangaroo sinew or plant fibres. These cloaks are worn by First Nations peoples, especially in cooler regions such as southeastern Australia. Possum fur is naturally insulating, provides excellent warmth and traps body heat. Many pelts are stitched together to make a cloak large enough to wrap around the body or for use as bedding to provide warmth and protection from the cold.

Insulating materials trap air, which reduces heat transfer. Possum fur and other natural materials have tiny air pockets that act as thermal barriers. The use of insulating materials demonstrates First Nations peoples' ability to adapt to varying climates.

3.14 Electricity

Introduction to electricity

Electricity is a form of energy (electrical energy) that is present when electrons travel along a path.

Recall from Year 8:

- atoms are electrically neutral; they have no overall charge but they are made up of particles (protons, electrons and neutrons) that do have electric charges
- protons have a positive charge
- electrons have a negative charge
- neutrons have no charge
- protons and neutrons are in the nuclei of atoms
- electrons form an 'electron cloud' and they move around the nuclei of atoms.

Atoms are electrically neutral because they have equal numbers of protons and electrons – the positive and negative charges are balanced, resulting in no overall charge.

However, sometimes electrons can move between atoms. This results in an imbalance in the number of protons and electrons. The atoms are now charged and are referred to as ions (Figure 3.21).

- Positive ions result from a loss of electrons and are called cations.
- Negative ions result from the gain of electrons and are called anions.

Protons cannot move between atoms.

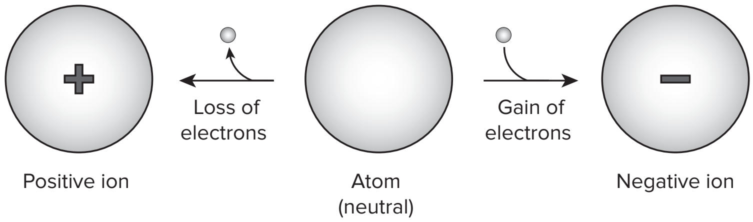


Figure 3.21: The formation of positive and negative ions

Electrical energy is a form of energy resulting from the presence of charged particles. Electricity is the transmission of electrical energy by the movement of charged particles and can exist as **static** electricity or **current** electricity.

Static electricity

Static electricity results from a build-up of electric charge on a surface. This occurs when two different materials are rubbed together. Electrons move from one material to the other so that the two materials have opposite charges.

When two objects with opposite charges come near each other, there is **electrostatic attraction** between them. When Styrofoam clings to other materials such as plastic, this is electrostatic attraction.

If you have been 'zapped' by touching a metal door handle, then you have experienced what happens when two oppositely charged objects come into contact with each other. An **electrical discharge** occurs as electrons move to neutralise the charge difference between the two objects.

If the difference in electrical charge between two objects builds up enough, electrons can jump across the gap between the two surfaces, which creates a spark. Lightning is an example of a spark from the build-up of static electricity.

Current electricity

Current electricity is the flow of electric charge through a wire or electrical component. The flow of electricity is generated from a power source, such as a battery or power point.

We use current electricity to power electrical devices. The electrical energy is transformed into other forms of energy such as heat (toaster), light (torch), sound (headphones) or mechanical energy (blender).

Activity 3.14.1

1. Summarise static electricity. Include diagrams to help you to remember.
2. Write key points and key words and draw diagrams to show your understanding of current electricity.
3. Create a Venn diagram to compare static electricity and current electricity.

3.15 Electric circuits

Electric circuits must have an energy source such as a battery or power point. An electric circuit is the path the electrons travel when current electricity is used to power an electrical device. Electric circuits can be very simple (e.g. in lamps) or very complicated (e.g. in computers).

All electric circuits contain four main components:

- a source of electrical energy – the source of electrons that flow through the circuit (e.g. batteries and mains electricity)
- components that use the energy – components such as light bulbs, heating elements and electric motors convert electrical energy into another type of usable energy
- connecting wires – connect all the components, usually made of metals such as copper and are covered in an insulating material to prevent electric shock when you touch them
- switches – to turn the circuit on (closed) or off (open).

For electricity to flow through an electric circuit, the circuit needs to be closed.

There are other components of electric circuits, which affect the movement of electrons in the circuit. Circuit diagrams are simplified illustrations the represent how the components are arranged and connected in an electric circuit. Each component is represented by a simple symbol, some of which are shown in Table 3.5.

Table 3.5: Components of an example electric circuit

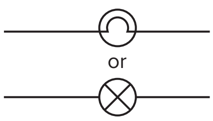
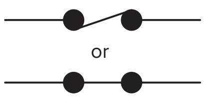
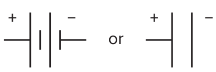
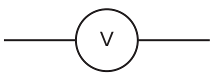
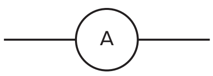
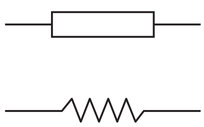
Component	Symbol	Function
Wire		Connects all components and allows electricity to flow from one component to the next
Light bulb		Converts the electrical energy into light energy and allows electricity to flow
Switch (open)		Creates a break in the circuit where electricity cannot pass
Switch (closed)		Ensures that the circuit is closed, and electricity can pass through all the components of the circuit
Battery (power supply)		Converts chemical energy into electrical potential energy
Voltmeter		Measures the voltage of the circuit and is connected in parallel
Ammeter		Measures the electric current through the circuit and is connected in series
Resistor		Used to reduce the flow of current or voltage, because they resist the flow of current

Figure 3.22 shows how an electric circuit can be represented by a circuit diagram. Circuit diagrams are simplified diagrams that depict the components and how the electrons pass.

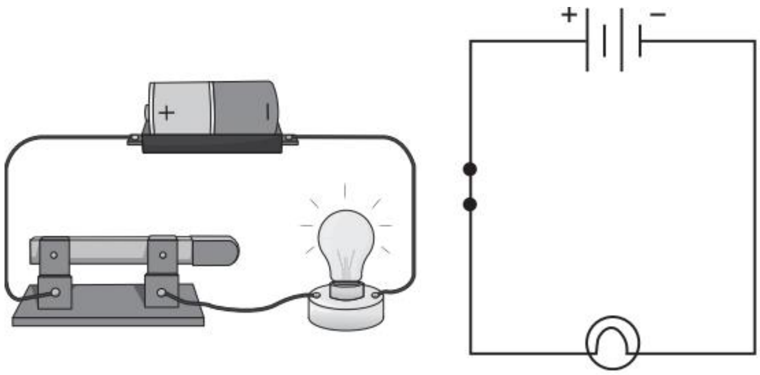


Figure 3.22: A simple electric circuit and the circuit diagram that represents it

Activity 3.15.1

Draw a diagram of an electric circuit. Include the names of the components of the circuit and the symbols used to represent these parts. Annotate your diagram with notes listing the function of each component.

Components in an electric circuit can be connected in series or in parallel.

Series circuit

In a series circuit, components are connected one after another, in a single loop, so that there is only one possible path for the electrons to flow. Figure 3.23 shows a series circuit.

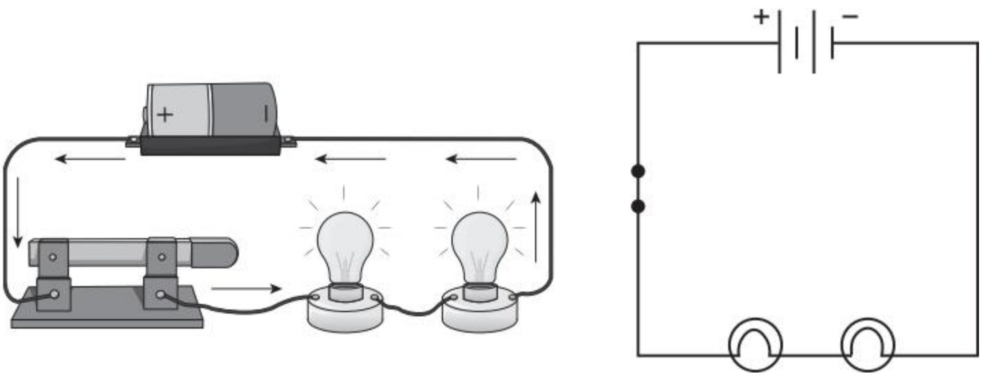


Figure 3.23: These components are connected in series.

Parallel circuit

In a parallel circuit, there are two or more paths for the current to flow and components connected can be connected independent of each other. Instead of one single loop, there are many loops that the current runs through. This is shown in Figure 3.24.

If one component stops working, other components will continue to work as the loops ere independent of each other.

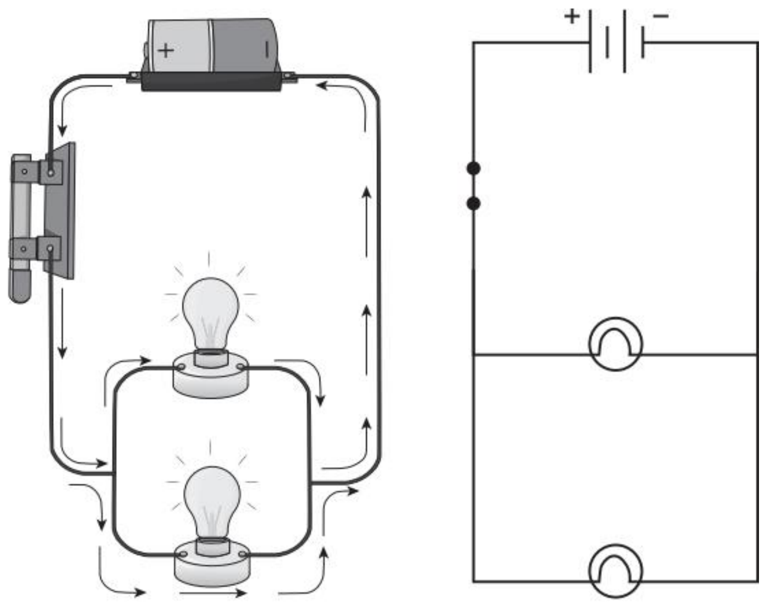


Figure 3.24: These components are connected in parallel.

Parallel circuits are more difficult to assemble than series circuits but they are more practical. This is because if one component in a series circuit stops working, the whole circuit stops working, whereas if a component in a parallel circuit stops working, the circuit can still work because there is another path for the electrons to flow through.

In parallel circuits, the same voltage passes through all the components – the voltage is not shared and all the components receive the same amount of voltage.

In a series circuit, the voltage is divided among the components – the more components there are, the less voltage is available for each component.

Activity 3.15.2

Create a Venn diagram to compare a series circuit and a parallel circuit.

Measuring electricity

Electricity can be measured in terms of **voltage** and **current**. Electrical components can be rated in terms of their **resistance**.

Voltage

Voltage is a measure of the **energy of electrons** in an electric circuit and is measured in **volts (V)**. Voltage can refer to two aspects of electric circuits, supply voltage and voltage drop:

- Supply voltage is the energy supplied by the power source.
- Voltage drop is the energy used by the component. Voltage drop is measured by a voltmeter.

A voltmeter must be connected in **parallel** to measure the voltage drop so it doesn't use any of the energy for itself (Figure 3.25 on the next page).

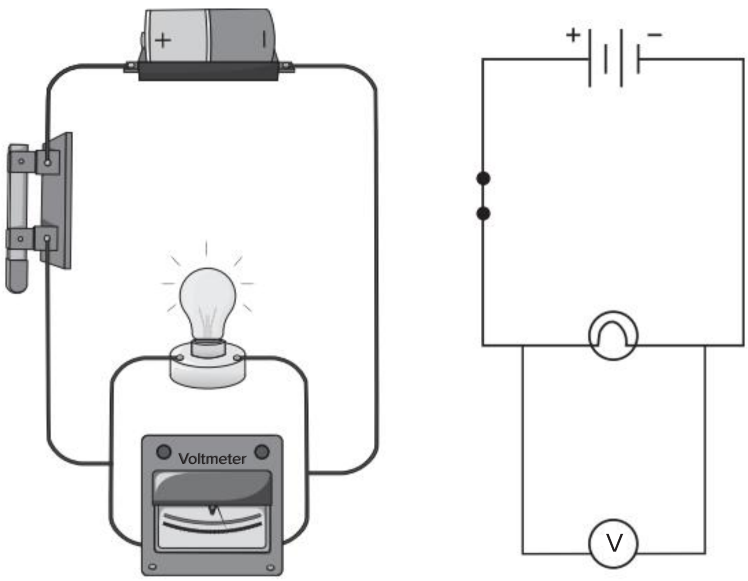


Figure 3.25: Voltmeters must be connected in parallel.

Current

Current is a measure of the **flow of electrons** in an electric circuit and is measured in amperes, usually called **amps (A)**.

Current is measured by an ammeter. An ammeter must be connected in **series** to measure current flow through a component (Figure 3.26). This allows the ammeter to detect the amount of electric charge flowing through it and therefore the component.

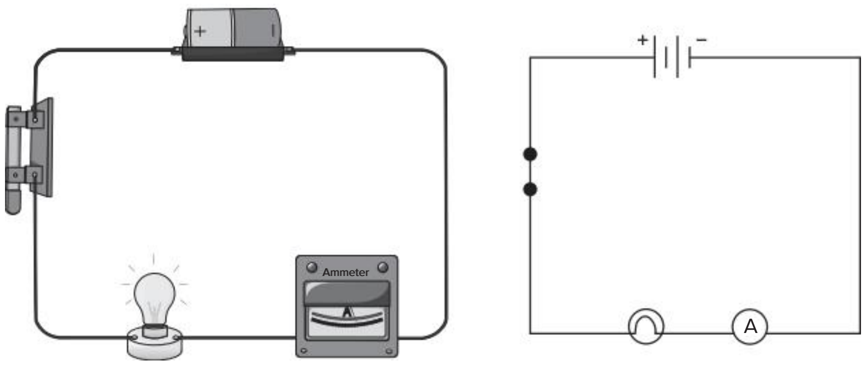


Figure 3.26: Ammeters must be connected in series.

Resistance

Resistance is a measure of the restriction of current flow and is measured in ohms (Ω).

Resistors are electrical components designed to reduce current. Different components have different degrees of resistance:

- Conductors have low resistance and easily conduct electricity. All metals conduct and silver, copper, aluminium and gold are the best conductors.
- Semiconductors have some resistance but still conduct electricity. Silicon and germanium are widely used as semiconductors in electronic devices.
- Insulators have very high resistance and do not conduct electricity. Rubber, plastic and porcelain are insulators.

Activity 3.15.3

Create a table to show the key components involved in measuring electricity.

Voltage in series circuits

When components are connected in series, voltage is shared between them. The total voltage across all components in a loop must equal the voltage being supplied to the loop. For example, if the supply for an electric circuit is 12 V and there are three light bulbs connected in series, the voltage across each bulb is 12 V ÷ 3 = 4 V.

Voltage in parallel circuits

When components are connected in parallel, the voltage is not shared between them. This is because the total voltage in each loop must equal the voltage being supplied to it.

For example, if the supply voltage for the electric circuit is 12 V and there are three light bulbs connected in parallel, the voltage across each bulb is 12 V (Figure 3.27).

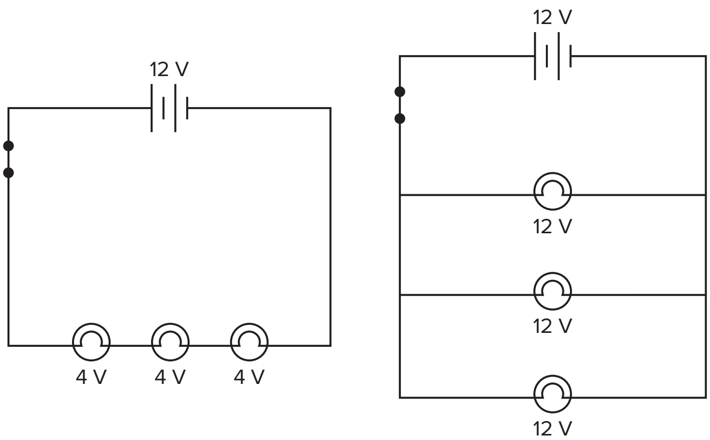


Figure 3.27: Voltage in a series circuit and a parallel circuit

Activity 3.15.4

Draw two diagrams to show the difference in voltage in series circuits and parallel circuits.

Current in series circuits

When components are connected in series, current is not shared between them. Current is the measure of electron flow and all electrons flow through each component.

For example, if the current coming from a power source is 3 amps (A) and there are three light bulbs connected in series, the current flowing through each bulb is 3 A.

Current in parallel circuits

When components are connected in parallel, current is shared between them. This is because the electron flow is distributed between each component, as each electron flows through only one of the components.

For example, if the current from a power source is 3 A and there are three light bulbs connected in parallel, the current flowing through each bulb is 3 A ÷ 3 = 1 A (Figure 3.28 on the next page).

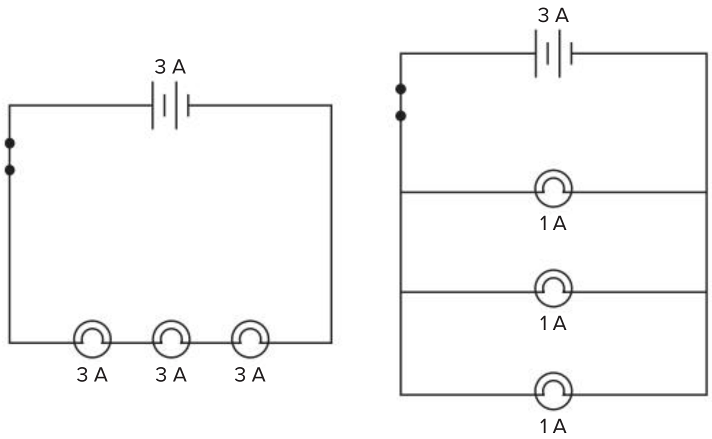


Figure 3.28: Current in a series circuit and a parallel circuit

Activity 3.15.5

Draw two diagrams to show the difference in current in series circuits and parallel circuits.

Electric circuits summary

- Components that are connected in series share voltage but not current.
- Components that are connected in parallel share current but not voltage.
- Light bulbs connected in parallel will be brighter than light bulbs connected in series if the supply voltage and light bulbs are the same.
- Adding another bulb in parallel will not affect the brightness of other bulbs but adding another light bulb in series will reduce the brightness of all bulbs (Figure 3.29).
- Light bulbs connected in parallel can be controlled by separate switches and are not affected when other bulbs 'blow'.
- Light bulbs connected in series can only be controlled by a single switch and are affected by other bulbs blowing.

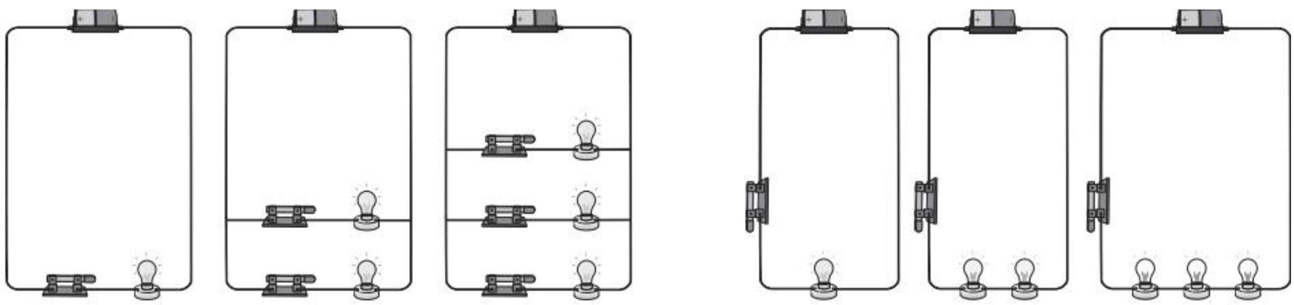


Figure 3.29: When more light bulbs are added to a parallel circuit, the brightness of each bulb stays the same. In contrast, when more light bulbs are added to a series circuit, the brightness of each bulb is reduced.

Activity 3.15.6

Explain how light bulbs are affected differently in a series circuit and a parallel circuit.

3.16 Energy transfer and transformation – input, output and efficiency

When energy is transferred or transformed, some of the energy can be transferred to the surroundings or 'wasted'. This means that the transfer and transformation of energy is not 100 per cent efficient.

Light bulbs

Many energy transfers lose energy as heat in the process. For example, in a light bulb, electrical energy is transformed into light energy. After a while, the light bulb becomes hot. The light bulb is losing energy as heat.

Systems and appliances such as tools, vehicles and machines can be thought of as having input energy and output energy. **Input** energy refers to the amount of energy put into a device, and **output** energy refers to the amount of energy that comes out. A device may change the type of energy but not the amount (law of conservation of energy). **Efficiency** is the ratio of useful output energy to the total input energy:

$$\text{Efficiency} = \frac{\text{useful output energy}}{\text{total input energy}}$$

The input energy of a light bulb is the supplied electrical energy. The output energy is the light and heat produced by the light bulb. The efficiency of a light bulb is a measure of how much of the input energy is converted to useful light energy.

The more energy a light bulb wastes, the less efficient it is. For example, incandescent light bulbs are inefficient because most of their energy is wasted as heat. Fluorescent bulbs and LEDs (light-emitting diodes) are more efficient than incandescent bulbs.

Activity 3.16.1

Explain input energy, output energy and efficiency.

Calculating efficiency

We can measure the energy efficiency of a system, including a light bulb, using this formula:

$$\text{Efficiency (\%)} = \frac{\text{useful output energy}}{\text{total input energy}} \times 100$$

where energy is measured in joules (J).

A Sankey diagram is a type of flow diagram that visually summarises all the **energy transfers** taking place in a process. The thicker the line or arrow, the greater the amount of energy involved. Figure 3.30 on the next page shows a Sankey diagram.

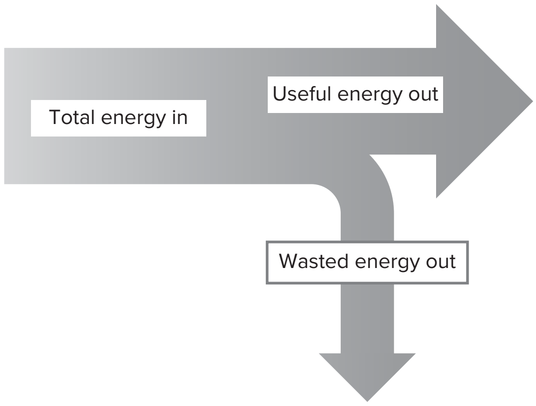


Figure 3.30: A Sankey diagram

The Sankey diagram in Figure 3.31 is for an incandescent lamp. You can see that most of the electrical energy is transferred as heat energy rather than as light energy.

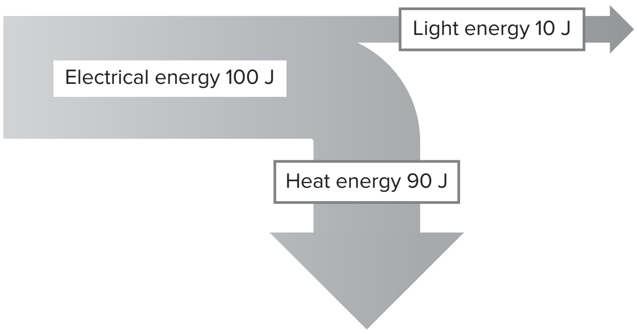


Figure 3.31: A Sankey diagram for an incandescent lamp

We can calculate the efficiency of the incandescent lamp:

Useful output energy = 10 J

Total input energy = 100 J

$$\text{Efficiency (\%)} = \frac{\text{useful output energy}}{\text{total input energy}} \times 100$$

$$= \frac{10}{100} \times 100$$

$$= 10\%$$

This means that only 10 per cent of the electrical energy supplied is transferred as light energy. This light bulb is not very efficient because most of the energy supplied is not transferred usefully. Most of the energy will be heat and this is why these types of light bulbs become very hot when left on.

The Sankey diagram in Figure 3.32 is for an LED lamp. You can see that much less electrical energy is 'wasted' as heat energy.

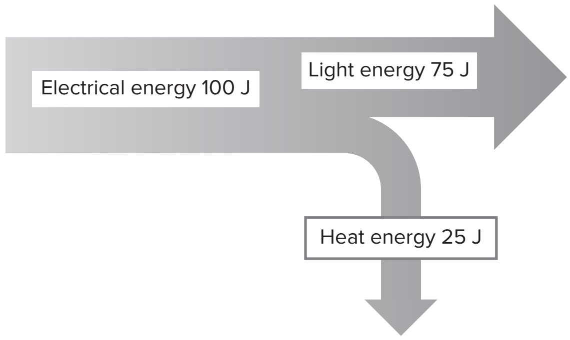


Figure 3.32: A Sankey diagram for a LED lamp

We can calculate the efficiency of the LED lamp:

Useful output energy = 75 J

Total input energy = 100 J

$$\text{Efficiency (\%)} = \frac{\text{useful output energy}}{\text{total input energy}} \times 100$$

$$= \frac{75}{100} \times 100$$

$$= 75\%$$

This means that 75 per cent of the electrical energy supplied is transferred as light energy. This light bulb is more efficient than the incandescent light bulb.

Activity 3.16.2

1. Define 'Sankey diagram' and explain its purpose.
2. Calculate the efficiency of an appliance that uses:
   a. 500 J of energy to produce an output of 100 J.
   b. 500 J of energy to produce an output of 400 J.
   c. 1200 J of energy to produce an output of 80 J.

Efficiency of First Nations peoples' ground ovens

A ground oven is a traditional cooking method that has been used by First Nations peoples for thousands of years. A shallow pit is dug into the ground, often in sandy or clay soils that retain heat. A fire is built in the pit and stones are placed on top of the fire to absorb heat. Once the fire burns down, the stones remain hot.

The food (meat, vegetables or tubers such as yams) is wrapped in natural materials such as leaves or bark to protect it from direct contact with the stones and ash. The wrapped food is then placed on the hot stones. The pit is covered with soil or sand to trap heat, creating a sealed cooking environment.

The food cooks slowly for several hours using the retained heat from the stones and the insulating properties of the earth. The advantages of ground ovens are summarised in Table 3.6 on the next page.

Table 3.6: The advantages of ground ovens

Advantage	Description
Heat retention	• The stones absorb and retain heat from the fire, ensuring even cooking over a long period. • The insulating layer of soil minimises heat loss, making the cooking process highly energy efficient.
Even cooking	• The radiant heat from the stones cooks food evenly.
Sustainable materials	• Only natural materials (stones, soil, leaves and firewood) are used, making it environmentally sustainable.
Minimal resource use	• Requires minimal firewood compared to open-fire cooking because the heat is contained and used efficiently. • The slow cooking method reduces the need for constant attention.
Cultural adaptation	• First Nations peoples adapted the ground oven to suit local resources and environmental conditions, ensuring optimal use of available materials.

Science as a human endeavour: Energy efficiency

Energy efficiency is the process of reducing the energy wasted when we do work. Heat is a common by-product of energy transfers, such as in light bulbs. When lots of energy is wasted on by-products, it is inefficient energy.

Energy efficiency means using less energy to produce the same product or service. For example, using a low-energy light bulb will still provide you with light but it is more energy efficient than using a high-energy light bulb.

Much of the energy we use is electrical energy produced by burning coal. Coal is a fossil fuel and is **non-renewable**. It will eventually run out. Also, burning coal causes harmful carbon emissions (the release of carbon compounds such as carbon dioxide), which contribute to climate change.

Earth depends on us to be energy efficient. Climate change is causing extreme weather events, rising sea levels and the acidification of our oceans. If we can be more energy efficient, we can create a more sustainable future for our planet.

We can be more energy efficient by reducing our energy consumption and choosing **renewable** sources of energy such as solar, hydro, wind and geothermal power for our homes, businesses and cars. This helps reduce greenhouse gas emissions and potentially slows climate change.

Key terms

renewable energy	energy that comes from a source that will never run out; renewable sources of energy are more environmentally friendly
non-renewable energy	energy from a source that will eventually run out; most non-renewable energy sources are fossil fuels that release harmful carbon compounds

Chapter 4 – Chemistry

Recall from Year 8 that:

- atoms are the fundamental subunits of matter. They can exist individually (in some elements) or be joined to other atoms by chemical bonds (in most elements and all compounds)
- molecules are discrete structures containing two or more atoms bonded together in a fixed arrangement. Molecules can be one type of atom or more than one type of atom (more common)
- lattices are continuous networks of atoms joined by chemical bonds. Lattices can consist of one type of atom or more than one type of atom (more common)
- elements and compounds are both pure substances
- elements are made up of one type of atom. The atoms can exist separately as molecules or as a lattice
- compounds are made up of more than one type of atom and can exist as discrete molecules or as lattices.

4.1 The atom

Matter is anything that has mass and takes up space (volume). Atoms are the basic building blocks of matter. Atoms are made up of tiny subatomic particles, which are:

- protons
- electrons
- neutrons.

Each of these particles has distinct properties and roles within the structure of an atom (Table 4.1).

Table 4.1: Properties and roles of the subatomic particles

Property	Proton	Electron	Neutron
Location	Nucleus	Orbiting nucleus in shells, sometimes called energy levels	Nucleus
Charge	+1	–1	Neutral
Mass	Relatively heavy, 1 atomic mass unit (1 amu)	Extremely light	1 atomic mass unit (1 amu)
Roles	• Determines identity of element (e.g. an atom with 6 protons is always carbon) • Number of protons is called **atomic number**, which is unique for each element • Contributes to atom's **mass number**	• Involved in chemical reactions and bonding • Number of electrons equals number of protons in a neutral atom • Electrons in outermost shell determine chemical properties of element	• Helps stabilise nucleus by reducing repulsion between protons • Number of neutrons can vary in the same element, leading to different **isotopes** • Contributes to atom's mass number

The structure of an atom is illustrated in Figure 4.1.

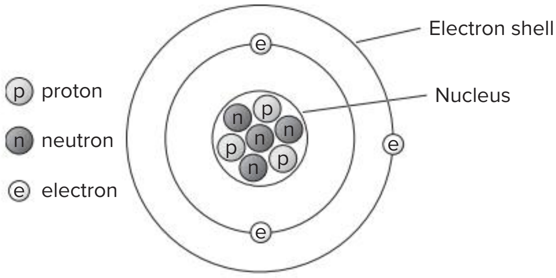


Figure 4.1: The structure of an atom

Key term

atomic number	the number of protons in an atom, this determines the element
mass number	the number of protons plus the number of neutrons
isotopes	atoms with the same number of protons but different numbers of neutrons; they have almost the same chemical properties but have different mass and physical properties. Stable isotopes do not emit radiation; unstable isotopes do emit radiation

Protons and neutrons are about the same size and so are considered to have the same mass. Electrons are so tiny that their mass is negligible and we do not include their mass in calculations. The only particles that contribute to the mass of an atom are the protons and neutrons:

Mass number = number of protons + number of neutrons

You can also determine the number of electrons by:

Number of neurons = mass number – atomic number

There are also forces within an atom:

- electrostatic force – the attraction between the positively charged protons and negatively charged electrons
- nuclear force – the strong force holding the protons and neutrons together in the nucleus.

In summary, atoms are made up of protons, electrons and neutrons. Protons and neutrons form a dense cluster at the centre of an atom – the nucleus. Protons define the element; electrons determine chemical behaviour and neutrons stabilise the nucleus. The balance of these particles determines the atom's properties, including its mass, charge and stability.

The atomic number of an element is fixed but the mass number can vary. Atoms that have the same atomic number (number of protons) but different mass numbers (number of neutrons) are called isotopes.

Activity 4.1.1

1. **a.** List the three subatomic particles in an atom.
   b. Explain the properties and roles of the subatomic particles.
2. Write the word formula for calculating an element's mass number.
3. Define 'atomic number'.

Science as a human endeavour: Atomic models

Since the time of the ancient Greeks, there have been many models and theories about the atom. Atoms are not simple to visualise, and we have not always known the shape and composition of what makes up matter.

Table 4.2 lists some atomic models through time. Each model led to the next. In science, scientists use the knowledge and discoveries of other scientists to help them build their ideas and theories. The Bohr model is the one that is most commonly used today.

Table 4.2: Atomic models though time

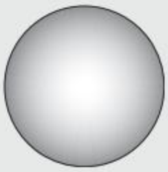
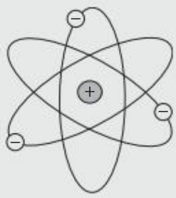
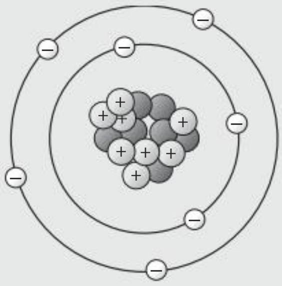
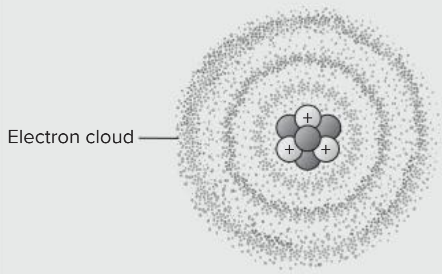
Period	Model	Observations
600 BCE	Continuum model – earth, fire, air, water	• Ancient Greek philosophers believed that all matter was made up of the four elements of earth, air, fire and water. • They proposed that matter could be divided infinitely, and that there was no smallest unit.
460 BCE	Solid ball (sphere) model 	• Greek philosopher Democritus proposed that all matter was made up of small, solid particles that could not be divided. • He used the word *atomos*, which means 'indivisible', to describe these particles.
1904	Plum pudding model 	• British scientist J.J. Thomson discovered the negatively charged electron. • He predicted that there must also be positive charges to balance the negative charges. • He proposed that an atom is a positively charged ball with electrons stuck in it, like plums in a plum pudding.
1909	Nuclear model 	• New Zealand physicist Ernest Rutherford, working in England, conducted an experiment in which he fired a beam of positively charged alpha particles at gold foil. He found that most particles went through the foil, and some bounced back. • He concluded that an atom is mostly empty space. This resulted in the nuclear model, which proposes a positive nucleus and a cloud of electrons around it.

Table 4.2: Atomic models though time (continued)

Period	Model	Observations
1912 and 1932	Planetary model 	• In 1912, Danish physicist Niels Bohr made changes to the nuclear model by proposing that electrons only travel in certain paths around the nucleus, similar to how the planets orbit the Sun. • In 1932, English physicist James Chadwick discovered neutrons. This changed the understanding of the atom and showed that the nucleus was made of positively charged protons and neutrons that had no charge.
1932–present	Bohr model/Electron cloud model 	• The electron cloud model proposes that electrons exist in regions around the nucleus called 'clouds'. The electron cloud represents the probability of finding an electron in a particular region of space. This helps scientists predict the location of electrons, but it is impossible to predict the location of an electron precisely. Key scientists involved in the development of the electron cloud model were Werner Heisenberg and Erwin Schrödinger.

4.2 The periodic table

An element is a pure substance that only contains atoms that have the same number of protons. The periodic table arranges elements according to their:

- atomic number – the number of protons in the nucleus of the atom (Figure 4.2)
- number of electron shells – electrons orbit the nucleus in 'shells'
- number of valence electrons – electrons in the outermost shell that can generally form bonds with other atoms by sharing electrons. (You don't need to fully understand this concept but it's good to know!)

Elements with similar properties are grouped together in the periodic table.

Activity 4.2.1

Complete this sentence: The periodic table of elements arranges elements on the basis of their ____

PERIODIC TABLE OF THE ELEMENTS

1 H 1.0079 Hydrogen																	2 He 4.0026 Helium
3 Li 1.941 Lithium	4 Be 9.0122 Beryllium											5 B 10.811 Boron	6 C 12.011 Carbon	7 N 14.007 Nitrogen	8 O 15.999 Oxygen	9 F 18.998 Fluorine	10 Ne 20.180 Neon
11 Na 22.990 Sodium	12 Mg 24.305 Magnesium											13 Al 26.982 Aluminium	14 Si 28.086 Silicon	15 P 30.974 Phosphorus	16 S 32.065 Sulfur	17 Cl 35.453 Chlorine	18 Ar 39.948 Argon
19 K 39.098 Potassium	20 Ca 40.078 Calcium	21 Sc 44.956 Scandium	22 Ti 47.867 Titanium	23 V 50.942 Vanadium	24 Cr 51.996 Chromium	25 Mn 54.938 Manganese	26 Fe 55.845 Iron	27 Co 58.933 Cobalt	28 Ni 58.693 Nickel	29 Cu 63.546 Cooper	30 Zn 65.39 Zinc	31 Ga 69.723 Gallium	32 Ge 1.0079 Germanium	33 As 74.992 Arsenic	34 Se 78.96 Selenium	35 Br 79.904 Bromine	36 Kr 83.80 Krypton
37 Rb 85.468 Rubidium	38 Sr 87.62 Strontium	39 Y 88.906 Yttrium	40 Zr 91.224 Zirconium	41 Nb 92.906 Niobium	42 Mo 95.94 Molybdenum	43 Tc 98 Technetium	44 Ru 101.07 Ruthenium	45 Rh 102.91 Rhodium	46 Pd 106.42 Palladium	47 Ag 107.87 Silver	48 Cd 112.41 Cadmium	49 In 114.82 Indium	50 Sn 118.71 Tin	51 Sb 121.76 Antimony	52 Te 127.60 Tellurium	53 I 126.90 Iodine	54 Xe 131.29 Xenon
55 Cs 132.91 Cesium	56 Ba 137.33 Barium	57 - 71 La - Lu	72 Hf 178.49 Hafnium	73 Ta 180.95 Tantalum	74 W 183.84 Tungsten	75 Re 186.21 Rhenium	76 Os 190.23 Osmium	77 Ir 192.22 Iridium	78 Pt 195.08 Platinum	79 Au 196.97 Gold	80 Hg 200.59 Mercury	81 Tl 204.38 Thallium	82 Pb 207.2 Lead	83 Bi 208.98 Bismuth	84 Po 209 Polonium	85 At 210 Astatine	86 Rn 222 Radon
87 Fr 223 Francium	88 Ra 226 Radium	89 - 103 Ac - Lr	104 Rf 261 Rutherfordium	105 Db 262 Dubnium	106 Sg 266 Seaborgium	107 Bh 264 Bohrium	108 Hs 269 Hassium	109 Mt 268 Meitnerium	110 Uun 271 Ununnilium	111 Uuu 272 Unununium	112 Uub 1.0079 Ununbium	113 Uut Ununtrium	114 Uuq 289 Ununquadium	115 Uup Ununpentium	116 Uuh Ununhexium	117 Uus Ununseptium	118 Uuo Ununoctium
Lanthanide series		57 La 138.91 Lanthanide	58 Ce 140.12 Cerium	59 Pr 140.91 Praseodymium	60 Nd 144.24 Neodymium	61 Pm 145 Promethium	62 Sm 150.36 Samarium	63 Eu 151.96 Europium	64 Gd 157.25 Gadolinum	65 Tb 158.93 Terbium	66 Dy 162.5 Dysprosium	67 Ho 164.93 Holmium	68 Er 1.0079 Erbium	69 Tm 168.93 Thulium	70 Yb 173.04 Yttersium	71 Lu 1.0079 Lutetium	
Actinide series		89 Ac 227 Actinide	90 Th 232.04 Thorium	91 Pa 231.04 Protactinium	92 U 238.03 Uranium	93 Np 237 Neptunium	94 Pu 244 Plutonium	95 Am 243 Americium	96 Cm 247 Curium	97 Bk 247 Berkelium	98 Cf 251 Californium	99 Es 252 Einsteinium	100 Fm 257 Fermium	101 Md 258 Mendelevium	102 No 259 Nobelium	103 Lr 1.0079 Lawrencium	

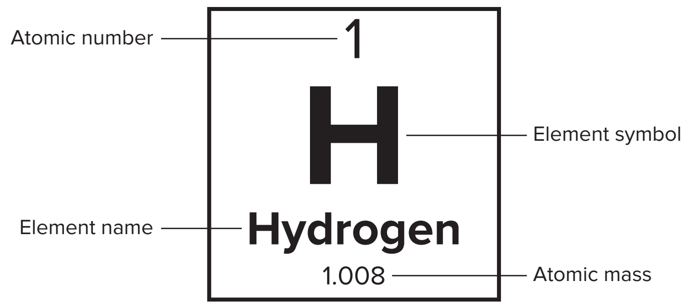
Figure 4.2: There are 118 elements in the periodic table, and more will be added as they are discovered.

Each box in the periodic table tells you information about a particular element, including the:

- atomic number – the number of protons in the atom
- atomic mass = number of protons + number of neutrons
- element name
- symbol of the element (also called the 'chemical symbol')

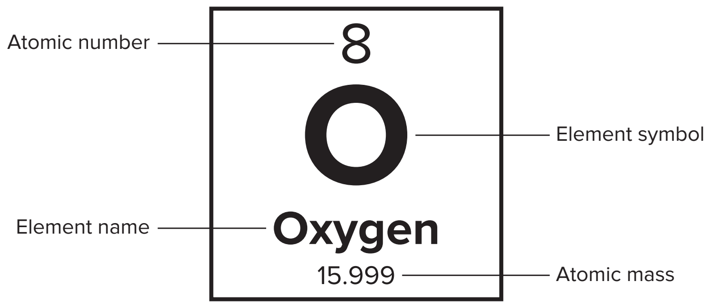
The chemical symbol lets you write chemical equations faster.

Let's take a closer look at the element hydrogen:



The atomic number is 1. This means that the element hydrogen has 1 proton. To balance the positive charge, a neutral atom of hydrogen has 1 electron. The mass number is approximately 1, which means that the single proton makes up the mass of the hydrogen atom. There are no neutrons in a hydrogen atom. The chemical symbol is H.

Let's take a closer look at the element oxygen:



The atomic number is 8. This means that the element oxygen has 8 protons. To balance the positive charge, a neutral atom of oxygen has 8 electrons. The mass number is approximately 16, which tells us that the number of protons and neutrons is 16. Therefore, we can infer that there are also 8 neutrons in an oxygen atom. The chemical symbol is O.

Activity 4.2.2

Draw and label two elements similar to the diagrams of H and O from the periodic table. Include their atomic number, mass, element name and element symbol.

Structure of the periodic table

The periodic table is made up of columns and rows

There are 18 columns called groups. Elements in the same group have the same number of electrons in their outermost shells (valence electrons) and often have similar properties.

There are seven rows called periods. Elements in the same period have the same number of electron shells. For example, sodium (Na) and phosphorus (P) are both in period 3, so they have three electron shells.

Activity 4.2.3

Summarise the information that the groups and periods on the periodic table tell us about elements.

Electron shells

Electron shells are also called **energy levels**. Electron shells are the regions around the nucleus where electrons are most likely to be found. The shells represent different energy levels, where the innermost shell has the lowest energy level and the outermost shell has the highest energy level.

Electrons in the innermost shell are highly attracted to the positively charged nucleus. Outer electrons are not as attracted because they are further away from the nucleus. Therefore, it is easier for the outermost electrons to 'jump' up or down energy levels, absorbing or releasing energy.

The shells closer to the nucleus are smaller and hold fewer electrons. The inner shells begin to fill up with electrons before the outer shells. The first shell can hold a maximum of 2 electrons.

Once the first electron shell is full, the second shell begins to fill. The second shell can hold a maximum of 8 electrons.

Once the second shell is full, the third shell begins to fill. The third shell can hold a maximum of 18 electrons. However, when the third shell contains 8 electrons, the fourth shell begins to fill. So the fourth shell begins to fill before the third shell is full. For the first 20 elements, the most electrons the third shell will contain is 8.

Table 4.3: The maximum number of electrons in each electron shell

Shell	Maximum number of electrons
First	2
Second	8
Third	18 (but typically fills up to 8 for the first 20 elements)
Fourth	32

Valence shell and valence electrons

The outermost electron shell of an atom is known as the **valence shell** and electrons in the valence shell are known as **valence electrons**. Generally a valence shell holds a maximum of 8 valence electrons. This principle is often referred to as the octet rule. This rules states that atoms tend to gain, lose or share electrons to achieve a stable electron configuration with 8 valence electrons (or 2 in hydrogen). An atom with 8 valence electrons is considered to have a stable electron configuration, similar to a noble gas. Nobel gases have low reactivity.

Although the octet rule is a useful guideline, there are some exceptions, particularly with heavier elements. For example, some elements may have more than 8 valence electrons in their valence shell.

The number of valence electrons largely determines the chemical properties of an element because they play a key role in chemical bonding and reactions. Atoms with similar numbers of valence electrons have similar chemical properties.

Activity 4.2.4

Summarise electron shells. Include a diagram to help you remember.

4.3 Bohr model

There have been many models to try to understand the structure of atoms. We currently use the Bohr model to show the arrangement of electrons around the nucleus (Figure 4.3).

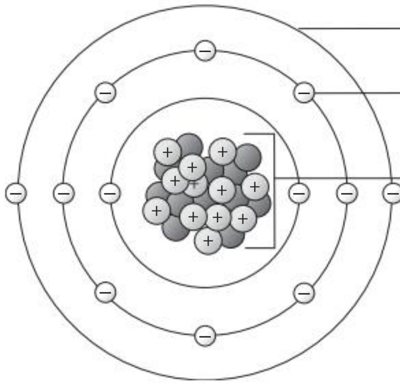


Figure 4.3: The Bohr model of an atom consists of a positively charged nucleus with protons and neutrons, electrons that orbit the nucleus and electron shells.

Fun fact

Most atoms tend to have 8 electrons in their outermost shell to be stable (this applies mostly to main group elements). This is called the octet rule.

When drawing a Bohr diagram, it is not necessary to show the structure of the nucleus. You just need to draw the shells of the electrons around the nucleus so we can get a better understanding of how the electrons are arranged. To construct a Bohr diagram:

- draw the nucleus at the centre of the atom and represent it by the chemical symbol for the element
- find the atomic number of the element (number of protons = number of electrons in a neutral atom)
- fill the electron shells represented as rings around the nucleus. Remember that the first shell contains a maximum of 2 electrons
- create a new shell when all previous shells are at their maximum capacity.

Note: Electrons come in pairs, except for the first two in the innermost shell.

Activity 4.3.1

List the steps you need to take to draw a Bohr diagram of an element.

Here is the element box for the element hydrogen.

1
H
Hydrogen
1.008

This tells us that:

- the atomic number is 1, so a neutral atom of hydrogen has 1 proton
- there is 1 electron (to balance the 1 proton)
- there are no neutrons.

To construct the Bohr diagram for hydrogen:

1. draw the chemical symbol for hydrogen ‘H’ in the centre to represent the nucleus
2. draw a ring for the electron shell
3. draw 1 electron on the electron shell.

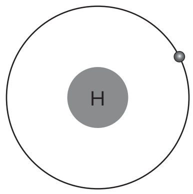


Figure 4.4: The Bohr diagram for hydrogen

In the Bohr diagram for hydrogen (Figure 4.4), you can see that hydrogen has 1 valence electron. The **electron configuration** for hydrogen is 1. The electron configuration is simply a list of the number of electrons in each shell.

Here is the element box for the element oxygen.

8
O
Oxygen
15.999

This tells us that:

- the atomic number is 8, so a neutral atom of oxygen has 8 protons, 8 neutrons and 8 electrons
- the inner shell can have a maximum of 2 electrons
- the outer shell holds the remaining 6 electrons.

To construct the Bohr diagram for oxygen:

1. draw the chemical symbol for oxygen ‘O’ in the centre to represent the nucleus
2. draw one ring for the electron shell

3. draw 2 electrons on the electron shell (the maximum number of electrons for the inner shell)

4. draw another electron shell

5. draw the remaining 6 electrons on that electron shell. (Remember: each subsequent shell after the innermost shell must have its maximum number of electrons before you can draw another electron shell.)

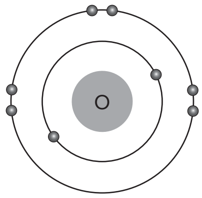


Figure 4.5: The Bohr diagram for oxygen

In the Bohr diagram for oxygen (Figure 4.5), you can see that it has 6 valence electrons. The electron configuration for oxygen is 2,6.

Activity 4.3.2

Draw a Bohr diagram for the element sodium (Na). Write how many valence electrons there are and the electron configuration.

We will now look at a slightly more complicated example – chlorine.

The element box for chlorine tells us the:

- atomic number is 17, so it has 17 protons, 17 neutrons and 17 electrons
- inner shell can have a maximum of 2 electrons
- next electron shell has the maximum number of 8 electrons, which means we can draw another electron shell
- outer shell will have the remaining 7 electrons.

To construct the Bohr diagram for chlorine:

1. draw the chemical symbol for chlorine 'Cl' in the centre to represent the nucleus

2. draw one ring for the electron shell

3. draw 2 electrons on the electron shell (the maximum number of electrons for the inner shell)

4. draw another electron shell

5. draw 8 electrons on it (the maximum number of electrons for the second electron shell)

6. draw another electron shell

7. draw the remaining 7 electrons on it.

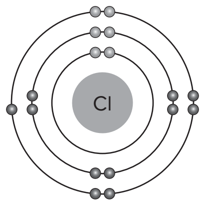


Figure 4.6: The Bohr diagram for chlorine

In the Bohr diagram for chlorine (Figure 4.6), you can see that it has 7 valence electrons. The electron configuration for chlorine is 2,8,7.

Activity 4.3.3

Draw a Bohr diagram for calcium (Ca). Write how many valence electrons there are and the electron configuration.

Isotopes

Atoms of the same element with different mass numbers are isotopes. This means the number of neutrons are different even though the number of protons stay the same.

Different isotopes of an element are identified by their mass number; for example, carbon-12 or carbon-14.

Isotopic notation

Isotopic notation allows us to quickly calculate an isotope's mass number, atomic number and the number of neutrons and protons in the nucleus using a visual symbol.

To write isotopic notation, place the atomic number as a subscript and the mass number (protons plus neutrons) as a superscript to the left of the atomic symbol.

For example: ${}^{12}_{6}C$ or ${}^{14}_{6}C$

4.4 Radioactivity

Radioactivity is the process by which unstable atomic nuclei decay, releasing energy in the form of radiation. Radiation is energy in the form of subatomic particles or electromagnetic waves. Radiation emitted from unstable nuclei is called nuclear radiation. The release of radiation from the nuclei of atoms is also known as radioactivity, radioactive decay or nuclear decay.

Remember that atoms of the same element with the same number of protons but different numbers of neutrons are called isotopes. For example, carbon-12 has 6 protons and 6 neutrons, but carbon-14 has 6 protons and 8 neutrons.

As atoms get larger and have more neutrons in the nucleus, the repulsion between protons overcomes the strong nuclear force, which holds protons and neutrons together in the nucleus. Some particles split away from the nucleus, and a huge amount of energy is released in the form of radiation.

Isotopes that undergo **nuclear decay** are called **radioisotopes**. There are three ways an atom can undergo nuclear decay:

- alpha decay
- beta decay
- gamma decay.

Alpha decay

Alpha decay is the ejection of alpha particles from a nucleus. An alpha particle consists of 2 protons and 2 neutrons and is identical to a helium nucleus, which has 2 protons and 2 neutrons (Figure 4.7). Alpha decay results in a decrease in atomic number and mass number.

Uranium-238 is an example of an element that decays by ejecting alpha particles.

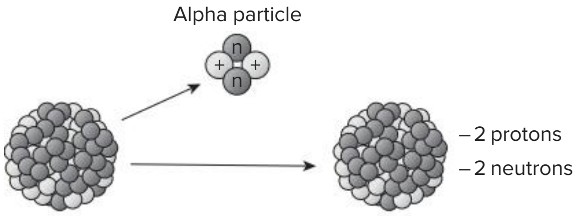


Figure 4.7: Alpha decay

Beta decay

Beta decay is the ejection of beta particles from a nucleus. A beta particle is identical to an electron – very small, light and negatively charged. The beta particle ejected during beta decay is not one of the electrons orbiting the nucleus. Instead, it forms when a neutron is converted into a proton and an electron. Beta decay results in an increase in atomic number but the mass number remains the same.

Carbon-14 is an example of an element that decays by ejecting beta particles.

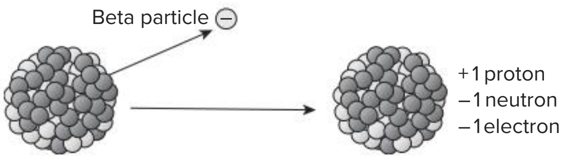


Figure 4.8: Beta decay

Gamma decay

Gamma decay is the emission of gamma rays from the nucleus. Gamma rays are not particles but are a type of electromagnetic wave, like X-rays but they have more energy. Gamma radiation results from the movement of protons and neutrons in high-energy nuclei. Gamma decay does not change the number of protons or neutrons in a nucleus, so the atomic number and mass number stay the same.

This type of decay does not release any particles but occurs when particles rearrange into new positions. This releases gamma radiation (electromagnetic waves), a very powerful type of radiation that can cause significant damage and harm to living things (Figure 4.9). Cobalt-60 is an example of an element that emits gamma rays.

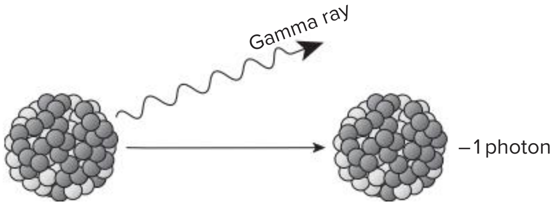


Figure 4.9: Gamma decay

Radioactive decay is a random process in which an unstable nucleus emits radiation to become more stable. This can lead to the formation of a new element.

The three types of radiation penetrate materials to different extents:

- Alpha radiation can be blocked easily because the particles are large and slow and can only travel a few centimetres in the air. A piece of paper can block alpha radiation. However, if it is breathed in or ingested, it can be deadly.
- Beta radiation is much smaller than alpha radiation and travels much faster. It can only travel a few metres in the air. The beta particles can travel through skin easily and cause radiation burns, sickness and mutation. It can be blocked by a 1 mm thick sheet of aluminium.
- Gamma radiation has no particles but is a form of electromagnetic radiation (waves) and can travel several hundred metres in air. This radiation travels extremely quickly. Gamma radiation can pass through organs, skin and bones. The radiation can cause burns, sickness, mutation and cancer. Gamma radiation can be stopped or blocked by a thick slab of concrete or lead.

Activity 4.4.1

Explain the different types of radioactive decay. Include diagrams to help you remember.

Half-life

Half-life is the rate or speed of nuclear decay. The half-life of a radioisotope is the time it takes for half of the radioactive nuclei in a sample to decay. Depending on the isotope, this can take from a fraction of a second to billions of years.

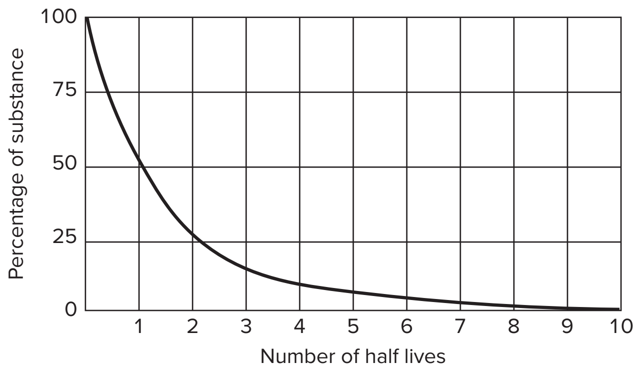


Figure 4.10: This graph shows the hypothetical half-life curve of a substance.

The impact of radiation on living things depends on the type of radiation and the amount of radiation.

Each day we are exposed to small amounts of **natural radiation** such as:

- solar radiation from the Sun
- cosmic radiation from stars
- terrestrial radiation from rocks and soil, including uranium
- internal radiation from within our bodies or other living things.

We can also be exposed to human-made radiation such as:

- medical sources – X-rays, nuclear medicine
- consumer products – television, smoke detectors
- building materials and fuels.

It is important to remember that the total dose of radiation that the average person receives from both natural and human-made sources has not been shown to cause harm.

Excessive exposure to UV radiation from the Sun or exposure to nuclear radiation from nuclear weapons or nuclear accidents has been shown to cause cancer.

Activity 4.4.2

List the different types of natural and human-made radiation sources.

Science as a human endeavour: The history of radioactivity

Table 4.4: Key discoveries in the history of radioactivity

Year	Discovery	Scientist	Description
1895	X-rays	Wilhelm Röntgen	• German physicist Röntgen discovered X-rays, a type of high-energy radiation used in medical imaging. • X-rays are not radioactive but paved the way for studying radiation.
1896	Natural radioactivity	Henri Becquerel	• French physicist Becquerel discovered radioactivity while studying phosphorescence in uranium salts. • He found that uranium emitted radiation that could fog photographic plates, even in the absence of light.
1898	Radium and polonium	Marie and Pierre Curie	• Polish physicist Marie Curie and her husband Pierre Curie coined the term 'radioactivity'. • They discovered two new radioactive elements: polonium (Po) and radium (Ra). • They were awarded the Nobel Prize in Physics (1903) alongside Becquerel. • Marie Curie later won a second Nobel Prize in Chemistry (1911).
1902	Types of radiation	Ernest Rutherford	• Rutherford, known as the 'father of nuclear physics' identified three types of radiation: – alpha (α) particles: positively charged, can be stopped by paper – beta (β) particles: negatively charged, can penetrate paper but are stopped by aluminium – gamma (γ) rays: high-energy electromagnetic waves, highly penetrating.
1911	Nuclear model of the atom	Ernest Rutherford	• Rutherford described the atom as a tiny, dense, positively charged core – a nucleus – around which light, negatively charged electrons circulate.
1932	Neutron	James Chadwick	• Discovered the neutron, a neutral particle in the nucleus • Helped explain why some elements are radioactive

Activity 4.4.3

Create a timeline showing the key discoveries for radioactivity. Draw diagrams to help you remember.

Applications of radioactivity

Carbon dating

There are many applications of radiation and radioactivity. A common one is carbon dating.

Carbon dating, also known as radiocarbon dating, is a method for determining the age of once-living organisms by measuring the amount of carbon-14 remaining in the sample. It is commonly used in archaeology, palaeontology and geology to date ancient objects.

Carbon-14 (C-14) is a radioisotope of carbon and decays over time. The half-life of C-14 is approximately 5730 years. After 5730 years, half of the original C-14 has decayed. After another 5730 years, only one-quarter remains, and so on.

By measuring the remaining C-14, scientists can:

- accurately date ancient artefacts such as tools, pottery and textiles
- estimate the age of fossils (e.g. bones of extinct animals)
- study climate changes by dating layers of peat or sediment
- identify the time of death from human remains.

There are some limitations to carbon dating. Carbon dating:

- is not effective for dating materials up to 50 000–60 000 years old
- only works on organic material
- doesn't work on rocks or metals.

Carbon dating has played a key role in uncovering the deep history of First Nations peoples and has confirmed that they have lived on the continent for at least 65 000 years. This means that the cultures of First Nations peoples are the oldest on Earth.

At the Madjedbebe Rock Shelter in Arnhem Land, Northern Territory, charcoal from ancient fires and stone tools have been carbon dated and found to be over 65 000 years old. Charcoal used in rock art has been dated to determine the age of paintings at sites such as Nawarla Gabarnmang and Ubirr, which have been dated to tens of thousands of years ago. Remains and tools found at Lake Mungo in New South Wales were dated to more than 40 000 years ago.

Activity 4.4.4

1. Summarise carbon dating and how it is used.
2. Describe how carbon dating has been used to confirm that First Nations peoples have lived on the continent for a least 65 000 years.

4.5 Reactions

Recall from Year 8 that there are two types of reactions: physical reactions and chemical reactions.

Physical reactions/physical change

A physical reaction is when changes occur in the appearance of a substance, but the type of substance does not change. The substance may change shape, size, colour, texture or state of matter, but the same substance is present before and after the change. It could be the melting of ice to water (solid to a liquid) or crushing rock into smaller parts. It is also the formation of mixtures such as whisking eggs with milk, preparing a salad or creating a potting mix.

Another example of a physical change is chopping wood (Figure 4.11). When we chop or cut wood, we are physically changing it to a smaller size.

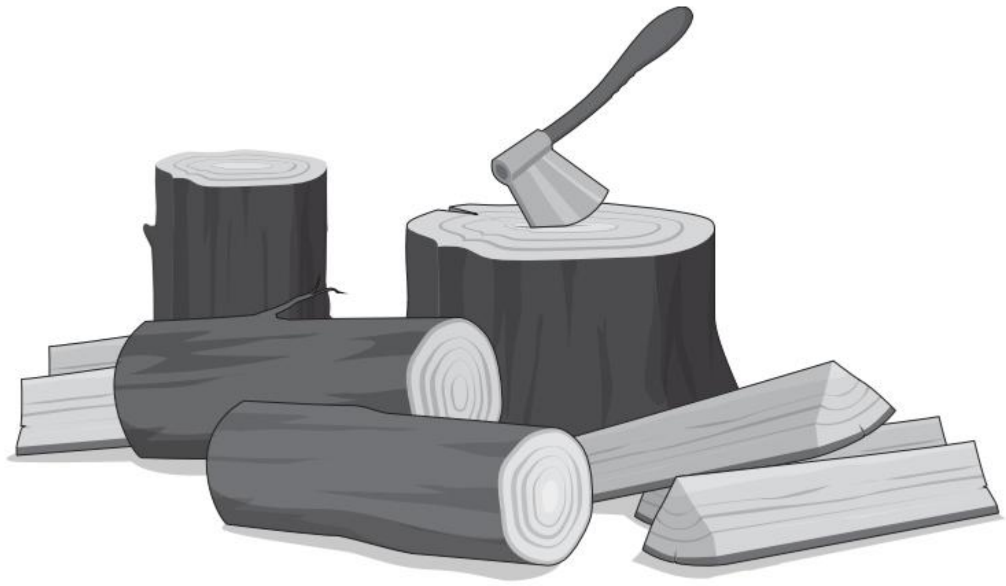


Figure 4.11: Chopping wood involves a physical change.

Consider the three main states of matter: solid, liquid and gas. When matter changes states, it is a physical change or reaction caused by an increase or decrease in temperature (Figure 4.12).

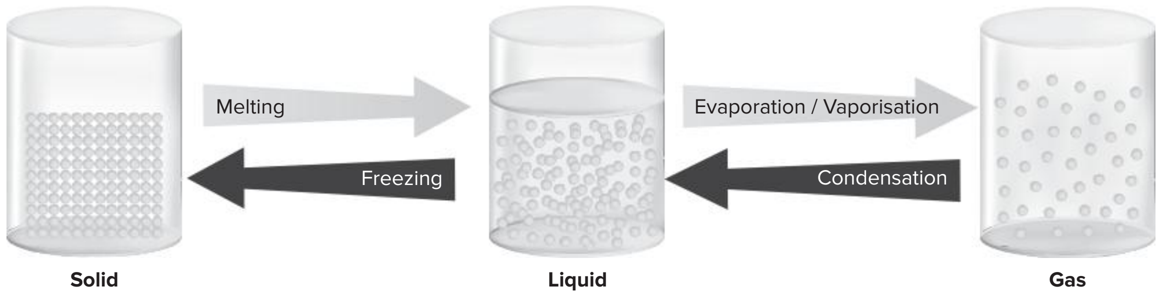


Figure 4.12: The changing states of matter

Chemical reactions/chemical change

There are many types of chemical reactions. But it is not always easy to determine if a chemical reaction has occurred or whether a change in appearance is purely physical. This is because often a chemical reaction involves a physical change as well.

A chemical reaction is where the chemical nature of the matter has changed, and a new substance is formed. The atoms in the matter have rearranged to form something new.

There are certain signs that indicate that a chemical reaction has taken place:

- Colour change – rusting of iron, ripening of fruit, bleaching hair and burning toast are some examples. However, not all colour changes indicate a chemical change.
- Formation of bubbles or odours – the smell of rotting rubbish, the fumes from car exhaust and fizzing when acid contacts a metal are some examples. However, not all bubbles and odours indicate a chemical change.

- Formation of a solid substance – also known as a precipitate.
- Temperature change (release or absorption of heat) – chemical reactions involve the transfer of heat energy, which is sometimes accompanied by light and occasionally sound. Burning coal in a steam engine, igniting fireworks, activating instant cold packs are some examples. However, not all changes in temperature are caused by a chemical reaction.

Burning wood is a chemical reaction called combustion (Figure 4.13). When wood is burnt, it is transformed to ash, which has a different chemical composition, and carbon dioxide is released into the atmosphere. Water vapour is also produced. We can't see the gas produced, but it is there.

A chemical reaction is when one chemical becomes a completely different chemical.

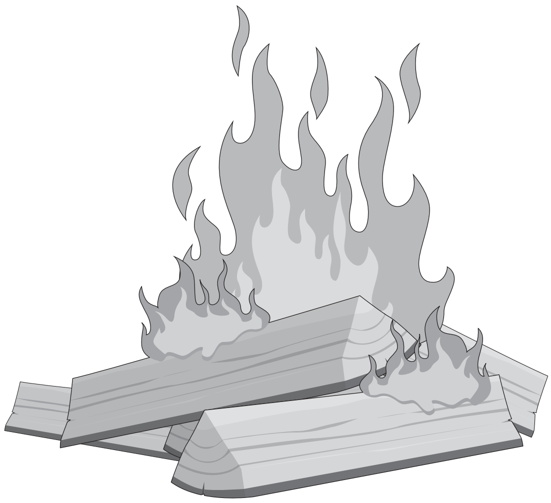


Figure 4.13: Burning wood involves chemical changes.

Atoms, molecules and chemical reactions

Atoms are the smallest particles of an element. Atoms can join with other atoms to form bigger structures called molecules. For example, a water molecule is made up of two elements: hydrogen and oxygen.

Bonding

Bonding is the process by which atoms combine to form molecules. Atoms join to form molecules through chemical reactions. Bonds can be:

- single – one pair of shared electrons
- double – two pairs of shared electrons
- triple – three pairs of shared electrons.

You will learn more about bonding in later years.

Chemical equations

Chemical reactions always involve the rearrangement of how atoms are grouped.

A chemical reaction can be described in an abbreviated form, known as a chemical equation. A chemical reaction involves two or more substances, known as **reactants**, interacting to form one or more new substances, known as **products**.

Reactants → products

The arrow represents the transition of the reactants (on the left side of the arrow) into products (on the right side of the arrow).

Chemical equations can be written with words or formulas.

Word equations include the chemical names of all reactants and products. For example, the word equation for the chemical reaction between baking soda and vinegar is:

sodium hydrogen carbonate + acetic acid → sodium acetate + carbon dioxide + water

Formula equations include the chemical symbols for all reactants and products. For example, the formula equation for carbon dioxide is:

$$C + O_2 \rightarrow CO_2$$

The formula equation for the reaction between baking soda and vinegar is:

$$NaHCO_3 + CH_3COOH \rightarrow NaCH_3COO + CO_2 + H_2O$$

Physical and chemical reactions occur in accordance with the **law of conservation of mass**. Therefore, for chemical reactions:

- the total number of each type of atom is the same before and after a reaction
- the total mass of the products is equal to the total mass of the reactants.

So, although chemical reactions involve the formation of new substances, they don't involve the formation of new atoms. The only difference between reactants and products is how the atoms are arranged, which is a result of the breaking and forming of chemical bonds.

Often a formula equation doesn't show equal numbers of each type of atom on both sides of the equation. When a formula equation shows unequal numbers of atoms on either side of the equation, the equation is said to be **unbalanced**.

Consider the equation for the reaction between nitrogen and hydrogen to form ammonia:

$$N_2 + H_2 \rightarrow NH_3$$

The left side of the equation shows 2 nitrogen atoms, whereas the right side shows 1. The left side of the equation shows 2 hydrogen atoms, whereas the right side shows 3. The equation is not demonstrating the law of the conservation of mass.

To demonstrate the conservation of mass by having equal numbers of atoms on either side of the equation, the equation needs to be **balanced**.

Equations are balanced by adding **coefficients** (numbers) in front of the chemical formulas of reactants and products. A balanced equation shows equal numbers of each type of atom on both sides of the equation.

There are some great tutorials on YouTube that clearly demonstrate how to balance equations. They are useful to watch and work alongside with to gain an understanding of the main concepts and steps involved to balance chemical equations.

Activity 4.5.1

1. Explain what a chemical reaction is.
2. Summarise the differences between word equations and formula equations.
3. Explain the law of conservation of mass.
4. Describe an unbalanced equation and a balanced equation.
5. Demonstrate how to balance an unbalanced equation.

4.6 Chemical reactions and energy

Remember that there are two main types of energy: kinetic and potential energy.

- Kinetic energy is the energy in moving objects.
- Potential energy is stored energy.

Thermal energy and chemical reactions

Thermal energy (heat) is a type of kinetic energy. Thermal energy is the energy that comes from the movement of particles in a substance. The faster the particles move, the more thermal energy the substance has. Thermal energy is very important for chemical reactions to occur.

Reactions happen when molecules collide with each other. This is called **collision theory**.

For a reaction to occur, a minimum amount of energy is required to start it. This is called activation energy. Some reactions have a low activation energy and will proceed at room temperature. Reactions with a higher activation energy require heat to be added for the reaction to occur.

Chemical potential energy and reactions

The energy stored in the bonds of molecules is a type of potential energy called **chemical potential energy**. Each molecule has its own amount of potential energy stored in its bonds. This means that when substances react to form new substances, the amount of energy changes.

Sometimes this produces extra energy, which needs to be accounted for by the **law of conservation of energy**. This law states that energy cannot be created or destroyed. So there is a **conversion** between types of energy.

An example is the reaction between hydrochloric acid (HCl) and sodium hydroxide (NaOH) to produced salt (NaCl) and water (H_2O):

$$HCl + NaOH \rightarrow NaCl + H_2O$$

The products contain less energy than the reactants and the products. The reaction gives off heat, as seen by measuring the rise in temperature of the reaction with a thermometer. The chemical potential energy has not been lost; it has been converted to heat.

All chemical reactions involve energy changes and the transfer of heat energy. Depending on the example, energy can be released or absorbed.

When energy is **released**, it is called an **exothermic** chemical exchange – energy is released in the form of heat and sometimes light and sound. Examples are combustion (burning wood), burning a candle and lighting a match.

When energy is **absorbed**, it is called an **endothermic** chemical exchange – heat energy is absorbed from the surrounding environment. Examples are cooking an egg and photosynthesis.

Activity 4.6.1

1. Explain the law of conservation of energy.
2. Describe how chemical reactions involve energy changes and transfer of heat. Write an example of an exothermic chemical exchange and an endothermic chemical exchange.

The next section discusses some real-life examples of chemical reactions and how they are used.

4.7 Acid and base reactions

Whether a substance is an acid or a base depends on the type of ion it releases when dissolved in a solution. Acids are chemical substances that can act as proton (hydrogen ions, H^+) donors and release H^+ ions in a solution. There are acids in some foods, and this makes them taste sour; for example, citrus fruits and vinegar. Acids can react with bases to form salts. Acids are also corrosive.

Bases (or alkalis) are chemical substances that are proton acceptors and release OH^- ions in a solution. Bases in food taste bitter and soapy. Examples of bases are cleaning bleach and soap. Bases react with acids to produce salts. Bases can be caustic (meaning it can burn or corrode things, especially living cells).

The acidity or alkalinity of a chemical is measured on the **pH scale**, which is a scale from 0 to 14 (Figure 4.14). Some general rules about the acidity or alkalinity of chemicals are:

- Acids have a pH between 0 and 7.
- Bases have a pH between 7 and 14.
- Neutral substances are pH 7.

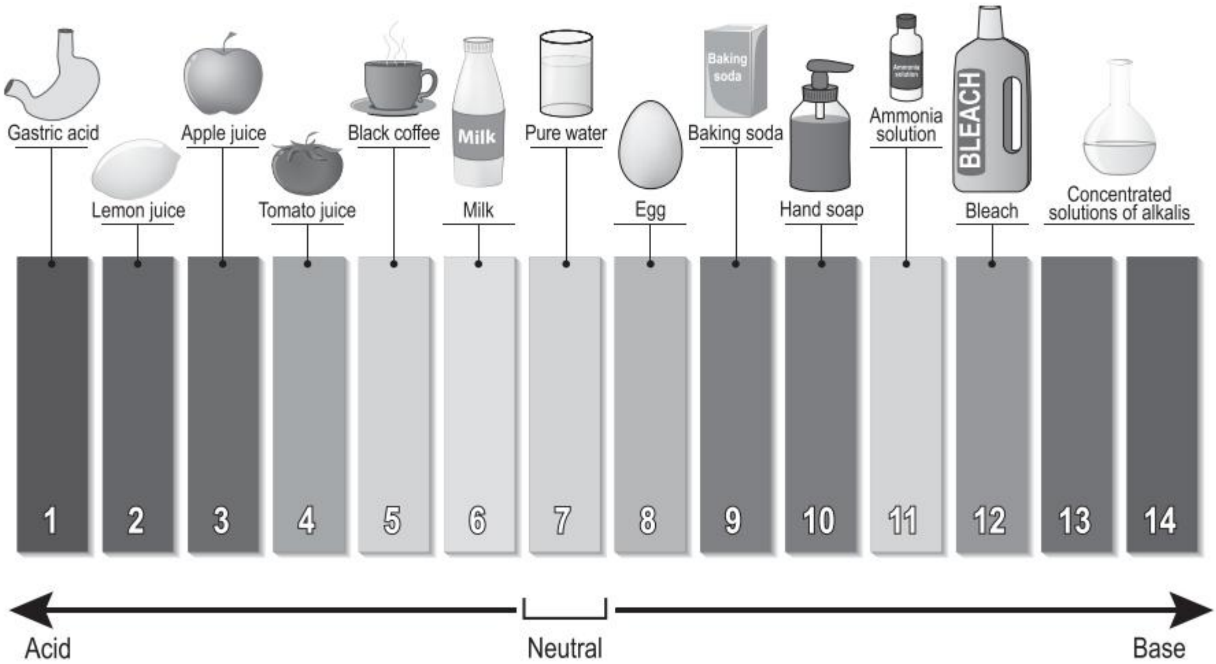


Figure 4.14: The pH scale

Activity 4.7.1

1. **a** Explain what an acid is, including examples.
   b Explain what a base is, including examples.
2. Describe what pH measures and give some examples of substances that are acidic, alkaline and neutral.

There are three main types of acid reactions:

1. Acid–metal reaction – an acid reacts with a metal (such as iron or copper) to produce a salt and hydrogen gas.

   Acid + metal → salt + hydrogen gas

2. Acid–base (or neutralisation) reaction – an acid reacts with a base and they neutralise each other to form a salt and water.

   Acid + base → salt + water

3. Acid–carbonate reaction – an acid reacts with a carbonate to produce a salt, water and carbon dioxide gas.

   Acid + carbonate → salt + water + carbon dioxide gas

Acids and bases are used in food and cooking, in batteries, in digestion, for soil treatments and to treat insect bites.

When you bake a cake, you might add baking soda. Baking soda is sodium bicarbonate, an alkaline chemical that reacts with acids in cooking. For example, baking soda and lemon juice react to produce carbon dioxide gas. This is an example of an acid–carbonate reaction. This creates air pockets in a cake, allowing it to rise.

Activity 4.7.2

1. Describe the three main types of acid reactions.
2. Summarise a real-world example of an acid–carbonate reaction.

4.8 Combustion reactions

A combustion reaction is a chemical reaction in which a substance (usually a fuel) reacts with oxygen gas (O_2) to produce carbon dioxide (CO_2), water (H_2O) and energy in the form of heat and light.

Three components are required for combustion:

- a fuel
- oxygen
- heat – the energy required for the combustion reaction to begin.

Fuels include methane, propane and octane, natural gas, petrol, diesel, kerosene, wood, coal, ethanol and hydrogen gas.

Complete combustion occurs when there is plenty of oxygen available and produces carbon dioxide, water and energy:

Reactants → products

Fuel + oxygen gas → carbon dioxide + water + energy

Fuel + O_2 → CO_2 + H_2O + energy

The reaction is **exothermic**, meaning the reaction releases heat (and light).

Incomplete combustion occurs when oxygen is limited and produces carbon monoxide, soot (carbon), water and less energy in the form of heat and light.

Reactants → products

Fuel + oxygen gas → carbon monoxide + carbon + water + energy

$$\text{Fuel} + O_2 \rightarrow CO + C + H_2O + \text{energy}$$

The reaction is exothermic, but it releases less energy than complete combustion does.

In our daily lives, combustion occurs in:

- cooking
- heating
- transport – combustion of petrol and diesel in car engines
- burning candles
- lighters
- fireworks
- power plants – combustion of coal to produce electricity
- rocket propulsion – combustion of hydrogen and oxygen fuels rockets.

Activity 4.8.1

1. List the three components required for combustion.
2. Identify the reactants and products of a complete combustion chemical reaction. Write the word and formula equations for a complete combustion chemical reaction.
3. Explain why complete combustion is an example of an exothermic chemical reaction.
4. Identify the reactants and products of an incomplete combustion. Write the word and formula equations for an incomplete combustion chemical reaction.
5. List four examples of where we use combustion in our daily lives.

Combustion has the following environmental impacts:

- Complete combustion produces the greenhouse gas CO_2, which contributes to global warming.
- Incomplete combustion produces CO, a toxic gas harmful to humans and animals.
- Incomplete combustion releases carbon particles (soot) into the air, contributing to air pollution.
- Combustion of some fuels such as coal releases sulfur oxides and nitrogen oxides into the atmosphere, leading to acid rain.

Large emissions of carbon dioxide, which is a by-product of many industrial processes, into the environment causes Earth to get hotter – this is called global warming. Global warming is a significant contributor to climate change, causing sea levels to rise due to ice caps melting and more extreme weather conditions such as droughts and bushfires.

Activity 4.8.2

List the environmental impacts of complete combustion and incomplete combustion.

First Nations peoples' knowledge of combustion and firestick farming

For tens of thousands of years, First Nations peoples have used fire as a tool to maintain ecosystems and support sustainable living.

These methods are based on deep ecological knowledge and understanding of the land and Country, passed down through generations.

Scientific principles in practice include:

- fire regimes – First Nations peoples use knowledge of the seasons, weather and plant cycles to determine the best times to burn
- patch burning – small, controlled areas are burnt at a time, creating a mosaic of burnt and unburnt patches that support diverse habitats
- carbon cycling – combustion releases carbon dioxide, but the regrowth of plants absorbs carbon dioxide, creating a balanced carbon cycle.

Firestick farming is the practice of using controlled, low-intensity burns to manage the land. Controlled burns use low-temperature combustion, which avoids intense fires that could damage the soil and ecosystems.

There are many benefits to firestick farming (Table 4.5).

Table 4.5: The benefits of firestick farming

Benefit	Description
Ecosystem health	• Stimulates the growth of fresh grass and certain plants, which provide food for animals • Helps maintain open woodlands and grasslands, preventing overgrowth of dense vegetation
Biodiversity	• Encourages the return of specific plants and animals adapted to fire-prone environments • Creates habitat diversity, benefiting a wide range of species
Bushfire prevention	• Reduces fuel loads (e.g. dry vegetation) that could lead to catastrophic bushfires
Cultural significance	• Supports traditional practices, strengthening the connection between people and Country • Embedded in First Nations peoples' spiritual and cultural lives

Firestick farming is becoming increasingly recognised as a valuable tool in modern land management and bushfire mitigation.

Fun fact

Some plants in Australia depend on fire for their germination. For example, plants in the banksia species require fire to open their cones and release their seeds into the soil.

4.9 Cellular respiration

Cellular respiration is a chemical process that takes place in the cells of living things and produces the energy that all living things need to survive.

Cellular respiration is a slow, controlled form of combustion because it involves the reaction of glucose with oxygen to produce energy.

$$\text{Glucose + oxygen gas} \rightarrow \text{carbon dioxide + water + energy}$$

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

The energy is used in growth, repair, movement, reproduction, maintaining homeostasis and immunity. Both animals and plants get the oxygen they require from their surrounding environment, but they obtain their glucose through very different processes of digestion and photosynthesis.

Activity 4.9.1

1. Explain the process of cellular respiration and write the word and formula equations for cellular respiration.
2. Identify how many of each element is in each substance excluding energy. Determine if the equation is balanced.

4.10 Photosynthesis

Plants produce their own food by photosynthesis. Photosynthesis uses the energy of sunlight to synthesise glucose (and oxygen) from carbon dioxide and water (Figure 4.15). Green algae and some bacteria can also carry out photosynthesis.

$$\text{Carbon dioxide + water} \xrightarrow{\text{sunlight}} \text{glucose + oxygen}$$

$$6CO_2 + 6H_2O \xrightarrow{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$

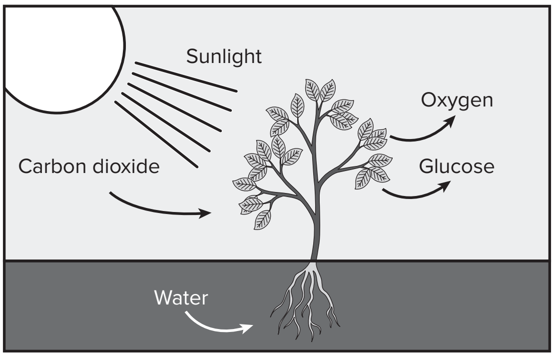


Figure 4.15: During photosynthesis, a plant converts water and carbon dioxide to glucose and oxygen.

From the equations, you can see that photosynthesis is the opposite process to cellular respiration because the products of cellular respiration are used in photosynthesis to produce glucose and oxygen.

Photosynthesis removes carbon from the atmosphere when it uses carbon dioxide to produce glucose. This helps to control the levels of carbon dioxide in the atmosphere and therefore the temperature of the atmosphere. So, photosynthesis is important in mitigating climate change.

Activity 4.10.1

Explain the process of photosynthesis and write the word and formula equations for photosynthesis.

4.11 Comparing cellular respiration and photosynthesis

Cellular respiration and photosynthesis have some similarities and differences.

The similarities between cellular respiration and photosynthesis are that they both:

- are complex chemical processes
- occur in the cells of living things
- involve common molecules – glucose, oxygen, carbon dioxide and water
- involve energy conversions.

The differences between cellular respiration and photosynthesis are shown in Table 4.6.

Table 4.6: The differences between cellular respiration and photosynthesis

Feature	Cellular respiration	Photosynthesis
Organisms	Animals	Plants, green algae and some bacteria
Location	Mitochondria	Chloroplasts
Reactants	Glucose and oxygen	Carbon dioxide and water
Products	Carbon dioxide and water	Glucose and oxygen
Type of process	Exothermic (releases energy from glucose)	Endothermic (absorbs energy from sunlight)
Energy requirement	Does not require sunlight	Requires sunlight

Activity 4.11.1

Create a table or Venn diagram to compare cellular respiration and photosynthesis.

Chapter 5 – Science inquiry skills

5.1 Investigation design

Designing an investigation means thinking about the best way to test a hypothesis by manipulating one or more variables while controlling any others. By creating a well-structured investigation, you will minimise bias and ensure the data your investigation produces is reliable.

Aim

The aim, in simple terms, is the *purpose* or goal of the experiment. It explains *why* you are conducting the experiment and briefly includes *what* will be done and *how* it will be measured.

An aim usually starts with the word *'To'* followed by *a verb* that describes what you are intending to do or measure.

Try to avoid using the verb 'see'. Instead, use words such as:

Investigate	Determine	Compare
Measure	Calculate	Observe

Example: 'To investigate how increasing temperature of water can affect how fast salt dissolves.'

Key fact: Variables

Remember your variables! For an investigation into the temperature of water dissolving salt, they would be:

- Independent variable (IV): *Something you change*
  Example: Temperature of water
- Dependent variable (DV): *Something you measure*
  Example: How long it takes for salt to dissolve in water
- Controlled variable (CV): *Something you keep the same*
  Example: Amount of salt, amount of water, type of salt

Hypothesis

Using the variables that you have identified, you can create a hypothesis. A hypothesis is a *prediction* that describes what you think will happen before the experiment is conducted. It is *how the IV affects the DV*.

A hypothesis usually follows the *'If, then'* format. Be sure to mention the IV and DV in the sentence!

Example: 'If the temperature of the water increases, then the salt would dissolve faster.'

Materials and method

This section is where you will need to decide how you will test your hypothesis, including identifying the materials and any apparatus you need, and the method you will use to conduct your investigation. The materials are usually presented as dot points, with specific amounts. The method is written in numerical order. An example using our salt experiment is shown below.

Materials

- 5 identical beakers of 20 mL water
- 0˚C, 20˚C, 50˚C, 70˚C, 100˚C water baths
- Thermometer
- 5 g of salt for each experiment
- Stopwatch
- Stirring rod

Method

1. Place a beaker of 20 mL water into each of the 5 water baths of different temperatures.
2. Using a thermometer, measure the temperature of the water until it reaches the same temperature as the water bath.
3. Pour 5 g of salt into the 0˚C beaker of water.
4. Start the stopwatch.
5. Stir consistently and frequently until the salt stops dissolving.
6. Record the time taken for the salt to dissolve.
7. Repeat steps 2–6 for each temperature: 20˚C, 50˚C, 70˚C, 100˚C.

Results

Before you conduct your investigation, it helps to draw a results table (either on paper or using a digital spreadsheet such as Microsoft Excel or Google Sheets). Creating a results table will help you record your results clearly. Each measurement you take is one point of data.

Table 5.1: Results table for our investigation

Temperature of water (˚C)	Time taken for salt to dissolve (secs)	Observations
0	204	Water turned cloudy Some salt dissolved Lots of salt was still a solid at the bottom of the beaker
20	157	Water turned cloudy Some salt dissolved Some salt was still a solid at the bottom of the beaker
50	96	Water turned cloudy then turned clear Most of the salt dissolved, with little salt pieces left at the bottom of the beaker

Table 5.1: Results table for our investigation (continued)

Temperature of water (°C)	Time taken for salt to dissolve (secs)	Observations
70	63	Water stayed clear Water had small bubbles forming All salt had dissolved
100	26	Water was bubbling and boiling Steam was escaping from the beaker All salt dissolved quickly

Putting your data into a table might also give you a clue about any trends and patterns in your investigation. For example, Table 5.1 shows us that as the temperature rises, the time taken for the salt to dissolve reduces.

Key fact: Quantitative and qualitative data

Data can be quantitative or qualitative. Quantitative data refers to data that uses numerical information; for example, your measurements in seconds. Qualitative data refers to data that uses descriptive information; in this case, your observations during the experiment: 'water was bubbling' 'some salt was still a solid' and so on are qualitative data.

Another way to help you identify trends or patterns is to present your data visually, usually with a graph of some kind. Graphing data will be discussed in section 5.2 on page 101.

Improvements

Another important element of investigation design is reflecting on the process and deciding if you need to make any improvements. Did your investigation produce the results you expected? How might you improve your experiment? A poor design can lead to false positives, misleading conclusions, or irreproducible results — all major issues in scientific research.

Considering the different terms below will help you understand your results and potentially make improvements.

- **Accuracy:** *The value is close to the true value* (theoretical value or value determined if the experiment was done perfectly).
- **Precision:** *The experimental values were close to each other.* (But were they close to the true value? Look at your method to make sure nothing distorted the results.)
- **Repeatability:** *Being able to collect similar or the same results under the same conditions every time.* This element is crucial. You should be able to repeat the investigation and get pretty much the same results.

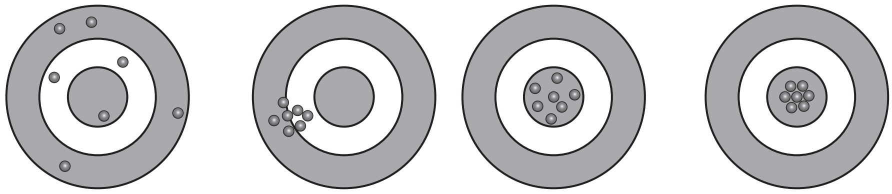


Figure 5.1: Remember, something can be accurate but not precise, or precise but not accurate. The best investigations are accurate and precise.

- **Reproducibility:** *Being able to collect similar or the same results under different conditions.* Reproducibility means you might change who conducts the investigation or the time of day you do it but still get a similar or the same outcome. Another scientist should be able to follow your method and replicate your results.
- **Validity:** *How well the experimental method allows the scientist to investigate the aim.* A valid investigation is one that measures what it is supposed to. This can often be an area to look for improvements. Did you really control all the necessary variables, so you only changed the IV? Did you check your equipment before you started to ensure any measurements are accurate?

Conclusion

A conclusion is a brief statement that *summarises your findings* and *any trends* you discovered. It is also useful to discuss whether your results supported or contradicted your aim and hypothesis.

For example: Salt was observed to dissolve faster in water that was at a higher temperature than at a lower temperature, supporting the hypothesis that increasing the temperature of water would decrease the time taken for salt to dissolve.

5.2 Graphing data

Another way to help you identify trends or patterns is to present your data visually. You are probably already familiar with concept maps, flow charts and Venn diagrams, for example. When conducting science investigations, we often show data using a graph of some kind.

Graphs

The type of graph you construct depends on the types of observations you make. Following are some examples.

Pie graph

A pie graph shows the proportions of each grouping within a total. The whole pie represents 100 per cent, half is 50 per cent and a quarter is 25 per cent.

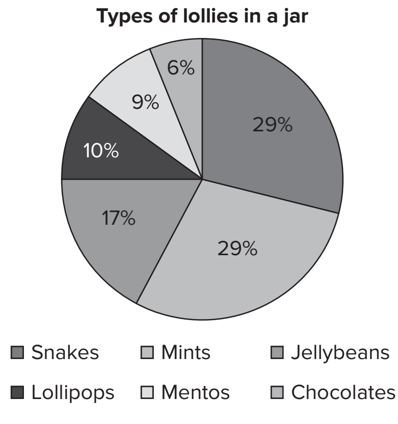


Figure 5.2: A pie graph

Column graph

It's best to use a column graph when you have a set of observations that can be separated into definite categories and counted.

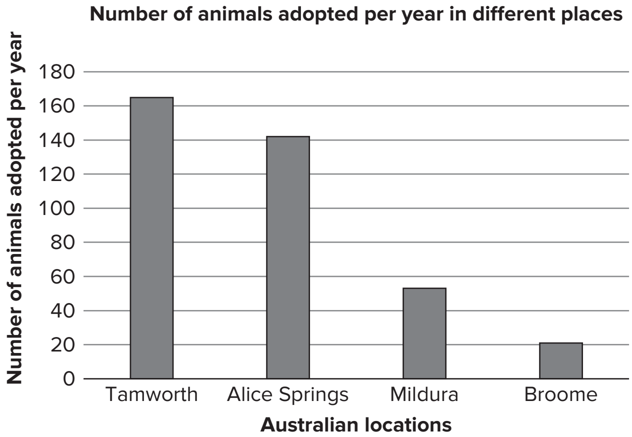


Figure 5.3: A column graph

Line graph

A line graph requires two sets of measurements that show continuous variation.

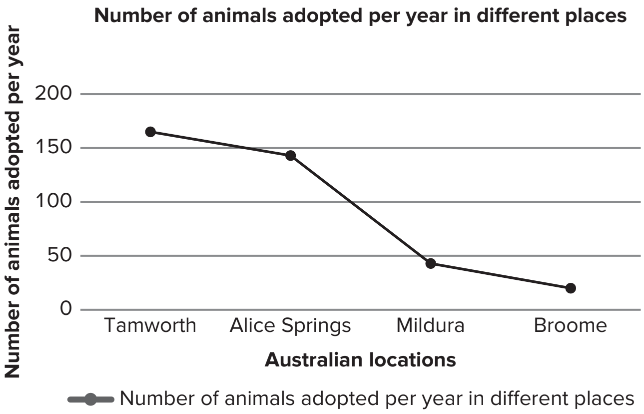


Figure 5.4: A line graph can show you changing amounts of something, or how a measurement changes over time.

Scatter plot

A scatter plot is used to show the relationship between two variables. It displays data as individual points on a graph. The value of the independent variable is typically shown on the *y*-axis and the dependent variable on the *x*-axis.

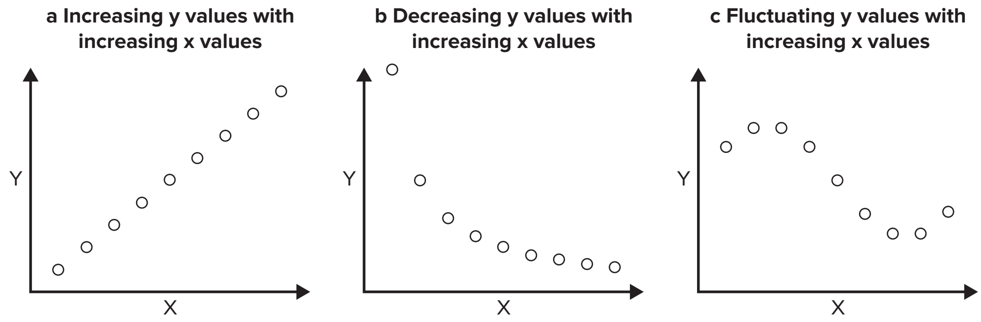


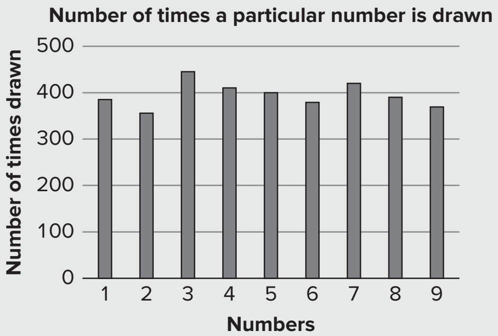
Figure 5.5: These three different scatter plots show the relationship between x and y values.

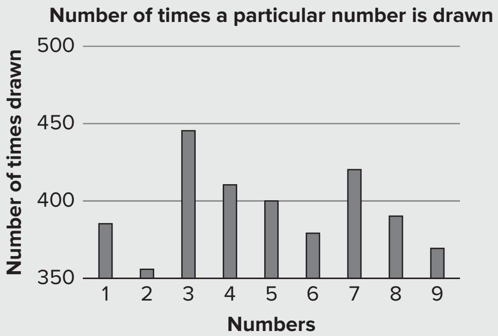
Scientists can draw a 'line of best fit' through the points of a scatter plot to show a trend. Where do you think a line of best fit would go in the three graphs of Figure 5.5?

Warning: Graphs can lie!

Be aware that some people modify the way they present their data to manipulate the viewer.

For example, look at the two graphs below showing how often a particular number from 0–9 is drawn in a lottery. The same data is shown both times, but the graphs look different.





Why do the two graphs look so different? What has changed?

In this instance, the *y*-axis on second graph now starts at 350 instead of starting at 0. This makes the differences look much more dramatic!

If someone asked if they should avoid a particular number, the second graph might make you think they should avoid the number 2 because it appears far lower than the other numbers.

However, if you look at the first graph, you can see the difference between the numbers is not so large. In fact, whether a number is drawn or not depends on random chance, one number is not more 'lucky' or 'unlucky' than any other.

People may distort the way a graph looks to try to influence the viewer's opinion. Make sure you examine and understand all the elements of a graph to decide if what you are seeing is a realistic representation.

Elements of a graph

When creating your own graph, use the SALT checklist to ensure you have included all the key components.

S	Scale: • accurate horizontal and vertical scales chosen • the independent variable is shown on the vertical axis, called the *y*-axis • the dependent variable is shown on the horizontal axis, called the *x*-axis
A	Axes: • the scale is clearly shown on each axis • the scale goes up by the same amount each time • the vertical axis starts at zero
L	Label: each axis is labelled with the data measured and unit of measurement used
T	Title: clearly shows the purpose of the graph

Graphs are useful tools that can help you understand the results of investigations. Also, using these visual components when communicating what you have learned will make your results easier to understand and interpret.

Chapter 6 – Study skills and exam advice

6.1 Effective revision

Take notes

While this book covers all the essential concepts you will cover this year, be sure to take your own notes in class as well. Research shows that handwriting your own notes requires your brain to synthesise and summarise the learning as you go, which helps you to remember it better.

When you go back to study, use a combination of this book and your notes to help you revise. However, don't just reread the information – this doesn't do much to embed it in your memory. Instead, reorganise your information to help you recall, understand and apply it effectively.

One way to do this is to use visual tools. Create a concept map about a key concept or draw a process as a flow chart or scientific diagram. In particular, note down any tricky words or formulas you might need to remember.

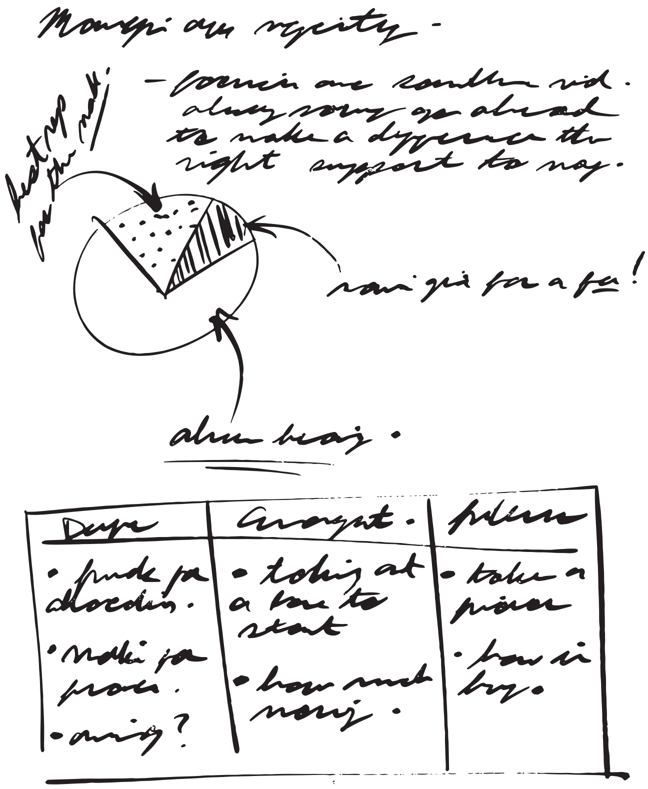


Figure 6.1: Use a combination of summaries and visual elements to help you memorise material

Practise questions

Make sure you answer example questions or do a practice test to help you prepare – being familiar with the test format and requirements will help you feel more confident during the actual test, which will help you stay focused. You can also see how you go the first time you do the practice test and then test yourself again after you have worked to memorise the material.

Another useful strategy is to write questions for someone else to answer. You and a friend can create questions and test one another and afterwards can discuss things you didn't understand or areas where you could extend your answers.

6.2 Exam strategies

Whether you are doing a practice test or the real thing, use the following strategies to help you perform at your best:

- **Read the instructions carefully.** Pay close attention to details like the number of questions, time limit, and any specific instructions for answering. For example, some tests may require you to choose only one correct answer, while others may allow for multiple correct responses.
- **Scan the questions**. As well as going over the instructions, if you have time, quickly scan the questions. Are there any key concepts you can see, or questions you might flag as challenging? Which questions receive the most marks? Doing an initial scan will help you plan your time.

  This strategy can also help you to stay calm as you can become familiar with the test as a whole.
- **Manage your time.** Time management is one of most overlooked aspects of performing well in a test. At the start, do a quick calculation of how much time you can spend on each question. Remind yourself to stay on track, particularly if you get stuck. Move on and come back to the question at the end rather than wasting 10 minutes on something that you are struggling with.
- **Review your work.** Go back to any questions you marked to come back to, sometimes the answer will jump out at you after you have taken a break. If it doesn't, try to make the best guess you can.

  Then, if you have time, look at the test in general. Are there any questions you misinterpreted? Anything you've overlooked? Skim your answers to make sure you haven't missed anything.

> **Key fact**
>
> Try to leave 5–10 minutes at the end of a test to do a final review.

Question types

Most science tests you encounter will include both multiple-choice and short-answer questions. Use different strategies to get the most out of your answers.

Multiple choice

When answering a multiple-choice question, you will usually choose from three or four options. Sometimes the correct answer will jump out at you. At other times, you will need to make an educated guess. Use the following strategies to answer these questions:

- **Use elimination**. Eliminate any options you know are wrong. This will make the other options clearer.
- **Look for clues.** Pay attention to key phrases and the information provided in the question. Sometimes, the correct answer may be hidden within the question itself.

  Then look for clues in the answer choices themselves. Certain words or phrases may indicate that an answer is incorrect or only partially correct. This will help you determine the best option.

- **Watch out for similar-sounding answers.** If some of the options sound similar, circle or underline the terms that are different in each option and clarify what they mean. This will help you tell the difference between a correct answer and a distraction.

  Another idea is to put the answers into your own words. This can make what is being said much clearer and lead you to the correct choice.

Key fact

Never leave a multiple-choice question blank. Take a guess and you may end up with a mark.

Short answer

Most tests usually have fewer short-answer questions but award more marks for them. These questions test your general understanding of a topic more than how much you have memorised a list of facts. You need to approach them in a different way. Use the following strategies to answer these questions:

- **Look at how many marks are allocated.** This will give you an indication of how long to spend on an answer, as well as a clue about how much to include. For example, a question that asks you to explain the key elements of a particular concept and awards four marks is probably looking for you to write four points in your answer.
- **Highlight the key words**. Explaining something is different to stating something, which is different to comparing something. Make sure you understand exactly what the question is asking you to do.
- **Answer directly and clearly.** Provide what is asked for but avoid writing too much or adding unnecessary detail. If you aren't sure, use your general understanding of the topic to make an educated guess about what the question is looking for.
- **Reread the question after you have answered it.** Ensure you have covered everything that was asked. Be on the lookout for questions that have two or three parts. Have you addressed everything that was asked?

Answers

Chapter 1 Biology

Activity 1.2.1

- Organisation – Living things are highly organised. They contain specialised coordinated parts. All organisms are made up of cells, which carry out specific organised functions.
- Metabolism – Life depends on a range of chemical reactions. These chemical reactions allow an organism to sustain itself and do work – such as moving, catching prey, growing, reproducing and maintaining body structure. The total of these biochemical reactions in an organism is called its metabolism.
- Homeostasis – All organisms require optimal conditions to survive. Organisms regulate their internal environment to maintain the conditions needed for cell function.
- Growth – Organisms can grow. Individual cells can grow, and multicellular organisms accumulate many cells through cell division.
- Reproduction – Organisms can reproduce to create more organisms.
- Response – Organisms can sense the environment around them and respond to stimuli or changes in the environment.
- Evolution – Populations of organisms undergo evolution, so that the genetic make-up changes over time to adapt to a changing environment.

Diagrams will vary.

Activity 1.3.1

This cell is eukaryotic because it has a nucleus and membrane-bound organelles.

Activity 1.4.1

Atom → molecule → organelle → cell → tissue → organ → organ system → organism

Activity 1.4.2

Answers will vary.

Activity 1.5.1

Answers will vary. Refer to Table 1.2.

Activity 1.5.2

The nervous system controls and coordinates all body activities, including voluntary (solving maths problems) and involuntary (breathing) actions.

The primary functions of the nervous system:

- Monitor changes to the internal and external environment, via sensory receptors (e.g. you notice a that branch is falling above you).
- Interpret these changes (e.g. you decide what action to take).
- Effect a response by activating muscles or glands (e.g. you move your body out of the way of the falling branch).

Activity 1.5.3

- Cell body – contains the nucleus and other cell organelles
- Dendrite – receives nerve impulses from other nerve cells
- Axon – sends nerve impulses to other nerve cells
- Nucleus – controls and processes information
- Axon ending (terminal) – passes message to next neuron
- Myelin sheath – insulates axon and protects impulse.

Diagrams will vary. Refer to Figure 1.6.

Activity 1.5.4

- Sensory neurons – detect changes in the environment via receptors and send messages to the brain.
- Motor neurons – send messages from the brain to muscles or glands that carry out a response.
- Interneurons – connect sensory neurons to motor neurons.

Diagrams will vary. Refer to Figure 1.7.

Activity 1.5.5

1. Central nervous system and peripheral nervous system
2. Brain and the spinal cord
3. The peripheral nervous system (PNS) is a long network of nerves that connects the central nervous system to the rest of the body. Messages are passed through the body to get a response or action. The PNS consists of sensory neurons, which detect changes, and motor neurons, which effect a response.
4. The somatic nervous system controls voluntary actions (actions that you have control over) (e.g. deciding to move) as well as the sensory signals you get from touching objects (e.g. a hot saucepan). The autonomic nervous system controls everything in your body that is automatic such as breathing, heartbeat, digestion and blinking. The autonomic nervous system is made up of two more parts.
5. The sympathetic nervous system prepares your body for 'fight or flight' when you encounter a stressful or scary situation. Fight or flight responses makes you either jump into action or run and hide.

   The parasympathetic nervous system promotes 'rest and digest' activities. This system helps you to return to a calm and relaxed state by reducing heart rate and stimulating digestion, so the body gets back to normal after experiencing stress.
6. a. Monitor changes to the internal and external environment, interpret these changes, effect a response by activating muscles or glands. It is important because it allows us to make decisions quickly about our environment.

   b. Nerve cells transmit electrical signals called nerve impulses. The electrical signals are very fast, which means we can have very quick reactions.

   c. Reflex arcs are not initiated by the brain but come directly from the spinal cord. This allows for a quicker response because it bypasses the neural route between the spinal cord and brain.

Activity 1.6.1

1. The endocrine system regulates body functions through hormones.
2. Refer to Table 1.3.
3. Hormones are chemical substances that are produced in the endocrine glands. They have a specific regulatory effect on organs.
4. Adrenaline is produced in the adrenal medulla of the adrenal glands. This hormone increases heart rate and breathing rate and opens the blood vessels in the lungs. It also dilates pupils and brings blood to muscles. This hormone is essential for survival because it allows the body to prepare itself to combat danger and threats.

Activity 1.7.1

1. Homeostasis is the process of maintaining a constant internal environment so that the human body can function optimally.
2. Receptors are sensitive to a particular stimulus. Effectors enact a response that has an effect on that stimulus.
3. A stimulus is something that produces a reaction in an organ or tissue, e.g. water, temperature, sugar, carbon dioxide and urea levels.

Activity 1.7.2

Answers will vary. Refer to Table 1.4.

Activity 1.7.3

Answers will vary. Refer to Figure 1.12.

Activity 1.7.4

Answers will vary. Refer to Figure 1.13.

Activity 1.7.5

When the feedback loop is broken or disrupted, the body cannot lower blood sugar to healthy levels. Negative feedback can be restored in the endocrine system through medication or lifestyle changes that help to regulate hormone levels and promote balance in the body.

Activity 1.8.1

1. Answers can include saliva, mucous, tears, skin, stomach acid, cilia. Physical barriers stop pathogens from entering the body by blocking or trapping them. Chemical barriers kill pathogens before they can enter the body.
2. T cells attack and kill pathogens, while B cells develop antibodies to neutralise pathogens.

Activity 1.9.1

1. The ability to reproduce is one of the key indicators of life and is essential to the survival of species.
2. Refer to Table 1.7.

Activity 1.10.1

1. Binary fission occurs when a parent cell divides into two identical daughter cells. The two daughter cells are genetically identical.

   Budding occurs when a new organism grows as an outgrowth (bud) on the parent and eventually detaches, growing into a complete and independent organism. Diagrams will vary; refer to Figures 1.15 and 1.16.

2. Efficiency – no need to find a mate, which saves time and energy. Rapid reproduction – can produce more offspring.

Activity 1.11.1

1. Sexual reproduction results in offspring that are genetically different from the parents. It involves specialised reproductive cells called sex cells, or gametes.
2. In animals, the male sex cells (gametes) are sperm cells (sometimes called spermatozoa) and the female sex cells are egg cells (also called ova, singular ovum). In plants, the male sex cells are pollen grains and the female sex cells are ovules.
3. Gametes contain half the genetic information of body cells, so when a male and female gamete combine, they produce a full set of DNA in offspring.
4. Sex cells are produced in specialised reproductive tissues called gonads. In animals, the male gonads are the testes and the female gonads are ovaries. In plants, the male gonads are anthers and the female gonads are ovaries.
5. Time consuming – finding a mate and producing offspring takes time. Limited reproduction – fewer offspring are produced compared to asexual reproduction.

Activity 1.12.1

1. The human reproductive system produces gametes. Gametes have half the normal amount of genetic material.

   Female reproductive system:

   - A female produces eggs in her ovaries. The eggs are released once a month.
   - An egg combines with spermatozoa in the fallopian tubes. If fertilised, the egg moves from the fallopian tubes to the uterus.
   - The egg implants in the uterine wall, where it develops into a baby over nine months.
   - The mother's body forms a large organ called a placenta, which provides oxygen and nutrients to the growing baby.

   Male reproductive system:

   - A male produces spermatozoa (sperm) in the testes.
   - The sperm travels through the epididymis to mature and then continues through to the vas deferens.
   - The sperm combines with fluid from the seminal vesicles before exiting the penis through the urethra.
   - The mature sperm can then fertilise an egg.

2. Diagrams will vary. Refer to Figure 1.17.

Activity 1.13.1

1. Most plants reproduce sexually. This includes flowering plants. Flowering plants, also known as angiosperms, have their reproductive components in their flowers.

   Male reproductive part: The stamen produces pollen (male gametes). It consists of the:

   - anther – produces and stores pollen; contains pollen sacs where male gametes are formed
   - filament – a stalk that supports the anther; positions the anther for efficient pollen dispersal.

   Female reproductive part: The carpel, or pistil, produces eggs and houses the seeds. It consists of the:

   - stigma – the sticky top where pollen grains land during pollination
   - style – a tube-like structure that connects the stigma to the ovary and allows pollen to travel to the ovary
   - ovary – contains ovules (female gametes); develops into a fruit after fertilisation
   - ovule – located inside the ovary; contains the egg cell; develops into seeds after fertilisation.
2. Diagrams will vary. Refer to Figure 1.18.
3. Diagrams will vary. Refer to Figure 1.19.

Chapter 2 Earth and space

Activity 2.1.1

Earth can be thought of as being made up of four interconnected systems, known as Earth's spheres. In the same way that the human body is made up of systems that work together, all Earth's spheres are linked, and each one is necessary to keep Earth in balance. The spheres are biosphere, atmosphere, hydrosphere and geosphere.

Activity 2.1.2

1. Diagrams will vary. Refer to Figure 2.1 and text.
2. Answers will vary.

Activity 2.2.1

1. The carbon cycle describes the movement of carbon through Earth's spheres. It ensures that carbon is recycled and available for all organisms. Key processes are photosynthesis, respiration, decomposition, combustion, carbon sequestration and ocean–atmosphere exchange.
2. Diagrams will vary. Refer to Figure 2.3.

Activity 2.3.1

1. Combustion is an exothermic (releases energy) chemical reaction. The burning of fossil fuels is a combustion reaction. Burning fossil fuels has dramatically increased the movement of carbon from the ground back into the atmosphere and oceans as CO_2. This is occurring hundreds to thousands of times faster than it took to bury it (decompose through the process of decomposition), and much faster than it can be removed by photosynthesis and other natural methods such as weathering. Burning fossils fuels for energy is artificially increasing the natural greenhouse effect. This results in an increase in global warming. This alters Earth's climate system and affects Earth's spheres.

2. The greenhouse effect occurs in the following steps:
   - The Sun emits energy in the form of sunlight that reaches Earth (solar radiation).
   - Earth's surface absorbs some of this energy and radiates it back as heat (infrared radiation).
   - Greenhouse gases in the atmosphere trap some of this heat, preventing it from escaping into space, keeping Earth warm.
3. Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapour, fluorinated gases
4. Higher concentrations of greenhouse gases, in particular CO_2, are causing Earth's average surface temperature to rise. This is called global warming.

Activity 2.4.1

1. Global warming refers to the increase in Earth's average surface temperature due to the enhanced greenhouse effect caused by human activities.

   Global warming is caused by:
   - burning fossil fuels for electricity generation and transportation – releases large amounts of carbon dioxide
   - deforestation – reduces the number of trees that absorb carbon dioxide
   - agriculture – produces methane and nitrous oxide
   - industrial processes – emit greenhouse gases such as chlorofluorocarbons (CFCs) and fluorinated gases.
2. Climate change, rising sea levels, ecosystem disruption, impacts on human health, ocean acidification
3. Diagrams will vary, Refer to Table 2.4.

Activity 2.5.1

1. Biological carbon sequestration is the storage of CO_2 in vegetation such as grasslands and forests, as well as in soils and oceans, within ecosystems. It is a natural process that helps regulate the carbon cycle and mitigate the effects of global warming. Examples are photosynthesis, carbon storage in biomass, soil carbon sequestration, marine carbon sequestration. Diagrams will vary.
2. Geological carbon sequestration is the process of storing CO_2 in underground geologic formations, or rocks. Typically, CO_2 is captured from an industrial source – such as steel or cement production, a power plant or natural gas processing facility – and injected into porous rocks for long-term storage. Examples are power plants and factories. Diagrams will vary.

Activity 2.7.1

1. The carbon footprint measures the total greenhouse gases (mainly CO_2) emitted by an activity, product or individual, expressed as CO_2 equivalent (CO_2e).

   Carbon footprint = activity level × emission factor
2. Diagrams will vary.

   Human activities that release carbon emissions include:
   - burning fossil fuels for electricity and heat – the largest source of carbon dioxide emissions
   - using cars, planes and ships, which burn fossil fuels

- cutting down trees, which releases absorbed carbon in the form of CO_2
- farming livestock, which produce methane, a potent greenhouse gas
- production of cement and steel, which releases significant amounts of CO_2.

3. Diagrams will vary. Refer to Table 2.6.

Chapter 3 Physics

Activity 3.1.1

Energy is the ability to do work (perform an action) or cause change.

Activity 3.2.1

Energy cannot be created or destroyed, only transferred and transformed. Diagrams will vary.

Activity 3.3.1

Answers will vary.

Activity 3.4.1

Answers will vary.

Activity 3.5.1

Answers will vary.

Activity 3.6.1

- In transverse waves, the particles oscillate up and down, which creates crests (high points) and troughs (low points). Examples are all electromagnetic waves, seismic S waves and waves created by moving a rope up and down.
- In longitudinal waves, the particles oscillate back and forth. There are areas where particles are very close to each other (compressions) and areas where particles are far apart from each other (rarefactions or expansions). Examples are sound waves and seismic P waves.
- In surface waves, the particles oscillate in a circular motion. Surface waves are considered a hybrid of transverse and longitudinal waves. Surface waves occur at the interface of two different mediums. When you throw a stone into water, the ripples occur because you cause a disturbance on the water's surface, which travels from one point to another. Examples are waves in water and seismic surface waves.

Activity 3.7.1

Wavelength (λ) is the distance (m) between two corresponding points on a wave (e.g. crest to crest); the distance a wave travels during one cycle.

Frequency (f) is the number of wave cycles per second. It is measured in hertz (Hz), 1 Hz = 1 cycle per second.

Amplitude is the height of a wave from the rest position; i.e. the distance between the central starting position and the maximum point of oscillation (crest or trough). It indicates the energy of the wave (higher amplitude = more energy).

Velocity (v) is how fast the wave travels (m s^{-1} or km s^{-1}). The velocity of both mechanical and electromagnetic waves depends on the medium they are travelling through. For example, sound waves travel through the air at 340 m s^{-1} and through water at 1500 m s^{-1}. Light waves travel through the air at 300 000 km s^{-1} and through water at 225 000 km s^{-1}.

Activity 3.7.2

Frequency and wavelength are inversely proportional. This means:

- the higher the frequency, the shorter the wavelength
- the lower the frequency, the longer the wavelength.

$v = f \times \lambda$

Activity 3.8.1

The particle model explains how energy moves through different forms of matter by the movement and interactions of particles. The wave model describes how all forms of energy in the electromagnetic spectrum travel as waves. These forms of energy do not require particles to vibrate to allow energy to travel.

Activity 3.8.2

Electromagnetic waves are transverse waves that can travel though matter as well as through a vacuum. An electromagnetic wave has an electric field and a magnetic field oscillating together on planes that are perpendicular to each other. The two oscillations are synchronised; therefore, they have the same frequency and wavelength. Refer to Figure 3.11.

Activity 3.8.3

1. The different electromagnetic waves make up the electromagnetic spectrum. Electromagnetic waves have a range of frequencies and wavelengths. The higher the frequency of the radiation, the more energy it has. Diagrams will vary.
2. radio waves < microwaves < infrared light < visible light < UV light < X-rays < gamma rays

Activity 3.8.4

Answers will vary.

Activity 3.9.1

Light is a form of energy that is transferred as a wave and is visible to the human eye. Light waves are electromagnetic waves, which means they involve oscillating electric and magnetic fields.

Activity 3.9.2

When light encounters matter, it can be:

- transmitted – passes through the substance. Regular transmission occurs when light passes directly through. Diffuse transmission occurs when light scatters as it passes through.
- reflected – bounces off the substance. Regular reflection occurs when light is reflected directly. Diffuse reflection occurs when light is scattered as it is reflected.
- absorbed – is trapped by the substance and energy is transformed into heat.

Activity 3.10.1

Sound is a form of energy that is transferred as a wave. Sound waves are mechanical waves involving the vibration of particles. Sound waves are longitudinal waves; the sound is the result of particles vibrating back and forth, in line with the direction the sound wave is travelling.

Sound can travel through solids, liquids and gases but not through a vacuum.

Examples of sound waves:

- a drum is struck, causing the drum skin to vibrate, which generates sound
- a speaker receives an electrical signal, causing it to vibrate back and forth, which generates sound
- your vocal cords vibrate, which produces your voice – sound.

Activity 3.11.1

Ultraviolet light, also called UV light, has wavelengths of 10–400 nanometers, shorter than those of violet light, but longer than X-rays. Some studies have shown that people under 30 years old can see some ultraviolet light, but this ability disappears with age.

The infrared spectral band begins with waves that are just longer than those of red light, so infrared is invisible to the human eye.

Activity 3.12.1

1. Energy cannot be created or destroyed; it can only be transferred and transformed.
2. Energy transfer is the movement of energy from one place to another. Energy transformation is when energy changes from one form to another. Diagrams will vary.

Activity 3.13.1

Thermal energy, or heat energy, is the energy resulting from the movement of particles (molecules and atoms) in a substance. Diagrams will vary.

Activity 3.13.2

1. Answers will vary.
2. Thermal conductors are essential for effective heat transfer in cooking and heating. Thermal conductors include metals such as iron and copper, ceramics and glass. Other materials are thermal insulators. These are materials that do not easily conduct heat and include rubber, plastic such as Styrofoam, gases such as air, and fibres such as wool. Thermal insulators are essential for preventing heat transfer. They are commonly used in clothing to retain warmth and in building insulation to improve energy efficiency.

3. Conduction is the movement of heat energy in a substance by direct contact between particles. The particles collide, forcing energy along an object. Conduction usually only happens in solids and liquids because their particles are closer together than in gases. Convection is the transfer of heat energy through indirect means. Heat transfer occurs in fluids when particles start to move faster as they heat up. Convection only happens in liquids and gases. Radiation is different from the other types of heat transfer. Radiation does not require particles for heat to be transferred; instead, heat is transferred through electromagnetic waves. Heat waves radiate out from a hot object in every direction. Any energy that can travel through space (a vacuum) is radiant energy.

Activity 3.14.1

1. Static electricity results from a build-up of electric charge on a surface. This occurs when two different materials are rubbed together. Electrons move from one material to the other so that the two materials have opposite charges. When two objects with opposite charges come near each other, there is electrostatic attraction between them. Diagrams will vary.
2. Answers will vary.
3. Answers will vary.

Activity 3.15.1

Diagrams will vary.

Activity 3.15.2

Answers will vary.

Activity 3.15.3

Voltage, current, resistance. Tables will vary.

Activity 3.15.4

Diagrams will vary.

Activity 3.15.5

Diagrams will vary.

Activity 3.15.6

When more light bulbs are added to a parallel circuit, the brightness of each bulb stays the same. In contrast, when more light bulbs are added to a series circuit, the brightness of each bulb is reduced.

Activity 3.16.1

The input energy of a light bulb is the supplied electrical energy. The output energy is the light and heat produced by the light bulb. The efficiency of a light bulb is a measure of how much of the input energy is converted to useful light energy.

Activity 3.16.2

1. A Sankey diagram is a type of flow diagram that visually summarises all the energy transfers taking place in a process. The thicker the line or arrow, the greater the amount of energy involved.
2. a. $\frac{100}{500} \times 100 = 20\%$ efficiency

   b. $\frac{400}{500} \times 100 = 80\%$ efficiency

   c. $\frac{80}{1200} \times 100 = 6.7\%$ efficiency

Chapter 4 Chemistry

Activity 4.1.1

1. a. Protons, electrons, neutrons

   b. Refer to Table 4.1.
2. Mass number = number of protons + number of neutrons
3. Atomic number is the number of protons in an atom; this determines the element.

Activity 4.2.1

The periodic table of elements arranges elements on the basis of their increasing atomic number.

Activity 4.2.2

Answers will vary.

Activity 4.2.3

There are 18 columns called groups. Elements in the same group have the same number of electrons in their outermost shells (valence electrons) and often have similar properties.
There are seven rows called periods. Elements in the same period have the same number of electron shells.

Activity 4.2.4

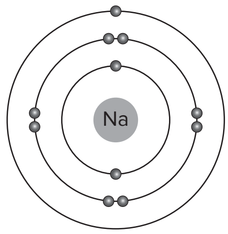
Electron shells are also called energy levels. Electron shells are the regions around the nucleus where electrons are most likely to be found. The shells represent different energy levels: the innermost shell has the lowest energy level and the outermost shell has the highest energy level. The shells closer to the nucleus are smaller and hold fewer electrons. The inner shells begin to fill up with electrons before the outer shells. Diagrams will vary.

Activity 4.3.1

To construct a Bohr diagram:

- draw the nucleus at the centre of the atom and represent it by the chemical symbol for the element
- find the atomic number of the element (number of protons = number of electrons in a neutral atom)
- fill the electron shells represented as rings around the nucleus; the first shell contains a maximum of 2 electrons
- create a new shell when all previous shells are at their maximum capacity.

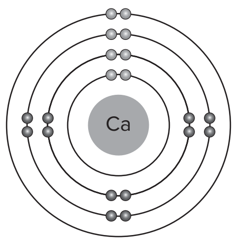
Activity 4.3.2



Sodium has 1 valence electron. These are the electrons in the outermost shell, which is the third shell in this case.

Electron configuration 2,8,1

Activity 4.3.3



Calcium has 2 valence electrons. These are the electrons in the outermost shell, which is the fourth shell in this case.

Electron configuration 2,8,8,2

Activity 4.4.1

Alpha decay is the ejection of alpha particles from a nucleus, which decreases atomic number and mass number. Alpha radiation can be blocked easily because the particles are large and slow and can only travel a few centimetres in air. However, if it is breathed in or ingested, it can be deadly.

Beta decay is the ejection of beta particles from a nucleus, which increases atomic number but not mass number. A beta particle is much smaller and faster than an alpha particle. A beta particle can only travel a few metres in the air. Beta particles can travel through skin easily and cause radiation burns, sickness and mutation. It can be blocked by a 1 mm thick sheet of aluminium.

Gamma decay is the emission of gamma rays from the nucleus. Gamma rays are not particles but are a type of electromagnetic wave, like X-rays but they have more energy. This type of decay does not release any particles but occurs when particles rearrange into new positions. This releases gamma radiation, a very powerful type of radiation that can cause significant damage and harm to living things. It can travel several hundred metres in air extremely quickly. Gamma radiation can pass through organs, skin and bones. The radiation can cause burns, sickness, mutation and cancer. Gamma radiation can be stopped or blocked by a thick slab of concrete or lead.

Diagrams will vary.

Activity 4.4.2

Natural radiation:

- solar radiation from the Sun
- cosmic radiation from stars
- terrestrial radiation from rocks and soil, including uranium
- internal radiation from within our bodies or other living things.

Human-made radiation:

- medical sources – X-rays, nuclear medicine
- consumer products – television, smoke detectors
- building materials and fuels.

Activity 4.4.3

Answers will vary.

Activity 4.4.4

1. Carbon dating, also known as radiocarbon dating, is a method for determining the age of once-living organisms by measuring the amount of carbon-14 remaining in the sample. It is commonly used in archaeology, palaeontology and geology to date ancient objects.
2. Charcoal from ancient fires and stone tools from the Madjedbebe Rock Shelter in Arnhem Land, Northern Territory, have been carbon dated and are more than 65 000 years old.

Activity 4.5.1

1. A chemical reaction is where the chemical nature of the matter has changed, and a new substance is formed. The atoms in the matter have rearranged to form something new. A chemical reaction involves two or more substances, known as reactants, interacting to form one or more new substances, known as products.
2. Word equations include the chemical names of all reactants and products. Formula equations include the chemical symbols for all reactants and products.
3. The law of conservation of mass says that the total number of each type of atom is the same before and after a reaction. Total mass of the products is equal to the total mass of the reactants. Although chemical reactions involve the formation of new substances, they don't involve the formation of new atoms. The only difference between reactants and products is how the atoms are arranged, which is a result of the breaking and forming of chemical bonds.

4. When a formula equation shows unequal numbers of atoms on either side of the equation, the equation is said to be unbalanced. To demonstrate the conservation of mass by having equal numbers of atoms on either side of the equation, the equation needs to be balanced. Equations are balanced by adding coefficients (numbers) in front of the chemical formulas of reactants and products. A balanced equation shows equal numbers of each type of atom on both sides of the equation.
5. Answers will vary.

Activity 4.6.1

1. Energy cannot be created or destroyed.
2. All chemical reactions involve energy changes and the transfer of heat energy. A reaction gives off heat, as observed by measuring the rise in temperature of the reaction with a thermometer. The chemical potential energy has not been lost; it has been converted to heat. Depending on the example, energy can be released or absorbed. An exothermic reaction releases energy in the form of heat, light and sound. Examples are combustion (burning wood), burning a candle and lighting a match. An endothermic reaction absorbs energy from the surrounding environment. Examples are cooking an egg and photosynthesis.

Activity 4.7.1

1. a. An acid is a chemical substance that can act as a proton donor. Examples: citrus fruits and vinegar
   b. A base is a chemical substance that accepts protons. Examples: cleaning bleach and soap
2. pH measures the acidity/alkalinity of a chemical on the pH scale, which is a scale from 0 to 14. Examples: lemon juice (acid), pure water (alkaline), bleach (base).

Activity 4.7.2

1. Acid–metal reaction – an acid reacts with a metal (such as iron or copper) to produce a salt and hydrogen gas.

   Acid + metal → salt + hydrogen gas

   Acid–base (or neutralisation) reaction – an acid reacts with a base and they neutralise each other to form a salt and water.

   Acid + base → salt + water

   Acid–carbonate reaction – an acid reacts with a carbonate to produce a salt, water and carbon dioxide gas.

   Acid + carbonate → salt + water + carbon dioxide gas
2. Baking soda is sodium bicarbonate, an alkaline chemical that reacts with acids when making a cake. For example, baking soda and lemon juice react to produce carbon dioxide gas. This is an example of an acid–carbonate reaction. This creates air pockets in a cake, allowing it to rise.

Activity 4.8.1

1. A fuel, oxygen and heat
2. Complete combustion occurs when there is plenty of oxygen available and produces carbon dioxide, water and energy:

   Reactants → products

   Fuel + oxygen gas → carbon dioxide + water + energy

   Fuel + O_2 → CO_2 + H_2O + energy
3. The reaction is exothermic, meaning the reaction releases heat (and light).
4. Incomplete combustion occurs when oxygen is limited and produces carbon monoxide, soot (carbon), water and less energy in the form of heat and light.

   Reactants → products

   Fuel + oxygen gas → carbon monoxide + carbon + water + energy

   Fuel + O_2 → CO + C + H_2O + energy
5. Answers will vary.

Activity 4.8.2

Complete combustion:

- produces the greenhouse gas CO_2, which contributes to global warming
- combustion of some fuels such as coal releases sulfur oxides and nitrogen oxides into the atmosphere, leading to acid rain.

Incomplete combustion:

- produces CO, a toxic gas harmful to humans and animals
- releases carbon particles (soot) into the air, contributing to air pollution.

Activity 4.9.1

1. Cellular respiration is a chemical process that takes place in the cells of living things and produces the energy that all living things need to survive. It is a slow, controlled form of combustion because it involves the reaction of glucose with oxygen to produce energy.

   Glucose + oxygen gas → carbon dioxide + water + energy

   $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy

2. $C_6H_{12}O_6$

6C	$6O_2 = 12O$
12H	$6CO_2$ = 6C and 12O
6O	$6H_2O$ = 12H and 6O

Yes, it is balanced.

Activity 4.10.1

Photosynthesis is the process by which plants produce their own food. Photosynthesis uses the energy of sunlight to synthesise glucose (and oxygen) from carbon dioxide and water.

Carbon dioxide + water $\xrightarrow{\text{sunlight}}$ glucose + oxygen

$$6CO_2 + 6H_2O \xrightarrow{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$

Activity 4.11.1

Answers will vary.

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