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SUMMARY GUIDES

Science

10

Geethanjali Michalik & Pat O'Shea

Summary Guides

Science 10

Geethanjali Michalik and Pat O'Shea

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Summary Guides – Science 10/Geethanjali Michalik and Pat O’Shea

Geethanjali Michalik and Pat O’Shea assert the moral right to be identified as the authors of this work.

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Insight Publications acknowledges the Traditional Custodians of the Country on which we meet and work, the Boonwurrung People of the Kulin Nation. We pay our respects to their Elders past and present, and extend that respect to all Aboriginal and Torres Strait Islander peoples.

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

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Introduction

The *Summary Guides – Science* series has been written by practising educators who are passionate about creating user-friendly, accessible guides for science.

The explanations and exercises in these guides develop core science knowledge and skills for personal, work and civic life, and provide the base knowledge to understand science comprehensively. Science will be part of your daily life no matter what you choose to do as an adult – understanding it will help you think critically and make sense of the world.

This book summarises key concepts clearly. It includes real-world examples, step-by-step explanations and exercises for you to complete. 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.

Gee and Pat

About the authors

Geethanjali Michalik is a dedicated educator with a strong background in science education and a passion for empowering learners through meaningful and accessible learning experiences. With experience in developing science programs in Australia and Singapore, Geethanjali has led teams in delivering high-quality, inquiry-based science education aligned with the Australian Curriculum.

In addition to her leadership in science education, Geethanjali is the founder of a girls' program dedicated to inspiring confidence, leadership and a passion for science, technology, engineering and mathematics (STEM) in young women. Through this initiative, she continues to advocate for inclusive and empowering learning environments. Her goal remains consistent: to create engaging, equitable and impactful learning opportunities that ignite a lifelong love of science.

Pat O'Shea is a passionate teacher with a long history of involvement in science education generally and chemistry teaching in particular. This involvement includes:

- roles with the VCAA developing resources for the VCE Chemistry course
- being an author or co-author of many textbooks and trial exams
- maintaining a website that distributes free resources for chemistry teachers
- many years of presentations with STAV (Science Teachers Association of Victoria).

Pat's emphasis has always been on investigative learning, where students are encouraged to develop their passion for science through hands-on experimentation.

Chapter 1 – Genetics

1.1 Biology overview

Biology is a branch of science that studies living things. A biologist is a scientist who studies biology. Biologists try to understand the natural world and everything that lives in it, including plants, animals, fungi, bacteria, viruses, algae and **protozoa**.

Key term

protozoa	tiny organisms made up of one cell; the word means ‘first animals’
-----------------	--------------------------------------------------------------------

By the end of this chapter, you will be able to:

- determine the relationship between genes, chromosomes and the deoxyribonucleic acid (DNA) of an organism’s genome
- understand how genetic information passed on to offspring from both parents by meiosis and fertilisation increases variation
- understand how Mendelian inheritance predicts the ratio of offspring genotypes and phenotypes in monohybrid crosses involving dominant and recessive alleles or in genes that are sex-linked
- comprehend pedigree diagrams showing patterns of inheritance of simple dominant and recessive characteristics
- grasp the concept of exploring environmental and other factors that cause mutations, and identify changes in DNA or chromosomes, exploring the role of DNA in cancer or genetic disorders
- understand First Nations peoples’ knowledges of heredity: kinship and family structures, especially marriage laws.

1.2 Introduction to genetics

In this chapter, we will be looking into how biology and structures within your cells make you, you – your **traits**. Traits can be physical (e.g. brown eyes, black hair) or behavioural (e.g. your hobbies).

Key term

trait	a distinguishing characteristic; can be physical or behavioural (e.g. your hair colour or what your hobbies are)
--------------	------------------------------------------------------------------------------------------------------------------

Activity 1.2.1

List all your physical and behavioural traits.

Physical traits

Physical traits can be acquired or inherited.

- Acquired traits are traits that you develop during your lifetime (e.g. pierced ears) because of the influence of lifestyle, experience or the environment. They are not coded for by DNA and so are not inherited from your parents.

- Inherited traits are traits that you inherit genetically, such as your eye colour. You gain these traits from your parents.

Activity 1.2.2

Categorise the physical traits you listed in Activity 1.2.1 as acquired or inherited. What do you notice?

1.3 Genes, DNA and chromosomes

What is a genome?

The **genome** is the complete set of instructions of an organism that are used to express physical traits. It includes all the DNA (or ribonucleic acid [RNA] in some viruses) that carries the instructions for the organism to develop and function.

Key term

genome	an organism's complete set of instructions, containing all the genetic information needed for it to develop and function
---------------	--------------------------------------------------------------------------------------------------------------------------

Why is the genome important?

Understanding the genome helps scientists:

- understand genetic diseases and develop treatments
- study evolution and how species are related
- improve agriculture by breeding plants and animals with desirable traits.

Genes

Your inherited traits are passed on from your parents through a molecule called a **gene**. Genes contain information or instructions to make specific proteins that are expressed as physical traits. Genes are made up of sequences of DNA.

Key term

gene	the basic unit of heredity; made of DNA
-------------	-----------------------------------------

Fun fact

The Human Genome Project was a massive international initiative to map the entire human genome. It started in 1990 and was completed in 2003, providing new opportunities to advance medicine and biology.

Deoxyribonucleic acid (DNA)

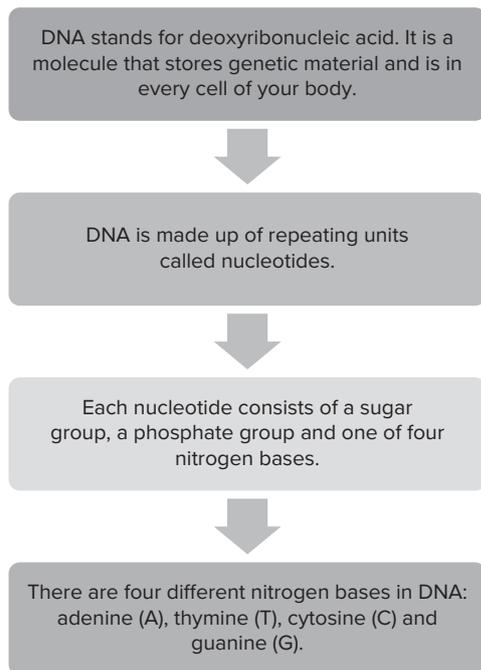


Figure 1.1: DNA explained

The four nitrogen bases pair with each other in the following ways.

- Adenine (A) pairs with thymine (T) ('apples in trees').
- Cytosine (C) pairs with guanine (G) ('cars in garages').

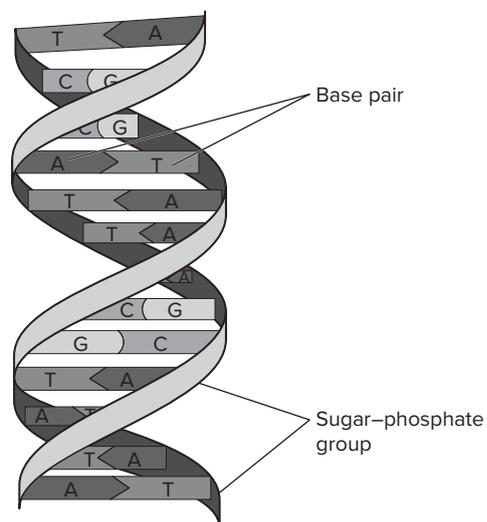


Figure 1.3: Nitrogenous base pairing: adenine (A) pairs with thymine (T) and cytosine (C) pairs with guanine (G)

This pairing forms chemical bonds called base pairs. The pairs of nitrogen bases form a spiral ladder structure that when packed tightly forms a double helix structure (Figure 1.3).

It is the unique and different sequences of these bases that codes for different genetic instructions and therefore different physical traits.

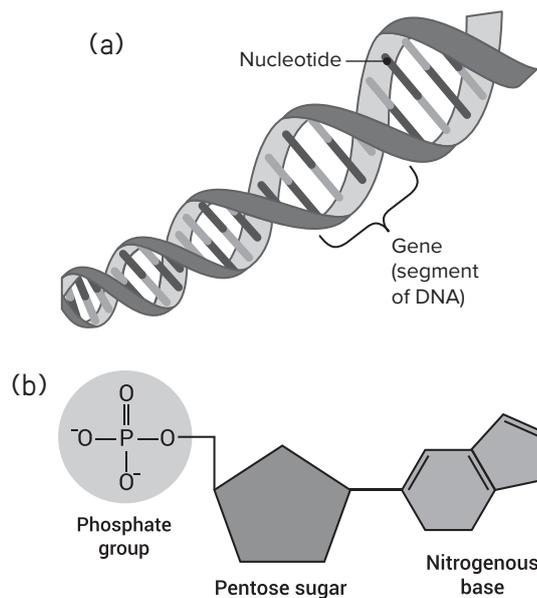


Figure 1.2: (a) A nucleotide and (b) its constituents: a phosphate group, a sugar group and a nitrogenous base

Chromosomes

Genes are short pieces of DNA that provide instructions for making proteins, which carry out various functions in the body. A single molecule of DNA tightly coils around proteins called **histones**. The many tight coils of DNA and histones form a structure called a **chromosome**.

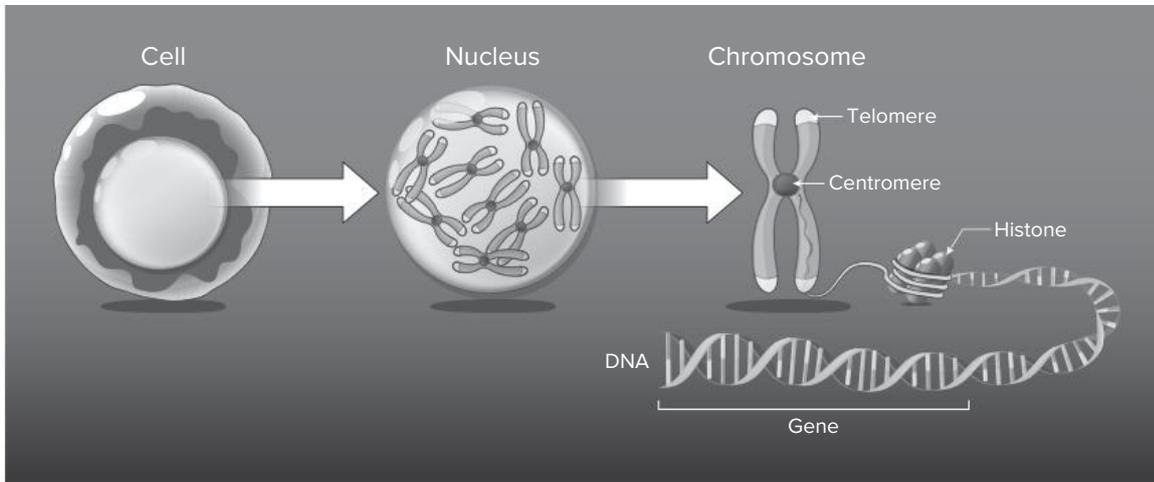


Figure 1.4: A chromosome, a gene and a DNA molecule. Telomeres are repetitive DNA sequences that protect the ends of chromosomes. The centromere links the two strands (chromatids) together, among many other functions.

Key terms

histone	a type of protein in chromosomes that binds to other chromosomes
chromosome	a structure made up of proteins and DNA organised into genes

Chromosomes exist in the nucleus of all your cells. Humans have 23 pairs of chromosomes in each cell. The two chromosomes in each pair are inherited from each parent. One of these pairs is the sex chromosomes (XX or XY).

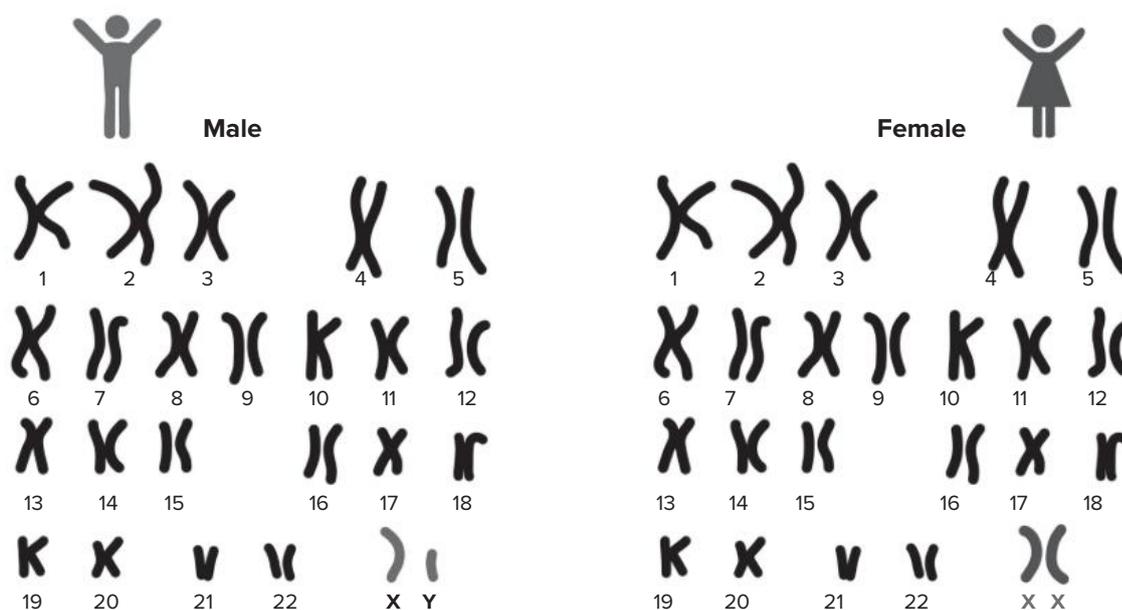


Figure 1.5: Humans have 23 pairs of chromosomes, including the sex chromosomes (XX = female, XY = male) and 22 autosomes.

Together, all the genes and chromosomes make up the genome of an organism. They carry the genetic information for that organism in every cell.

Alleles

An **allele** is a specific version of a gene. Although all individuals of a species have the same genes, the variations in these genes make individuals unique.

Key term

allele	a version of a gene
---------------	---------------------

You can think of the genome as being like a library containing all the information needed to build and maintain an organism. Each gene is like a book in the library, and alleles are the different editions of that book. While the general story remains the same, the details can vary, leading to differences in traits.

Alleles can be described as either dominant or recessive.

- A **dominant** allele is expressed in an organism's traits, even if only one copy is present. For example, in humans, brown eye colour is often dominant.
- A **recessive** allele is only expressed if both copies of the gene are the same. For instance, blue eye colour typically requires two copies of the blue allele.

Key terms

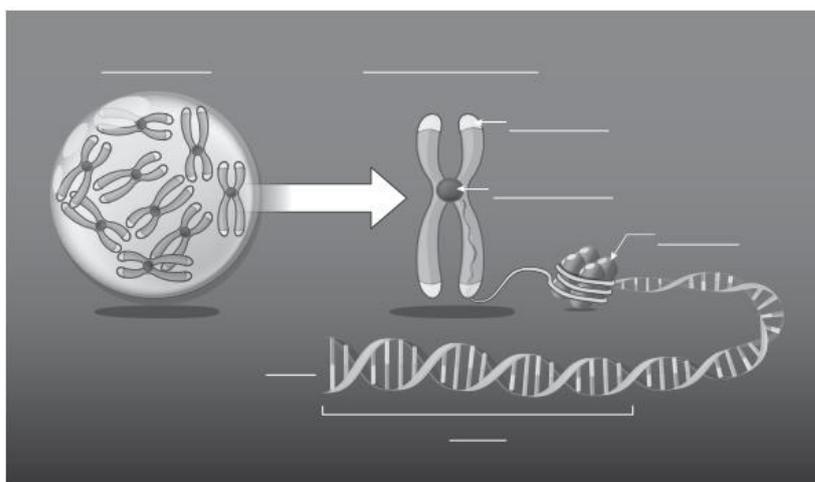
dominant	the allele expressed by an organism, even if only one copy is present
recessive	the allele that is only expressed when two copies are present

Fun fact

Corn has more genes than humans. Corn has about 32 000 genes, whereas humans have about 20 000 genes!

Activity 1.3.1

Label the following diagram with the correct terms.



1.4 How genetic information is passed to offspring

Genetic information is passed from parents to offspring through the process of **meiosis** and fertilisation.

In humans, during meiosis a cell that contains 46 chromosomes undergoes cell division to reduce the number of chromosomes by half. This produces sperm or egg cells (gametes) that have 23 chromosomes.

Key term

meiosis	cell division that results in four daughter cells that have half the number of chromosomes
----------------	--------------------------------------------------------------------------------------------

Meiosis

Meiosis occurs in specialised cells called germ cells in the reproductive organs (testes in males and ovaries in females). In humans, during meiosis, a cell that contains 46 chromosomes undergoes cell division to reduce the number of chromosomes by half. This produces sperm or egg cells called **gametes** with only 23 chromosomes, which are genetically unique. This process ensures that offspring inherit a mix of genetic material from both parents, increasing genetic variation within a population.

Key term

gamete	a reproductive cell containing one set of chromosomes
---------------	-------------------------------------------------------

When a sperm and an egg combine during fertilisation, the resulting **zygote** has a complete set of chromosomes – half from each parent. This restoration of chromosome number is critical for maintaining genetic stability across generations.

Key term

zygote	a fertilised egg cell formed when an egg cell is fertilised by a sperm cell.
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Phases of meiosis

Meiosis involves two rounds of division: meiosis I and meiosis II (Figure 1.6). Each phase is made up of specific stages (Table 1.1).

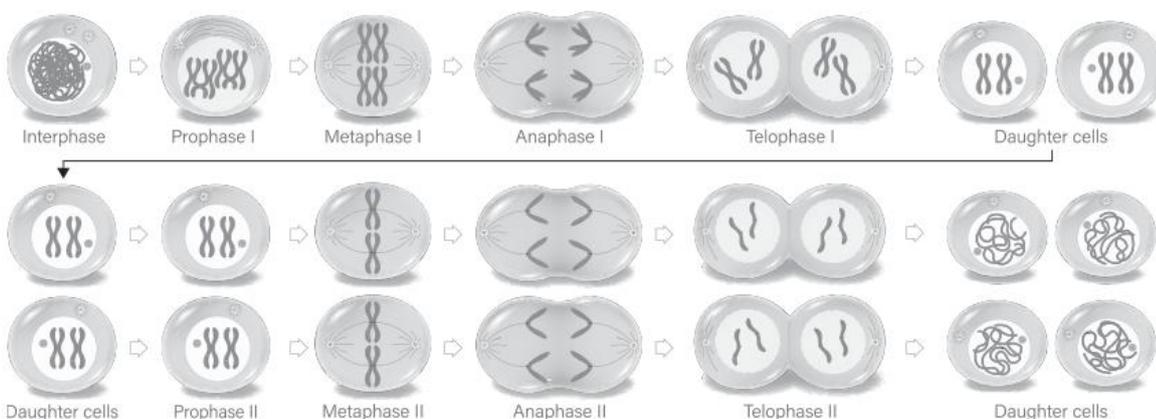


Figure 1.6: A summary of meiosis

Table 1.1: The stages of cell division

Stage	Description
Meiosis I: Reduction division	
Prophase I	<ul style="list-style-type: none"> Chromosomes become more compact and become visible. During a process called synapsis, pairing up of homologous chromosomes (a chromosome from each parent) occurs. During this pairing, genetic variation is introduced in a process called 'crossing over'. This is where sections of DNA are exchanged between chromosomes to create new combinations of alleles.
Metaphase I	<ul style="list-style-type: none"> The homologous chromosome pairs align in the centre of the cell. Another source of genetic variation occurs here due to the random orientation of each pair.
Anaphase I	<ul style="list-style-type: none"> The homologous chromosome pairs are pulled apart to opposite ends of the cell.
Telophase I and cytokinesis	<ul style="list-style-type: none"> The cell divides into two, each containing half the original number of chromosomes (the haploid number).
Meiosis II: Division of sister chromatids	
Prophase II	<ul style="list-style-type: none"> Within the haploid cells, the chromosomes begin to condense again.
Metaphase II	<ul style="list-style-type: none"> As in metaphase I, the chromosomes align in the centre of each cell.
Anaphase II	<ul style="list-style-type: none"> The sister chromatids separate and get pulled to the opposite end of the cell.
Telophase II and cytokinesis	<ul style="list-style-type: none"> The cells divide again, resulting in four haploid gametes, each with a unique combination of genetic material.

Importance of meiosis

- Genetic diversity: The genetic variation produced by meiosis is essential for evolution and adaptation.
- Prevention of chromosome disorders: Meiosis ensures the correct number of chromosomes in gametes. Errors in meiosis, such as a failure of chromosomes to separate, can lead to conditions such as Down syndrome, in which an individual has an extra chromosome 21.

Fertilisation

Genetic variation is further increased during fertilisation when genetic material from two parents combines. This variation is crucial to evolution because it provides a population with the ability to adapt to changing environments and disease.

This genetic variation ensures resilience in crops, as diverse traits can help plants survive diseases or environmental changes. For example, a farmer cross-pollinates two varieties of apples – one that is sweet and one that is tart. The offspring apples inherit a mix of genetic traits due to the process of meiosis (which creates diverse gametes) and fertilisation (which combines DNA from both parent apples).

Fun fact

The chances of two siblings (excluding identical twins) inheriting exactly the same genetic make-up are approximately one in 70 trillion!

Activity 1.4.1

Simulate meiosis with coloured beads or pipe cleaners to represent chromosomes. Show how crossing over creates unique gametes.



1.5 Mendelian inheritance and monohybrid crosses

Austrian scientist Gregor Mendel (1822–1884) developed the Mendelian inheritance concept to explain how traits are passed from one generation to the next.

Mendel experimented with pea plants to show that traits are determined by pairs of alleles, one inherited from each parent. As discussed earlier, these alleles can be dominant or recessive.

- Dominant alleles are expressed over the recessive alleles when both are present. Dominant traits are present in every generation and are represented by capital letters (e.g. AA, Aa).
- Recessive alleles are only expressed when two copies are present. Recessive traits skip generations and are represented by lower case letters (e.g. aa).

Genotype

The **genotype** is the set of genes inherited from an organism's parents and is encoded in the DNA and made up of alleles. The specific trait that is expressed is determined by the unique combination of these alleles.

For example:

- **Homozygous** dominant (AA): both alleles are dominant.
- Homozygous recessive (aa): both alleles are recessive.
- **Heterozygous** (Aa): one allele is dominant and the other is recessive.

Key terms

genotype	an individual's complete set of genetic material
homozygous	having two identical alleles of a gene
heterozygous	having two different alleles of a gene

Phenotype

The **phenotype** is the physical trait that can be observed in an organism. Examples of phenotypes are eye colour and hair texture in humans, and flower colour in plants.

While the genotype provides the potential for a particular trait, the phenotype is what we can see or measure. Environmental factors, such as diet, climate and lifestyle, can influence the phenotype and how it is expressed.

Key term

phenotype	the set of physical traits of an individual
------------------	---------------------------------------------

Mendel's experiment

In a **monohybrid cross**, one trait is studied. A homozygous dominant individual is crossed with a homozygous recessive individual. When two organisms mate, their offspring inherit a combination of genes from each parent. This event is called a genetic cross.

For example, in Mendel's pea plant experiments, flower colour is determined by a single gene:

- genotype AA or Aa: purple flowers (dominant trait)
- genotype aa: white flowers (recessive trait).

The possible genotypes and phenotypes of offspring can be predicted using a **Punnett square**.

To use a Punnett square:

- Determine the genotype of each parent. Mendel looked at homozygous purple flowers (AA) and homozygous white flowers (aa).
- Split the alleles for each parent and add them around the edges of the Punnett square.
- Work out the new possible genetic combinations inside the Punnett square.

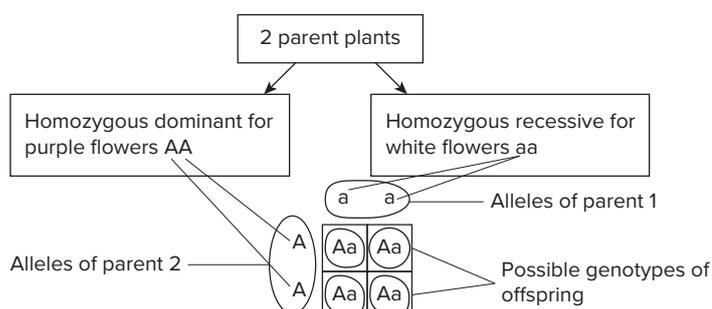


Figure 1.7: Mendel's monohybrid cross between a plant that was homozygous for purple flowers (AA) and a plant that was homozygous for white flowers (aa)

Key terms

monohybrid cross	a cross between two homozygous organisms to study the inheritance of a single characteristic or gene
Punnett square	a grid used to predict the possible genotypes of offspring in a cross between two individuals

The Punnett square predicts that the genotypes of the offspring would all be heterozygous Aa. Therefore, all four plants would have purple flowers because the dominant trait would be expressed in their genotype (Aa).

The second generation of these plants would involve a cross between two individuals with the genotype Aa, as shown in Figure 1.8.

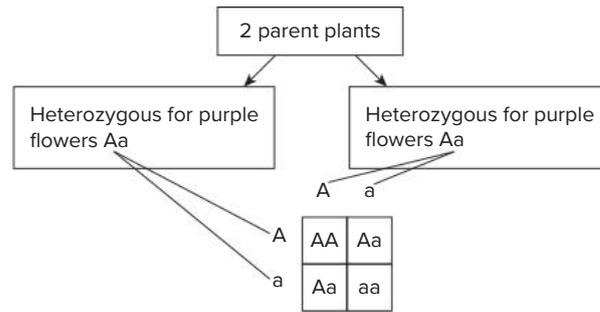


Figure 1.8: Mendel's cross between two plant that were both heterozygous for purple flowers (Aa)

This time, the Punnett square predicts that the offspring genotypes would be AA, Aa, Aa and aa. Both AA and Aa genotypes produce purple flowers. Therefore, the phenotypic ratio would typically be:

AA, Aa, Aa (dominant) : aa (recessive)

3 : 1

There would be three purple-flowered plants to every one white-flowered plant.

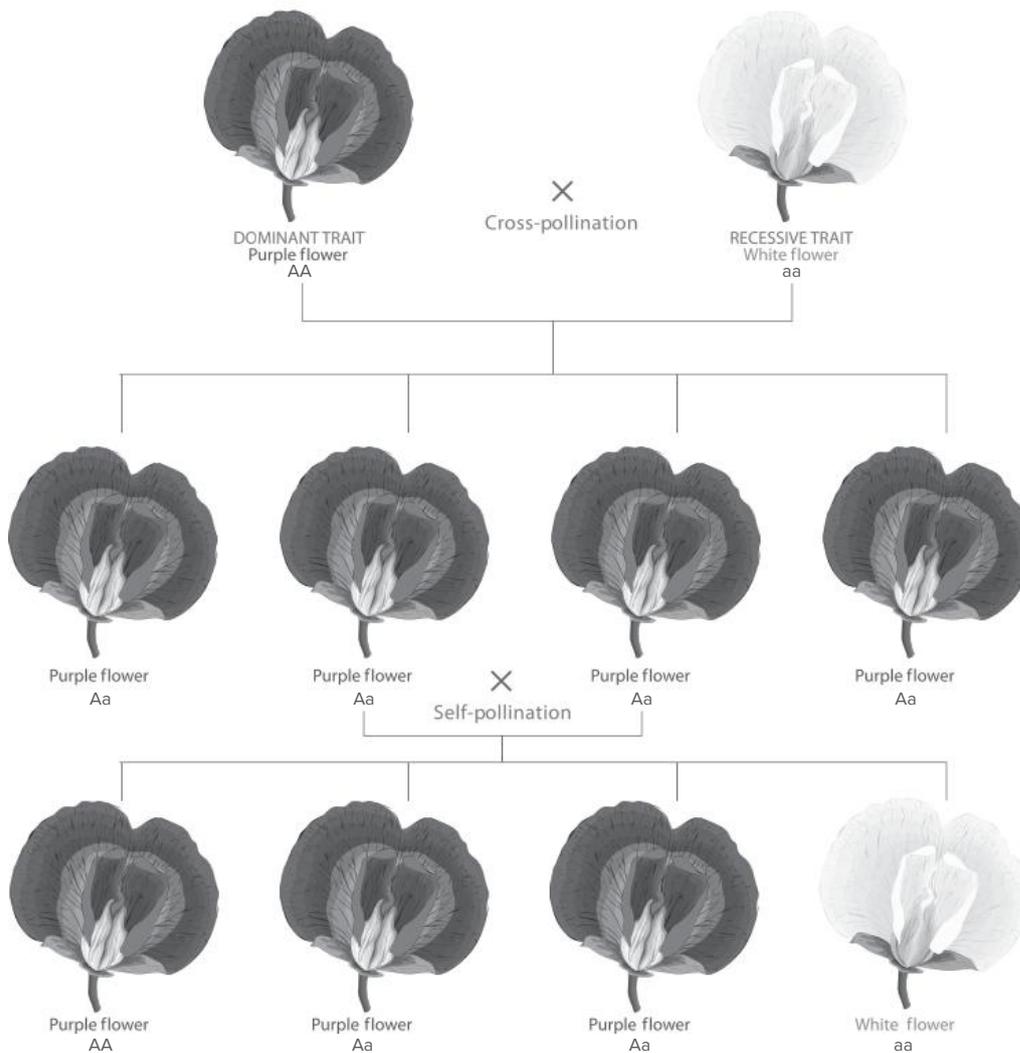


Figure 1.9: Mendel's monohybrid cross experiment

Activity 1.5.1

In pea plants, tall (T) is dominant to short (t). A heterozygous tall plant is crossed with a homozygous short plant.

1. Draw a Punnett square to show the cross.
2. What are the possible genotypes and phenotypes of the offspring?
3. What is the probability of having a tall plant?

Activity 1.5.2

In guinea pigs, black fur (B) is dominant to white fur (b). Two heterozygous guinea pigs are crossed.

1. Use a Punnett square to predict the offspring's genotypes and phenotypes.
2. What percentage of the offspring will have black fur?
3. What percentage will have white fur?

Activity 1.5.3

Earlobe attachment is controlled by a single gene, where free earlobes (F) are dominant to attached earlobes (f). A person with free earlobes (heterozygous) and a person with attached earlobes have children.

1. Use a Punnett square to predict the genotypes and phenotypes of their children.
2. What is the probability of their child having attached earlobes?

Sex-linked traits

Some traits are carried on the sex chromosomes X and Y. They are called sex-linked traits. Since females have two X chromosomes (XX) and males have one X and one Y (XY), sex-linked traits can affect males and females differently. A trait is sex linked if it does not affect males and females equally.

Because males only have one X chromosome, they are more likely to express recessive sex-linked traits than females who have two X chromosomes.

Most sex-linked traits occur on the X chromosome because it carries many more genes than the Y chromosome. Those on the X chromosome are referred to as X-linked traits. For example, red-green colour blindness is much more common in males because males only have one X chromosome. If that X chromosome carries a gene for colour blindness (represented as X^c), they will show the trait. But females would need to inherit two copies of the gene (X^cX^c) to be colourblind. If a female has one normal X (X) and one with the trait (X^c), she is called a **carrier** – she doesn't show symptoms but can pass the gene on.

How to write sex-linked genotypes

The specific alleles are represented by superscripts on the X chromosome:

- X = normal vision
- X^c = colourblind gene
- Y = Y chromosome (no superscript because it usually doesn't carry the same trait)

Therefore, a:

- colourblind male = X^cY
- male with normal vision = XY
- female with normal vision = XX
- female carrier = X^cX
- colourblind female = X^cX^c

Some traits are Y-linked, meaning the gene is found only on the Y chromosome and therefore is only passed from father to son. These are much rarer but include traits such as excessive hair growth on the ears.

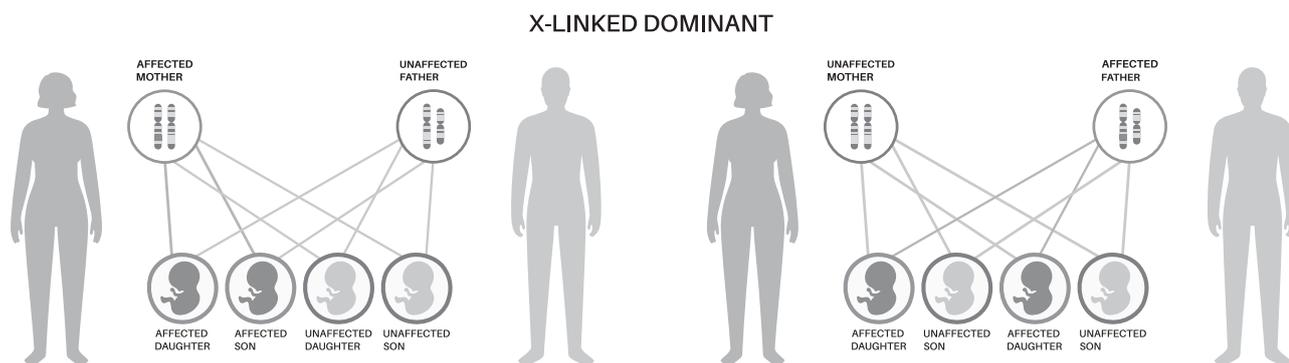


Figure 1.10: Sex-linked traits are carried on the X or Y chromosome. Here the sex-linked trait is carried on the X chromosome.

Key term

carrier	an individual who can pass an inherited (genetic) disease to their children but who does not have the disease
----------------	---------------------------------------------------------------------------------------------------------------

A carrier mother (X^cX) and a normal vision father (XY) have children. The offspring produced could be XX (daughter with normal vision), X^cX (carrier daughter), X^cY (colourblind son) and XY (son with normal vision).

	X^c	X
X	X^cX	XX
Y	X^cY	XY

Activity 1.5.4

Use coloured dice to simulate genetic crosses. Assign each colour to a different allele and roll to determine offspring combinations.

Aim

To understand how traits are inherited through genetic crosses by simulating allele combinations using coloured dice.

Materials

- 2 different-coloured six-sided dice (e.g. red and blue)
- Pen or pencil and worksheet or notebook
- Key that matches each die colour to a parent
- Trait to investigate (e.g. pea plant height, guinea pig fur colour, earlobe attachment)
- Allele key (e.g. T = tall, t = short)

Procedure

1. Set up the allele key. Choose a trait to model; for example:
Trait: Height in pea plants
Dominant allele: T (tall)
Recessive allele: t (short)
2. Assign numbers 1–3 to one allele and 4–6 to the other on each die. For example:
Numbers 1–3 = T
Numbers 4–6 = t
(This means each allele has a 50% chance of being selected, simulating a heterozygous parent.)
3. Assign dice to parents. For example:
Red die = Parent 1
Blue die = Parent 2
You can change dice colours or assignments depending on the parent genotypes you want to simulate.
4. Choose parent genotypes. For example, cross Tt × Tt (both heterozygous tall pea plants).
5. Roll the dice one at a time.
Use the number from each die to determine which allele each parent contributes.
Record the offspring genotype (e.g. Tt, TT or tt).
Repeat for at least 20 rolls to gather enough data.
6. Record and organise data by creating a tally chart or table to record how many offspring have each genotype.

1.6 Pedigree diagrams

Another tool we can use to trace inheritance, especially through generations, is a **pedigree diagram**. Pedigree diagrams use symbols to represent individuals in a family and lines to show relationships over many generations.

Key term**pedigree diagram**

a chart that tracks the inheritance of a trait through generations of a family

Figure 1.11 shows a pedigree diagram and the symbols used to construct it.

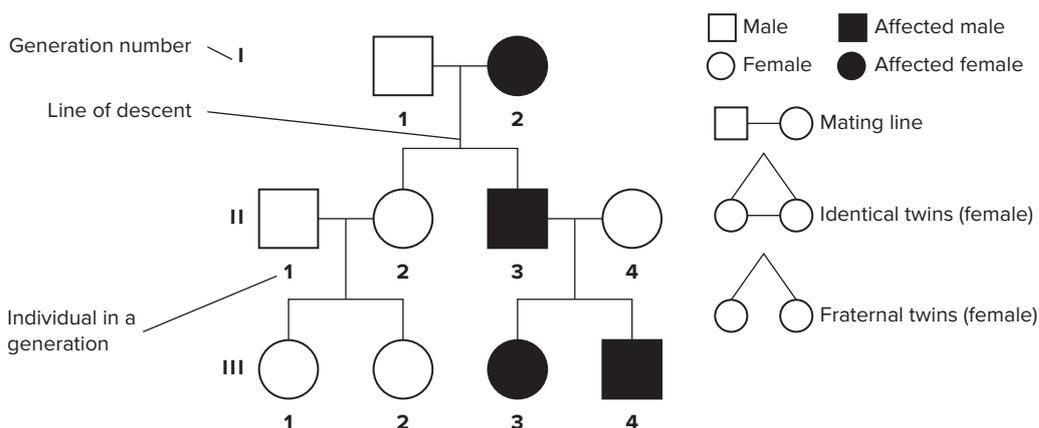


Figure 1.11: A pedigree diagram. Roman numerals symbolise generations. Arabic numerals symbolise individuals within a generation with birth order from left to right.

A pedigree diagram can be used to:

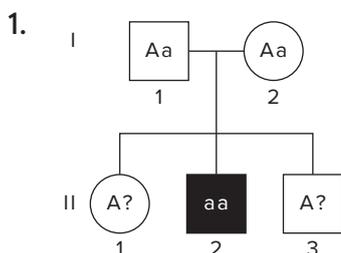
- determine whether a trait is dominant or recessive
- predict the likelihood of a trait appearing in future generations.

Example

In a family, a genetic condition is inherited in a recessive pattern. The condition is represented by the allele *a*, while the normal (unaffected) allele is *A*. The parents are Individual I-1 (male) and Individual I-2 (female) and both unaffected. They have three children: Individual II-1 (unaffected female), Individual II-2 (affected male) and Individual II-3 (unaffected male).

1. Draw a pedigree diagram for this family, indicating the genotypes of each individual. Use *AA*, *Aa* and *aa* as required.
2. Explain how Individual II-2 inherited the condition.
3. What is the probability that Individual II-1 is a carrier (*Aa*)?

Answers



2. Individual II-2 inherited one recessive *a* allele from each parent. Both parents must be carriers of the recessive allele (*Aa*) since they are unaffected but produced an affected child (*aa*).
3. Individual II-1 is unaffected so has genotype *AA* or *Aa*. According to Mendelian inheritance the probabilities of the different genotypes from an *Aa* × *Aa* cross are *AA* 25%, *Aa* 50% and *aa* 25%. Individual II-1 is unaffected, so she is not *aa*. Therefore, she is either *AA* or *Aa*, and the probability that she is a carrier (*Aa*) is 2 out of 3, or 67%.

Activity 1.6.1

In a family, a rare genetic condition is observed.

Generation 1: Individual I-1 (male, affected) marries Individual I-2 (female, unaffected).

Generation 2: They have four children: Individual II-1 (female, unaffected), Individual II-2 (male, affected), Individual II-3 (male, unaffected) and Individual II-4 (female, unaffected).

1. Draw a pedigree diagram for the family.
2. Based on the pedigree, determine whether the condition is dominant, recessive or sex-linked. Justify your answer.

1.7 Genetic mutations

Mutations are changes to the DNA sequence. They can be due to environmental factors (e.g. UV radiation, chemicals and viruses), and errors during DNA replication or cell division.

Some mutations are harmless, but others can cause significant changes in traits and lead to genetic disorders. For example, extended exposure to UV rays can damage the DNA in skin cells, which can lead to melanoma (skin cancer).

Point mutations occur on a single nucleotide and can result in diseases such as sickle cell anaemia.

Chromosomal mutations occur where there are duplications or deletions of chromosome segments, as seen with conditions such as Down syndrome.

Key term

mutation	a change to the structure of a gene
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DNA and cancers

Cancer can occur when mutations result in changes in the normal functioning of genes, in particular, when there are changes to cell growth and division.

For example, mutations in the *BRACA1* and *BRACA2* genes have shown an increased risk of breast and ovarian cancer. Research into these mutations helps scientists develop targeted treatments and preventative measures, such as regular screenings or lifestyle changes. Early detection of these mutations is important for guiding preventative treatment.

Activity 1.7.1

Research a specific genetic disorder or cancer type and create an infographic explaining its causes, symptoms and treatments.

1.8 First Nations peoples' knowledge of heredity

Marriage systems play a vital role in preventing the transmission of genetic conditions to future generations. Aboriginal and Torres Strait Islander peoples have long understood that certain traits and characteristics are passed down through family lines. Traditional kinship structures are designed to prevent closely related individuals from marrying, thereby reducing the likelihood of hereditary conditions, such as diseases or genetic abnormalities, being passed on.

Aboriginal and Torres Strait Islander peoples developed a deep understanding of hereditary traits and patterns of inheritance long before modern science revealed the existence and function of DNA and genes. This knowledge, akin to the work of Gregor Mendel in the 19th century, allowed them to observe how traits and illnesses could emerge in offspring from closely related individuals. Their kinship systems are highly intricate, providing a framework for identifying familial connections and relationships through 'skin names', which denote lineage and bloodlines.

Aboriginal kinship systems typically include three levels of organisation: moiety, totem and skin names, which are based on either the mother's or the father's lines of descent. These groups are unrelated to skin colour and instead serve as a way to identify relationships and societal roles. A critical function of skin groups is determining marriage eligibility, as they strictly define who individuals can and cannot marry.

End-of-chapter summary

- Genetics is a fascinating field that studies the intricate mechanisms of heredity and variation.
- Genes, chromosomes and DNA determine the traits and diversity seen across generations.
- Processes such as meiosis and fertilisation increase genetic variation.
- Mendelian principles provide predictive frameworks for inheritance patterns, as do tools like pedigree diagrams.
- Advanced research into mutations offers practical applications in medicine, agriculture and conservation.
- Integrating First Nations knowledge further enriches our understanding, demonstrating the importance of genetic diversity and sustainable practices.

Revision questions

1. What is the relationship between genes, chromosomes and DNA?
 - A. DNA is made of genes, which are stored in chromosomes.
 - B. Genes are made of DNA, and DNA is stored in chromosomes.
 - C. Chromosomes are made of DNA, and genes are stored in proteins.
 - D. DNA and chromosomes are made of genes.
2. How many chromosomes are in a human gamete?
 - A. 23
 - B. 46
 - C. 92
 - D. 12
3. Which of the following is an example of a dominant allele?
 - A. t (short plant)
 - B. B (brown eyes)
 - C. b (blue eyes)
 - D. r (wrinkled seeds)

4. What does a shaded square in a pedigree diagram represent?
 - A. A male who does not have the trait
 - B. A female who does not have the trait
 - C. A male who has the trait
 - D. A female who has the trait
5. What is the main cause of mutations that lead to skin cancer?
 - A. Inherited DNA changes
 - B. Exposure to UV radiation
 - C. Poor diet
 - D. Lack of physical activity
6. Explain how fertilisation contributes to genetic variation in offspring.
7. What is the difference between dominant alleles and recessive alleles?
8. What is a mutation, and how can it affect an organism?
9. A heterozygous tall plant (Tt) is crossed with a short plant (tt).
 - a. Draw a Punnett square for this cross.
 - b. What percentage of the offspring will be tall?
 - c. What percentage of the offspring will be short?
10. A pedigree diagram shows that a trait is present in every generation and affects males and females equally.

Is this trait likely dominant or recessive? Explain your reasoning.
11. A couple are both carriers of a recessive genetic disorder (Ss × Ss).
 - a. What is the probability that their child will inherit the disorder?
 - b. Explain how this probability is calculated.

Chapter 2 – Evolution and adaptation

2.1 Evolution and adaptation

We have learned how variations in our genes result in our unique traits. We can see this genetic variation in all living things. This diversity of life on Earth and how organisms adapt to their environments is explained by the process of evolution.

By the end of this chapter, you will be able to:

- outline processes involved in natural selection, including variation, isolation and selection, and examine biodiversity as a function of evolution
- analyse evidence for the theory of evolution and investigate changes caused by natural selection in a particular population, such as artificial selection
- relate genetic characteristics to survival and reproductive rates
- investigate some of the structural and physiological adaptations of First Nations peoples to the Australian environment.

2.2 Evolution

Evolution is the process in which variations in the genetic make-up of a species happen over time to adapt to its environment and improve its survival. Evolution's definition doesn't refer to changes in a whole species; it refers to populations instead. A population is a group of organisms of the same species living in the same place.

Key term

evolution	the change in the heritable characteristics of populations over successive generations
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We can observe evolution in cane toads. Over generations, cane toads in Australia have adapted to their new environment by developing longer legs, which has enabled the toads to spread more rapidly.

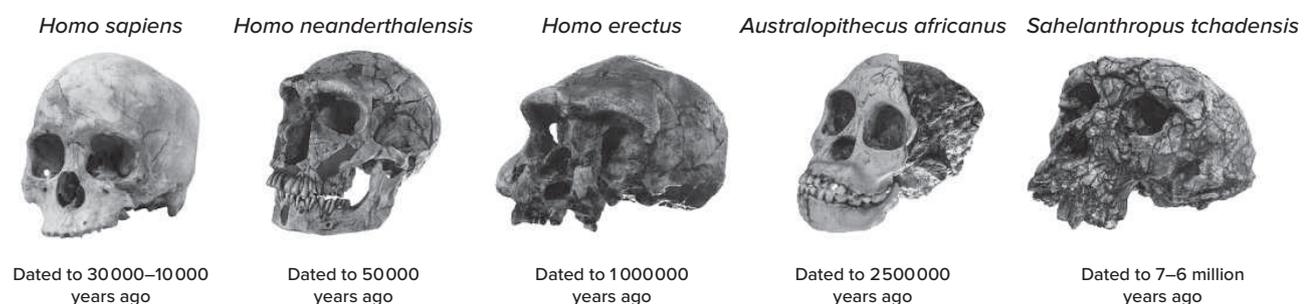


Figure 2.1: Evolution of the human skull

2.3 Natural selection

Central to the theory of evolution is a concept called **natural selection**, which is a mechanism that drives these changes by favouring traits that enhance survival and reproduction. It supports the development of new species and increases **biodiversity**.

Key terms

natural selection	the process by which organisms that are better adapted to their environment tend to survive and reproduce more successfully, passing on their advantageous traits to their offspring
biodiversity	the large range of different life forms in an ecosystem

Natural selection operates through three key processes that shape the evolution of species over generations.

- Variation:** Variation is the differences in traits in individuals within a population due to genetic mutations, recombination during meiosis and random fertilisation (e.g. variations in fur colour in rabbits [Figure 2.2]).

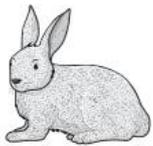
Allele	C	c^{ch}	c^h	c
Genotype	CC	$c^{ch}c^{ch}$	c^hc^h	cc
Phenotype	 Wild type: brown fur	 Chinchilla: black-tipped white fur	 Himalayan: white fur with black paws, nose, ears and tail	 Albino: white fur

Figure 2.2: Variation in fur colour of rabbits is controlled by genes.

- Isolation:** Isolation describes how populations may evolve independently when they are separated from each other by physical barriers. For example, unique species of finches on the Galapagos Islands evolved after being isolated from mainland finches.
- Selection:** Selection occurs when traits that improve survival or reproduction are favoured over others. As a result, these traits become more common in future generations. For example, lighter-furred rabbits might have a survival advantage in a snow environment because they are less visible.

Any challenge that affects an organism's ability to survive in a particular environment is called a selection pressure. Examples include:

- hunting by predators
- access to resources
- environmental factors



Figure 2.3: Rabbits in a snow environment

- vulnerability to diseases
- human activities (e.g. hunting and pollution).

Antibiotic resistance

When antibiotics are used to treat bacterial infections, some of the bacteria will have certain mutations that make them resistant to the antibiotic. The antibiotic-resistant bacteria survive and reproduce and so the number of antibiotic-resistant bacteria increases (Figure 2.4). They can also transfer their antibiotic-resistant genes to other bacteria. It is important to use antibiotics responsibly to slow their evolutionary process.

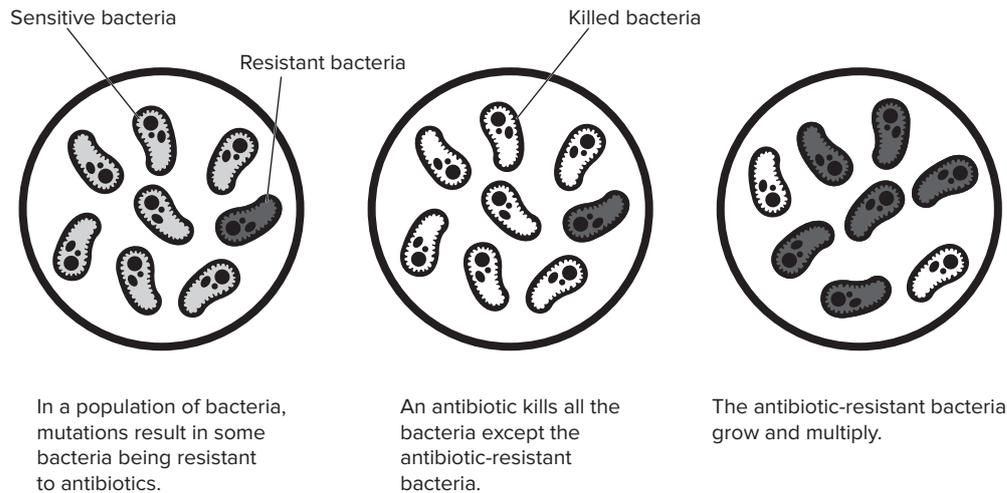


Figure 2.4: Antibiotic resistance in bacteria

Activity 2.3.1

A population of beetles with green and brown colouration lives in a forest. Over time, the forest floor becomes covered in brown leaves. Predict what might happen to the population colouration and explain your reasoning.

2.4 Theory of evolution

Early ideas about life

For most of history, people believed that living things had always been the same. But as explorers and scientists studied the natural world, they found fossils of strange creatures that no longer existed.

Lamarck's hypothesis: can traits be passed on from use?

One of the first scientists to propose an explanation was Jean-Baptiste Lamarck (1744–1829) in the early 1800s. He suggested that animals change during their lifetimes depending on how they use their bodies. These changes get passed to their offspring.

For example, Lamarck thought that if a giraffe stretched its neck to reach high leaves, its offspring would inherit a longer neck. Over generations, giraffes would continue to develop longer necks.

However, we now know this idea is incorrect. A person who lifts weights and builds muscle does not pass on those larger muscles to their children!

Darwin's journey: observing nature's patterns

A few decades later, Charles Darwin (1809–1882) set out on a five-year journey aboard the HMS *Beagle* to study plants, animals and fossils around the world. His most famous discoveries came from the Galápagos Islands, where he noticed that finches had different types of beaks on different islands.

Some finches had strong beaks for cracking seeds, while others had thin beaks for catching insects.

This led Darwin to ask why the same type of bird had different features depending on where it lived.

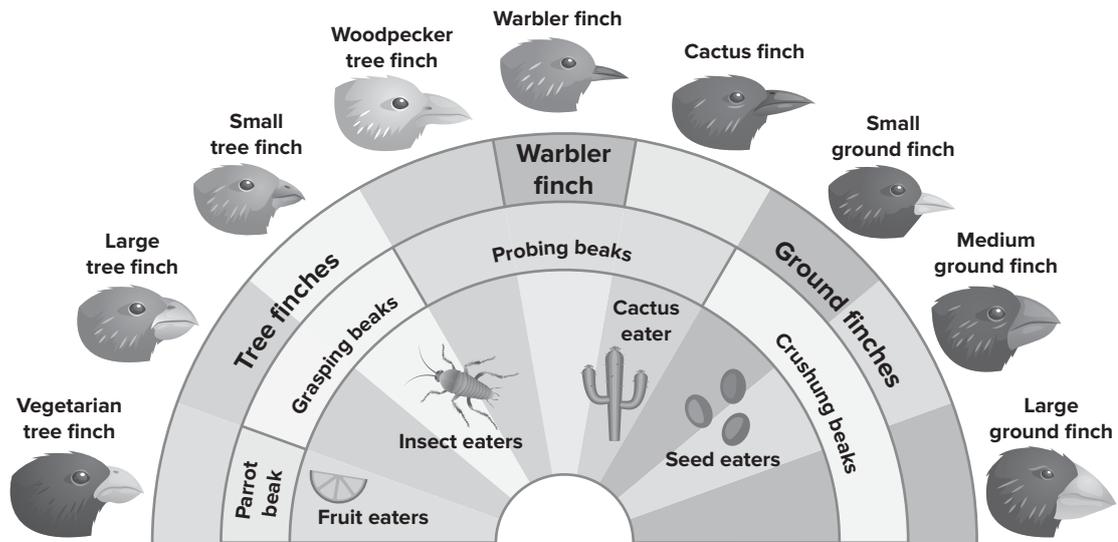


Figure 2.5: Biodiversity of finches in the Galapagos Islands

After years of research, Darwin developed a groundbreaking idea: species change over time because individuals with helpful traits are more likely to survive and reproduce.

The role of genetics: completing the puzzle

Darwin knew traits were inherited, but he didn't know how. At the same time, Gregor Mendel was experimenting with pea plants and discovering patterns of inheritance (which later became genetics).

Much later, scientists combined Darwin's theory of natural selection with Mendel's discoveries about genes to explain how evolution works at a deeper level, as discussed in the previous chapter.

Today, we also know that mutations – random changes in DNA – introduce new traits. If these traits are beneficial, then they help species adapt to their environments.

Modern evidence for evolution

Darwin's ideas were controversial at first, but today, evolution is widely supported by scientific evidence.

- **Fossil records:** Fossils give us a way of seeing how organisms have changed over millions of years. *Archaeopteryx* is a **transitional fossil** because it has features of both birds and reptiles, highlighting evolutionary links between these two organisms.

Key term

transitional fossil	a fossil that has traits of both ancestral and descendant groups
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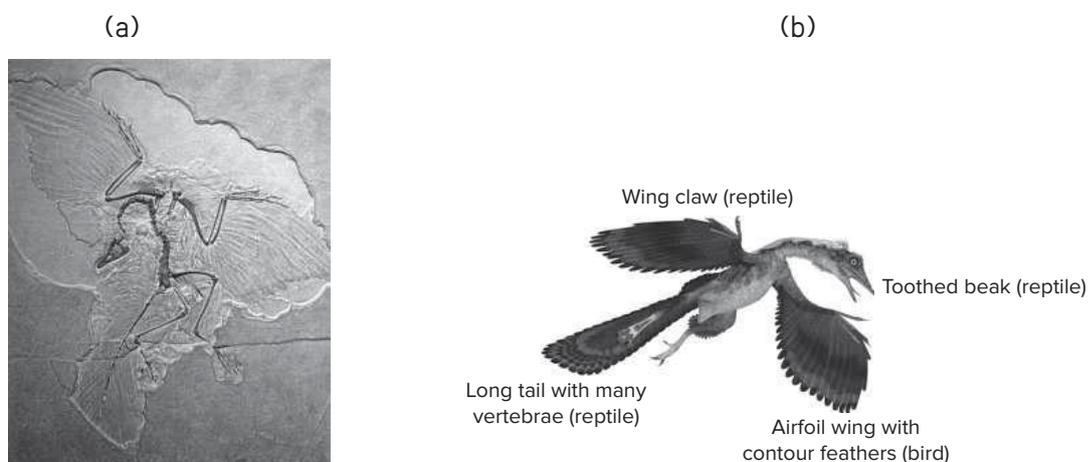


Figure 2.6: (a) An *Archaeopteryx* fossil and (b) a 3D illustration showing its features

- **Comparative anatomy:** Similarities in anatomical structures of different organisms suggest evolution from a common ancestor. For example, bats, whales and humans have the same basic forelimb bone structure adapted to different functions: flying, swimming and grasping.

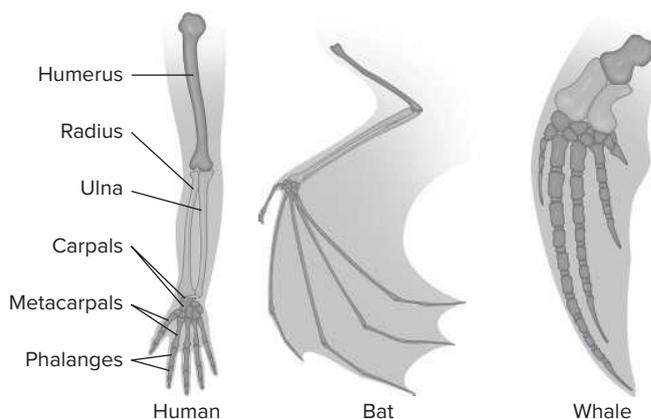


Figure 2.7: Bone structure similarities of humans, bats and whales

- **Molecular biology:** Similarities in the DNA and proteins of different species indicates a close evolutionary relationship. For example, humans and chimpanzees share 98 per cent of DNA, indicating common ancestry.
- **Observable evolution:** Changes within populations can be observed over a relatively short period of time. For example, in England before industrialisation, peppered moths were more commonly light-coloured and they blended in with lichen-covered trees, avoiding predation by birds. However, as soot from factories darkened the trees, darker moths gained a survival advantage and the population of the peppered moth transitioned to mainly the dark-coloured ones.

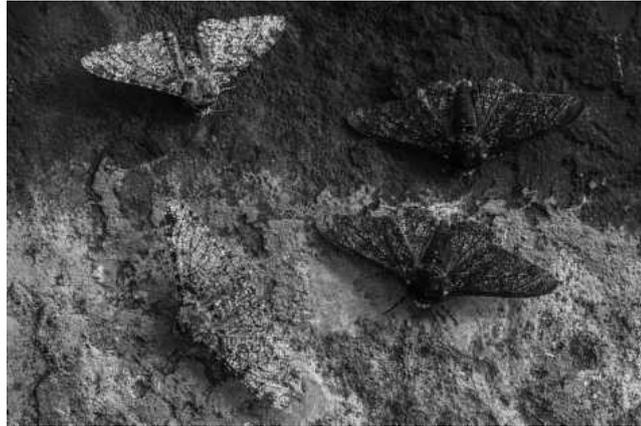


Figure 2.8: Lighter and darker peppered moth populations are selected for different environments.

Artificial selection

Selection and biodiversity can be influenced by **artificial selection**. For example, humans have intentionally bred plants and animals for desired traits. Domestic dogs were bred from wolves to produce a wide variety of breeds with specific characteristics.

Key term

artificial selection	a process in which humans choose organisms with specific traits to breed, aiming to increase the frequency of the traits in future generations
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Why evolution matters

Understanding evolution helps scientists solve real-world problems, from developing better medicines to protecting endangered species. It explains why diseases change over time and how plants and animals adapt to different environments.

Activity 2.4.1

There are two species of birds on separate islands:

- Bird A has a short, strong beak for crushing nuts.
- Bird B has a long, thin beak for catching insects.

How might these birds have evolved to have different beaks? What environmental factors might have influenced their traits?

2.5 Genetic characteristics and survival

As seen in the case of the peppered moth, genetic variation of traits plays a crucial role in determining an organism's ability to survive and reproduce.

As discussed in Chapter 1, genes are segments of DNA that determine traits such as eye colour and blood type. Genetic traits that increase an individual's ability to survive and produce offspring are more likely to be passed on to future generations (Table 2.1).

Table 2.1: Some genetic traits that improve the chances of survival

Trait	Description	Example
Camouflage	Makes animals less likely to be seen by predators, increasing their survival rate	The green colouration of tree frogs helps them blend into foliage, reducing predation.
Disease resistance	Genetic mutations that provide resistance to certain diseases, increasing survival rates	Wheat's resistance to rust disease. Rust is a fungal infection that affects wheat crops worldwide, reducing yields and threatening food production. Some wheat varieties carry a special resistance gene (R-gene) that helps them detect and defend against rust fungi.
Reproductive strategies	Genetic traits that enhance mating success	The vibrant plumage of peacocks increases the likelihood of passing on genes.

Survival and reproduction rates depend on how well an organism's traits match its environment. Over generations, beneficial traits become more common in the population while harmful traits become less common and may disappear.

2.6 Adaptations

Adaptations are traits that help organisms survive in their environment. Adaptations can be behavioural, structural (physical features) or physiological (internal processes).

Key term

adaptation	a trait that improves an organism's chance of survival
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Behavioural adaptations

A behavioural adaptation is a behaviour or an action that helps an organism to survive or reproduce.

Structural adaptations

A structural adaptation is a physical feature that helps an organism live in its environment. These features develop over generations and provide advantages such as protection, movement and access to food.

The following are examples of structural adaptations.

- Cactus spines: Cactus spines are small, sharp leaves. This adaptation reduces water loss and protects the plant from hungry animals in the desert.
- Silent wings of owls: Owls have soft-edged feathers that muffle the sound of their flight. This allows them to sneak up on their prey undetected.
- Thick feathers in penguins: Penguins have a dense layer of feathers that trap air and provide insulation, keeping them warm in freezing Antarctic temperatures.

Physiological adaptations

Physiological adaptations involve internal body processes that help organisms function better in their environment. These include changes in metabolism, chemical production and temperature regulation.

The following are examples of physiological adaptations.

- Hibernation in bears: During the cold months, some bears enter a deep sleep-like state. Their heart rate slows and their bodies use stored fat for energy, allowing them to survive without eating for months.
- Venom in snakes: Many snakes produce venom to immobilise their prey and aid digestion. This adaptation helps them catch food more easily and defend themselves against threats.
- Salt filtering in mangrove trees: Mangrove trees grow in salty coastal waters, and they have a special ability to remove excess salt through their roots or leaves. This prevents salt from harming the plant.

Adaptations in response to environmental changes

When environments change, species must adapt or face **extinction**. Evolution occurs as populations develop traits that help them survive new conditions. This process can be observed in invasive species, climate change responses and human-influenced environments.

Key term

extinction	the complete and permanent disappearance of a species from Earth
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As global temperatures rise, some species of coral are evolving to tolerate warmer waters. Scientists are studying these adaptations to inform conservation strategies and protect ecosystems.

2.7 Cultural practices of First Nations peoples

First Nations peoples have long used fire to manage landscapes, promoting biodiversity. Certain plants, such as the grass tree (*Xanthorrhoea*), have evolved to depend on fire for reproduction. The cultural practice of burning demonstrates an understanding of natural selection because fire-adapted traits are preserved and passed on in these ecosystems.



Figure 2.9: First Nations peoples understand that the grass tree (*Xanthorrhoea*) has evolved to depend on fire for reproduction.

First Nations peoples selectively managed yam populations, encouraging the growth of plants with favourable traits, such as larger tubers or better resistance to environmental stress. This practice mirrors artificial selection, ensuring sustainable food sources.

The practice continues today. In 2023, The University of Queensland reported on a collaboration between the Yidinji community in Far North Queensland, PhD candidate Fawale Samson Olumide and community elder Professor Henrietta Marrie from the Queensland Alliance for Agriculture and Food Innovation. They are working to bridge the gap between First Nations knowledge and western science, so the world can see Australian native yams are worth growing and harvesting.

‘It’s very exciting to bring in PhD students like Mr Olumide to work specifically on traditional food and traditional management of the food stock that we have left,’ Professor Marrie said. ‘There is so much work we need to do to record Indigenous knowledge about the food and its use to pass on to our younger generations.’



Figure 2.10: First Nations peoples managed yam populations by a process of artificial selection.

2.8 Adaptations of First Nations peoples

Upon their arrival in Australia, European colonisers observed that Aboriginal and Torres Strait Islander peoples exhibited a range of remarkable physical traits, such as heightened visual acuity, quick reflexes, superior jumping ability, throwing accuracy, spatial awareness, and exceptional running speed and endurance. These observations were recorded in the personal accounts and official documents of early European settlers.

The differences in these physical capabilities cannot be solely attributed to lifestyle and training and are believed to have a strong genetic basis. The theory of evolution by natural selection provides an explanation for how these traits, which confer survival and reproductive advantages, have become more common in specific populations over generations. The long-standing presence of Aboriginal and Torres Strait Islander peoples across various regions of Australia has led to the development of physical traits suited to these diverse environments.

Science as a human endeavour: Rosalind Franklin and the discovery of DNA's structure

Discovering the structure of DNA was a key breakthrough in biology, helping scientists explain how traits are inherited. While James Watson and Francis Crick are often credited with the discovery of DNA's double-helix shape, Rosalind Franklin's work played a vital role in making this possible.

Rosalind Franklin was a chemist and expert in X-ray crystallography, a technique used to study the structure of molecules. While working at King's College London in the early 1950s, she used X-ray diffraction to capture detailed images of DNA. One of her most famous images, known as 'Photograph 51', revealed an X-shaped pattern, indicating that DNA had a twisted, helical structure.

Franklin's work was highly detailed, and she was close to determining the full structure of DNA. However, without her knowledge, her data was shared with Watson and Crick, who used it – along with their own findings – to build their famous DNA model in 1953.

Although Watson, Crick, and Maurice Wilkins were awarded the Nobel Prize in 1962, Franklin's contribution was not widely recognised at the time. Today, she is celebrated as a key figure in DNA research, and her work continues to inspire scientists worldwide.

Science as a human endeavour: Genetic testing and its role in health

Genetic testing is a scientific process that examines a person's DNA to provide information about their genes. It has become an important tool in medicine, helping to diagnose diseases, assess health risks and even personalise treatments.

A sample is collected from a person, usually by a saliva swab, blood test or tissue sample. Scientists then analyse specific genes to look for variations or mutations that could indicate a higher risk for certain conditions. Uses of genetic testing include:

- diagnosing genetic conditions: identifying inherited disorders such as cystic fibrosis and sickle cell anaemia
- assessing health risks: determining if a person has a higher likelihood of developing health issues such as cancer and heart disease
- personalised medicine: helping doctors prescribe medications that are most effective based on a person's genetic make-up
- ancestry and forensics: tracing family history and solving criminal cases.

Although genetic testing provides valuable health insights, it also raises important ethical and social questions, including:

- privacy concerns: Who should have access to genetic information?
- emotional impact: learning about a potential health risk can cause anxiety or stress
- informed consent: people should fully understand the implications before undergoing testing.

Fun fact

Genetic testing helped scientists complete the Human Genome Project in 2003, which mapped 90 per cent of the genes in human DNA for the first time.

End-of-chapter summary

- Evolution and adaptation provide a framework for understanding the diversity and resilience of life on Earth.
- Through processes such as natural selection, species develop traits that enhance their survival and reproduction.
- Evidence from fossils, genetics and observable changes supports the theory of evolution, illustrating its ongoing impact on populations.
- First Nations peoples highlight the interplay between biology and culture, showcasing how humans have thrived in challenging environments.
- By studying these principles, we gain insights into the past, present and future of life on our planet.

Revision questions

1. Which of the following is an example of a structural adaptation?
 - A. The long neck of a giraffe
 - B. The ability of some fish to survive in both salt water and fresh water
 - C. Hibernation during winter
 - D. Sweating to regulate body temperature
2. Which type of evidence supports the theory of evolution by showing changes in species over time?
 - A. Fossil records
 - B. Genetic similarities
 - C. Comparative anatomy
 - D. All of the above
3. What term describes the separation of populations by physical barriers such as rivers or mountains?
 - A. Genetic drift
 - B. Isolation
 - C. Biodiversity
 - D. Adaptation
4. Which of the following best describes biodiversity?
 - A. The number of different species in an ecosystem
 - B. The total population of a single species
 - C. The genetic variation within a single species
 - D. The physical adaptations of animals in a region
5. Which of the following is *not* a requirement for natural selection to occur?
 - A. Variation in traits
 - B. Isolation of populations
 - C. Equal survival rates for all individuals
 - D. Environmental pressures

6. What is an example of artificial selection?
 - A. The development of antibiotic-resistant bacteria
 - B. The breeding of drought-resistant wheat
 - C. The evolution of dark-coloured peppered moths
 - D. The spread of cane toads in Australia
7. Which of the following is an example of a physiological adaptation?
 - A. A bilby's large ears
 - B. Camouflage in chameleons
 - C. Efficient sweating in humans
 - D. The sharp claws of a wombat
8. What adaptation helps corals survive warmer ocean temperatures?
 - A. Storing water in their tissues
 - B. Evolving to tolerate heat stress
 - C. Changing their reproductive cycles
 - D. Developing thicker skeletons
9. What is variation, and why is it important for natural selection?
10. Explain how fossils provide evidence for evolution.
11. What role does isolation play in the formation of new species?
12. Give an example of artificial selection and explain its impact on the population.
13. Cane toads were introduced to Australia and have spread rapidly. Over time, their leg length has increased, allowing them to travel further.
 - a. How does this demonstrate natural selection?
 - b. What are the ecological consequences of this adaptation?
14. Rising temperatures resulting from climate change have caused some Australian plants to flower earlier.
 - a. How might this affect pollinators?
 - b. How could natural selection influence these plants and pollinators?
15. Explain how genetic mutations contribute to evolution. Provide an example.
16. Investigate the role of genetic diversity in a population's ability to adapt to environmental changes.
17. Describe how physiological adaptations, such as the ability to conserve water, benefit desert-dwelling animals. Provide an example.

Chapter 3 – Earth and space

3.1 Earth and space overview

Earth and space science is a branch of science that studies Earth's systems such as geology, weather and the oceans as well as the universe beyond, including planets, stars and galaxies.

Studying Earth and space science is crucial for understanding and protecting our planet, preparing for natural disasters, managing resources and exploring the universe. It equips us to tackle global challenges and inspires us to learn more about Earth and beyond.

By the end of this chapter, you will be able to:

- describe the major components of the universe using appropriate scientific terminology and units
- understand the timeline of major changes in the universe from the Big Bang until the formation of the major components such as stars and galaxies; as well as learn types of evidence for the Big Bang theory
- describe how stars' light spectra and brightness can be used to identify compositional elements of stars, their movements and their distances from Earth
- be familiar with First Nations knowledges of celestial bodies and explanations of the origin of the universe
- identify the different technologies used to collect astronomical data and the types of data collected; and study recent advances in astrophysics, such as the discovery of gravitational waves, dark matter and dark energy.

3.2 The universe

The universe is an enormous and complex place that includes everything we can observe, from tiny particles to massive galaxies. From the birth of the universe to the stars we see in the night's sky, this section explores the major components of the universe, how we study them and what First Nations peoples have long understood about the cosmos.

3.3 Major components of the universe

Stars

Stars are enormous balls of burning gas mostly composed of hydrogen and helium. The Sun is our closest star, and it provides the light and heat needed to sustain life on Earth. The Sun produces heat and light through a process of **nuclear fusion** in its core.

Key term

nuclear fusion	the process by which two light atomic nuclei (e.g. hydrogen) combine to form a single heavier atomic nucleus (e.g. helium), releasing huge amounts of energy as light and heat
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We measure stars by using two scientific units.

- Luminosity is a measure of the brightness of stars and is the total energy a star emits per second.
- A light-year is the distance light travels in one year. One light-year is approximately 9.46 trillion kilometres.

Activity 3.3.1

Go outside at night and find the brightest star in the sky – the one with the greatest luminosity. Use a star map to identify its name. Can you find out its distance from Earth?

Planets and moons

Planets are large objects that orbit stars. Moons orbit planets.

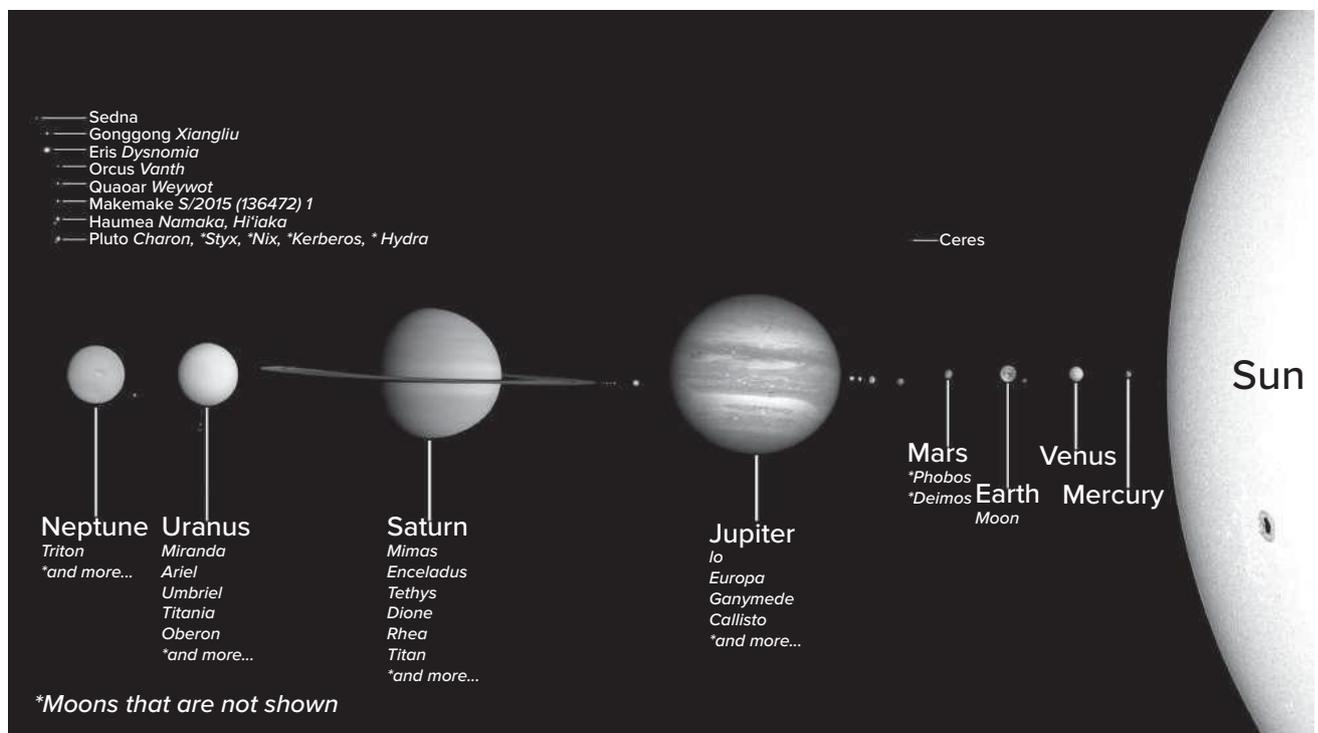


Figure 3.1: Planets and some of their moons in our solar system

Fun fact

The largest planet in our solar system is Jupiter, which has 318 times the mass of Earth.

Galaxies

A galaxy is a vast system made up of many stars, planets, gas and dust held together by gravity. There are billions of galaxies in the universe, each with unique features. Earth is part of the Milky Way Galaxy, which contains billions of stars, including the Sun (Figure 3.2). Our nearest galaxy neighbour is the Andromeda Galaxy.

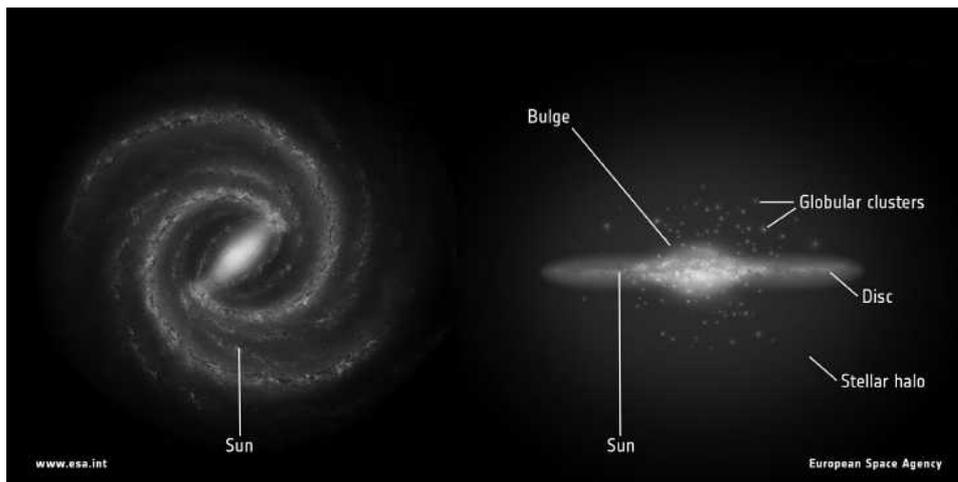


Figure 3.2: The anatomy of the Milky Way

Nebulae

A nebula is a huge cloud made of gas and dust in outer space. Nebulae are important because they are where new stars are born. As gravity pulls dust and gas together, they can form a new star and even new planets. The Orion Nebula is one of the brightest nebulae in the night sky and can be seen with the naked eye (Figure 3.3).



Figure 3.3: The Orion Nebula

Fun fact

Some nebulae glow because of radiation from nearby stars, whereas others look like dark clouds that block starlight.

Black holes

A black hole is an extremely dense region of space where gravity is so strong that nothing, not even light, can escape it. Black holes are formed when massive stars reach the end of their life cycle and collapse under their own gravity.

Black holes warp space and time, and scientists still don't fully understand their nature. Anything that gets too close to a black hole is pulled in and cannot escape.

Understanding the history of the universe helps us see how it evolved from the Big Bang to its current state. Scientists study the Big Bang theory to explain how everything in the universe began.



Figure 3.4: The supermassive black hole imaged by the Event Horizon Telescope is located in the centre of the elliptical galaxy M87, about 55 million light-years from Earth.

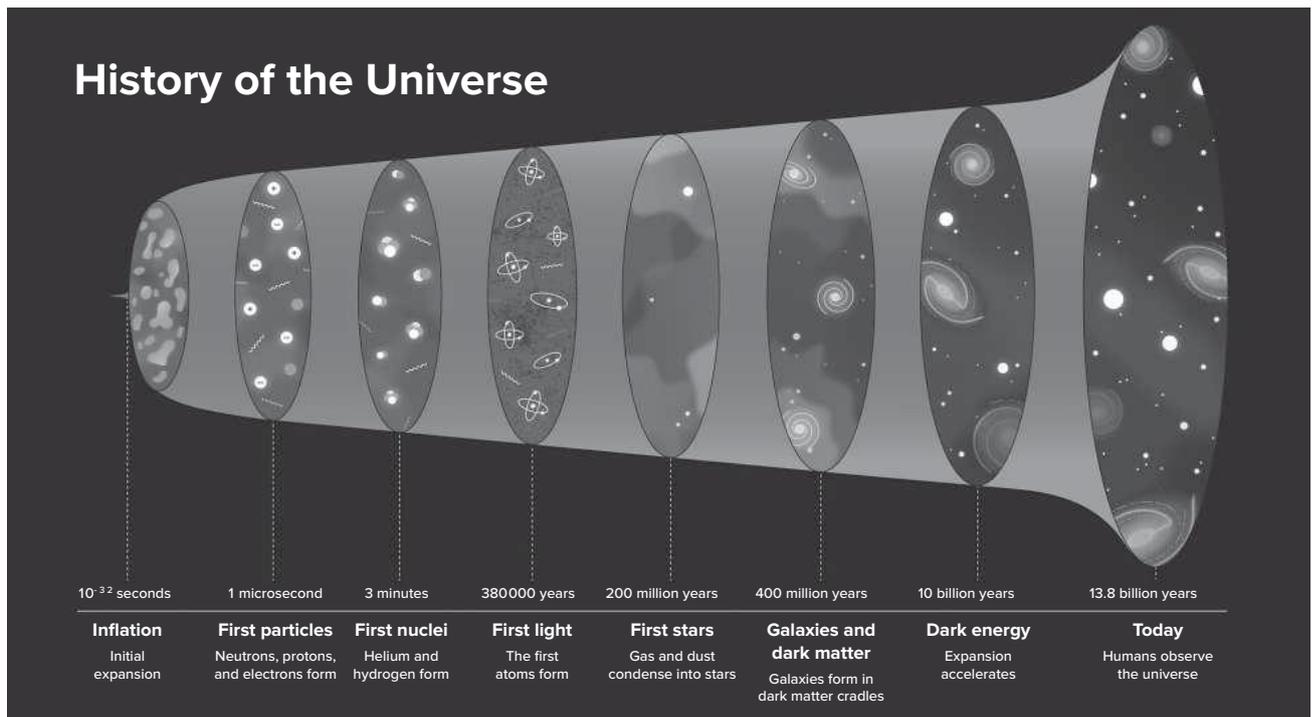


Figure 3.5: Evolution of the universe from the Big Bang to today

Fun fact

The name 'Big Bang' was coined by scientist Fred Hoyle who didn't believe in the theory at all. He thought the universe was always the same and didn't need a beginning.

The Big Bang theory

The Big Bang theory provides an explanation of how the universe began. Despite its name, the Big Bang wasn't an explosion in space – it was the rapid expansion of space itself. The theory explains that the universe began 13.8 billion years ago. All the universe's matter and energy were packed into an incredibly small, hot and dense point. It is theorised that this point then expanded so rapidly it created space, time and matter as we know it.

Table 3.1: The major events in cosmic history

Time	Events
First moments (0–1 second)	<ul style="list-style-type: none"> The universe was a hot, dense soup of energy. Tiny particles like quarks and electrons formed.
First few minutes	<ul style="list-style-type: none"> As the universe cooled, protons and neutrons combined to form hydrogen and helium nuclei.
380 000 years after the Big Bang	<ul style="list-style-type: none"> Atoms formed as electrons combined with nuclei. Light could travel freely, creating cosmic microwave background radiation.
Millions of years later	<ul style="list-style-type: none"> Gravity pulled gas together to form the first stars and galaxies.
Billions of years later (today)	<ul style="list-style-type: none"> The universe continues to expand, and galaxies keep moving apart.

Several types of evidence support the Big Bang theory.

- **Cosmic microwave background (CMB) radiation:** The universe was very hot after the Big Bang. As it expanded, it cooled, leaving behind faint traces of radiation. This radiation left over from the Big Bang can still be seen as a glow and has been detected across the universe even today.
- **Red shift of galaxies:** Astronomer Edwin Hubble discovered that distant galaxies are moving away from us, meaning the universe is expanding. The further away a galaxy is, the faster it is moving, which supports the idea of the Big Bang origin. This is known as redshift because the light from these galaxies shifts toward the red end of the spectrum as they move away.
- **Abundance of light elements:** There is still an abundance of hydrogen, helium and small amounts of lithium today, which aligns with predictions from the Big Bang model.

Formation of stars and galaxies

After the Big Bang, the universe was mostly made of hydrogen and helium that were formed through nuclear reactions. The universe then began to cool enough to form atoms and allow light to travel freely. This is the CMB radiation, which scientists can still detect today, 200 million years later. These elements clumped together due to gravity, eventually forming the first stars.

The first stars were very different from the ones we see today; they were much larger and short lived. These stars began to collect together, which then formed galaxies. Our galaxy, the Milky Way, began forming about 13 billion years ago. The Milky Way is still evolving today, with new stars being born and older stars dying.

Activity 3.3.2

Model the expanding universe with a balloon and marker pen.

1. Draw dots on the balloon to represent galaxies.
2. Slowly inflate the balloon and observe how the dots move apart.
3. Discuss how this models the expanding universe.

3.4 How we use light to study stars

We can learn a lot about stars by studying the light they emit. The light emitted by stars provides valuable information about their composition, movement and distance from Earth.

Light spectra

The light from stars provides information about the elements that make up a star. Spectroscopy is the science of studying light. When light from a star passes through a prism, it splits into different colours to form a spectrum (a rainbow of colours). This spectrum reveals the presence of different elements in the star because each element absorbs light at specific wavelengths. Scientists analyse spectra to determine the composition of stars.

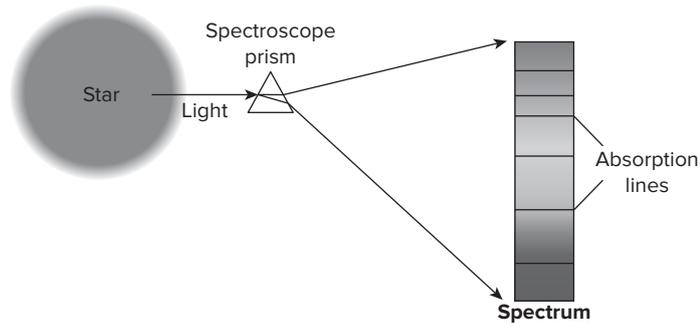


Figure 3.6: Spectroscopy of starlight

Fun fact

The most common elements in stars are hydrogen and helium, but stars also contain heavier elements such as oxygen, carbon and iron.

Brightness

The brightness of a star can tell us how far it is from Earth. For example, a brighter star is usually closer than a dimmer star. The term **apparent brightness** describes how bright a star appears from Earth and is affected by the distance from Earth. **Luminosity** refers to the total amount of energy a star emits.

Using the star's apparent brightness and known distance, astronomers can calculate the star's luminosity.

Key terms

apparent brightness	how bright a star appears to an observer on Earth
luminosity	the amount of energy a star emits

Activity 3.4.1

Compare the brightness of two stars you see in the sky. Which one appears brighter? Based on their apparent brightness, how do you think their distances from Earth compare?

Doppler effect

Stars are not stationary – they move. Using the **Doppler effect**, scientists can determine if a star is moving towards or away from Earth. When a star moves towards us, the wavelengths in its spectrum shorten and the colour of the light shifts towards the blue end of the spectrum. This is called a **blueshift**. When a star moves away from us, its wavelengths increase and the colour of the light shifts towards the red end of the spectrum – a **redshift**.

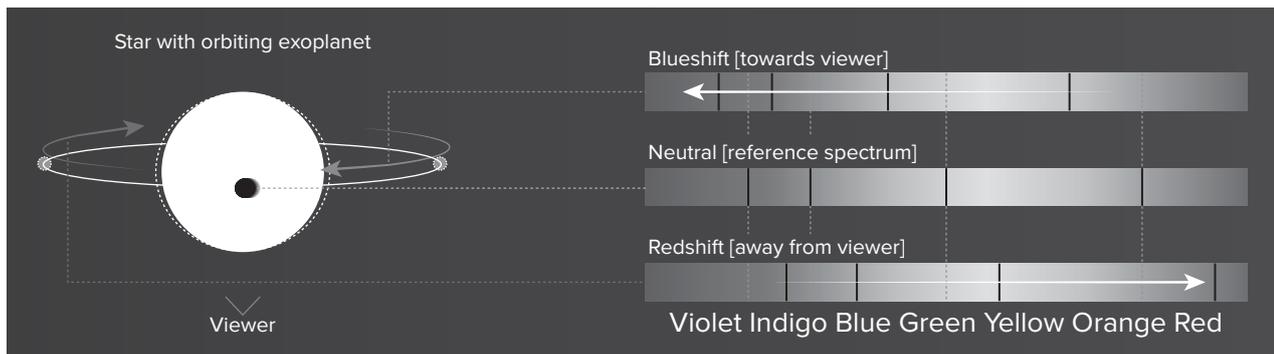


Figure 3.7: The Doppler effect

Key terms

Doppler effect	the increase (or decrease) in the frequency of sound, light or other waves as the source moves towards or away from the observer
blueshift	the shift to shorter wavelengths in the spectrum of an approaching star
redshift	the shift to longer wavelengths in the spectrum of a star that is moving away

Fun fact

The Andromeda Galaxy, which is moving towards the Milky Way, shows a redshift as it moves away from other galaxies but a blueshift as it approaches us.

3.5 First Nations peoples and the universe

First Nations peoples of Australia have deep knowledge of the night sky, developed over at least 65000 years, having used the sky for navigation, calendars and storytelling. Their stories and knowledge systems explain the movement of celestial bodies and offer insights into the origins of the universe.

One example is the story of the 'Emu in the Sky'. Within the story, the shape of the emu is created by spaces within the Milky Way. The emu's head is formed near the Coalsack Nebula, and its body is formed by dark dust clouds stretching along the Milky Way. The position of the emu in the night sky provides information about seasonal changes and events, such as when emus lay eggs.



Figure 3.8: The Emu in the Sky constellation

3.6 Technology in astronomy

Astronomers use a range of technologies to study the universe. As the technology and tools have become more advanced, they have provided more information about stars.

Telescopes

A telescope is an instrument that collects light and magnifies distant objects in the sky.

Table 3.2: Different types of telescope

Telescope	Description	Image
Optical	Use visible light to observe stars and planets	
Radio	Detect radio waves emitted by objects in space and allow scientists to study phenomena such as black holes and cosmic microwave background radiation	 Parkes radio telescope, NSW
Space	Orbit Earth and can capture clear images because they are free from Earth's atmosphere	 The Hubble Space Telescope

The James Webb Space Telescope

The James Webb Space Telescope was launched in 2021. It is the largest and most powerful space telescope ever built. As it orbits the Sun, the telescope detects infrared light from stars and planets. It has revolutionised our understanding of the universe by providing unprecedented images of distant galaxies and allowing scientists to study the early universe in greater detail.



Figure 3.9: An image taken by the James Webb Space Telescope

Fun fact

Almost 95 per cent of the universe is made of dark matter and dark energy, which we can't directly see.

3.7 Advances in astrophysics

In recent years, there have been groundbreaking discoveries in space research.

Gravitational waves

Gravitational waves were predicted by Albert Einstein more than 100 years ago, but were not detected until 2015. In 2015, scientists at the Laser Interferometer Gravitational-Wave Observatory (LIGO) in the US detected gravitational waves in space. These were detected as incredibly fast ($1.1 \times 10^9 \text{ km h}^{-1}$) ripples in space-time caused by massive objects like black holes colliding. Gravitational waves squeeze and stretch anything in their path. Scientists may be able to use gravitational waves to help them learn more about black holes, dark matter and the beginnings of the universe.

Dark matter and dark energy

These mysterious substances make up most of the universe, but scientists cannot directly see them. **Dark matter** is invisible because it does not absorb, reflect or emit light. The existence of dark matter and **dark energy** is inferred from their effects on galaxies and the expansion of the universe. Scientists think dark matter is made of unknown subatomic particles such as weakly interacting massive particles (WIMPs). Unlike dark matter, dark energy pushes galaxies apart, causing the universe's expansion to speed up.

Scientists use powerful telescopes and particle accelerators like the Large Hadron Collider in Switzerland to study these mysteries. Computer simulations help model how dark matter and dark energy influence the universe.

Key terms

dark matter	an invisible and hypothetical form of matter that does not absorb, reflect or emit light, which makes it hard to detect
dark energy	a hypothetical form of energy that is thought to be responsible for the accelerating expansion of the universe

Science as a human endeavour: Exploring how Vera Rubin's discovery of dark matter was validated

Vera Rubin, an influential astronomer, made groundbreaking contributions to the understanding of dark matter. Rubin's work, especially in studying galaxy rotation curves, was a crucial turning point in recognising the existence of dark matter.

The mystery of galaxy rotation curves

In the 1970s, Vera Rubin focused on studying how galaxies rotate. Galaxies are made up of stars, gas, dust and other materials that should behave according to gravitational principles, where objects closer to the centre of a mass rotate faster than those farther away, much like how planets in the solar system orbit the Sun.

However, Rubin noticed something unusual – stars on the outer edges of galaxies were moving far too quickly for their distance from the centre. If the stars were rotating too quickly, they should have been thrown out into space, but they weren't. Rubin concluded that there must be additional unseen mass – dark matter – exerting gravitational forces and holding these outer stars in their orbits.

Validation of Rubin's discovery

Although Rubin's discovery was initially met with scepticism, it was eventually validated through several lines of evidence.

- **Independent observations by other astronomers:** Rubin's work was confirmed when other astronomers found similar rotation curves in other galaxies. These independent observations reinforced the idea that galaxies were rotating faster than expected because of some unseen mass.
- **Advancements in computer simulations:** As computational power increased, astronomers could simulate galaxies and incorporate dark matter into their models. These simulations accurately reflected the actual observed rotation curves, offering further support for the existence of dark matter.
- **Cosmic microwave background radiation:** In the 1990s, the discovery of CMB radiation – the faint glow left over from the Big Bang – also supported dark matter. CMB patterns matched predictions that included dark matter, confirming that the universe's structure could only exist with the presence of unseen mass.
- **Gravitational lensing phenomenon:** Gravitational lensing, a phenomenon where massive objects bend light from more distant objects, provided additional evidence. In particular, galaxy clusters showed stronger lensing effects than could be explained by their visible mass, suggesting the presence of dark matter.

Conclusion

Vera Rubin's research fundamentally altered our understanding of the cosmos. By studying galaxy rotation curves, she provided key evidence for the existence of dark matter. As technology advanced, her findings were confirmed through independent observations, computer simulations and phenomena like gravitational lensing and CMB radiation. Although dark matter remains unseen, its effects are evident, and Rubin's work paved the way for a deeper exploration of this mysterious force that shapes the universe.

End-of-chapter summary

- The universe is a vast, dynamic place, and our understanding of its components, history and future continues to evolve.
- From the Big Bang to the formation of stars and galaxies, the development of new technologies like telescopes, and even the ancient stories from First Nations peoples, there is much to explore and discover. Whether it's through the study of light spectra, the search for dark matter, or learning from cultural stories, our understanding of the universe is constantly expanding.

Revision questions

1. What is the primary process that powers stars like our Sun?
 - A. Radioactive decay
 - B. Nuclear fission
 - C. Nuclear fusion
 - D. Gravitational collapse
2. What type of astronomical object is the Orion _____?
 - A. A black hole
 - B. A planet
 - C. A star
 - D. A nebula (cloud of gas and dust)
3. Which type of telescope allows scientists to observe the universe beyond the visible light spectrum?
 - A. Optical telescope
 - B. Radio telescope
 - C. Space telescope
 - D. Infrared telescope
4. Which of the following is used to measure the brightness of stars?
 - A. Luminosity
 - B. Wavelength
 - C. Spectrometer
 - D. Telescope magnification

5. What is a light-year a measure of?
 - A. Time
 - B. Mass
 - C. Distance
 - D. Brightness
6. What scientific discovery in 2015 confirmed Einstein's predictions?
 - A. Dark matter
 - B. The Big Bang
 - C. Gravitational waves
 - D. Radio waves
7. Which of the following best describes a nebula?
 - A. A dying star collapsing into a black hole
 - B. A cloud of gas and dust where new stars form
 - C. A planet orbiting a distant star
 - D. A galaxy made of millions of stars
8. Which of the following best describes dark matter?
 - A. A type of black hole
 - B. A form of matter that emits no light but has gravitational effects
 - C. A cluster of neutron stars
 - D. The energy released by the Big Bang
9. Explain how the Doppler effect helps scientists determine the movement of stars.
10. Describe what a nebula is and its role in star formation.
11. What is the difference between apparent brightness and luminosity when studying stars?
12. Explain what a black hole is and how it forms.
13. In the context of the Big Bang theory, what does the 'expansion of the universe' mean?
14. You observe a star and notice that its light is shifted to the red end of the spectrum. What does this tell you about the movement of the star, and why does this occur?
15. Consider a telescope that observes a distant galaxy. The light from the galaxy is observed in both optical and radio wavelengths. Why is it useful to study both types of light? What does each wavelength reveal about the galaxy?
16. How do astronomers determine the composition of a star?

Chapter 4 – Global systems and climate change

4.1 Global systems and climate change

By the end of this chapter, you will be able to:

- understand radiation from the Sun and how its interactions with the atmosphere, ocean and land are the foundation for the global climate system
- identify changes in global climate over time
- identify indicators of climate change such as changes in ocean and atmospheric temperatures, sea levels, biodiversity, species distribution, permafrost and sea ice
- examine the factors that drive deep ocean currents, their role in regulating global climate and their effects on marine life
- explain how quantum computing is used to model complex weather and climate systems
- predict changes to Earth's climate system and identify strategies to reduce or mitigate climate change.

4.2 Global climate and solar radiation

Earth's climate system is incredibly complex. It involves interactions between the atmosphere, oceans, land and ice. Understanding how these components work together helps us explain weather patterns, climate change and the impact of human activities.

Earth's climate system is driven by energy from the Sun, which is the ultimate source of energy for Earth. The Sun emits radiation, which heats Earth, drives wind and ocean currents, and influences weather and climate patterns. This energy is either absorbed by Earth or reflected back out into space.

The Sun emits radiation in the form of light and heat. The most important types of radiation it emits for Earth's climate are visible light and infrared radiation. When the Sun's radiation reaches Earth, it interacts with the atmosphere, oceans and land. These interactions form the foundation of the global climate system.

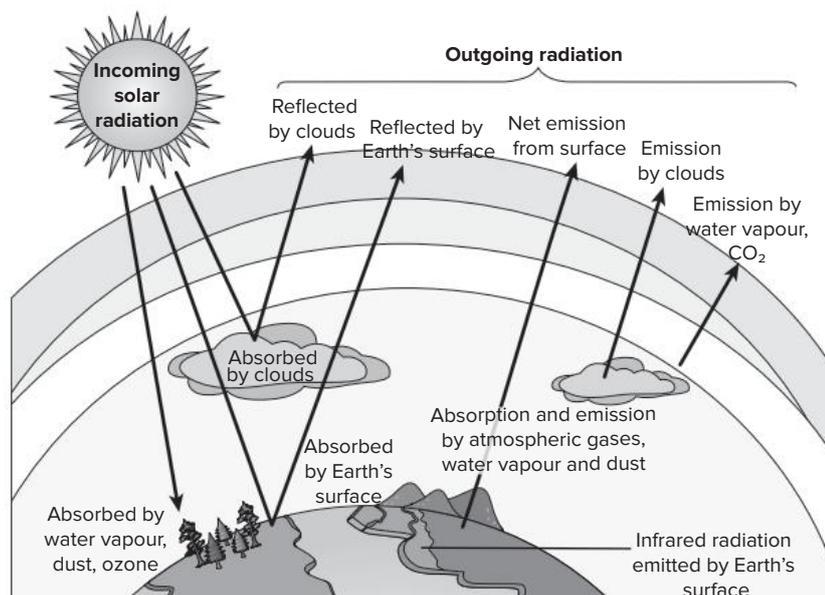


Figure 4.1: Solar radiation

When sunlight reaches Earth:

- approximately 70 per cent warms the planet as it is absorbed by land, oceans and the atmosphere
- approximately 30 per cent is reflected by clouds and ice back into space
- some is trapped on Earth by **greenhouse gases** such as methane and carbon dioxide in a process called the greenhouse effect.

Key term

greenhouse gas	a gas in Earth's atmosphere that absorbs infrared radiation, trapping heat (e.g. carbon dioxide, methane, nitrous oxide, water vapour and some synthetic gases)
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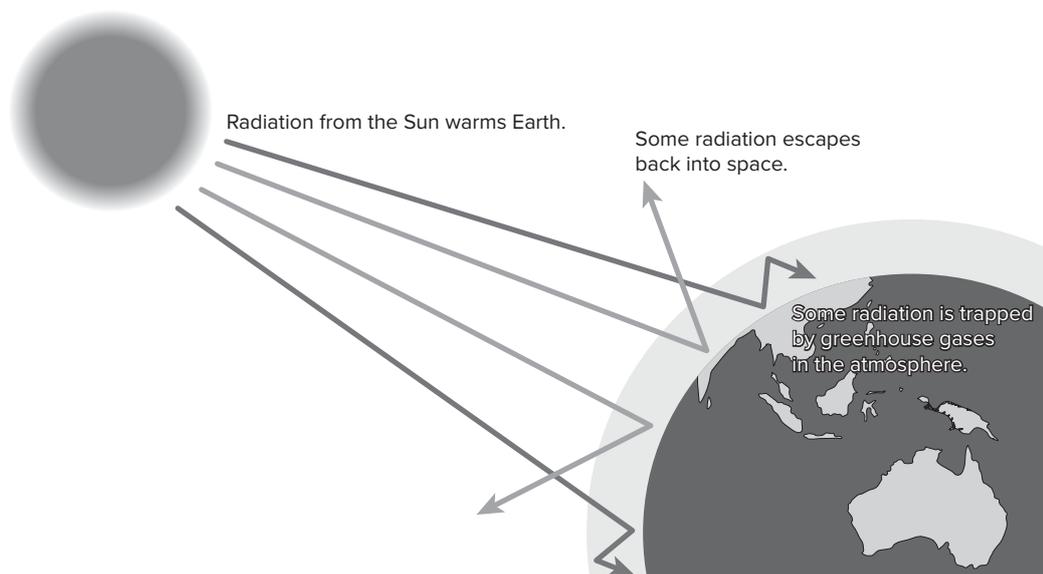


Figure 4.2: The greenhouse effect.

Different areas on Earth interact with this radiation in different ways.

- **Atmosphere:** Gases such as carbon dioxide, methane and water vapour in the atmosphere trap some of this heat.
- **Oceans:** The oceans absorb large amounts of solar radiation. The warm water affects sea levels, ocean currents and climate patterns as the water warms and expands.
- **Land:** Different land areas reflect and absorb solar radiation differently. Dark forests absorb more heat than ice in the polar caps.

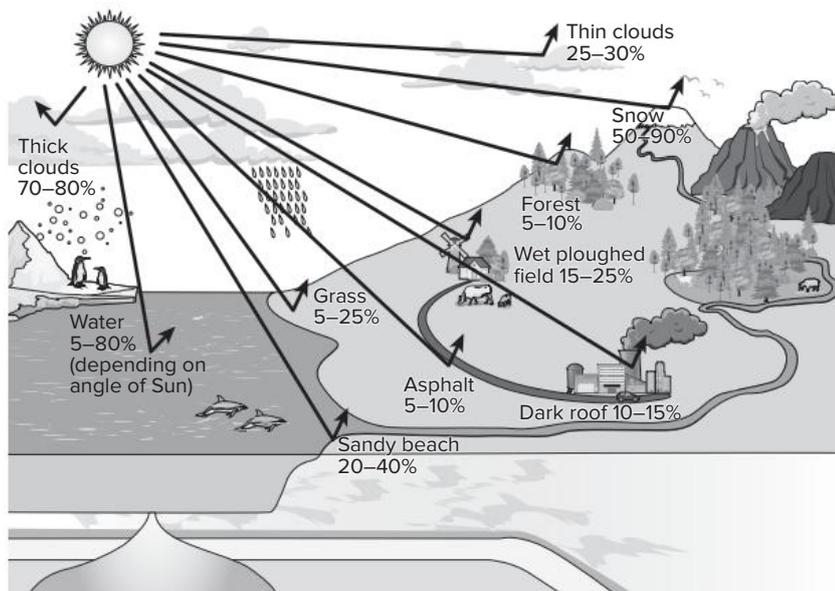


Figure 4.3: Reflection given as a percentage of solar radiation. So, for example, a dark roof reflects 10–15 per cent of solar radiation and absorbs 85–90 per cent. Choose a more reflective material for your roof to help keep your house cool.

Fun fact

The average temperature of Earth is about 15°C. Earth's average temperature would be around –18°C without the natural greenhouse effect.

Real-world connection: The greenhouse effect

Activity 4.2.1 demonstrates how Earth's atmosphere acts like a closed bottle, trapping heat from the Sun. Greenhouse gases like carbon dioxide (CO₂) and methane (CH₄) prevent heat from escaping into space, leading to global warming.

Activity 4.2.1

Home experiment: The greenhouse effect in a bottle

Aim

To investigate how trapping heat affects temperature by comparing a closed plastic bottle and an open one left in sunlight.

Materials

- 2 identical clear plastic bottles (1 L or larger)
- 2 thermometers
- Scissors or a utility knife
- Tape (optional, to secure the thermometer)
- Notebook and pen for recording results
- Sunny location outdoors

Procedure

1. Place one thermometer inside each bottle, making sure you can still read the temperature. If needed, tape the thermometer inside to keep it in place.
2. Leave one plastic bottle completely open at the top. Tightly seal the second plastic bottle with its cap.
3. Check and record the starting temperature inside each bottle before exposure to sunlight.
4. Place both bottles in a sunny outdoor spot where they will receive equal sunlight and so they are not in any shade.
5. Leave the bottles in direct sunlight for 30 minutes to 1 hour. Check the temperatures at regular intervals (e.g. every 10 minutes).
6. Record and compare the final temperatures.

Results and explanation

1. Which bottle had the higher temperature?
2. Why does this happen?

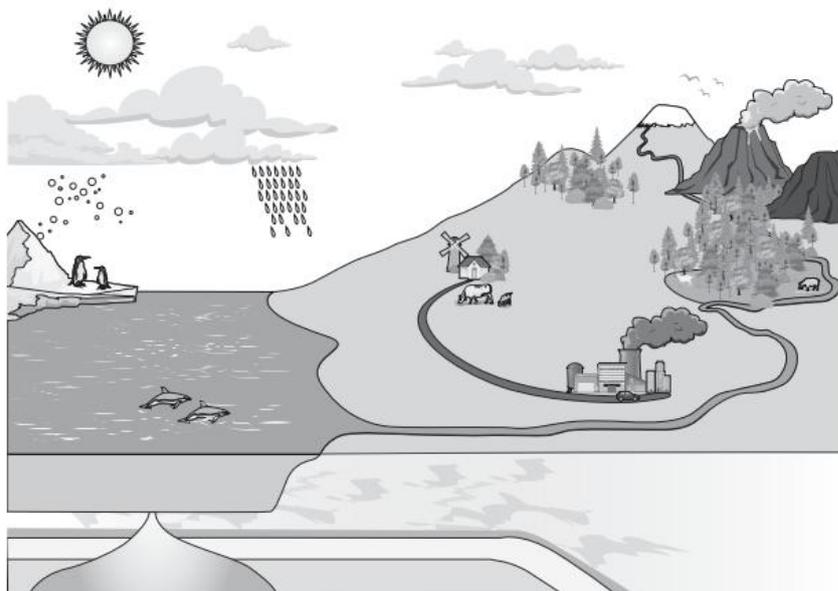
Further investigation

Try different variables.

- Use coloured bottles (clear versus dark coloured) and compare the results.
- Place the bottles in shade versus direct sunlight and compare the results.
- Use a bottle with a small hole instead of completely open or closed. What happens?

Activity 4.2.2

Annotate the following diagram with all the different paths of solar radiation and the difference in the amount of light reflected based on the area.



4.3 Changes in global climate over time

Earth’s climate has changed naturally over millions of years due to changes in Earth’s orbit, variations in solar activity and volcanic eruptions. However, human activities such as deforestation and burning fossil fuels have increased the concentrations of greenhouse gases in the atmosphere.

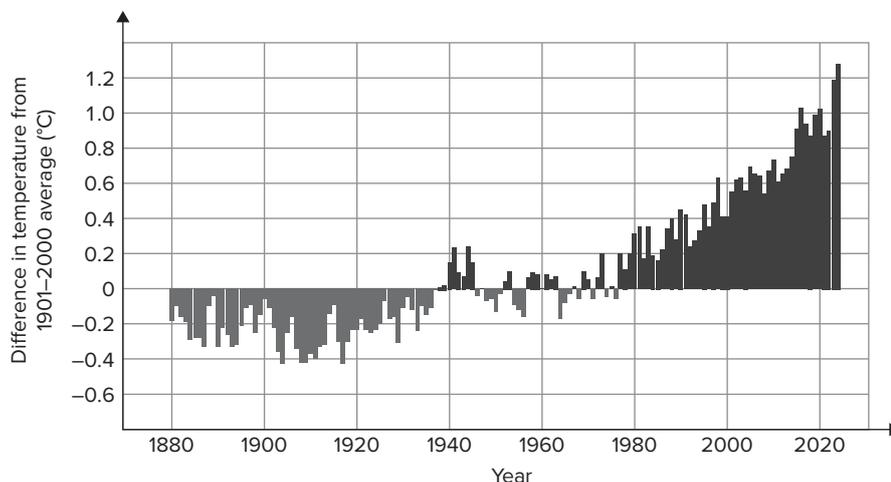


Figure 4.4: Global average difference in surface temperatures from 1901–2000 average. In 2020, the average surface temperature was nearly 1°C higher than the 1901–2000 average.

Fun fact

Earth’s climate has gone through five major ice ages in the past 2.4 billion years. We are currently in a warm phase between ice ages referred to as an interglacial period called the Holocene.

Indicators of climate change

Scientists use many indicators to track changes in Earth’s climate and help predict future trends (Table 4.1).

Table 4.1: Indicators of a changing climate

Indicator	Description	Example
Rising ocean and atmospheric temperatures	Global temperatures have increased on average by 1.1°C since the late 19th century. As a result, ocean temperatures have risen, causing more severe storms and coral bleach.	In 2016, the Great Barrier Reef had one of its worst coral bleaching events because of record-high ocean temperatures. Warmer waters stressed the coral, causing them to expel the algae that give them their colour and energy, turning them white and making them more vulnerable to disease.

Indicator	Description	Example
Rising sea levels	Increasing global temperatures are melting ice in Antarctica and the Arctic, which is causing sea levels to rise. This can cause flooding in coastal seas.	In 2023, the Indonesian government announced plans to relocate its capital from Jakarta to another island because rising sea levels and sinking land are causing severe flooding, threatening millions of residents.
Changes in biodiversity	As temperatures rise, many animals and plants are migrating to cooler regions to survive. This results in biodiversity changes in ecosystems, which can affect food chains.	As the Arctic warms, species such as the red fox are moving north into areas once dominated by the Arctic fox, leading to competition for food and habitat, which disrupts the balance of the ecosystem.
Permafrost thawing	Permafrost is the frozen ground in the Arctic. As it melts with increasing temperatures, it releases methane – a greenhouse gas. The melting Arctic ice has reduced habitats for animals such as polar bears.	In parts of Siberia, melting permafrost has made the ground unstable, causing buildings and roads to collapse. This also releases methane, which further accelerates global warming.

4.4 Deep ocean currents

Deep ocean currents are the large and powerful underwater movements that move heat around Earth and maintain its climate. Also known as **thermohaline circulation**, this system influences weather patterns and marine ecosystems.

Key term

thermohaline circulation	a global system of deep ocean currents driven by differences in water temperature and salinity
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Currents are driven by:

- Temperature differences: warm water rises and cold dense water sinks.
- Salinity levels: saltier water is heavier and sinks, causing currents.
- Wind and Earth rotation: Earth's rotation and wind on surface waters influence current direction.

For example, cold, salty water in the polar regions is denser and sinks. Warm water from the tropics rises and replaces the region of cold water.

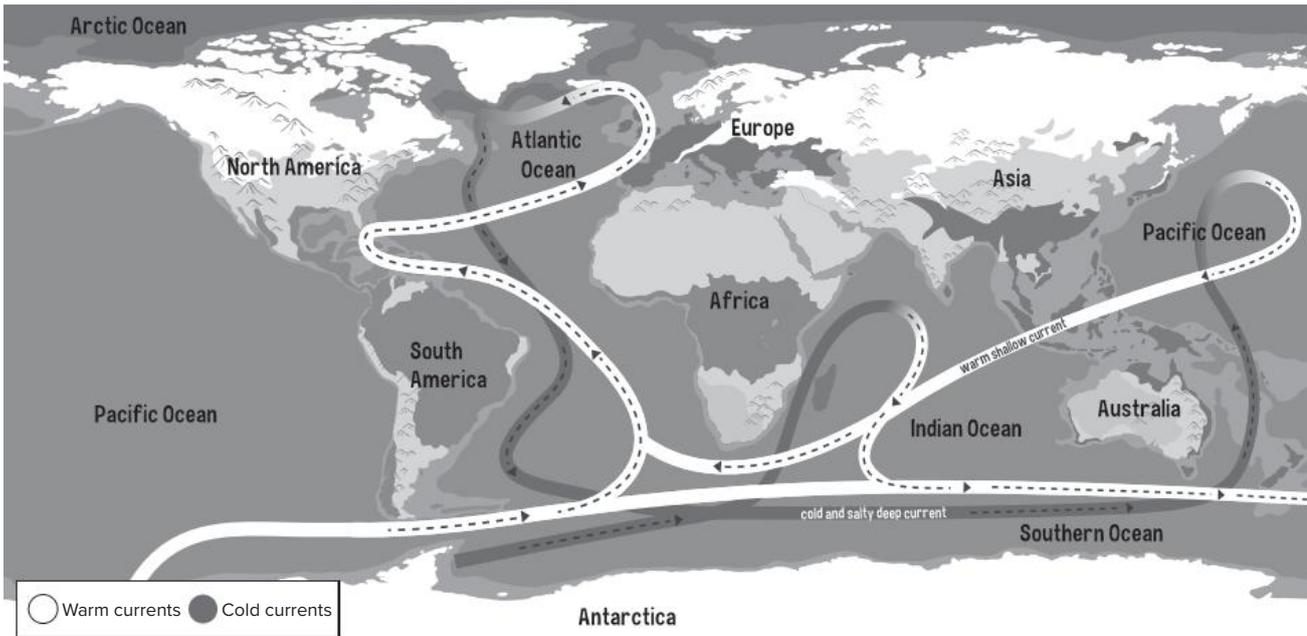


Figure 4.5: Thermohaline circulation

It takes about 1000 years to complete one full cycle of moving ocean water.

These currents:

- transport nutrients and oxygen to support marine ecosystems
- regulate regional climates
- circulate heat across the planet.

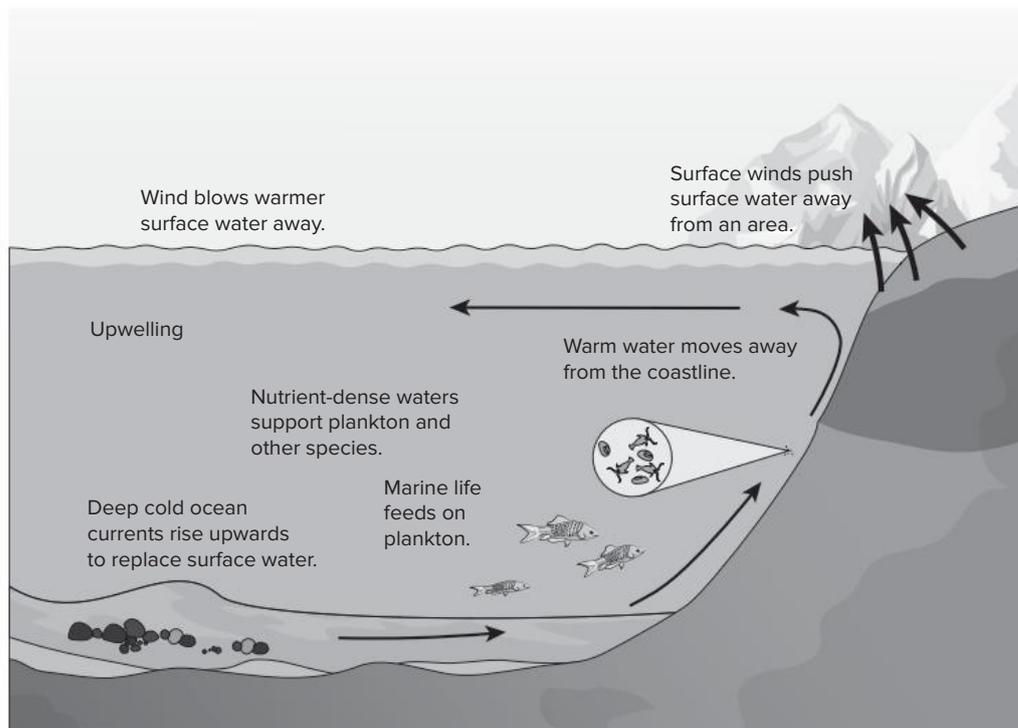


Figure 4.6: Deep ocean currents rise upwards to replace surface waters and bring nutrient-dense waters to the surface.

Activity 4.4.1

Home experiment: Modelling ocean currents

Aim

To understand how differences in temperature and salinity drive ocean currents by creating a simple model using coloured water.

Materials

- Cold water
- Warm water
- Salt
- Blue food colouring
- Red food colouring
- Large, clear container (e.g. glass baking dish or plastic tub)
- 2 small cups or jars
- Spoon for stirring

Procedure

1. To prepare the cold salty water, fill one small cup with cold water and add 2 tablespoons of salt. Stir until the salt has dissolved. Add a few drops of blue food colouring to make this water visible.
2. To prepare the warm fresh water, fill another small cup with warm water and add a few drops of red food colouring to make this water visible.
3. Half-fill the large container with room-temperature water. Gently pour the blue, cold salty water on one side of the container. Gently pour the red, warm fresh water on the opposite side.
4. Observe how the denser, cold salty water sinks to the bottom while the lighter, warm fresh water rises. Over time, you will see the colours swirl and mix, mimicking ocean currents.

Results and explanation

- Cold salty water is denser and sinks, representing deep ocean currents.
- Warm fresh water is lighter and rises, representing surface currents.
- These movements help distribute heat and nutrients throughout the ocean, playing a vital role in Earth's climate system.

Further investigation

Change the amount of salt or the temperature difference to see how it affects water movement. How do you think this relates to real ocean currents?

How oceans affect climate

Many ocean currents interact to maintain regional climates. For example, cold currents such as the Humboldt Current, which flows north from Antarctica along the west coast of South America, can cool down coastal areas, which can affect fish populations and rainfall. Warm currents such

as the Gulf Stream in the Atlantic Ocean make winters milder by warming air in the coastal regions. Disruptions to the currents can lead to extreme weather events, such as droughts and hurricanes.

4.5 Quantum computing and climate predictions

Climate systems can be complex, which makes it difficult for scientists to find patterns and predict future events.

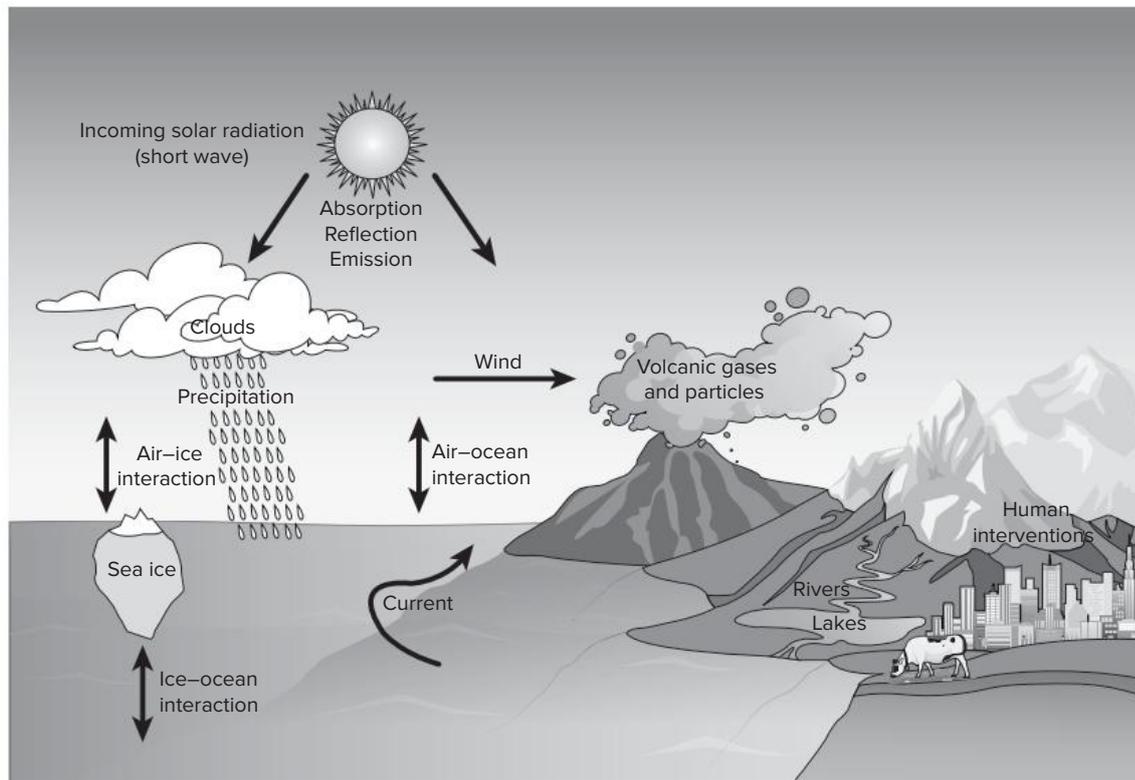


Figure 4.7: The climate system

Traditional computers do not have the computational power to model these complex climate systems, so quantum computers are used to help process the large amount of climate data.

Quantum computers help scientists:

- model accurate climate changes
- predict extreme weather events such as hurricanes
- develop effective strategies to reduce climate change.

4.6 Strategies to reduce climate change

There are many strategies to reduce the impacts of climate change. Table 4.2 lists some of them.

Table 4.2: Strategies for reducing the effects of climate change

Strategy	Description	Example
Reduce carbon emissions	Use renewable energy sources such as solar, hydroelectricity and wind instead of fossil fuels. Many countries are investing in renewable energy to cut carbon emissions.	Denmark generates nearly half of its electricity from wind power, reducing its reliance on fossil fuels and lowering greenhouse gas emissions.
Reforestation	Plant trees to absorb carbon dioxide and provide oxygen to help cool the planet.	In Brazil, large-scale reforestation projects in the Amazon rainforest aim to restore deforested areas. By planting millions of trees, these projects help absorb carbon dioxide from the atmosphere, slowing climate change and preserving habitats for wildlife.
Carbon capture technology	Collect and store carbon dioxide emissions before they reach the atmosphere.	In Norway, the Sleipner project captures carbon dioxide from natural gas production and stores it deep underground in rock formations beneath the North Sea. This prevents millions of tonnes of carbon dioxide from entering the atmosphere.
Sustainable living	Reduce waste, conserve water, recycle, reuse old items and use energy-efficient appliances.	A family can practise sustainable living by installing energy-efficient LED light bulbs, using a reusable water bottle instead of buying plastic ones and composting food scraps instead of sending them to landfill. These small changes help reduce waste and conserve natural resources.
Adapting to climate change	Improve agricultural practices and water management.	Farmers in drought-prone areas are adapting to climate change by using drip irrigation systems that deliver water directly to plant roots, reducing water waste. Additionally, some farmers are planting drought-resistant crops to ensure stable food production despite changing rainfall patterns.
Improving technology and innovations	Invest in electric cars and energy-efficient buildings.	Many cities are promoting the use of electric buses, which produce no exhaust emissions, helping to reduce air pollution. Similarly, modern buildings are being designed with smart insulation and solar panels to lower energy consumption and reliance on fossil fuels.

Activity 4.6.1

Calculate your carbon footprint using an online calculator. Can you adopt any of the strategies listed in Table 4.2 to lower it?

End-of-chapter summary

- Climate change is one of the biggest challenges facing humanity.
- By understanding the science behind global climate systems, monitoring key indicators and using new technologies such as quantum computing, we can take meaningful action to slow climate change and protect Earth for future generations.

Revision questions

1. What is the primary source of energy for Earth's climate system?
 - A. Volcanoes
 - B. The Moon
 - C. The Sun
 - D. Earth's core
2. Which greenhouse gas is the most responsible for trapping heat in Earth's atmosphere?
 - A. Oxygen
 - B. Nitrogen
 - C. Hydrogen
 - D. Carbon dioxide
3. Which of the following is *not* an indicator of climate change?
 - A. Rising sea levels
 - B. Changes in species distribution
 - C. Decreased volcanic activity
 - D. Melting of permafrost
4. What is the main cause of rising sea levels?
 - A. Tectonic plate movements
 - B. Increased evaporation
 - C. Melting ice caps and glaciers
 - D. Decreased precipitation
5. What is the major driver of deep ocean currents?
 - A. The rotation of Earth
 - B. Salinity and temperature differences in the water
 - C. The Moon's gravitational pull
 - D. Human activities

6. Which of these technologies is being used to model complex climate systems?
 - A. Quantum computing
 - B. Solar panels
 - C. Fossil fuel extraction
 - D. Hydroelectric dams
7. How does the greenhouse effect contribute to warming Earth?
 - A. It allows heat to escape into space.
 - B. It traps heat in the atmosphere with gases like carbon dioxide and methane.
 - C. It blocks solar radiation from reaching the surface.
 - D. It reflects heat away from the planet.
8. Which of the following is an indicator of climate change?
 - A. Rising sea levels
 - B. Decreasing global temperatures
 - C. Growing ice sheets
 - D. Increases in biodiversity and species distribution
9. Quantum computers are useful in climate science because they:
 - A. help collect satellite data.
 - B. can process complex climate models faster than traditional computers.
 - C. create more greenhouse gases to simulate climate change.
 - D. replace ocean buoys for monitoring sea temperatures.
10. What causes coral bleaching?
 - A. Too much sunlight being absorbed by corals
 - B. A drop in ocean temperature
 - C. An increase in ocean acidity and temperature
 - D. The presence of too many fish near coral reefs
11. Which of the following gases is *not* a greenhouse gas?
 - A. Nitrogen
 - B. Carbon dioxide
 - C. Methane
 - D. Water vapour
12. What are deep ocean currents?
13. What is permafrost, and why is its melting a concern?
14. How does the Sun's radiation influence global climate?

15. Explain two key indicators of climate change.
16. What is the greenhouse effect and why is it important?
17. How do deep ocean currents affect global climate?
18. How does quantum computing contribute to climate science?
19. Describe two major ways in which climate change is affecting global biodiversity.
20. A city's average temperature has increased by 2°C over the last 50 years. What could be some possible causes and effects of this temperature rise?
21. If Earth's ocean currents slowed down significantly, what might happen to the global climate?
22. If the average global temperature has increased by 1.1°C since pre-industrial times, and continues to rise at an average rate of 0.2°C per decade, how much warmer will Earth be in 50 years if this trend continues?
23. If the ocean's salinity in a region decreases due to increased fresh water from melting ice, how would this affect the local deep ocean currents?
24. Using current sea-level-rise trends, if sea levels rise by 3.2 mm/year, how much will they rise in 50 years?
25. Scientists predict that by 2100, Earth's average temperature could increase by up to 4°C if greenhouse gas emissions continue at current rates. Explain two consequences this would have on the environment and human societies.
26. A scientist is studying an area of the ocean where fish populations have declined. They suspect climate change is a factor. List three possible ways climate change could be responsible.

Chapter 5 – Physics

5.1 Physics overview

Physics involves studying the fundamental principles that control the behaviour of matter and energy in the universe. Physicists explore the laws of nature, seeking to understand phenomena ranging from the behaviour of subatomic particles to the large-scale structure of the cosmos. In this chapter, we will look specifically at the concepts of motion and the relationship between force, mass and acceleration of objects.

Think about it

- What could you measure to determine the speed of a runner?
- How is acceleration different from speed?
- How has science helped to make vehicles much safer?

By the end of this chapter, you will be able to:

- understand motion and the relationship between force, mass and acceleration
- investigate a moving object to analyse and propose relationships between distance and time, speed, force and acceleration
- use mathematical representations, including graphs and algebraic formulas, to quantitatively relate force, speed, acceleration and mass
- investigate how First Nations people increase speed and subsequent impact force using spear throwers and bows
- understand how a change in net force acting on an object affects its motion and relate this to safety features such as seatbelts
- investigate the application of Newton's laws in sport and how these are applied to improve an athlete's performance or safety
- construct an argument, supported by data, to support lower speed limits near schools or for trucks in urban environments
- investigate how driverless vehicles apply Newton's laws of motion to brake in time to avoid collisions.

5.2 Introduction to motion

What is motion?

Motion describes the movement of an object from one position to another. Whenever something changes its position – whether it's a bird flying, a car driving or a soccer ball rolling across the field – it is in motion. Scientists study motion to understand the world around us.

To understand motion, we need to ask:

- How fast is the object moving?
- How far does it go?

- What forces are acting on it?
- Why does it speed up, slow down or stop?

To answer these questions, we use concepts such as force, mass, acceleration, distance, time and speed.

Distance versus displacement

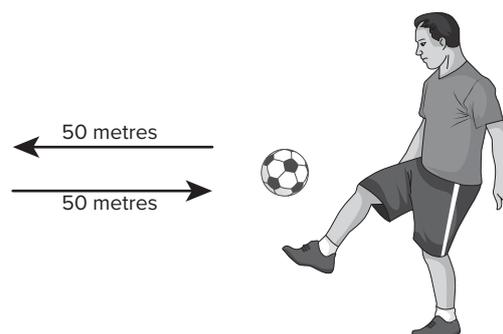
Distance is the total length of the path taken by an object, and it does not take direction into account. Because distance only measures the amount of movement, distance is known as a **scalar** quantity – it has size (magnitude) but no direction.

Displacement is how far the finishing point is from the starting point and the direction of the movement. Displacement is a **vector** quantity because it includes both magnitude and direction.

Key terms

distance	the total length of the path taken by an object, without considering direction
scalar	a quantity that has magnitude (size or amount) but not direction
displacement	how far a finishing point is from the starting point and the direction travelled
vector	a quantity that has both magnitude and direction

For example, if a footballer runs 50 metres from the centre of the ground, then returns to their original position, they have covered a distance of 100 metres but their displacement is 0 metres from the starting point (Figure 5.1).



Similarly, Figure 5.2 shows the distance a student covers (left-hand diagram) is different from their displacement (right-hand diagram).

Figure 5.1: The footballer has travelled a distance of 100 metres but their displacement is 0 metres.

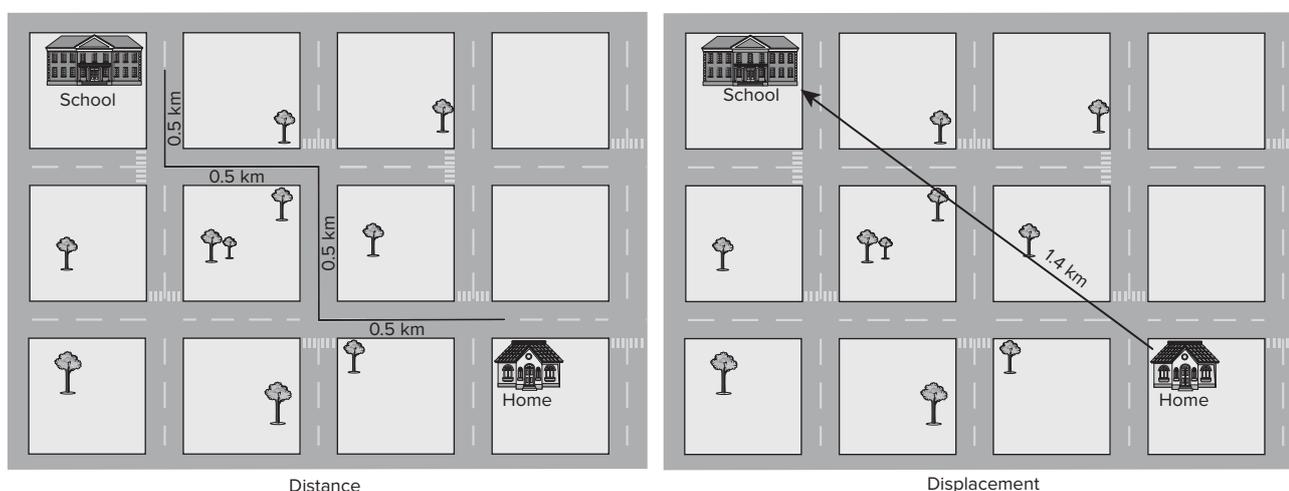


Figure 5.2: The distance (2 kilometres) covered by the student to get from home to school is different from their displacement (1.4 kilometres).

Activity 5.2.1

Mapping your journey

Aim

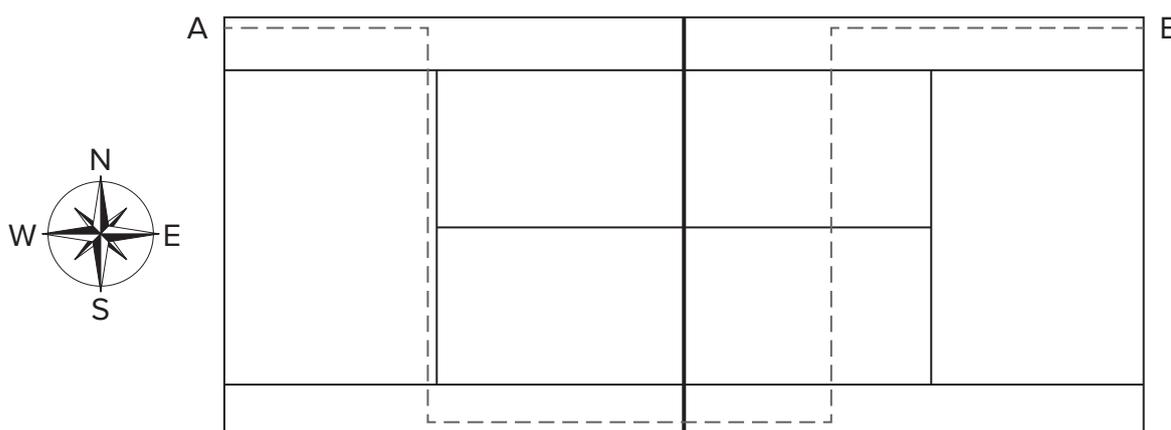
To understand distance and displacement.

Materials

- Measuring tape
- Smartphone with a step-counting app (optional)
- Notebook or paper
- Pencil or pen
- Ruler (for drawing straight lines)

Procedure

1. Plan a short route around your school playground, tennis court or netball court. The route can include twists, turns and backtracking to make it more interesting. The following example shows a route around a tennis court from point A to point B.



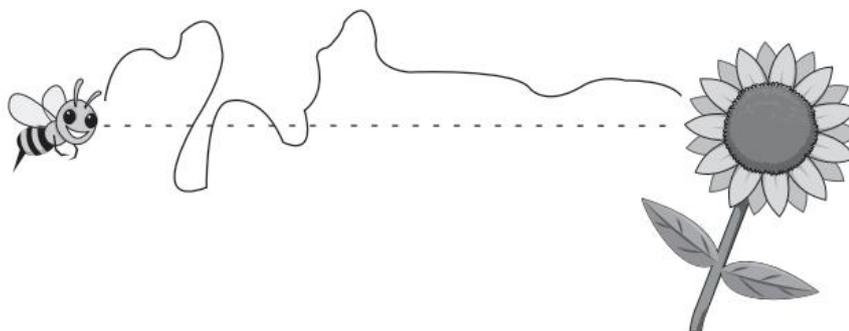
2. As you walk, record each segment of your journey in your notebook. Note the direction and distance of each segment. For example, for the route across the tennis court shown above:
 - from point A to service line = 3 metres east
 - from service line, south across court = 8 metres south.
3. Add up all the segments of your journey to find the total distance travelled.
4. Using a ruler, draw a simple map of your path on paper. Mark your starting point and finishing point. Use the ruler to measure the straight-line distance between these two points. This is your displacement. Don't forget to include the direction.
5. Compare the total distance and displacement. Were they the same? Why or why not?

Extension

- Try creating a more complex route, such as moving at angles to the court lines.
- Challenge yourself to predict the displacement before calculating it.

Activity 5.2.2

Use the diagram of the bee's motion below to explain the difference between distance and displacement.



5.3 Distance, time and speed

To fully describe motion, we need to measure:

- distance (d): how far an object travels, measured in metres (m)
- time (t): how long it takes for the object to move, measured in seconds (s)
- speed (v): how quickly an object is moving
- acceleration (a): the change in speed over time.

Calculating speed

The following is the formula for average speed. The actual speed might vary at different times along a journey.

$$s = \frac{d}{t}$$

where s = speed (m s^{-1}), d = distance (m) and t = time (s)

$$\text{or } d = s \times t$$

Examples

1. A runner covers 200 metres in 22 seconds. Determine their speed.

$$\begin{aligned} s &= \frac{d}{t} \\ &= \frac{200}{22} \\ &= 9.1 \text{ m s}^{-1} \end{aligned}$$

2. A snail crawls at 0.22 m s^{-1} for 35 seconds. How far does it travel?

$$\begin{aligned} d &= s \times t \\ &= 0.22 \times 35 = 7.7 \text{ m} \end{aligned}$$

3. A plane travels at 720 km h^{-1} for 6 hours and 20 minutes. How far does it travel?

$$\begin{aligned} d &= s \times t \\ &= 720 \times 6.33 = 4580 \text{ km} \end{aligned}$$

4. A car travels 940 kilometres in 8 hours and 15 minutes. Determine its speed.

$$\begin{aligned} 8 \text{ hours and } 15 \text{ minutes} &= 8 + \frac{15}{60} \text{ hours} \\ &= 8.25 \text{ hours} \end{aligned}$$

$$\begin{aligned} s &= \frac{d}{t} \\ &= \frac{940}{8.25} \end{aligned}$$

$$= 114 \text{ km h}^{-1} \text{ (Note: answer has been rounded up to a whole number.)}$$

Note: This example uses kilometres and hours rather than the SI units of metres and seconds. Most people would not find it easy to interpret vehicle speeds in m s^{-1} .

Distance–time graphs

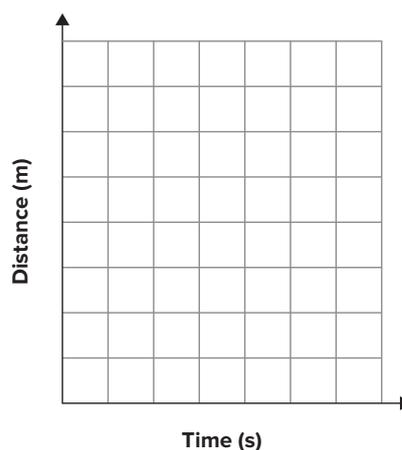
Distance–time graphs are a visual means of describing the motion of an object.

Activity 5.3.1

You are walking at 8 m s^{-1} .

Complete the following table for how far you travel after each second.

Time (s)	Distance (m)
0	0
1	
2	
3	
4	
5	



1. Draw a graph of your data using the axis titles shown. What do you notice about the graph?
2. Calculate the gradient of your line. What do you notice?
3. Add a second line to your graph that represents you walking at half the speed of the first walk.

The graph you drew in Activity 5.3.1 is a distance–time graph. We can see from the distance time graph that:

- if the graph is a straight line, you are moving at a constant speed
- the faster you move, the steeper the gradient
- the average speed is equal to the gradient
- a gradient of 0 means you are stationary.

In maths, you learn how to calculate the gradient of a straight line using $\text{gradient} = \frac{\text{rise}}{\text{run}}$. The gradient of a distance–time graph is average speed. Consider the distance–time graph shown in Figure 5.3. The average speed is $\frac{12 \text{ m}}{3 \text{ s}} = 4 \text{ m s}^{-1}$.

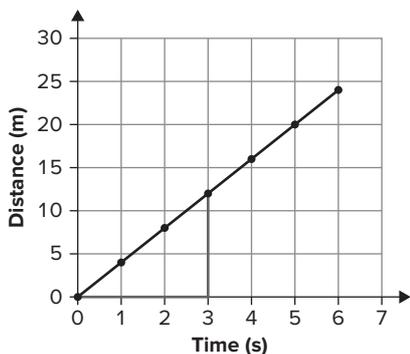
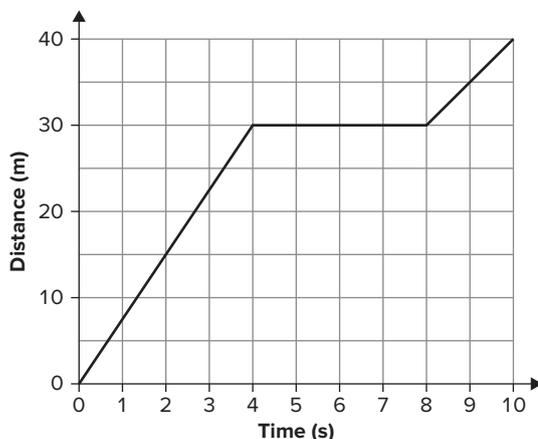


Figure 5.3: A graph of distance against time

Activity 5.3.2

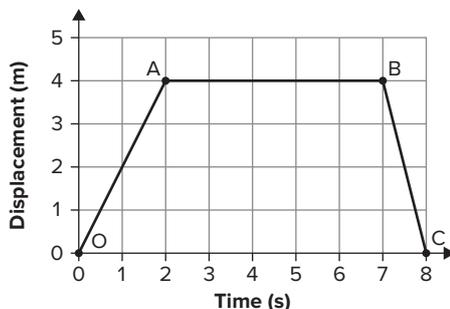
Consider the following distance–time graph.



1. Describe the journey represented by this graph.
2. Calculate the average speed during each sector.
3. Calculate the average overall speed for the journey.

Activity 5.3.3

Consider the following displacement–time graph of someone walking. Remember that because it shows displacement rather than distance, direction is also important.



1. Describe the motion represented in the graph.
2. What is the total distance covered in the 8 seconds?

Summary of distance–time and displacement–time graphs

A distance or displacement–time graph provides a clear way to visualise how the distance/displacement an object covers changes over time. On the graph, time is always shown on the x -axis, and distance or displacement is shown on the y -axis. By analysing the graph, you can interpret how an object moves.

- A straight sloping line indicates that the object is moving at a constant speed, and the steeper the slope, the faster the object is travelling.
- A horizontal line indicates that the object is stationary because no distance is being covered over time.
- A curved graph indicates that the object's speed is changing; a curve that becomes steeper shows acceleration, while a curve that flattens indicates deceleration.

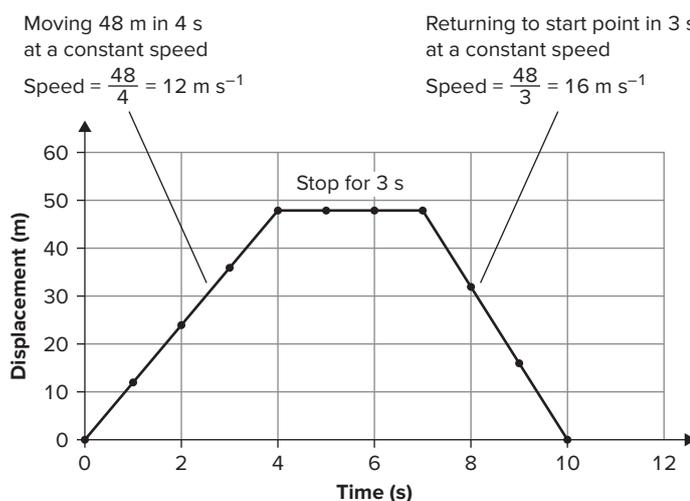


Figure 5.4: Using a displacement–time graph to determine average speed

Total distance = $48 + 48 = 96$ m. In 10 s, average

$$\text{speed} = \frac{96}{10} = 9.6 \text{ m s}^{-1}.$$

Fun fact

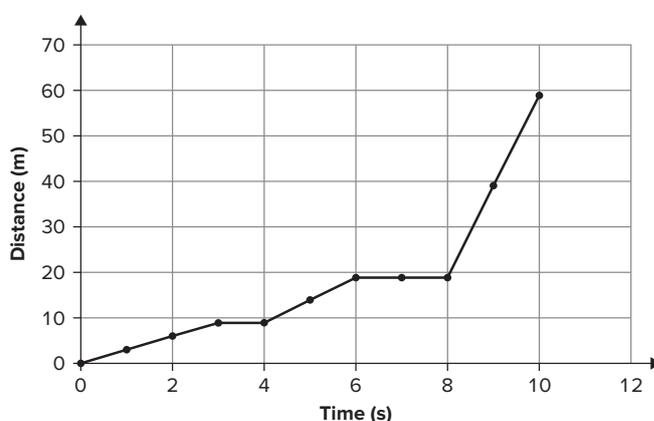
Distance–time graphs don't just measure speed on Earth; they're also used by astronomers studying celestial objects (e.g. tracking the movement of asteroids through space).

Activity 5.3.4

1. Complete the table.

Distance	Time	Speed
40 m	8.5 s	
500 m		25 m s^{-1}
	3.4 h	210 km h^{-1}
5 km		120 km s^{-1}

2. Calculate the speed of a:
 - a. person running 400 metres in 62.5 seconds
 - b. snail crawling 94 centimetres in 8.0 minutes
 - c. bullet travelling 650 metres in 1.2 seconds.
3. Calculate the distance travelled of a:
 - a. person running at 7.5 m s^{-1} for 16 seconds
 - b. lion running for 8 seconds at 14.8 m s^{-1} .
4. a. Find the speed of a bird travelling 140 kilometres in 1 hour and 15 minutes.
 b. Calculate the distance covered by a person travelling for 40 minutes at 12 m s^{-1} .
 c. Convert 10.3 m s^{-1} (Usain Bolt's world record speed in the 100-metre sprint) to km h^{-1} . Would he be breaking any of our typical speed limits for a car?
5. Describe the journey shown in the distance–time graph, including the average speed of each section.



Speed and velocity

Speed and velocity are closely related. Speed is a scalar quantity (only has magnitude), whereas velocity is a vector quantity (has magnitude and direction). Directions may include words such as forwards, backwards, left, right, north, south, east and west. In the straight-line motion examples in this chapter, speed and velocity are used interchangeably (except when discussing negative velocities on page 64).

A speed–time graph helps us understand how an object's speed changes over time. Consider Figure 5.5. Graph (b) is a speed–time graph prepared from graph (a), a distance–time graph. From Figure 5.5, you can conclude that:

- if distance is constant, then speed is 0
- if distance changes in a linear way, then speed is constant
- the steeper the gradient of the distance–time graph, the greater the speed; speed is the gradient of the distance–time graph.

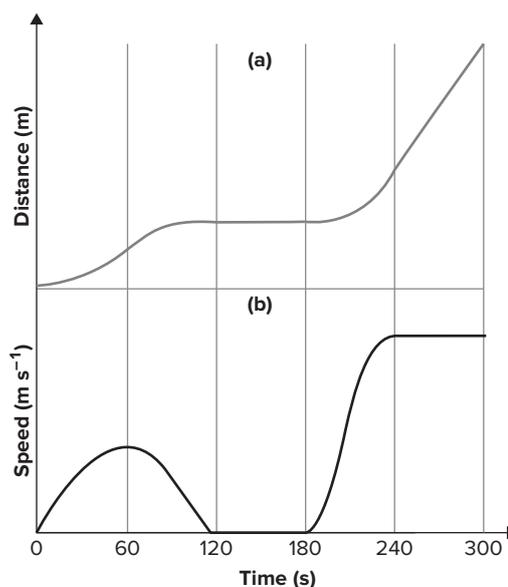
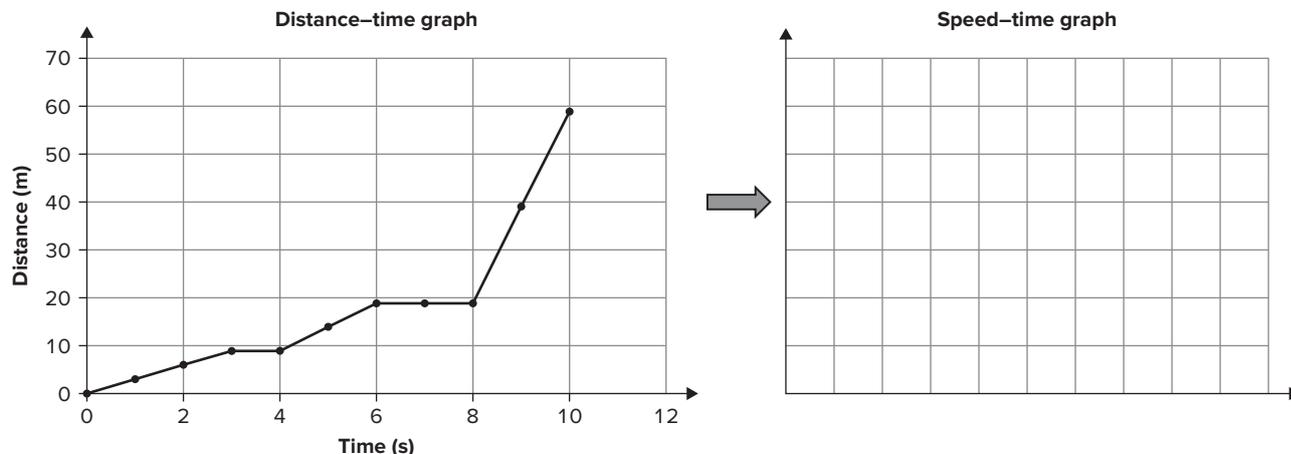


Figure 5.5: Converting a distance–time graph to a speed–time graph

Activity 5.3.5

Convert the following distance–time graph to a speed–time graph.



Extension: Calculating distance from a speed–time graph

Consider Figure 5.6. Between 2 and 4 seconds, the object travels at a constant 30 m s^{-1} . During this time, it travels $30 \times 2 = 60$ metres. You can determine this by using common sense or by applying the formula $d = s \times t$. However, you can also calculate distance by measuring the shaded area under the graph.

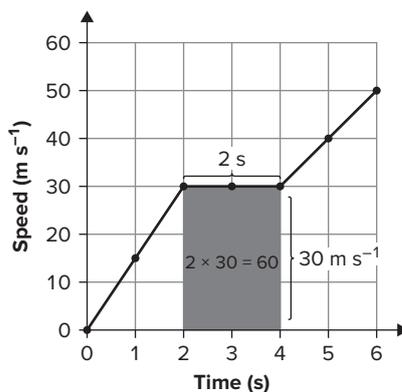


Figure 5.6: Finding distance by measuring the shaded area under a speed–time graph

This method works even when the speed is changing, as shown in Figure 5.7. By adding together the distances calculated from the different shaded parts of the graph, you can see that the total distance covered is $30 + 60 + 80 = 170$ metres.

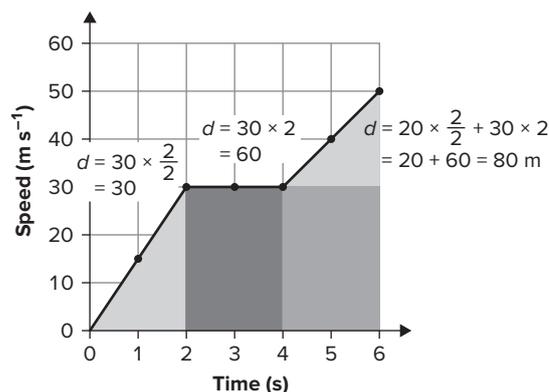


Figure 5.7: Finding distance by measuring the shaded area under a speed–time graph when speed is changing

Negative velocity

Velocity is a vector quantity, so it has direction. The graph in Figure 5.8 shows the motion of an object moving at a constant speed forwards for 2 seconds, then slowing down for 1 second and approaching 0 m s^{-1} before turning around and speeding up in the reverse direction for 1 second. It then travels at a constant speed in the reverse direction for 2 seconds. Because it travels forwards and backwards at the same speed and for the same amount of time, it ends up where it started from.

- Between $t = 0 \text{ s}$ and $t = 2 \text{ s}$, the velocity is positive ($+15 \text{ m s}^{-1}$), so the change in the displacement is also positive.
- Between $t = 2 \text{ s}$ and $t = 3 \text{ s}$, the velocity is positive but decreasing in magnitude.
- Between $t = 3 \text{ s}$ and $t = 4 \text{ s}$, the velocity is negative but increasing in magnitude.
- Between $t = 4 \text{ s}$ and $t = 6 \text{ s}$, the velocity is negative (-15 m s^{-1}), so the change in the displacement is also negative.

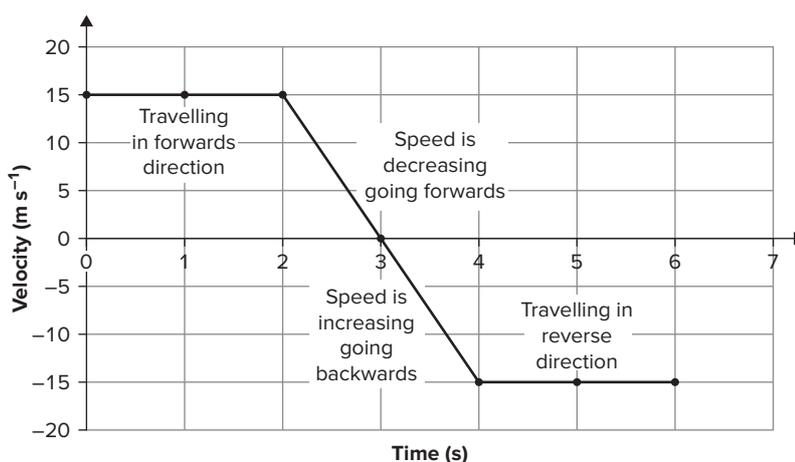


Figure 5.8: A graph of the motion of an object travelling with positive velocity and then with negative velocity

Summary of speed–time graphs

A speed–time graph provides a clear way to visualise how the velocity of an object changes over time. On the graph, time is always shown on the x -axis and velocity is always shown on the y -axis. By analysing the graph, you can interpret how an object moves.

- A horizontal line means the object is moving at a constant velocity – its speed and direction do not change.
- An upward-sloping line above the x -axis indicates acceleration, meaning the object is speeding up; a downward-sloping line above the x -axis shows deceleration (slowing down).
- If a velocity–time graph goes below the x -axis, then the object has changed direction and is moving in the opposite direction.
- The area under the line represents the total displacement, showing how far the object has travelled in a specific direction.

Fun fact

Roller coasters are designed using velocity–time graphs. Engineers carefully study these graphs to ensure the ride has thrilling accelerations and safe decelerations.

5.4 Acceleration

Acceleration is the rate of change of velocity. If you are changing speed quickly, you have a high acceleration.

$$\begin{aligned}
 a &= \frac{\text{change in velocity}}{\text{time}} \\
 &= \frac{\text{final velocity} - \text{initial velocity}}{\text{time}} \\
 &= \frac{v_f - v_i}{t} \quad \text{or} \quad \frac{v_f - v_i}{t_f - t_i}
 \end{aligned}$$

where a = acceleration (m s^{-2}), t = time (s), v = velocity (m s^{-1}).

During the first 20 seconds of motion, the speed of the object in Figure 5.9 is continually increasing. From 50 to 80 seconds, the velocity is continually decreasing – the object is slowing down. When the velocity of an object is changing, it is either accelerating or decelerating (negative acceleration).

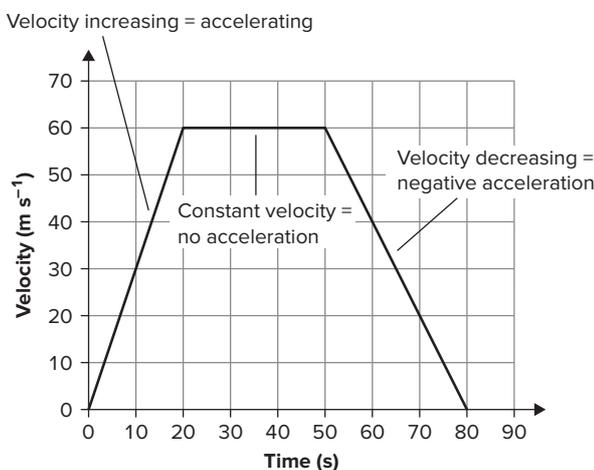


Figure 5.9: A graph of the motion of an object accelerating and decelerating

Examples

1. A runner goes from rest to 9 m s^{-1} in 3 seconds. Calculate their acceleration.

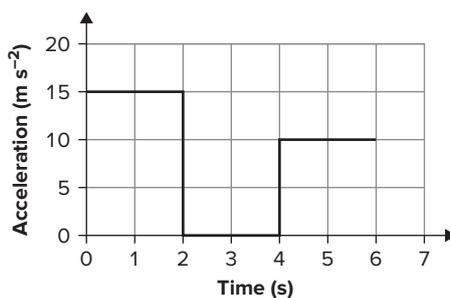
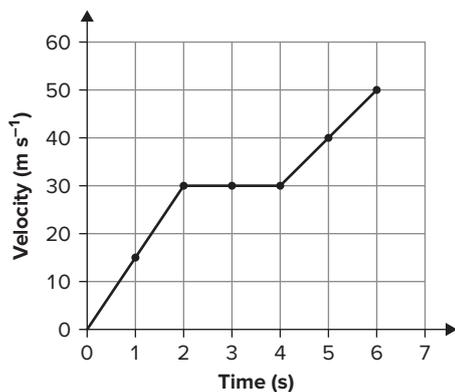
$$\begin{aligned}
 a &= \frac{\text{final speed} - \text{initial speed}}{\text{time}} \\
 &= \frac{9 - 0}{3} \\
 &= 3 \text{ m s}^{-2}
 \end{aligned}$$

2. A car travelling at 60 km h^{-1} approaches a red traffic light. It comes to rest in 1.5 s. Calculate its acceleration.

$$\begin{aligned}
 a &= \frac{\text{final speed} - \text{initial speed}}{\text{time}} \\
 &= \frac{0 \text{ km h}^{-1} - 60 \text{ km h}^{-1}}{1.5 \text{ s}} \\
 &= -40 \text{ km h}^{-1} \text{ s}^{-1}
 \end{aligned}$$

(Note the use of a negative sign.)

3. Convert the velocity–time graph shown to an acceleration–time graph.

**Key formulas**

Average speed:

$$v = \frac{\text{distance}}{\text{time}} = \frac{d}{t}$$

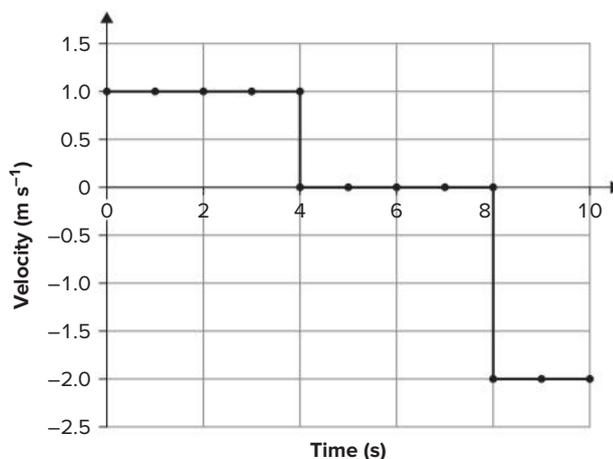
Acceleration:

$$a = \frac{\text{change in velocity}}{\text{time}} = \frac{\text{final velocity} - \text{initial velocity}}{\text{time}} = \frac{v_f - v_i}{t} = \frac{v_f - v_i}{t_f - t_i}$$

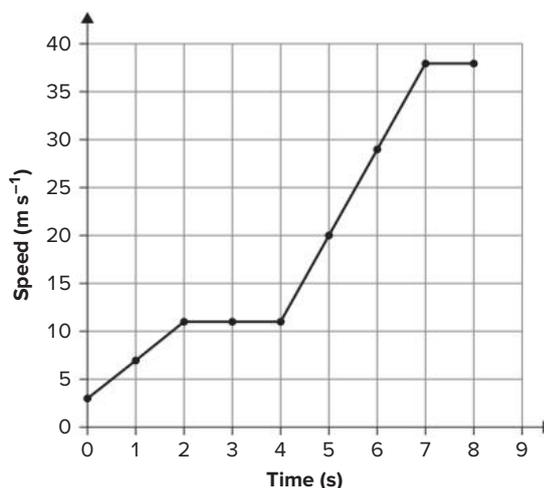
(Distance = area under a speed–time graph)

Activity 5.4.1

1. The motion of an athlete is shown in the following speed–time graph. Describe the motion of the athlete.



2. The motion of a fast bird is drawn in the following speed–time graph.



- Describe the motion of the bird.
 - Calculate the distance the bird travelled.
 - Calculate the acceleration of the bird during each sector of the graph.
 - Challenge: Draw an acceleration–time graph for this motion.
3. An athlete is competing in the 100-metre sprint.



Describe the athlete's probable motion during the race and just after the finish and explain at which points the athlete is accelerating.

- A cheetah accelerates from rest to 26 m s^{-1} in 3 seconds. A car reaches 44 m s^{-1} in 6.2 seconds. Calculate the acceleration of both. Which is accelerating faster?
- A car is at a red light. When the light changes to green, the car accelerates at 12 m s^{-2} for 8 seconds. Create a table to show the velocity of the vehicle after each second, similar to that on the next page.

Time (s)	Velocity (m s ⁻¹)

5.5 Newton's laws

What is force?

A **force** is any type of pull, push or twist applied to an object. Forces can make objects start moving, stop moving, speed up, slow down or even change direction. Forces are measured in **newtons (N)**, named after the famous scientist Sir Isaac Newton (1643–1727), who formulated the laws of motion.

Key terms

force	a push, pull or twist applied to an object
newton (N)	the unit of force

Examples of forces are the:

- push you give a shopping trolley
- pull of gravity keeping you on the ground
- friction that slows down a sliding box.

Forces can be represented with arrows that indicate the magnitude and direction of the force (Figure 5.10).



Figure 5.10: A force of 25 N pushes a ball along a flat surface

Some common types of forces are shown in Figure 5.11. Other forces include tension, elastic, applied and friction (including air resistance and water resistance).



Figure 5.11: Some examples of forces

Newton's first law

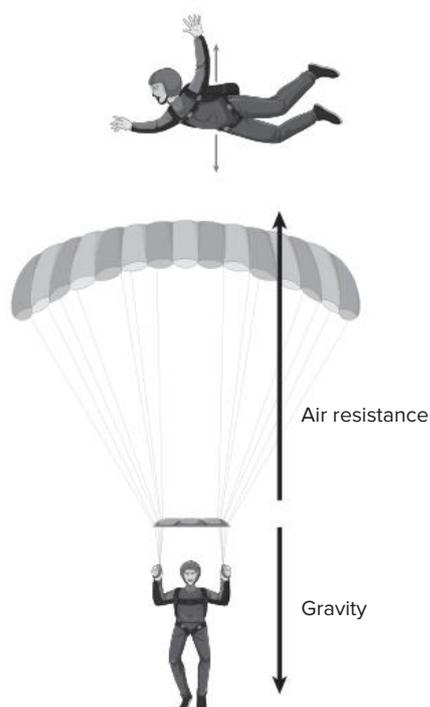
Newton's first law of motion states that an object at rest will stay at rest, unless an unbalanced force acts on it. An object in motion will keep moving in the same way unless an unbalanced force acts on it.



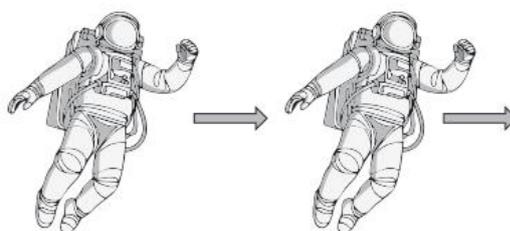
Figure 5.12: The ball stays at rest until an unbalanced force acts on it.

Examples

- Theoretically, a moving pool ball could roll forever. But it slows down because there is friction between the ball and the pool table surface. So, its motion is changed by the force of friction because friction acts in the opposite direction to motion.
- When a skydiver is falling at a constant speed, the force of gravity is balanced by air resistance (constant speed = balanced forces). When the skydiver opens their parachute, they slow down because air resistance is greater than gravity.



- If you are on a theme park ride and the ride corners quickly, your body tends to continue in the same direction it was travelling. It is the force of the ride 'pod' that changes your direction.
- If you left a spacecraft at 2 m s^{-1} , you would keep travelling, potentially forever, in the same direction at 2 m s^{-1} . Your motion is constant if there is no force acting on you.



- Two cars collide. The driver on the left is not wearing a seatbelt but the driver on the right is. The driver on the right is attached to the car so they have an unbalanced force (the seatbelt) that

stops them. The driver on the left is not attached to the car so continues at 60 km h^{-1} until the windscreen or another vehicle brings them to a halt.



Newton's second law

Newton's second law relates to how quickly something accelerates when you push on it. It is a formula that you can probably deduce from common sense.

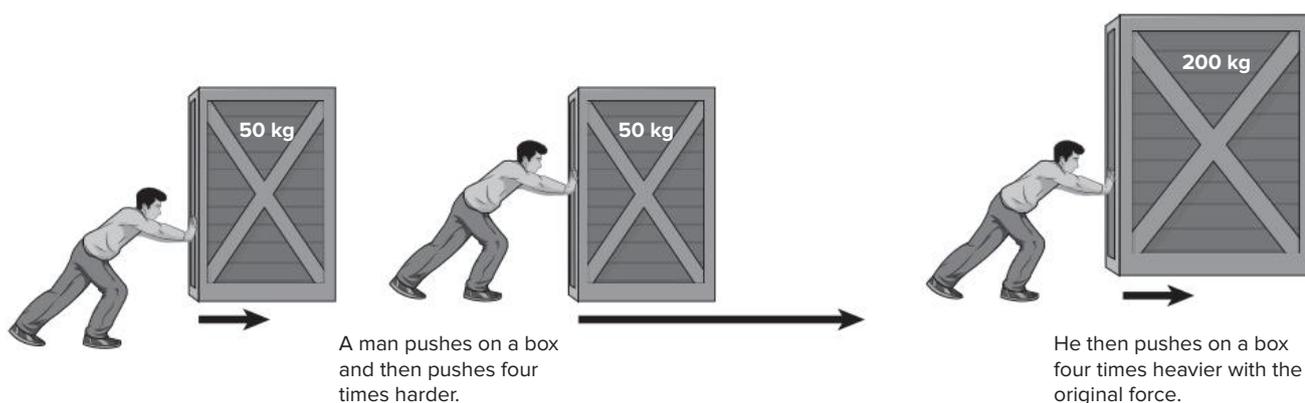


Figure 5.13: A man pushes on a box. He then pushes four times harder. How will the motion of the box change? He then pushes on a box four times heavier with the original force.

In the scenario in Figure 5.13, the variables are force (the push or pull on an object), mass (the amount of matter in an object) and acceleration (the rate at which an object speeds up, slows down or changes direction). How are these three variables related? The harder you push, the faster the object moves. The heavier an object, the harder it is to move. Newton's second law summarises this in the formula:

$$F = m \times a \quad \text{or} \quad a = \frac{F}{m}$$

where F = force in newtons (N), m = mass in kilograms (kg), a = acceleration in metres per second squared (m s^{-2}).

Note that it is acceleration, not velocity, in the formula. An unbalanced force causes an object to accelerate, not just move.

The more force you apply to an object, the faster it accelerates. However, heavier objects require more force to achieve the same acceleration. For example, when you push an empty shopping trolley, it's easy to make it move because it has low mass. However, if the trolley is full of groceries, it requires much more force to push its high mass.

Fun fact

A single newton of force is roughly the force you need to lift an apple!

Key fact: Newton's second law

An object will accelerate in the direction of an unbalanced force acting on it. The size of the acceleration depends on the size of the force and the mass of the object.

Examples

1. Calculate the force required to accelerate a 40 kilogram block at 2 m s^{-2} .

$$\begin{aligned} F &= m \times a \\ &= 40 \times 2 \\ &= 80 \text{ N} \end{aligned}$$

2. Calculate the force required to accelerate a 300 gram block at 5 m s^{-2} .

$$\begin{aligned} F &= m \times a \\ &= 0.3 \times 5 \\ &= 1.5 \text{ N} \end{aligned}$$

3. A force of 460 N is applied to a 66 kilogram block. Calculate the acceleration of the block.

$$\begin{aligned} a &= \frac{F}{m} \\ &= \frac{460}{66} \\ &= 7.0 \text{ m s}^{-2} \end{aligned}$$

Mass and weight

Although many people use mass and weight interchangeably, scientists know that they are very different things. Mass refers to the amount of matter in an object, whereas weight is the effect of gravity on an object.

Mass is constant. Your mass on the Moon is the same as your mass on Earth. The unit for mass is kilograms (kg) or grams (g).

Weight depends on where you are. Your weight is different on the Moon because the gravity of the Moon is less than that of Earth.

Weight is an example of Newton's second law:

$$F = ma$$

where weight, $W = m \times g$ (and g is the acceleration due to gravity, which has a constant value of 9.8 m s^{-2} on Earth).

You can measure weight using a spring balance. The unit for weight is the newton (N).

An item can have zero weight in space, but it will not have zero mass.

Imagine you are standing on scales in an elevator on the fifth floor of a building. If the elevator accelerates downwards, your weight will drop. (The elevator pushes back less.) If the elevator accelerates upwards, your weight will increase. (The elevator pushes back more.) When the elevator is travelling at a constant speed, your weight does not change. Your mass does not change in the elevator.

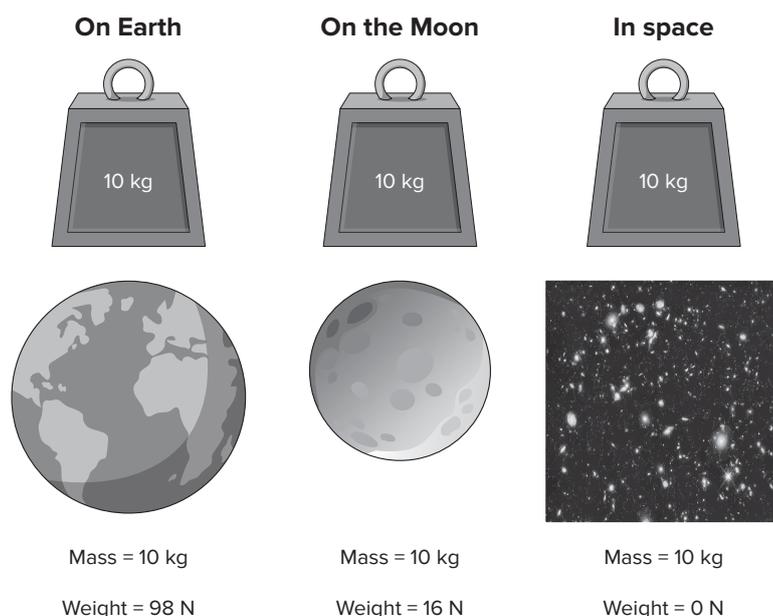


Figure 5.14: Mass is constant. Weight is variable. A 10 kg mass has a weight of 98 N on Earth, 16 N on the Moon and 0 N in space.

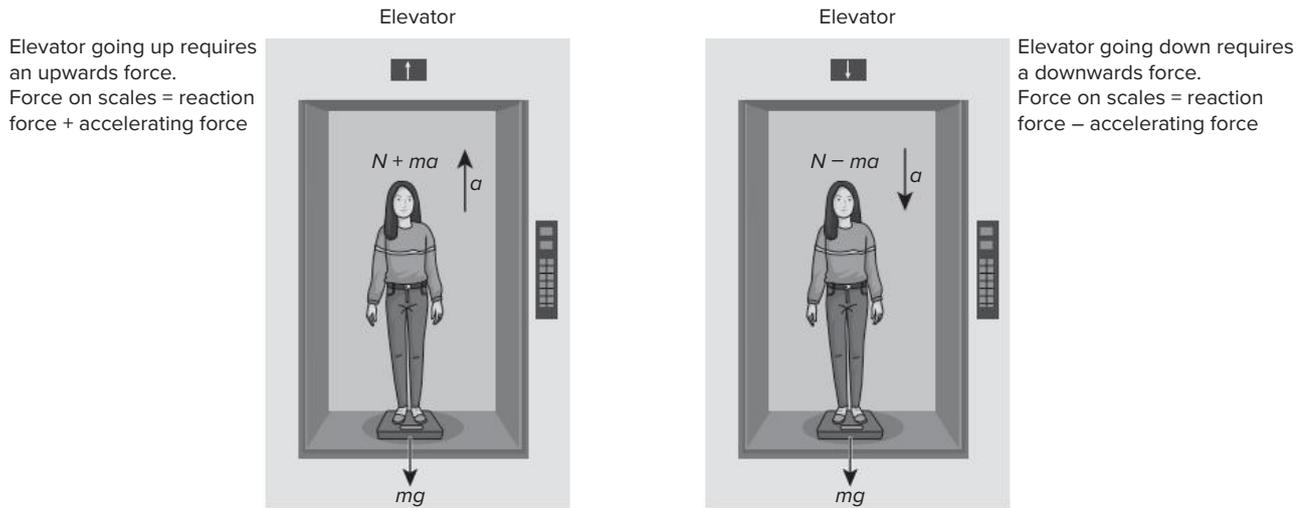
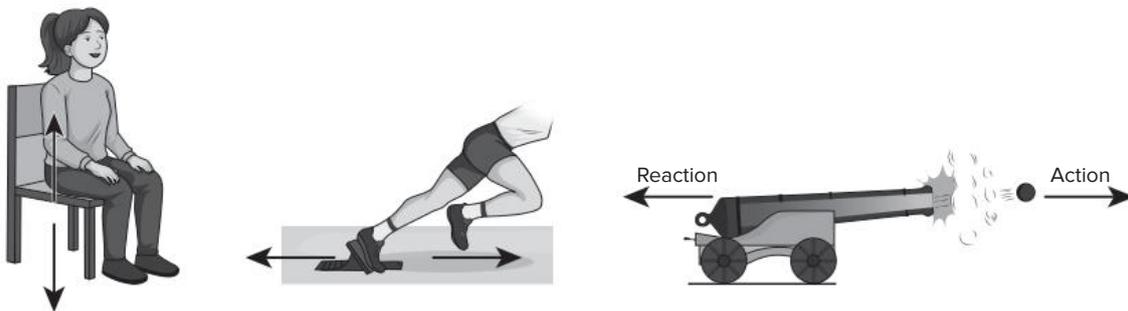


Figure 5.15: Mass does not change, but weight changes as the elevator accelerates up or down.

Newton’s third law

The force that object A exerts on object B is equal in magnitude and opposite in direction to the force that B exerts on A.



You sit on a chair – because of gravity you push on the chair but the chair pushes back with equal force.

The athlete pushes on the blocks and the blocks push back.

The cannon ball is pushed out while the cannon is pushed in the opposite direction.

Figure 5.16: For every force, there is an equal and opposite force.

Key fact: Newton’s third law

For every force, there is an equal and opposite force.

Examples

- **Rocket launch:** The force of the gas rushing downwards from the rocket engine causes an equal and opposite force to launch the rocket.
- **Elastic band:** As you apply a force to stretch the band, the band applies an equal and opposite force to pull the elastic band back into shape.

- **Tennis racquet striking ball:** The ball pushes one way on the strings and the strings push back in the opposite direction.

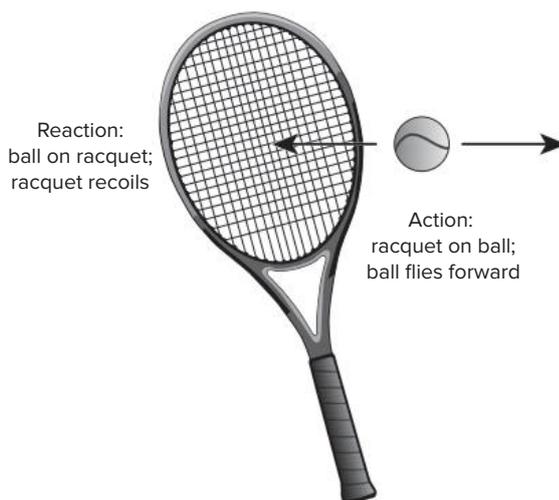


Figure 5.17: The racquet pushes on the ball (action) and the ball pushes back on the racquet (reaction).

- **Swimming:** A swimmer pushes water behind them. The water pushes back, propelling the swimmer forward.
- **Two magnets:** Like poles of two magnets are pushed towards each other. The repulsion force acts against the force pushing the magnets together.
- **Earth and Moon:** Earth's gravity attracts the Moon. The Moon exerts an equal and opposite force on Earth.



Figure 5.18: The repulsion force acts against the force that is pushing the two magnets together.

5.6 Newton's laws and the safe design of cars

Newton's laws have been used to change the design of cars to improve safety, as shown in Figure 5.19.

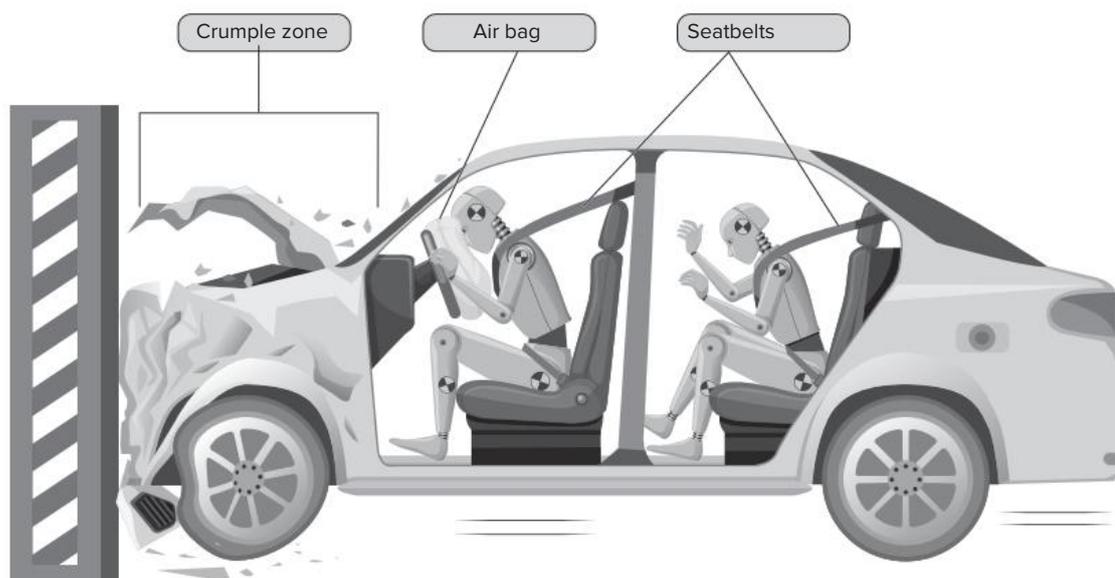


Figure 5.19: Crumple zones, air bags and seatbelts are all applications of Newton's laws that improve driver and passenger safety.

Seatbelts

Seatbelts use Newton’s first law – an object in motion will stay in motion unless acted upon by a force. In a collision, a passenger without a seatbelt continues at the same speed as they were travelling and hits or goes through the windscreen. A seatbelt stops the passenger continuing forward and spreads the impact to the stronger, lower parts of the body.



Figure 5.20: The seatbelt stops the person continuing through the windscreen.

Crumple zones

Cars are designed for the front section to deliberately crumple in an accident. This crumpling absorbs some of the energy of the impact, reducing its effect on the passengers. The main way it works is by increasing the time taken to impact.

When a car crashes, it decelerates rapidly. When it crumples, the collision effects take place over a longer period, so the deceleration is less.

As $F = ma$, the lower the deceleration, the lower the force on the passengers. A crumple zone can increase the time of impact from 0.1 second to 0.8 second, so it can reduce the force by a factor of 8.

Of course, the middle sections of the car cannot be designed as crumple zones because the occupants are there.

Air bags

Air bags use the same principle as crumple zones. By placing a cushion of gas in front of the driver, the deceleration of the driver’s head takes place over a longer period, reducing the force involved. Air bags use a rapid chemical reaction to produce gas very quickly.

Car tyre design

A car applies Newton’s third law to propel itself forward. The tyre pushes on the road and the road pushes back. If there is no grip between the road and the tyre, the tyre will skid. Tyre manufacturers research the best tread patterns to make the contact between road and tyre as efficient as possible.



Figure 5.21: The car is moving to the left. The friction between the tyre and road surface enables the car to push forward. If the tyre does not have a good tread, the car floats on the layer of water.

A car on a wet road needs to push water out from under its tyres. A good tread pattern allows this. A poor tread pattern leads to a build-up of water and the car ‘aquaplanes’ on the water layer between the tyre and the road surface.

5.7 The science behind safer roads

The importance of lower speed limits

Speed limits are not just rules – they are scientifically designed to reduce the number and severity of accidents and save lives. Newton’s laws of motion explain why lower speed limits are especially crucial in high-risk areas like school zones and urban environments with heavy truck traffic.

Newton’s laws and the impact of speed

- **Newton’s first law (inertia):** A moving object will continue moving at the same speed unless acted on by an external force. This means that when a car or truck is travelling fast, it requires a strong force, like brakes or a collision, to stop.
- **Newton’s second law ($F = ma$):** The greater the mass of a vehicle, the more force is needed to stop it. A truck, being much heavier than a car, takes a significantly longer distance to come to a stop.
- **Newton’s third law (action–reaction):** When a vehicle crashes, the force of the collision is exerted on both the vehicle and the object it hits. At higher speeds, this force increases, leading to more severe damage and injury.

Why lower speed limits matter

- **Stopping distance:** When speed increases, the total stopping distance (reaction distance + braking distance) increases exponentially.
- **Impact force:** The kinetic energy of a moving vehicle is proportional to the square of its speed. If car A is moving at 50 km h^{-1} and car B is moving at 25 km h^{-1} , then the force of impact for car A is four times greater than the force of impact for car B.

Investigation: The effect of using mobile phones on car stopping distance

Research suggests that motorists should not use their phones while driving. This raises a question as to how ‘bad’ it is and whether hands-free is any better.

It is legal to use your mobile phone in a hands-free device throughout Australia. However, this fact may lead drivers to think that hands-free use is safe.

In reality, evidence shows there is little difference in the risks when choosing a hands-free device over a hand-held one. For example, a car travelling at 45 km h^{-1} will travel roughly three car lengths per second.

A driver distracted for only a single second can travel quite far without being aware of any dangers.

This task investigates the effect of a distraction on braking distance.

- Stopping time = time to respond + time for car to stop once brake applied
- Stopping distance = reaction distance + braking distance
- Only the first part is affected by a distraction.

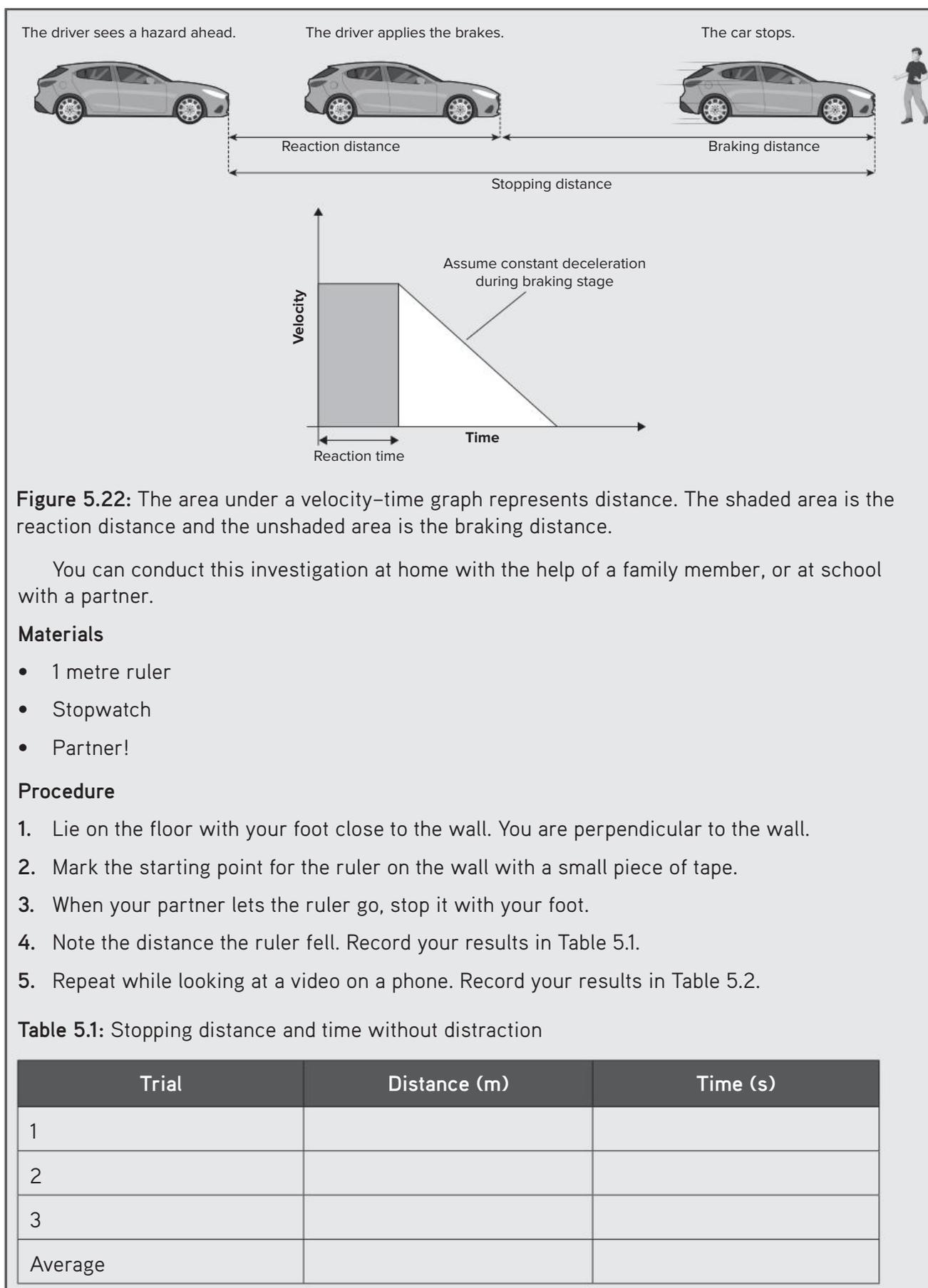


Table 5.2: Stopping distance and time with distraction

Trial	Distance (m)	Time (s)
1		
2		
3		
Average		

Assuming you are travelling at 60 km h^{-1} , use the motion formulas to calculate the reaction difference for the two scenarios.

Hint: Convert km h^{-1} to m s^{-1} :

$$60 \text{ km h}^{-1} = \frac{60 \times 1000 \text{ m}}{60 \times 60 \text{ s}} = \frac{60000}{3600} = 16.7 \text{ m s}^{-1} = 17 \text{ m s}^{-1}$$

Distance travelled before braking, without phone = _____ m

Distance travelled before braking, with phone = _____ m

Distance travelled during braking from 60 km h^{-1} is estimated at 20 m for a dry road and 29 m for a wet road.

Total distance required to stop on a dry road, without a phone = _____ m

Total distance required to stop on a dry road, with a phone = _____ m

Measure this distance out on the school yard. What conclusion can you draw?

5.8 Understandings of forces in First Nations communities

Across Australia and the islands of the Torres Strait, First Nations communities use tools to increase the velocity and accuracy of projectiles, primarily for hunting. Different groups developed various styles of spear-throwers; the most well-known First Nations term for them is the 'woomera' (from the Dharug language).

Spear-throwers provide an extension to the human thrower's arm, increasing the speed or distance a spear can travel. When you throw an object, your arm acts as a lever with your shoulder being the pivot point or fulcrum. Designs vary, but woomeras usually have a tapered handle to grip onto, while the other end has a 'peg', a bound piece of stone or wood to keep the spear in place while it is thrown. The use of a woomera effectively extends the length of your arm, making it a longer lever. The spear can be released with a greater force, hence a greater acceleration.

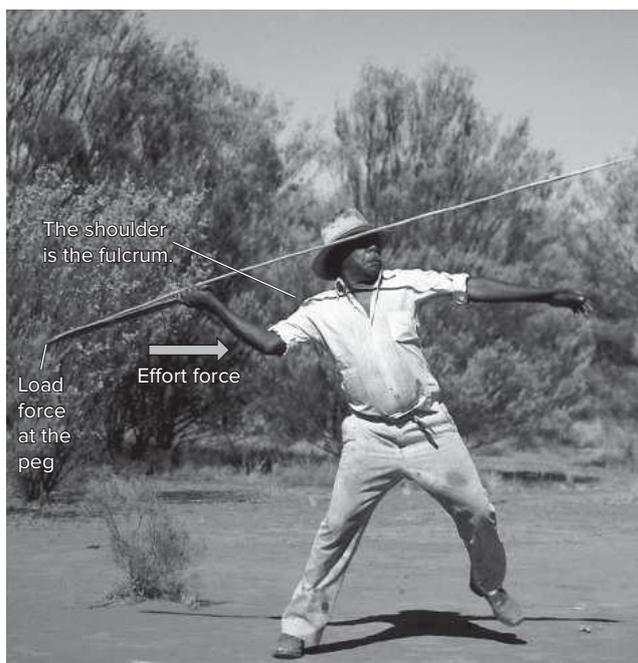


Figure 5.23: A woomera is a first-class lever. The shoulder of the thrower acts as the fulcrum, the effort force is delivered via the arm and the load is the spear.

Look it up

People from the Torres Strait Islands and nearby parts of northern Queensland use bows and arrows alongside spear-throwers. Research online to find out the physics behind how a bow and arrow works.

5.9 Newton’s laws in sports

Sports performance is deeply connected to the laws of physics. Every movement an athlete makes – whether sprinting, jumping or throwing – can be explained by Newton’s laws of motion. These principles help athletes improve their performance while also ensuring safety in sports. Let’s explore how these laws apply to real-world sporting situations.



Object in motion remains in motion at constant speed and in a straight line unless acted on by an unbalanced force.



The acceleration of an object depends on the mass of the object and the amount of force applied.



Whenever one object exerts a force on another object, the second object exerts an equal and opposite force on the first.

Figure 5.24: Newton’s laws of motion in sport

Newton's first law – the law of inertia

This law states that an object will remain still or keep moving at the same speed in a straight line unless a force acts on it. In sports, this explains why an athlete at the starting line won't move until they exert a force, and why a moving object (e.g. a football) won't stop unless friction, air resistance or another force slows it down.

Example

A sprinter remains completely still before the race starts. The moment the starter gun fires, they push against the blocks to overcome inertia and start moving. Likewise, when a soccer player kicks a stationary ball, they apply force to change its state of motion.

Fun fact

In space, where there is no air resistance, a ball kicked by an astronaut would keep moving in the same direction forever unless something stopped it!

Newton's second law – force, mass and acceleration

This law describes how an object's acceleration depends on the force applied to it and its mass ($F = ma$). The greater the force, the faster the acceleration – but if an object is heavier, more force is required to achieve the same acceleration.

Example

A cyclist pedalling harder will accelerate faster. However, if the cyclist is carrying a heavy backpack, they will need to apply more force to reach the same speed in the same time. This also explains why professional sprinters have powerful leg muscles – they need to produce a large force to achieve maximum acceleration.

Try this

Take two balls of different weights (e.g. a tennis ball and a basketball). Push them both with the same amount of force. Which one accelerates faster? This demonstrates how mass affects acceleration.

Newton's third law – action and reaction

This law states that every action has an equal and opposite reaction. In sports, this means that when an athlete pushes against the ground, the ground pushes back with the same force, allowing them to move.

Example

In swimming, an athlete pushes against the water using their legs and arms. In response, the water pushes them back in a forward direction through the water.

Activity 5.9.1

1. Observe a sporting event and identify moments where Newton's laws are at work. How do athletes apply force? What role does friction play?
2. Try running and then suddenly stopping. Do you notice how your body wants to keep moving forward? What does this tell you about inertia?

3. Jump and measure: Try jumping on different surfaces (e.g. grass, concrete, trampoline) and compare how high you can go. How does Newton’s third law apply to each surface?

Understanding Newton’s laws helps athletes improve speed, strength and technique. Engineers even use these principles to design better sports equipment, from running shoes to protective gear, making sports both more competitive and safer.

End-of-chapter summary

- From understanding how force, mass and acceleration are related, to applying Newton’s laws in sports and safety, motion is a fascinating area of science.
- It helps us design better tools, safer vehicles and more effective athletic techniques.
- Next time you’re riding in a car or watching a sports game, think about the science behind it – you’ll be amazed at how Newton’s laws are in action!

Revision questions

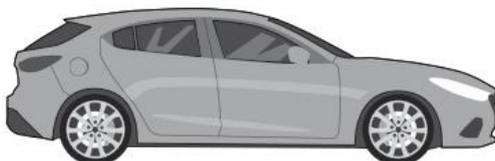
1. For each of the scenarios below, identify which of Newton’s laws is relevant and what that law tells us about the scenario.

a.

Same force



Small mass, large acceleration



Large mass, small acceleration

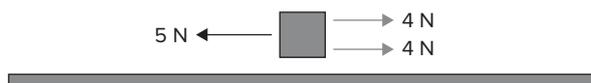
b.



c.



2. The forces on a 20 kg box are shown below.



Describe the motion of the box that will result from these forces.

3. A soldier using a rifle repeatedly notices their shoulder is very sore at the end of the day. Refer to one of Newton's laws to explain the sore shoulder.
4. a. In theory, if you push a box from rest with a constant force causing an acceleration of 3 m s^{-2} , what is the speed of the box after:
- 1 s?
 - 2 s?
 - 3 s?
 - 4 s?
- b. What conclusion can you draw about the speed?
5. In horse racing, horses are given weights to carry. The better the track record of the horse, the greater the weight assigned to it. Use Newton's second law to explain how this weighting system works.
6. An ice skater is crossing a rink at a constant speed. Discuss the forces acting on the ice skater.
7. a. A force of 550 N acts on a 3.4 kg log of wood. Calculate the acceleration of the log.
b. What is the force required to accelerate a brick of mass 3.8 kg at 12 m s^{-2} ?
8. A 75 kg base jumper jumps from the top of a building. Calculate the force acting on the jumper given that the acceleration is 10 m s^{-2} .
9. The mass of Mars is $0.65 \times 10^{24} \text{ kg}$ and the mass of Earth is $5.97 \times 10^{24} \text{ kg}$.
- How will your mass compare on each planet? Justify your answer.
 - How will your weight compare on each planet? Justify your answer.

Chapter 6 – Chemistry

6.1 Introduction to chemistry and its uses

Chemistry is often described as the basis for all of science – if you don't understand the building blocks of matter, how can you understand any of the other sciences? Chemistry is used to make the medicines that treat our illnesses, the fuels that enable us to run our homes and travel around the world, and the metals we use to create the infrastructure around us.

Pharmaceuticals

Chemists work in many industries. For example, some chemists work in pharmacies as 'compounding chemists' where they mix chemicals on site to produce medicines customised for individual patients.

In 1893, German chemist Joseph von Mering synthesised acetaminophen from phenol in a three-step process. Acetaminophen is more commonly known as paracetamol, or by the brand name Panadol. Paracetamol is just one of many examples of innovation and experimentation leading to the creation of many modern medicines.

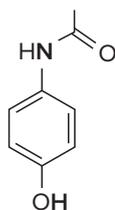


Figure 6.1: Paracetamol

Fuels and electricity generation

Traditional fuel is made from hydrocarbons – compounds of carbon and hydrogen. Crude oil is extracted from underground or under the sea and is separated into its different components by a technique called fractional distillation. The most common examples are the petroleum and diesel used to power combustion engines. Chemists have also been involved in combining elements, particularly silicon, to create solar panels. These panels harness solar energy to produce electricity.

Metallurgy

One of the earliest forms of chemistry involved using different chemicals to alter or strengthen metals. Metallurgy is the chemical process used to separate metals from **ore**. Metallurgists also use chemistry to create **alloys**. For example, adding carbon to iron produces steel – a very strong substance.

The chemical properties of metals are discussed further on page 96.

Key terms

ore	a naturally occurring rock or sediment that contains a useful substance, often a metal
alloy	a substance made by combining two or more elements

Your growing understanding of atoms, elements and how different chemicals react will help you understand how chemistry works to create a better world. By the end of this topic, you should be able to:

- relate aspects of the development of the periodic table
- explain the arrangement of the periodic table
- use the periodic table to predict the properties of elements
- describe the structure of each element in terms of the number of protons, neutrons and electrons and the arrangement of the electrons
- describe the differences in properties between metals and non-metals
- write correct ionic formulas
- classify reaction types and write balanced equations for reactions
- look up and use the relative atomic mass of elements
- describe instances of chemical understanding of First Nations peoples
- understand reaction rates and factors that affect reaction rate
- explain the use of chemistry in the manufacture of common commercial products.

6.2 Atoms

Atoms are the fundamental subunits of matter – the ‘building blocks’ of everything around us. Anything that has mass and occupies space (by having volume) is made up of atoms. This means the air you breathe, the water you drink and your body itself are all made up of atoms.

Atoms can exist individually, or they can be joined to other atoms by chemical bonds to form molecules and lattices. This is the case for most elements and all compounds. Elements and compounds are both pure substances. Elements are composed of one type of atom, which can exist as separate molecules or as lattices. Compounds are composed of more than one type of atom and can also be joined as molecules or as lattices.

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, which is 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, which again is more common.

Key terms

molecule	two or more atoms joined together by chemical bonds
lattice	a continuous network of atoms joined by chemical bonds

Atomic structure

The accepted structure of an atom – the Bohr model – is shown for carbon in Figure 6.2.

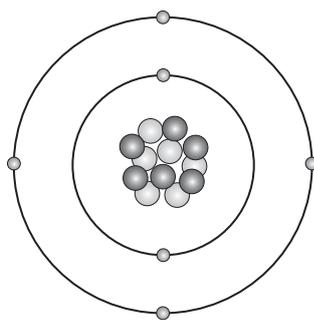


Figure 6.2: The Bohr model of a carbon atom

The subatomic particles in an atom are called protons, neutrons and electrons. The protons and neutrons are in a small nucleus in the centre of the atom and the electrons orbit the nucleus in a shell. Protons have a positive charge, neutrons have no charge and electrons have a negative charge.

Activity 6.2.1

1. Annotate Figure 6.2 to identify the different types of particles.
2. How many of each type of particle are there?
3. How do these particles differ?
4. How will the arrangement in other atoms differ?
 - The number of protons equals the number of electrons; therefore, atoms are neutral.
 - The number of neutrons is greater than or equal to the number of protons (for all elements except hydrogen, which does not have any neutrons).

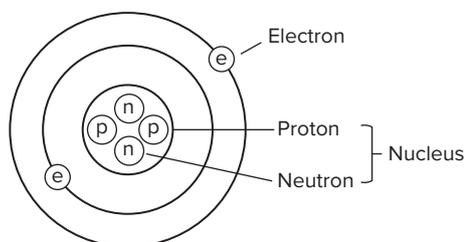


Figure 6.3: The subatomic particles in an atom

This information is summarised in Table 6.1. Note that the mass of an electron is much less than that of a proton or neutron.

Table 6.1: Key features of subatomic particles

Subatomic particle	Symbol	Charge	Location	Mass, relative to a proton
Proton	p	Positive (+)	Nucleus	1
Neutron	n	Neutral (0)	Nucleus	1
Electron	e	Negative (-)	Shell	$\frac{1}{1800}$

Key understanding

Atoms have a nucleus containing positive protons and neutral neutrons. Electrons are lighter than protons and neutrons, are negatively charged and move rapidly around the nucleus.

Fun fact

The word 'atom' comes from the Greek word *atomos*, meaning 'undivided'. Scientists measure the size of atoms in nanometres (a billionth of a metre), which varies from 0.1 to 0.5 nanometres in width. However, even though they are tiny, the space between the nucleus and electrons is relatively vast – an atom is 99.9 per cent empty space!

6.3 The periodic table

The periodic table is shown in Figure 6.4. The elements are listed in order of atomic number, starting with hydrogen with one proton, then helium with two and lithium with three.

1	1																	2	
1	H Hydrogen																		He Helium
2	3	4																	
2	Li Lithium	Be Beryllium																	
3	11	12																	
3	Na Sodium	Mg Magnesium																	
4	19	20	21	22	23	24	25	26	27	28	29	30							
4	K Potassium	Ca Calcium	Sc Scandium	Ti Titanium	V Vanadium	Cr Chromium	Mn Manganese	Fe Iron	Co Cobalt	Ni Nickel	Cu Copper	Zn Zinc							
5	37	38	39	40	41	42	43	44	45	46	47	48							
5	Rb Rubidium	Sr Strontium	Y Yttrium	Zr Zirconium	Nb Niobium	Mo Molybdenum	Tc Technetium	Ru Ruthenium	Rh Rhodium	Pd Palladium	Ag Silver	Cd Cadmium							
6	55	56	57–71	72	73	74	75	76	77	78	79	80							
6	Cs Caesium	Ba Barium		Hf Hafnium	Ta Tantalum	W Tungsten	Re Rhenium	Os Osmium	Ir Iridium	Pt Platinum	Au Gold	Hg Mercury							
7	87	88	89–103	104	105	106	107	108	109	110	111	112							
7	Fr Francium	Ra Radium		Rf Rutherfordium	Db Dubnium	Sg Seaborgium	Bh Bohrium	Hs Hassium	Mt Meitnerium	Ds Darmstadtium	Rg Roentgenium	Cn Copernicium							
	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71				
	La Lanthanum	Ce Cerium	Pr Praseodymium	Nd Neodymium	Pm Promethium	Sm Samarium	Eu Europium	Gd Gadolinium	Tb Terbium	Dy Dysprosium	Ho Holmium	Er Erbium	Tm Thulium	Yb Ytterbium	Lu Lutetium				
	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103				
	Ac Actinium	Th Thorium	Pa Protactinium	U Uranium	Np Neptunium	Pu Plutonium	Am Americium	Cm Curium	Bk Berkelium	Cf Californium	Es Einsteinium	Fm Fermium	Md Mendelevium	No Nobelium	Lr Lawrencium				

Figure 6.4: The periodic table

The periodic table can be used to determine the number of protons, neutrons and electrons in each atom. The **atomic number** is the number of protons in an atom of the element. A neutral atom has the same number of electrons and protons. The **atomic mass** is the combined mass of protons and neutrons.

For example:

- Aluminium has an atomic number of 13 and an atomic mass of 27. Therefore, it has 13 protons, 14 neutrons and 13 electrons.
- Hydrogen has an atomic number of 1 and an atomic mass of 1. Therefore, it has 1 proton, no neutrons and 1 electron.

- Oxygen has an atomic number of 8 and an atomic mass of 16. Therefore, it has 8 protons, 8 neutrons and 8 electrons.

Scientists use atomic notation (also called **nuclide notation**) to convey this information. Figure 6.5 shows the nuclide notation for nitrogen.

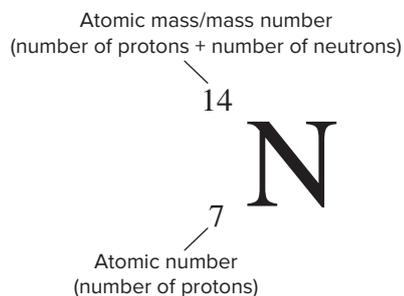


Figure 6.5: The nuclide notation for nitrogen (N)

Key terms

atomic number	an element's number of protons
atomic mass	the number of protons plus the number of neutrons of an element
nuclide notation	a shorthand way to show information about elements, in particular the number of protons and the number of neutrons

Isotopes

Isotopes are forms of an element that have different numbers of neutrons. All isotopes of an element have the same atomic number and number of protons, but different atomic masses. The nuclide notation shown in Figure 6.5 is also used for writing isotopes.

For example, there are two slightly different types of chlorine atoms: ${}_{17}^{35}\text{Cl}$ and ${}_{17}^{37}\text{Cl}$. You should be able to deduce that ${}_{17}^{37}\text{Cl}$ has two more neutrons than ${}_{17}^{35}\text{Cl}$. These different forms are isotopes of chlorine. The different isotopes are still chlorine because they have the same atomic number.

All elements have isotopes. Isotopes can be stable or unstable (radioactive). Some elements (e.g. uranium and plutonium) only exist in an unstable form.

Key term

isotopes	atoms of the same element with different numbers of neutrons
-----------------	--------------------------------------------------------------

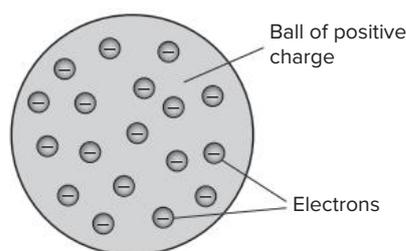
Activity 6.3.1

- Consider ${}_{19}^{39}\text{K}$.
 - State the correct names for the superscript and subscript.
 - Name the element.
 - Describe the structure of this atom.

2. Fill in the missing terms:

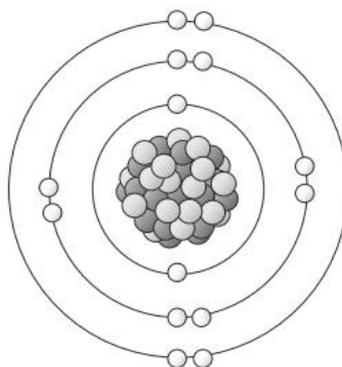
Atoms contain _____, _____ and _____. Atoms have a small, central nucleus containing _____ and _____, and the _____ are located in shells around the nucleus.

3. One form of uranium has 92 protons and 146 neutrons. Express this information in nuclide notation.
4. The following diagram shows an early model of an atom – the plum pudding model. Explain why this model is incorrect.



5. Magnesium has three different isotopes: ${}_{12}^{24}\text{Mg}$, ${}_{12}^{25}\text{Mg}$ and ${}_{12}^{26}\text{Mg}$.
- Why does magnesium have these different forms?
 - Will these atoms behave similarly in reactions?
 - Why is ${}_{11}^{24}\text{Na}$ not a form of magnesium?

6. Identify the following element. (Note: Not all particles in the nucleus are shown.)



7. Describe the Bohr models for phosphorus and neon, naming all particles.

6.4 Electron configuration

In 1913, Danish physicist Neils Bohr presented a model to explain how electrons are arranged (the **electron configuration**) around a nucleus of the atom. His model stated that:

- electrons have a negative charge
- electrons revolve around the nucleus in circular orbits, called shells
- inner shells fill first because they have the lowest energy levels
- the further a shell is from the nucleus, the more electrons it can hold.

Key term

electron configuration

the arrangement of electrons around the nucleus of an atom

This model can be explained with diagrams and examples. For example, Figure 6.6 shows a nucleus surrounded by electron shells. The inner shells fill first, then more electrons will fit in each shell as you move further from the nucleus.

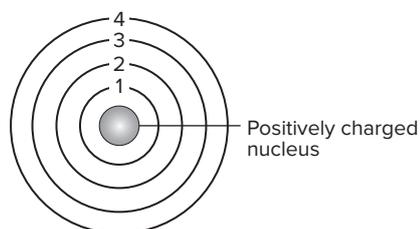


Figure 6.6: The possible electron shells and the numbers assigned to them

The number of electrons each shell can accommodate follows the rule $2n^2$, where n = the shell number. For example, the third shell on Figure 6.6 is $2n^2 = 2 \times 3^2 = 18$ electrons. This rule is demonstrated in Table 6.2.

Note: even though the third shell can hold up to 18 electrons, it will not have more than 8 electrons if it is the outer shell. For example, the electron configuration of potassium with 19 electrons is not 2,8,9 as this would leave the outer shell with over 8 electrons. Instead it is 2,8,8,1. In very large atoms such as uranium, the third shell is not the outer shell and it will hold the full 18 electrons.

Table 6.2: Visualising electron shells for the first 20 elements

Electron shell number	Formula $2n^2$	Number of electrons
1	$2 \times 1^2 = 2$	2
2	$2 \times 2^2 = 8$	Up to 8
3	$2 \times 3^2 = 18$	Up to 18
4	$2 \times 4^2 = 32$	Up to 32

Figure 6.7 shows how this can be applied to different elements.

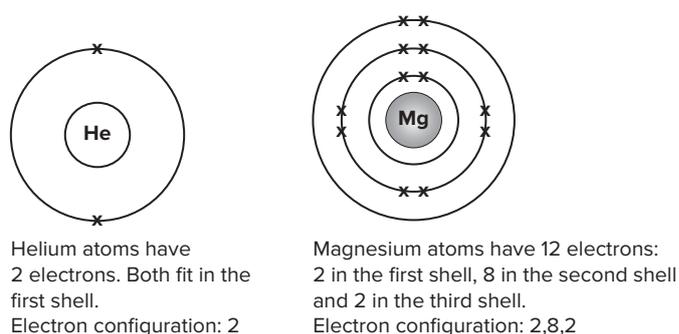


Figure 6.7: The electron configurations for helium and magnesium

The outer-shell electrons are referred to as the **valence** electrons.

Key term

valence electrons	the outer-shell electrons in an atom, which determine the chemical reactivity of the element
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Activity 6.4.1

Complete the following table for the first 20 elements. Remember, the outer shell cannot have more than 8 electrons.

Element	Symbol	Atomic number	Electron configuration
Hydrogen	H	1	1
Helium	He	2	
Lithium			2,1
Boron			
		6	
		7	
			2,7
Neon			
	Mg		
			2,8,3
		19	
Calcium			2,8,8,2 (not 2,8,10)

6.5 Emission spectroscopy

One of the most significant pieces of evidence for electron shells is emission spectroscopy. A simple version of **emission spectroscopy** is a flame test.

Figure 6.8 shows how a flame test is conducted. A wire made from an alloy of nickel and chromium (called nichrome) is dipped into an **ionic solution** (a solution containing **ions**) and the nichrome wire is placed in a hot flame.

Key terms

emission spectrum	the spectrum of electromagnetic radiation emitted by electrons in the excited atoms or molecules
ionic solution	a solution containing ions; these solutions can conduct electricity
ion	an atom that has gained or lost electrons, resulting in a positive or negative charge

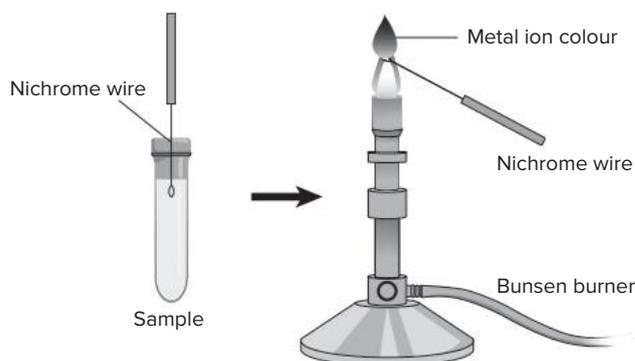


Figure 6.8: A flame test

The colour of the flame depends on the elements in the sample. Table 6.3 shows some of the colours produced by the flame test.

Table 6.3: Flame test colours of different metal compounds

Solution	Colour
Copper chloride	Green
Potassium chloride	Lilac
Strontium nitrate	Red
Sodium chloride	Yellow
Barium nitrate	Green

Think about it

How can you tell that it is the metal in the solution that is causing the flame colour?

Activity 6.5.1

1. Give an example of how the flame test could be useful.
2. Explain the limitations of the flame test.
3. What colour would you expect when testing:
 - a. sodium phosphate?
 - b. potassium iodide?

The different flame colours are explained by the movement of the electrons in the metal atoms in the flame. The heat of the flame supplies energy to the electrons in the metal atom. The electrons jump to one of the vacant outer-shell positions on the atom. The electron jump is shown in Figure 6.9.

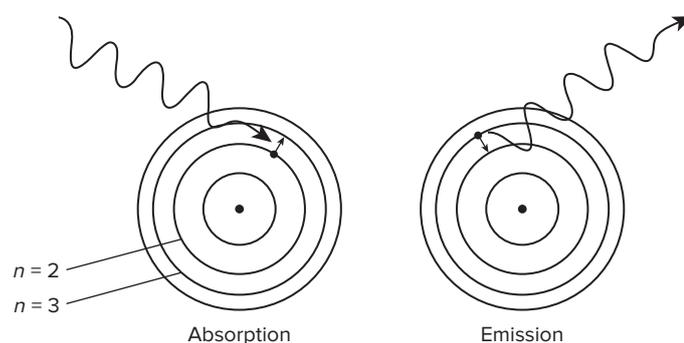


Figure 6.9: The atom absorbs energy from the flame and an electron jumps to a vacant higher shell. This energy is released as light when the electron returns to its original shell.

The lowest energy state of an atom is referred to as its ground state. When the atom absorbs energy, and an electron moves to an outer shell, the atom is in an excited state. When the atom returns to the ground state, it releases energy.

Each metal produces a different colour in the flame test because the electron jump is different for each metal atom. Different jumps release a different amount of energy, leading to a different coloured light. So the coloured light can be used to identify different metals.

The light emitted provided scientists with evidence for electrons being in shells. The wavelength of the light provides information about the energy levels in particular metals. A spectroscope is a device used to study the light emitted by an atom. Sodium shows a series of emissions such as in Figure 6.10. There are multiple wavelengths emitted because the excited electron can go to different empty shells of the atom. When the electron returns from a different shell, the wavelength of the emission is different.



Figure 6.10: Sodium atoms emit radiation of several different wavelengths.

 **Activity 6.5.2**

Refer to the periodic table to help you answer the following questions.

												1 Groups												18	
	1											2							2						
1	H <small>Hydrogen</small>																	He <small>Helium</small>							
												13	14	15	16	17									
2	Li <small>Lithium</small>	Be <small>Beryllium</small>											B <small>Boron</small>	C <small>Carbon</small>	N <small>Nitrogen</small>	O <small>Oxygen</small>	F <small>Fluorine</small>							Ne <small>Neon</small>	
													13	14	15	16	17							18	
3	Na <small>Sodium</small>	Mg <small>Magnesium</small>											Al <small>Aluminium</small>	Si <small>Silicon</small>	P <small>Phosphorus</small>	S <small>Sulfur</small>	Cl <small>Chlorine</small>							Ar <small>Argon</small>	
			3	4	5	6	7	8	9	10	11	12	13	14	15	16	17							18	
Periods	4	K <small>Potassium</small>	Ca <small>Calcium</small>	Sc <small>Scandium</small>	Ti <small>Titanium</small>	V <small>Vanadium</small>	Cr <small>Chromium</small>	Mn <small>Manganese</small>	Fe <small>Iron</small>	Co <small>Cobalt</small>	Ni <small>Nickel</small>	Cu <small>Copper</small>	Zn <small>Zinc</small>	Ga <small>Gallium</small>	Ge <small>Germanium</small>	As <small>Arsenic</small>	Se <small>Selenium</small>	Br <small>Bromine</small>							Kr <small>Krypton</small>
5	Rb <small>Rubidium</small>	Sr <small>Strontium</small>	Y <small>Yttrium</small>	Zr <small>Zirconium</small>	Nb <small>Niobium</small>	Mo <small>Molybdenum</small>	Tc <small>Technetium</small>	Ru <small>Ruthenium</small>	Rh <small>Rhodium</small>	Pd <small>Palladium</small>	Ag <small>Silver</small>	Cd <small>Cadmium</small>	In <small>Indium</small>	Sn <small>Tin</small>	Sb <small>Antimony</small>	Te <small>Tellurium</small>	I <small>Iodine</small>							Xe <small>Xenon</small>	
6	Cs <small>Caesium</small>	Ba <small>Barium</small>	57–71	Hf <small>Hafnium</small>	Ta <small>Tantalum</small>	W <small>Tungsten</small>	Re <small>Rhenium</small>	Os <small>Osmium</small>	Ir <small>Iridium</small>	Pt <small>Platinum</small>	Au <small>Gold</small>	Hg <small>Mercury</small>	Tl <small>Thallium</small>	Pb <small>Lead</small>	Bi <small>Bismuth</small>	Po <small>Polonium</small>	At <small>Astatine</small>							Rn <small>Radon</small>	
7	Fr <small>Francium</small>	Ra <small>Radium</small>	89–103	Rf <small>Rutherfordium</small>	Db <small>Dubnium</small>	Sg <small>Seaborgium</small>	Bh <small>Bohrium</small>	Hs <small>Hassium</small>	Mt <small>Mtnerium</small>	Ds <small>Darmstadtium</small>	Rg <small>Roentgenium</small>	Cn <small>Copernicium</small>	Nh <small>Nihonium</small>	Fl <small>Flerovium</small>	Mc <small>Moscovium</small>	Lv <small>Livermorium</small>	Ts <small>Tennessee</small>							Og <small>Oganesson</small>	

- Write the electron configurations of lithium, sodium and potassium. How does this link to their positions on the periodic table?
- Write the electron configurations of helium, neon and argon. How does this link to their positions on the periodic table?

The periodic table reflects the electron configurations. It has rows (periods) and columns (groups).

- Magnesium: 2,8,2 is in the third period because it has 3 shells. It has 2 outer-shell electrons so it is in group 2.
- Chlorine: 2,8,7 is in the third period because it has 3 shells. It has 7 electrons in its outer shell so it is in group 17.
- Group 13 elements have 3 outer-shell electrons (13 – 10). For groups 13–18, the number of outer-shell electrons equals the group number minus 10.
- Group 17 elements have 7 outer-shell electrons (17 – 10).

Many elements have similar properties to the other elements in the same group because they have the same number of electrons in the outer shell. The electron configurations of the group 1 metals, known as the alkali metals, are:

- Li 2,1
- Na 2,8,1
- K 2,8,8,1.

Each of these alkali metals is grey, conducts electricity and is very reactive. The alkali metals are so reactive that they are stored in oil to stop them mixing with air or water.

There is a trend to the reactivity. As you go down group 1, the metals become more reactive. Rubidium and caesium are highly reactive metals, even more reactive than potassium.

Look it up

Search for the video 'Brainiac alkali metals' to see an exciting demonstration of the properties of group 1 metals.

The following is a summary of the usefulness of the periodic table.

- The properties of an element can often be predicted from its position on the periodic table.
- The period of an element tells you how many electron shells the element has.
- The number of valence electrons can be determined from the group number.
- Elements in the same group often have very similar properties.
- There are trends in properties such as reactivity within a group.

Activity 6.5.3

1. Name the element in:
 - a. period 2, group 15
 - b. period 3, group 2
 - c. period 4, group 18
 - d. period 4, group 8.
2. Identify the group and period of:
 - a. aluminium
 - b. scandium.
3.
 - a. What is the relationship between the groups of the periodic table and the electron configuration of each element?
 - b. What is the relationship between the periods and electron configuration?
4. Identify the period and group of elements with the following electron configurations and name the elements.
 - a. 2,3
 - b. 2,8,6
 - c. 2,8,8,1

Extension: Electron configuration

In Year 11 chemistry, the electron model is developed further, based on mathematical modelling and **quantum mechanics**. Here is an introduction to this learning.

Quantum mechanics

The Bohr theory of electron shells has been modified over the last century as the electrons in each shell have been found to have small energy differences. Quantum mechanics predicts that:

- electrons do not travel in circular paths; they occupy an **orbital**
- orbitals can hold up to two electrons
- orbitals are regions in which the electrons travel
- there are different types of orbitals
- electron shells have subshells, matching the different types of orbitals.

Key terms

quantum mechanics	the theory that describes the behaviour of matter and light at and below the scale of atoms
orbital	a mathematical expression that describes the probability of an electron being in a particular location in an atom

The four types of atomic orbitals are labelled s, p, d and f. Each orbital has a characteristic shape: s orbitals are spherical, p orbitals are dumbbell shaped, d orbitals are usually shaped like a cloverleaf and f orbitals have different, more complex shapes (Figure 6.11).

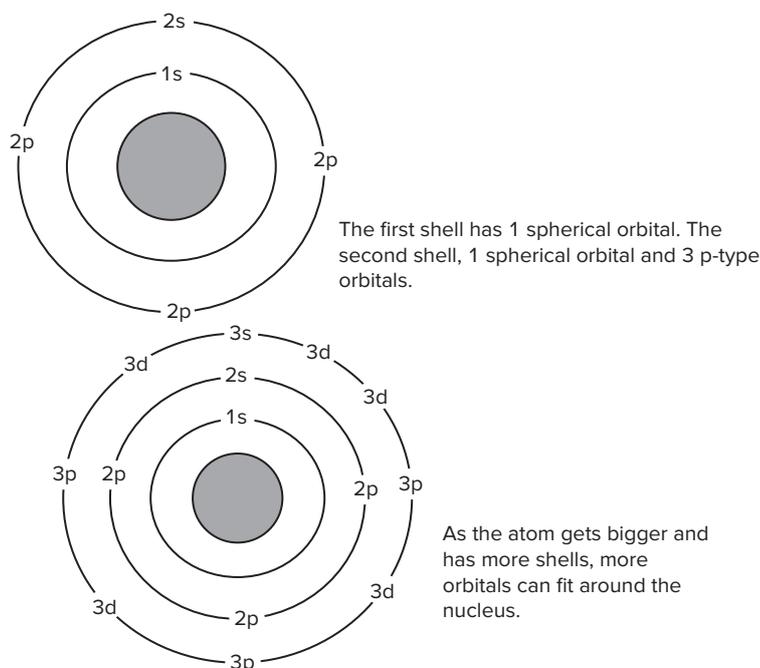


Figure 6.11: Examples of orbitals, showing shells and subshells

For example, ${}_{2}\text{He}$ (He) has two electrons, which occupy the first orbital in the innermost shell. Its electron configuration is expressed as $1s^2$. The orbital is a spherical region.

Nitrogen (${}_{7}\text{N}$) has seven electrons. The first two electrons are in the first s orbital, the next two are in the s orbital in the second shell and the final three are in p orbitals in the second shell. Its electron configuration is expressed as $1s^2 2s^2 2p^3$.

Other examples of neutral elements are:

- ${}_{1}\text{H } 1s^1$
- ${}_{6}\text{C } 1s^2 2s^2 2p^2$
- ${}_{11}\text{Na } 1s^2 2s^2 2p^6 3s^1$
- ${}_{17}\text{Cl } 1s^2 2s^2 2p^6 3s^2 3p^5$.

Table 6.4 shows that the further the shell is from the nucleus, the **more orbitals** there are and the **more different types** of orbitals there are.

Table 6.4: Electron orbitals

Shell	Number of electrons	Number of subshells	Number of orbitals	Orbital types
1	2	1	1	s
2	8	2	4	s p p p
3	18	3	9	s p p p d d d d d
4	32	4	16	s p p p d d d d f f f f f f f f

The electron configuration of an element is often the configuration of the previous element with one more electron added. After argon, the 4s subshell can sometimes fill before the 3d subshell. This is due to the 4s subshell having a lower energy level. The order of filling can be deduced from the chart in Figure 6.12.

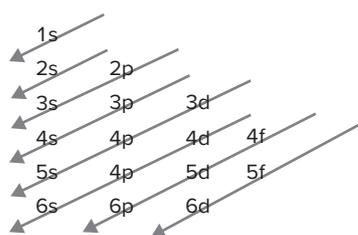


Figure 6.12: The order of filling of subshells in an atom

This is illustrated in the following examples of neutral elements.

- ${}_{20}\text{Ca } 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$
- ${}_{22}\text{Ti } 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^2$
written as $1s^2 2s^2 2p^6 3s^2 3p^6 3d^2 4s^2$
- ${}_{97}\text{Rb } 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^1$
written as $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 5s^1$

6.6 Metals

Most elements can be classified as metals or non-metals. For example, iron, copper and gold are metals; oxygen and sulfur are non-metals. Metals and non-metals have different properties.

Table 6.5: Some metals and their properties

Metal	Distinctive property	Application(s) using this property
Tungsten	High melting point, 3422°C	Filaments in older style light globes
Mercury	Liquid at room temperature	Thermometers
Platinum	Low reactivity	Electrodes in fuel cells
Nickel	Catalyst	Catalysts for many pharmaceutical processes
Gold	Yellow appearance and low reactivity	Jewellery
Beryllium	Invisible to X-rays	Radiation windows and particle colliders
Rhodium	Most expensive metal (\$270/g in May 2025)	Catalytic converter in cars
Tantalum	High acid resistance	Pipes and containers in corrosive environments
Plutonium	Glows like an ember due to high level of decay	Nuclear reactors and weapons
Osmium	Densest metal; twice as heavy as lead	When very hard, sharp metallic objects are required

Metals have the following properties:

- electrical and thermal conductors
- lustrous (shiny) surface
- malleable and ductile
- generally dense
- generally high melting points
- generally hard.

Think about it

Why do metals have these properties?

Metallic bonding

In a metal:

- the atoms are arranged in a 3D lattice
- the outer-shell electrons become **delocalised** – they move throughout the structure.

A metal is therefore an arrangement of positive ions with delocalised electrons moving randomly through it (Figure 6.13). Metal ions can have charges other than +1. For example, in magnesium the central particles are Mg^{2+} ions, and for each ion there are two free (delocalised) electrons.

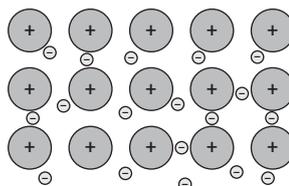


Figure 6.13: Metallic structure. Each positive ion contains the nucleus of the atom and electrons other than the outer-shell electrons.

Key term

delocalised electron	an electron that is not connected to a single atom or part of a covalent bond
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Structure and properties of metals

The properties of metals are explained by the metallic model.

- High melting points: The attraction between the positive ions and the delocalised electrons is strong.
- Electrical conductivity: If one side of a metal sheet is attached to a positive terminal and the other to a negative terminal, the delocalised negatively charged electrons will flow to the positive terminal. This is an electric current.
- Malleability: If a metal is struck with a hammer, layers of metal ions can slide past each other without shattering the structure. The delocalised electrons make this movement easy (Figure 6.14).

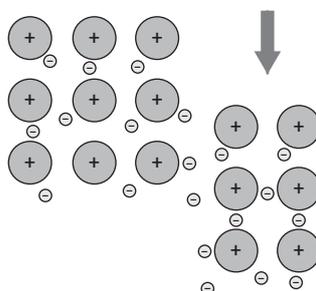


Figure 6.14: Malleability: one part can slide past another.

- The reactivity of different metals varies. Gold objects have been preserved for centuries without reacting, whereas sodium needs to be stored in oil to stop it reacting.

Activity 6.6.1

- Write the electron configuration of aluminium.
 - Explain how you know aluminium is a metal.
- Rearrange the following metals in order of reactivity (lowest to highest): nickel, lithium, magnesium, potassium.
- Complete the following table.

Property	Meaning	Why metals have this property
Ductile		
Conduct electricity? Yes/no		
Lustrous		[No answer required.]
Relatively high melting and boiling points		

6.7 Ionic compounds

Elements tend to react to achieve full outer electron shells.

- Atoms become charged if they lose or gain electrons. Atoms with a charge are called ions.
- Metals lose electrons to complete their outer shell. This makes them positively charged. They are called **cations**.
- Non-metals gain electrons to complete their outer shells. This makes them negatively charged. They are called **anions**.

Key terms

cation	a positively charged ion
anion	a negatively charged ion

Key fact

Elements tend to complete outer shells. This fact determines how they will react.

Remember it

Which is positive – a cation or an anion? A cation has a cat in it, so it is *pawsitive*!

Ionic compounds are crystalline solids formed by neatly packed ions of opposite charge. Ionic compounds are usually formed when metals react with non-metals.

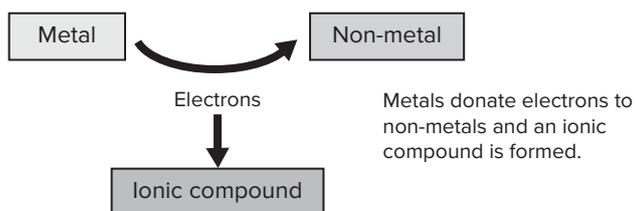


Figure 6.15: How ionic compounds form

It is common for metals and non-metals to react to form ionic compounds. For example, magnesium atoms tend to lose 2 electrons and oxygen atoms tend to gain 2 electrons, so when they react with each other, they form the compound magnesium oxide (Figure 6.16).

O: electron configuration 2,6 Will gain 2 electrons to complete its outer shell. Forms O^{2-} (electron configuration 2,8) Anion	Mg: electron configuration 2,8,2 Will lose 2 electrons to complete its outer shell. Forms Mg^{2+} (electron configuration 2,8) Cation
---------------------------------------------------------------------------------------------------------------------------------------------	--------------------------------------------------------------------------------------------------------------------------------------------------

Figure 6.16: The ionic compound formed from magnesium and oxygen is MgO , magnesium oxide.

Metals and non-metals can also react in ratios other than 1:1. For example, Figure 6.17 shows magnesium and chlorine reacting in a 1:2 ratio.

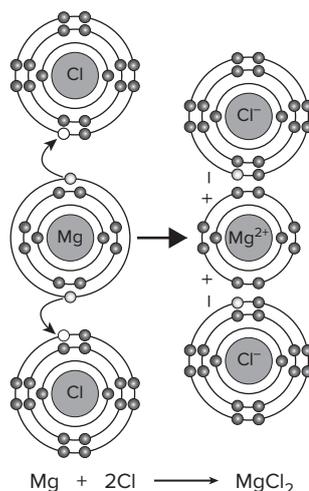


Figure 6.17: Two chlorine atoms (7 electrons in outer shell) are required to react with one magnesium atom (2 electrons in outer shell) to form the ionic compound magnesium chloride ($MgCl_2$).

Naming ionic compounds

When naming ionic compounds:

- name the metal before the non-metal (e.g. sodium fluoride not fluoride sodium)
- add a suffix to the non-metal to indicate the presence or absence of oxygen; for example, sodium sulfide (Na_2S) has the suffix -ide because it contains no oxygen, whereas sodium sulfite (Na_2SO_3) and sodium sulfate (Na_2SO_4) both contain oxygen so their names end in -ite and -ate
- put the charge on the metal in brackets if there is more than one option; for example, $Fe(II)Cl_2$ for Fe^{2+} , $Fe(III)Cl_3$ for Fe^{3+}

- indicate any water molecules that are incorporated into the crystal structure; for example, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ indicates five water molecules are included in each CuSO_4 .

Look it up

Counterintuitively, sodium and oxygen form sodium oxide, not sodium oxate or sodium oxite. Research why.

In general, metal atoms often donate electrons to non-metal atoms to form ionic compounds. The electron rearrangement leads to both anions and cations gaining complete outer electron shells.

Using electrovalence tables to name ionic compounds

Tables of ion charges (electrovalency tables) like Table 6.6 make writing correct formulas easier than drawing all the electrons. Look up the electrovalence of the metal, then the non-metal, and balance the charges.

For example:

- three silver ions (Ag^+) react with one nitride ion (N^{3-}) to produce silver nitride (Ag_3N)
- one calcium ion (Ca^{2+}) reacts with two chloride ions (Cl^-) to produce calcium chloride (CaCl_2).

Table 6.6: Cation (metals) and anion (non-metal) electrovalencies

Common cations			
1+	2+	3+	4+
Hydrogen H^+	Magnesium Mg^{2+}	Aluminium Al^{3+}	Tin(IV) Sn^{4+}
Lithium Li^+	Calcium Ca^{2+}	Chromium Cr^{3+}	Lead(IV) Pb^{4+}
Sodium Na^+	Strontium Sr^{2+}	Iron(III) Fe^{3+}	
Potassium K^+	Barium Ba^{2+}		
Copper(I) Cu^+	Copper(II) Cu^{2+}		
Silver Ag^+	Iron(II) Fe^{2+}		
Ammonium NH_4^+	Nickel Ni^{2+}		
	Lead(II) Pb^{2+}		
	Zinc Zn^{2+}		
Common anions			
1-	2-	3-	
Fluoride F^-	Sulfide S^{2-}	Nitride N^{3-}	
Chloride Cl^-	Sulfite SO_3^{2-}	Phosphate PO_4^{3-}	
Bromide Br^-	Sulfate SO_4^{2-}		
Iodide I^-	Carbonate CO_3^{2-}		
Hydroxide OH^-	Oxide O^{2-}		
Nitrate NO_3^-	Dichromate $\text{Cr}_2\text{O}_7^{2-}$		
Hydride H^-			

Ions such as ammonium (NH_4^+) and carbonate (CO_3^{2-}) are **polyatomic** ions, which are formed by bonding between more than one element.

Key term

polyatomic	consisting of more than one atom
------------	----------------------------------

Using the crossover method to name ionic compounds

Some students find the crossover method useful for writing chemical formulas. The method involves crossing over the numerical values of the ion charges and using them as subscripts for the other ion. For example, to find the formula of aluminium sulfide (Al^{3+} and S^{2-}), cross over the 3 from Al and the 2 from S, resulting in Al_2S_3 . To find the formula of calcium fluoride (Ca^{2+} and F^-), cross over the 2 from Ca and the single minus sign from F, resulting in CaF_2 .



Using brackets when naming ionic compounds

If a formula includes more than one polyatomic ion, then brackets are required. For example:

- Sodium hydroxide is formed from Na^+ and OH^- . One of each ion is required, no brackets are required and so the formula is NaOH .
- Barium hydroxide is formed from Ba^{2+} and OH^- . Two OH^- ions are required to balance Ba^{2+} and so the formula is $\text{Ba}(\text{OH})_2$. It would be incorrect to write BaOH_2 because it shows only one oxygen atom (the '2' is only attached to the H in this case).
- Calcium phosphate is formed from Ca^{2+} and PO_4^{3-} . The formula is $\text{Ca}_3(\text{PO}_4)_2$ because three Ca^{2+} ions are balanced by two PO_4^{3-} ions.

Properties of ionic compounds

Table salt (NaCl) forms small, hard but brittle crystals with a high melting point. This gives us a clue about the properties of ionic compounds. They:

- have high melting points and boiling points as ionic bonding is strong
- are hard and brittle, often crystalline
- do not conduct electricity as solids
- do conduct electricity as liquids or as solutions in water.

Structure of ionic compounds

Figure 6.18 shows the structure of NaCl , a typical ionic compound.

- Ionic solids are 3D lattices.
- They contain positive metal ions and negative non-metal ions.

- The electrostatic forces between the ions are strong.
- The structure is rigid, making it hard and brittle.
- They conduct only as liquids when the ions are free to move.

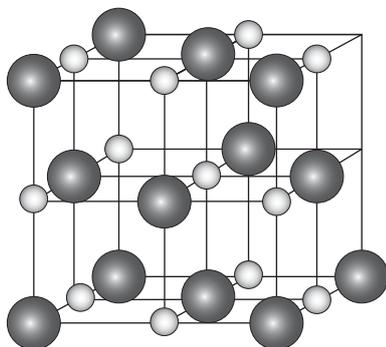


Figure 6.18: The structure of NaCl – an ionic compound

Look it up: Does a formula matter?

In chemistry, each substance is given a chemical formula. Does it matter how exact this formula is? What can we learn from a formula? Conduct some online research to answer the following questions.

- What will happen if you test a sample of iron with a magnet?
 - What will happen if you test a sample of sulfur with a magnet?
 - If iron and sulfur react to form a compound, will the compound be magnetic? Will it be a hard, tough solid?
- Fill in the table, for each compound listed.

Name	Formula	Magnetic (Y/N)	Description
Iron sulfide			
Iron(II) sulfate			
Iron(III) sulfate			
Iron nitrate			

- What conclusions can you draw? Are the properties of a compound an average of those of the elements that make it up?
 - Do all compounds of iron and sulfur behave the same?
- Table salt has the formula NaCl. It is edible and is often added to food. It is safe to handle. Research the properties of both sodium and chlorine to find out whether the properties of a compound are a combination of the elements it is made from.

Activity 6.7.1

Titanium oxide (TiO_2) (also known as rutile) forms a very white, fine powder that is added to paint and paper to give them texture, and to make white plastics and rubber products. It is also used in cosmetics and as a raw material for the production of the metal titanium.

Research why the following compounds are useful to society. Give their formulas and other common names: silver iodide, borax, slaked lime, magnesium silicate, saltpetre, ammonium nitrate, yellowcake, caustic soda, calcium chloride.

Activity 6.7.2

- Determine the ion formed by each of the following elements. The first one has been done for you.

Atom	Atomic number	Electron configuration	Gain or lose electrons	Ion electron configuration	Cation or anion	Ion symbol and charge
Na	11	2,8,1	Lose	2,8	Cation	Na^+
K						
	12					
		2,8,7				
N						
	5					
		2,8,3				
F						
Li						
		2,2				
Ca						

- What two things do you notice about ion formation and the periodic table? (Hint: Consider the groups and metals/non-metals.)
- Magnesium and chlorine react to form an ionic compound.
 - Draw the electrons around a magnesium and a chlorine atom.
 - Draw the electrons after a compound forms between magnesium and chlorine.
 - Show the charge on the two ions formed, the formula of the compound and its name.
- Aluminium and oxygen react to form an ionic compound.
 - Describe the electrons around an aluminium and an oxygen atom.
 - Describe the electrons after a compound forms between aluminium and oxygen.
 - Show the charge on the two ions formed, the formula of the compound and its name.

5. Write the correct formulas for the following compounds.

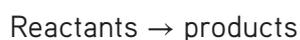
Name	Formula	Name	Formula
Ammonium iodide		Ammonium sulfate	
Sodium sulfide		Sodium sulfite	
Sodium sulfate		Magnesium hydroxide	
Silver carbonate		Calcium nitride	
Iron(II) chloride		Potassium carbonate	
Barium carbonate		Copper(I) iodide	
Aluminium sulfate		Aluminium bromide	
Lithium nitride		Sodium oxide	
Strontium sulfide		Lead(II) hydroxide	

6. Name the following compounds.

Formula	Name	Formula	Name
NaI		NaF	
CaF ₂		Al(NO ₃) ₃	
MgS		SnCl ₄	
AgI		CuO	
(NH ₄) ₂ CO ₃		Ba ₃ N ₂	
NiSO ₄		K ₂ S	
KNO ₃		Ag ₃ N	
AlPO ₄		Ba(OH) ₂	
PbI ₂		Fe(NO ₃) ₃	

6.8 Chemical equations

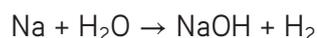
Chemical equations provide a clear, universally understood way to represent chemical reactions. They are preferable to word equations because they show the ratios between all the chemicals and the state of matter they are in. These equations take the form:



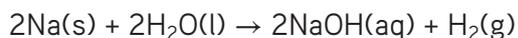
The substances present at the start of a reaction are the **reactants**, and the new substances formed are the **products**.

One of the most important features of a chemical equation is that it should be balanced. It should also show the physical state of each substance. For example, the following chemical

equation for the reaction between sodium and water is not balanced and the physical state of each substance is not shown.



The correct way to write the equation is:



By adding the numbers, called **coefficients**, in front of the chemical formulas, the equation is balanced.

Key terms

reactant	a substance present at the beginning of a reaction
product	a substance formed in a chemical reaction
coefficient	a whole number placed in front of a chemical formula to balance a chemical equation

In the chemical equation for the reaction between sodium and water, the following terms are included to indicate the states of matter:

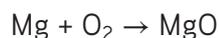
- s = solid
- l = liquid
- g = gas
- aq = aqueous solution (something dissolved in water).

Balancing equations

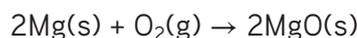
Chemical equations need to be balanced to follow the **law of conservation of mass**. Remember that mass cannot be created or destroyed, only transformed. Therefore, each side of an equation must have the same number of atoms.

For example, magnesium reacts with oxygen gas to form magnesium oxide (MgO).

Magnesium + oxygen gas → magnesium oxide



This equation describes the reactants and products, but it is not balanced. Two oxygen atoms react but only one appears in the products. To account for the conservation of mass, the balanced equation is:



When you balance an equation, you only change the coefficients of the reactants and products, not the formulas. For example, to balance the above equation you could not change the formula of magnesium oxide to MgO₂.

Writing balanced equations

Use the following three-step process to write a balanced equation.

1. Write the equation in words.
2. Replace the names with the correct formulas.
3. Balance the equation by adding coefficients.

Activity 6.8.1

For each of the following reactions use the three-step process to write a balanced equation, including states.

1. Sulfur and oxygen gas

Word equation	
Formula equation	
Balanced equation	

2. Magnesium and oxygen gas

Word equation	
Formula equation	
Balanced equation	

3. Silver nitrate and sodium chloride solutions

Word equation	
Formula equation	
Balanced equation	

4. Sulfuric acid (hydrogen sulfate) and sodium hydroxide

Word equation	
Formula equation	
Balanced equation	

Predicting the products

One way to predict the products of a reaction is by swapping the cations. For example, if you have the reactants AB and CD, you can predict the products as AD and BC. Figure 6.19 shows some examples of this method.

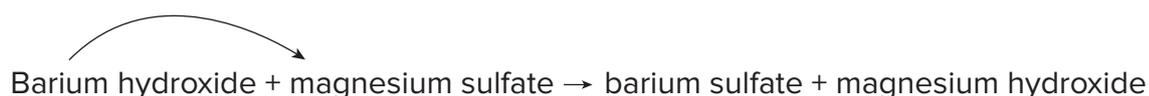


Figure 6.19: Predicting the products by swapping the cations

Activity 6.8.2

Complete each word equation by identifying the products, and then write a balanced equation.

- Copper sulfate + magnesium hydroxide →
- Potassium bromide + silver nitrate →

3. Sodium hydroxide + nitric acid (hydrogen nitrate) →
4. Sodium carbonate + calcium chloride →

Types of reactions

Chemical reactions can be classified into the following types.

- **Synthesis (or composition)**, where two or more reactants form a single product:
Carbon + oxygen → carbon dioxide
 $C(s) + O_2(g) \rightarrow CO_2(g)$
- **Decomposition**, where a reactant breaks up to form two or more products:
Calcium carbonate → calcium oxide + carbon dioxide
 $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$
- **Precipitation**, where a solid forms when two aqueous solutions are mixed:
Silver nitrate + sodium chloride → silver chloride + sodium nitrate
 $AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$
- **Displacement**, where a more reactive metal replaces a less reactive metal in a solution:
Zinc + copper chloride → zinc chloride + copper
 $Zn(s) + CuCl_2(aq) \rightarrow ZnCl_2(aq) + Cu(s)$

Activity 6.8.3

1. Balance the following equations.
 - a. $S + O_2 \rightarrow SO_2$
 - b. $H_2 + I_2 \rightarrow HI$
 - c. $N_2 + H_2 \rightarrow NH_3$
 - d. $C_2H_6 + O_2 \rightarrow CO_2 + H_2O$
 - e. $Al + O_2 \rightarrow Al_2O_3$
 - f. $Fe + S_2 \rightarrow Fe_2S_3$
 - g. $Ca + H_2O \rightarrow Ca(OH)_2 + H_2$
 - h. $NH_3 + O_2 \rightarrow NO + H_2O$
2. Write balanced equations for the following reactions.
 - a. Potassium chloride + silver nitrate
 - b. Calcium iodide + silver nitrate
 - c. Hydrochloric acid (hydrogen chloride) + sodium hydroxide
 - d. Lead(II) nitrate + lithium chloride
 - e. Aluminium + oxygen gas

Extension: Relative atomic mass

Atoms are too small to weigh easily. However, scientists can use a mass spectrometer to compare their masses (Figure 6.20).

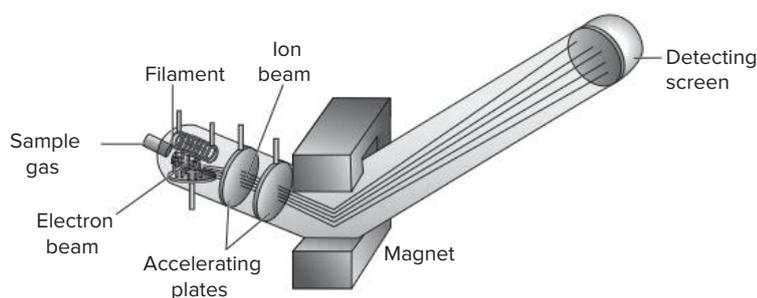


Figure 6.20: A mass spectrometer. Light atoms are easy to deflect. Heavy atoms are harder to deflect.

A mass spectrometer compares the mass of each element to that of carbon (Figure 6.21).

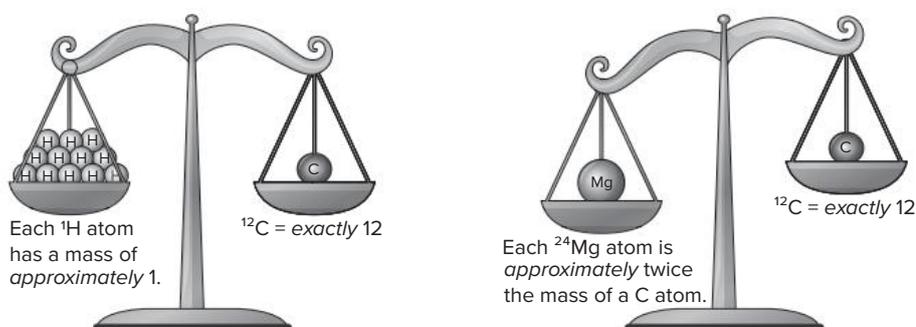


Figure 6.21: All atoms are compared to carbon, which is assigned a mass value of 12.

Carbon atoms are 12 times heavier than hydrogen atoms. Magnesium atoms are just over twice the mass of carbon atoms. Therefore, if carbon has a value of 12, hydrogen will be 1 and magnesium 24.3.

These values are relative atomic masses because the mass is relative to the mass of carbon.

The principle of relative masses can be extended to compounds:

$$\begin{aligned} \text{Relative formula mass of MgCl}_2 &= \text{relative mass of magnesium} + 2 \times \text{mass of chlorine} \\ &= 24.3 + 2 \times 35.5 = 95.3 \end{aligned}$$

$$\begin{aligned} \text{Relative molecular mass of H}_2\text{O} &= 2 \times \text{relative mass of hydrogen} + \text{mass of oxygen} \\ &= 2 \times 1 + 16 = 18 \end{aligned}$$

Note that relative masses do not have a unit because they are relative values. Also note that we use the terms 'relative molecular mass' for the relative mass of a molecule and 'relative formula mass' for the relative mass of an ionic compound.

Percentage composition

The relative atomic masses of elements can be used to find the percentage of each element in a compound.

Examples

1. Find the percentage of hydrogen in water.

$$\%H = \frac{2 \times \text{mass hydrogen}}{\text{mass water}} \times 100 = \frac{2}{2 + 16} \times 100 = \frac{200}{18} = 11.1\%$$

2. Find the percentage of Al in Al_2O_3 .

$$\%Al = \frac{2 \times \text{mass aluminium}}{\text{mass Al}_2\text{O}_3} \times 100 = \frac{2 \times 27}{(2 \times 27) + (3 \times 16)} \times 100 = \frac{5400}{102} = 52.9\%$$

 **Activity 6.8.4**

1. Estimate the relative atomic mass of:
 - a. titanium if it is 4 times heavier than carbon
 - b. uranium if it is 238 times heavier than hydrogen
 - c. antimony if it is 10 times heavier than carbon
 - d. helium if it is a third of the mass of carbon.
2. Refer to a periodic table to find the relative atomic mass of:
 - a. copper
 - b. nickel
 - c. strontium
 - d. lead.
3. Relative atomic masses can be used to determine the relative mass of compounds.
For example: $\text{H}_2\text{O} = 2 \times \text{H} + \text{O} = 2 + 16 = 18$
Determine the relative formula mass of the following.
 - a. CO_2
 - b. HNO_3
 - c. NaCl
 - d. HCl
 - e. LiOH
 - f. $\text{Cu}(\text{OH})_2$

Extension: Covalent bonding

Non-metal atoms can bond to each other by sharing electrons. The bonds formed are called **covalent bonds**. Many non-metal compounds form small, discrete molecules.

Key term**covalent bond**

a bond formed by the sharing of electrons between two atoms

Formation of covalent bonds

A fluorine atom has seven valence electrons. If it shares an electron with another fluorine atom, both atoms can complete their outer shell, and the more stable fluorine molecule (F_2) is formed. F_2 is an example of a diatomic molecule because it contains two atoms only.

Electron dot diagrams (or Lewis diagrams) are a simpler way of representing covalent bonds – they show the outer-shell electrons only. Figure 6.22 shows the electron dot diagram for fluorine atoms and the fluorine molecule.

Key term

electron dot diagram

a representation of the valence electrons of an atom, consisting of dots around the element symbol (also called a Lewis diagram)

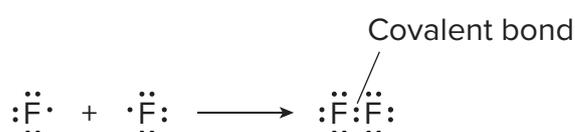
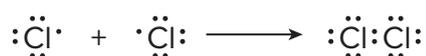


Figure 6.22: Electron dot diagram showing the formation of a covalent bond by the sharing of two electrons between two fluorine atoms to form a fluorine (F_2) molecule

When two non-metals share an electron from each atom, the bond is called a single covalent bond. Hydrogen atoms can share their outer-shell electrons in a single covalent bond (H–H) to form a H_2 molecule. Two electrons are a complete outer shell for hydrogen:



Chlorine atoms can also form single covalent bonds (Cl–Cl) to form a Cl_2 molecule:

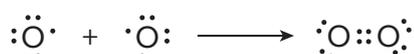


Covalent bonding is different from ionic bonding because:

- electrons are shared – they are not transferred from one atom to the other
- no ions are formed
- no large structure is formed, just a small F_2 molecule
- only non-metals are involved.

Double and triple covalent bonds

Oxygen has six valence electrons and needs to share two electrons with another oxygen atom to form a molecule of O_2 . When each atom shares two electrons, the bond is a double covalent bond ($O=O$):

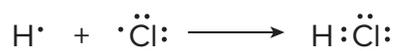


Nitrogen has five valence electrons and needs to share three electrons with another nitrogen atom to form a molecule of N_2 . When each atom shares two electrons, the bond is a triple covalent bond ($N \equiv N$):



Polyatomic molecules

Atoms of different elements can share electrons to form polyatomic molecules. For example, a hydrogen atom and a chlorine atom can share electrons to form H-Cl:



Properties of molecular compounds

The big difference between molecular compounds and both metals and ionic compounds is the existence of molecules instead of large lattice structures. Molecular compounds:

- have low melting points and boiling points
- do not conduct electricity as either solids or liquids.

6.9 First Nations chemistry

There are many documented examples of processes used by First Nations people that demonstrate their understanding of chemical reactions.

Removing toxins from food

Early European colonists often could not eat native fruits or seeds that First Nations people regularly included in their diets. This was because First Nations people knew how to prepare them safely.

The seeds shown in Figure 6.23 are from the cycad (*Macrozamia*) palm. The following comment came from an unnamed Dutch explorer writing in 1697.

I ate five or six of them, drunk the water from one of the already mentioned pits [this is presumably a reference to a freshwater soak near the river]; but after about three hours I and five others who had eaten of these Fruits, begun to vomit so violently that there was hardly any difference between us and death; so it was with the greatest difficulty that I with the Crew reached the shore.



Figure 6.23: The seeds from the fruit of the *Macrozamia* are poisonous, but the Noongar people know how to process them to make them safe to eat.

It was later found that the Noongar people of this region buried the seeds in damp sand for several weeks. A natural fermentation process occurred that converted the toxins to harmless chemicals.

In a similar fashion, First Nations people knew to prepare nardoo flour from spores of the *Marsilea drummondii* fern by cooking them at relatively high temperatures before using them. The heat denatures thiaminases enzymes that make the nardoo indigestible and toxic.

Adhesives

Depending on what is available in their area, First Nations peoples create different adhesives. One type of glue is made from a mix of grass tree resin, charcoal and kangaroo scats. This mix is worked in a fire to form an adhesive to help attach axe heads and other tools. Another type of adhesive is kiti, which is made from spinifex seeds. It is shown in Figure 6.24.



Figure 6.24: To make the glue known as kiti, resin from spinifex seeds is heated until soft and compacted into a lump.

Medicines

First Nations peoples have a wide repertoire of medicines that they can extract from plants. Tea-tree oil and eucalyptus oil are two common examples. During a smoking ceremony, the oils released in the smoke of a plant are a natural disinfectant that can cleanse the local area. Both of these oils are commercially available as antiseptics.



Figure 6.25: A smoking ceremony releases natural disinfectants in the form of oils.

Paints

First Nations artwork uses many different rock types to create vivid red, white and yellow hues. Kaolin clay is often the source of white paints, while iron-rich minerals provide many of the reddish colours. First Nations peoples used an extensive trading system to circulate rocks and clays from rich deposits to all parts of the country. Paint could be dissolved in water or oil depending on whether it was to be used for body art or rock art.

6.10 Reaction rates

The scientific term for the speed of a reaction is **rate of reaction**. The rate refers to how quickly reactants are converted to products.

Some reactions occur within split seconds (e.g. explosions); other reactions occur very slowly (e.g. rusting of iron or ripening of fruit).

The rate of reaction is influenced by:

- temperature
- concentration of reactants
- surface area
- catalysts.

Reaction rates can be explained by collision theory – reactants need to collide in the correct orientation and with sufficient energy for a reaction to occur. The factors above all influence how frequently the reactants collide.

Reaction rate and temperature

At higher temperatures, particles move faster. Therefore, they will collide more, and there will be more collisions at the right orientation and with enough energy for a reaction to occur. Both of these factors increase the reaction rate.

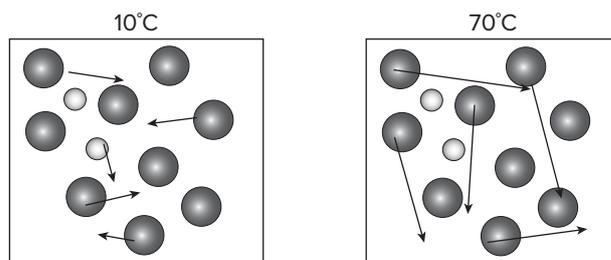


Figure 6.26: The container on the right is at a higher temperature, so the particles move faster and collide more, increasing the reaction rate.

Reaction rate and concentration

The more concentrated a solution is, the more collisions there are and the faster the reaction rate.

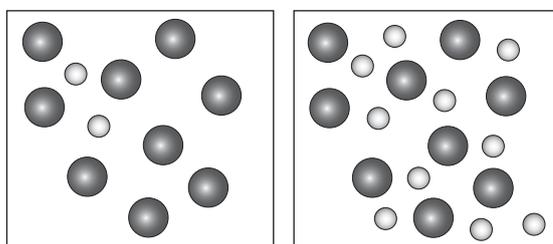


Figure 6.27: The container on the right contains more of one of the reactants – it is more concentrated. Because they are closer to each other, the particles will have more collisions.

Reaction rate and surface area

Increasing the surface area of a reactant exposes more particles to the other reactant, so the number of successful collisions increases and the rate of reaction increases. If you crush a tablet, it will dissolve faster. If you chew your food well, it is in smaller particles and stomach acid will be able to contact more particles, so the rate of digestion is higher.

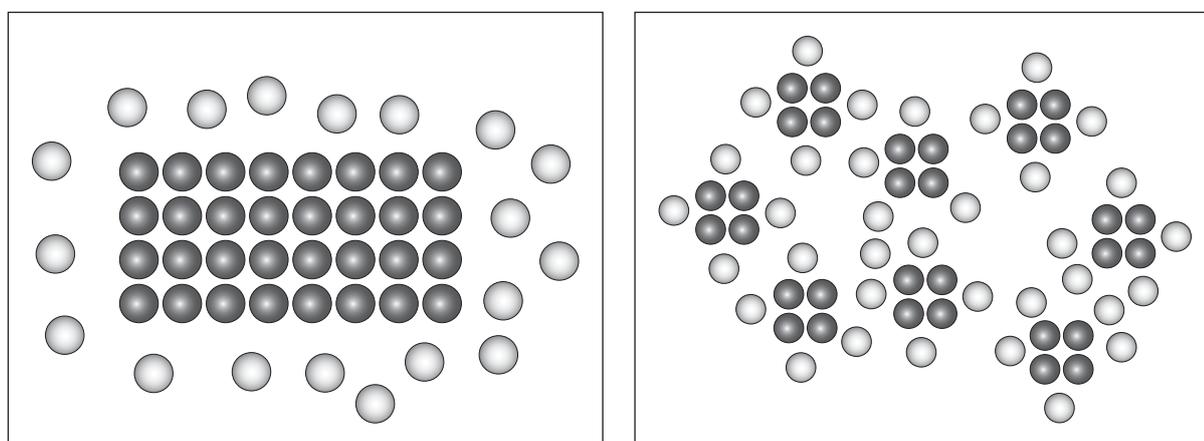


Figure 6.28: The reactant in the container on the right has been broken into smaller particles. There will be more collisions between reactants.

End-of-chapter summary

Chemistry is the study of matter and the particles it is made from – atoms. Chemists rely heavily on the periodic table, and the patterns evident in it, to predict and understand the properties of each element. Chemists understand that chemical reactions can be used to change the grouping of atoms and the properties of the compounds they form. Chemists conduct experiments to investigate reactions and the changes occurring during a reaction. Year 10 chemistry covers:

- atomic theory
- periodic table trends
- bonding between elements
- properties of compounds
- chemical reactions.

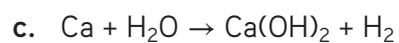
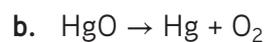
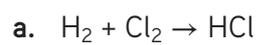
Revision questions

Use the periodic table in Figure 6.4 and the internet to answer questions 1–7.

1. Name the element that:
 - a. is the heaviest
 - b. has the highest melting point
 - c. has the highest electrical conductivity
 - d. is the most expensive metal.
2.
 - a. Name five dangerous elements and explain why each one is dangerous.
 - b. Name three radioactive elements.
 - c. Name five elements that have been known for several centuries.
3. Name the main element in:
 - a. old car batteries
 - b. new car batteries
 - c. living things
 - d. the atmosphere.
4. Choose three items in your classroom. Conduct some online research to find out the elements each item is made of.
 Write the chemical symbol of each element on a sticky note. Fix the notes to the items. For example, glass is made of silicon and oxygen – put a sticky note on the window with Si and another beside it with O.
5. Research what an allotrope is and list three elements that have allotropes.

6. Select an element you know nothing about. Make a quick profile of this element. Include its abundance, uses, where it is found and any unusual properties.
7. Lithium has become increasingly important for its use in batteries. Conduct some research on where lithium is found and how much processing is required.
8. How does the flame test provide insight into how fireworks provide different colours?
9. What special name is given to the electrons in the outer shell?
10. Group 18 elements are referred to as the noble gases. Conduct some online research to find out why these elements were so difficult to discover. Describe their properties. Why do they have these properties?
11. Look up the melting points of the group 17 elements. Graph the melting points. What is the trend of this property?
12. Write a balanced chemical equation for the reaction of potassium and copper chloride.
13. Deduce the electrovalence of the ion shown as X in:
 - a. XOH
 - b. XF_2
 - c. $\text{X}_2(\text{SO}_4)_3$
 - d. Al_2X_3
 - e. NaX
 - f. CaX
14. Ion Y has an electrovalence of 3-. What is the chemical formula of the compound formed between barium and Y?
15. Cobalt forms compounds $\text{Co}(\text{OH})_2$ and CoI_2 . What is the electrovalence of the cobalt ion?
16. Iron can have an electrovalence of 2+ or 3+. What are the chemical formulas of the two different sulfate compounds that iron can form?
17.
 - a. What is the chemical formula of potassium iodide?
 - b. What are the properties of potassium iodide?
 - c. How are the properties of potassium iodide similar to and different from the properties of potassium?
18. Classify the following reactions.
 - a. $\text{S} + \text{O}_2 \rightarrow \text{SO}_2$
 - b. $\text{CaBr}_2 + 2\text{AgNO}_3 \rightarrow \text{Ca}(\text{NO}_3)_2 + 2\text{AgBr}(\text{s})$
 - c. $\text{Fe} + \text{PbI}_2 \rightarrow \text{FeI}_2 + \text{Pb}$
 - d. $\text{Na}_2\text{CO}_3 \rightarrow \text{Na}_2\text{O} + \text{CO}_2$
 - e. $2\text{H}_2\text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{O}_2$

19. Balance the following equations.



20. Extension: Find the percentage composition of the elements in the following.



Chapter 7 – Science inquiry skills

7.1 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 or timer
- Stirring rod

Method

1. Place a beaker of 20 mL water into each of the five 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 timer.
5. Stir consistently and frequently until the salt stops dissolving.
6. Record the time taken for 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 up 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 note down your results clearly. Each measurement you take is one point of data.

Table 7.1: Results table for our investigation

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

Temperature of water (°C)	Time taken for salt to dissolve (s)	Observations
70	63	The water stayed clear. Water had small bubbles forming. All salt had dissolved.
100	26	The 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 7.1 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: 'the water was bubbling', 'some salt was still a solid' and so on.

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 7.2 on page 121.

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.

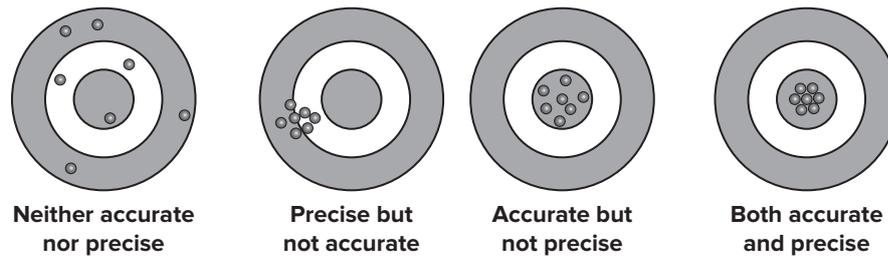


Figure 7.1: Remember, something can be accurate but not precise, or precise but not accurate. The best investigations are accurate and precise.

- **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 independent variable? 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 at a higher temperature than at a lower temperature, supporting the hypothesis that increasing the temperature of water would increase the time taken for salt to dissolve.

7.2 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. 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. The following are some examples.

Pie graph

A pie graph shows the proportions of each grouping within a total (Figure 7.2). The whole pie represents 100 per cent, half is 50 per cent and a quarter is 25 per cent.

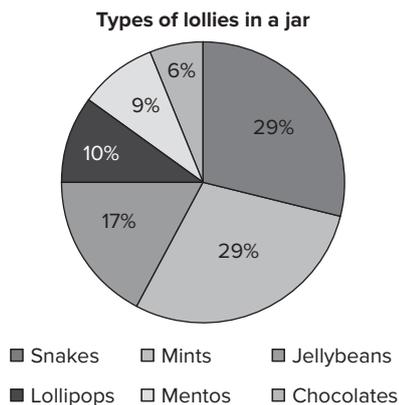


Figure 7.2: A pie graph

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 7.3).

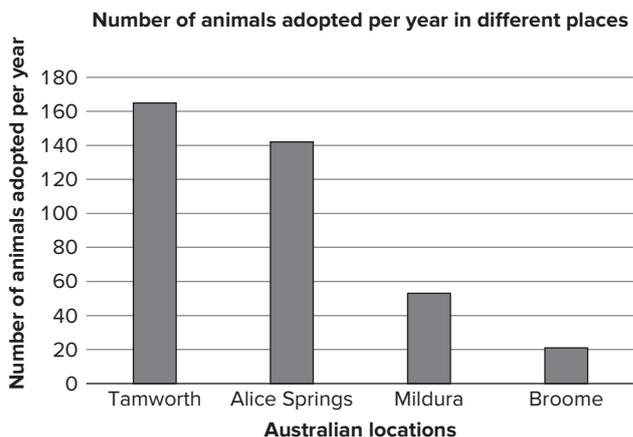


Figure 7.3: A bar or column graph

Line graph

A line graph requires measurements that show continuous variation (Figure 7.4).

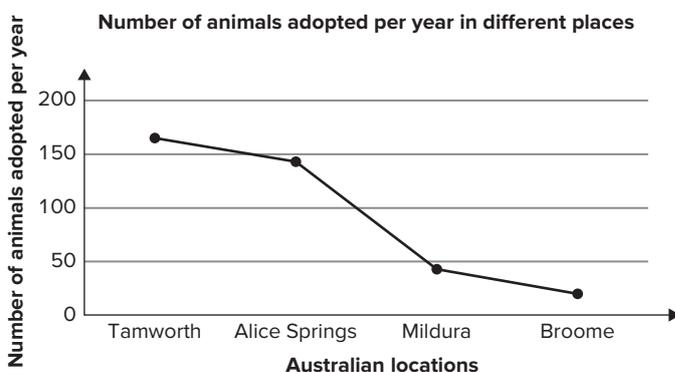


Figure 7.4: A line graph can show you changing amounts of something, or how a measurement changes over time.

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.

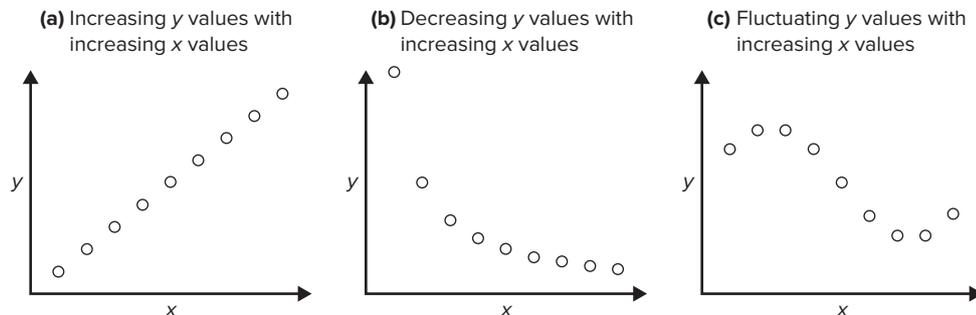


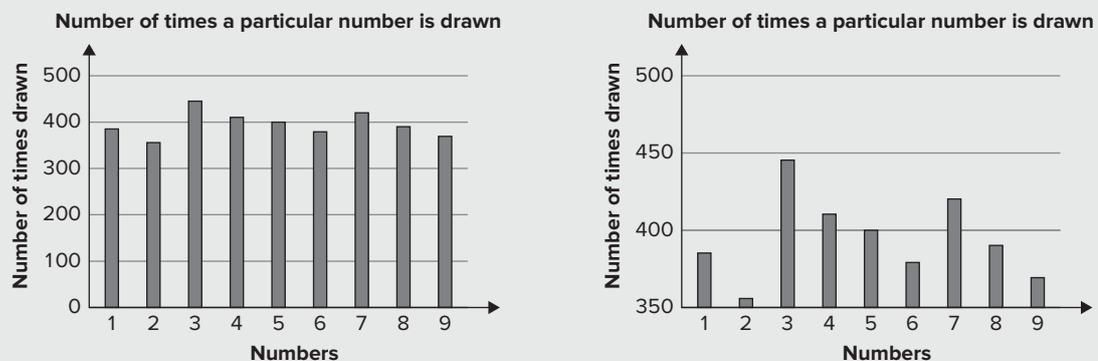
Figure 7.5: These three different scatter plots show the relationship between x and y values.

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 7.5?

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 to 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 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	<p>Scale:</p> <ul style="list-style-type: none"> • accurate horizontal and vertical scales chosen • the independent variable is shown on the horizontal axis, called the <i>x</i>-axis • the dependent variable is shown on the vertical axis, called the <i>y</i>-axis.
A	<p>Axes:</p> <ul style="list-style-type: none"> • 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 learnt will make your results easier to understand and interpret.

Chapter 8 – Study skills and exam advice

8.1 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.

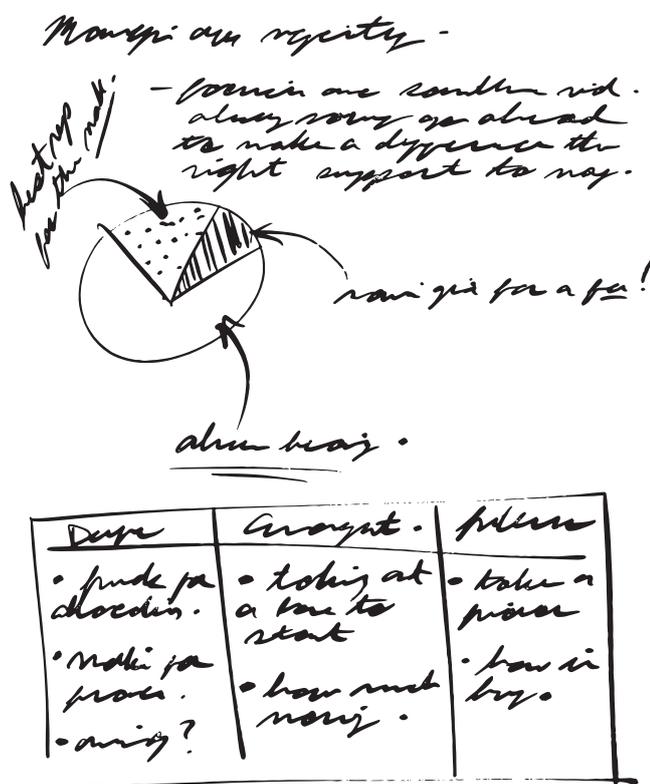


Figure 8.1: Use a combination of summaries and visual elements to help you memorise material.

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.

8.2 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, do a brief scan of the questions if you have time. Are there any key concepts you can see, or any 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 read your answers to make sure you haven't missed anything.

Key recommendation

Try to leave 5 to 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 might 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 recommendation

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 will 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 4 marks is probably looking for you to write four points in your answer.
- **Highlight the key words.** Explaining something is different from stating something, which is different from 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 – Genetics

Activity 1.2.1

Answers will vary.

Activity 1.2.2

Answers will vary.

Activity 1.3.1

Refer to Figure 1.4.

Activity 1.4.1

Answers will vary.

Activity 1.5.1

1.

	t	t
T	Tt	Tt
t	tt	tt

2. Genotypes: 50% Tt, 50% tt

Phenotypes: 50% tall, 50% short

3. 50%

Activity 1.5.2

1.

	B	b
B	BB	Bb
b	Bb	bb

Genotypes: 25% BB, 50% Bb, 25% bb

Phenotypes: 75% black fur, 25% white fur

2. 75%

3. 25%

Activity 1.5.3

1.

	F	f
f	Ff	ff
f	Ff	ff

Genotypes of the children: 50% Ff, 50% ff

Phenotypes: 50% free earlobes, 50% attached earlobes

2. 50%

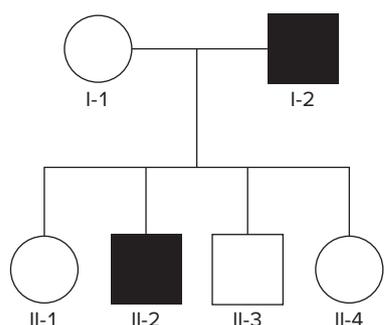
Activity 1.5.4

Answers will vary.

Activity 1.6.1

1. You can draw the pedigree using the following conventions:

- squares for males, circles for females
- shaded symbols indicate affected individuals
- connect parents with a horizontal line; draw vertical lines to their children.



2. Let's analyse the pattern:

- An affected father (I-2) and an unaffected mother (I-1) have both affected and unaffected children.
- The trait appears in both Generations I and II, and it affects both males and females.

This suggests a recessive trait because:

- If it were dominant, more of the children would be affected.
- If it were sex-linked, it would most likely affect males disproportionately. However, both male and female offspring are affected or unaffected.

So, this is probably autosomal **recessive** inheritance.

Activity 1.7.1

Answers will vary.

Revision questions

1. B
2. A
3. B
4. C
5. B
6. Fertilisation combines DNA from two parents, bringing together 23 chromosomes from the sperm and 23 chromosomes from the egg. This creates a unique combination of genetic material, increasing variation in the offspring.

7. Dominant alleles mask the effects of recessive alleles in heterozygous genotypes. For example, the allele for brown eyes (B) is dominant to the allele for blue eyes (b). So a person with the genotype Bb has brown eyes.

8. A mutation is a change in the DNA sequence. It can be harmless, beneficial or harmful. For example, a mutation in skin cells caused by UV radiation can lead to cancer.

9. a.

	T	t
t	Tt	tt
t	Tt	tt

b. 50% tall (Tt)

c. 50% short (tt)

10. A dominant trait appears in every generation because only one copy of the allele is needed to express the trait.

11. a. 25%

b. Using a Punnett square shows there is a 1 in 4 chance (ss) that the child will inherit two recessive alleles and have the disorder.

Chapter 2 – Evolution and adaptation

Activity 2.3.1

As the forest floor becomes covered in brown leaves, the brown beetles will have a better chance of survival than the green beetles. This is because their brown colour allows them to blend in with the environment, making them less visible to predators such as birds.

Over time, this natural camouflage gives brown beetles a survival advantage. They are more likely to avoid being eaten, survive to adulthood and reproduce, passing on their brown colouration to their offspring. The green beetles, being more visible, are more likely to be caught and eaten before they can reproduce.

As generations pass, the population will probably shift towards having more brown beetles. This process is an example of natural selection, where individuals with traits better suited to their environment are more likely to survive and reproduce.

Activity 2.4.1

Bird A and Bird B probably evolved different beak shapes through the process of natural selection. On their separate islands, the birds faced different environments and food sources, which acted as selective pressures.

Bird A lived in an environment where nuts and hard seeds were the main food source. Birds with short strong beaks were better able to crack open these hard foods. They survived more easily and had more offspring, passing on the trait for strong beaks.

Bird B, on the other hand, lived in an environment where insects were the main source of food. Birds with long thin beaks could reach into narrow spaces like bark or flowers to catch insects. These birds were more successful and passed on their useful beak shape to future generations.

Over many generations, the birds on each island became better adapted to their environment, resulting in two different species with beaks shaped by their diet and habitat.

Revision questions

1. A
2. D
3. B
4. A
5. C
6. B
7. C
8. B
9. Variation refers to the differences in traits among individuals within a population. It is important for natural selection because it provides the raw material for evolution; some traits may give individuals a better chance of survival and reproduction in a specific environment.
10. Fossils show the physical characteristics of organisms that lived in the past. By studying fossils, scientists can observe changes in species over time, identify transitional forms and trace the evolutionary history of organisms.
11. Isolation prevents gene flow between populations, allowing them to evolve independently. Over time, genetic differences accumulate, leading to the development of new species.
12. Answers will vary.
13.
 - a. Cane toads with longer legs are better able to migrate and find new habitats, giving them a survival and reproductive advantage. Over time, this trait becomes more common in the population.
 - b. The increased spread of cane toads can lead to competition with native species, predation on local wildlife and disruption of ecosystems.
14.
 - a. Pollinators may miss the flowering period, reducing their food supply and disrupting their life cycles.
 - b. Plants that adapt to synchronise with pollinator activity may have higher reproductive success, while pollinators that adjust their behaviour to match flowering times may survive better.
15. Genetic mutations introduce new traits into a population. If a mutation provides an advantage in survival or reproduction, it may become more common over generations. For example, the development of antibiotic resistance in bacteria is due to mutations that help bacteria survive exposure to antibiotics.
16. Genetic diversity provides a range of traits that may help individuals survive environmental changes. Populations with higher diversity are more likely to have individuals with traits suited to new conditions, increasing the chances of survival and adaptation.
17. Physiological adaptations such as producing concentrated urine reduces water loss, helping animals survive in arid environments. For example, kangaroo rats in deserts conserve water by producing highly concentrated urine and obtaining moisture from their food.

Chapter 3 – Earth and space

Activity 3.3.1

Answers will vary.

Activity 3.3.2

Answers will vary.

Activity 3.4.1

Answers will vary.

Revision questions

1. C
2. D
3. B
4. A
5. C
6. C
7. B
8. B
9. The Doppler effect allows scientists to detect whether a star is moving towards or away from Earth by analysing shifts in its light spectrum. If the star is moving towards Earth, its light shifts to shorter wavelengths (blue shift). If it is moving away, the light shifts to longer wavelengths (red shift).
10. A nebula is a large cloud of gas and dust in space. Nebulae play a crucial role in star formation because they are the birth places of new stars. As gas and dust particles within the nebula are pulled together by gravity, they can clump together to form new stars and planetary systems.
11. Apparent brightness refers to how bright a star appears from Earth, whereas luminosity refers to the total amount of light a star emits. Apparent brightness depends on the star's distance from Earth, whereas luminosity is an essential property of the star.
12. A black hole is a region in space with an extremely strong gravitational pull, so strong that not even light can escape from it. Black holes form when massive stars collapse under their own gravity at the end of their life cycle.
13. The expansion of the universe refers to the observation that galaxies are moving away from each other, meaning space itself is stretching. This supports the idea that the universe began as a singular point in the Big Bang and has been expanding ever since.
14. The red shift indicates that the star is moving away from Earth. This occurs because as the star moves away, the wavelengths of its light are stretched, shifting the light towards the red end of the spectrum.
15. Studying both optical and radio wavelengths allows astronomers to gather a broader range of information. Optical light provides insight into the visible properties of stars, planets and galaxies, whereas radio waves reveal information about hidden regions, such as gas clouds, black holes and nebulae, that are not visible in optical light.

16. Astronomers use spectroscopy, which involves analysing the light emitted by a star. When light passes through a star's atmosphere, different elements absorb specific wavelengths, creating dark lines in the star's spectrum. By studying these absorption lines, scientists can determine which elements are present.

Chapter 4 – Global systems and climate change

Activity 4.2.1

1. The closed bottle will probably be at a higher temperature than the open one.
2. The closed bottle traps heat, mimicking the greenhouse effect, where heat from the Sun gets trapped by Earth's atmosphere. The open bottle allows warm air to escape, preventing heat from building up inside.

Activity 4.2.2

Refer to Figure 4.3.

Activity 4.4.1

Answers will vary.

Activity 4.6.1

Answers will vary.

Revision questions

1. C
2. D
3. C
4. C
5. B
6. A
7. B
8. A
9. B
10. C
11. A
12. Deep ocean currents, also known as thermohaline circulation, are currents driven by differences in water temperature and salinity.
13. Permafrost is ground that remains frozen year-round. When it melts, it releases methane, a greenhouse gas that contributes to global warming.
14. The Sun's radiation provides the energy that drives Earth's climate system. Some of this energy is absorbed by the land and oceans, and some is reflected back into space. The interaction of solar energy with the atmosphere, oceans and land regulates temperature, weather patterns and climate.

15. The two key indicators of climate change are rising global temperatures and rising sea levels, which result from the melting of ice caps and glaciers as well as thermal expansion of seawater.
16. The greenhouse effect is the process by which certain gases in the atmosphere trap heat from the Sun, preventing it from escaping back into space. This effect helps maintain Earth's temperature, making the planet habitable. However, an excess of greenhouse gases such as carbon dioxide and methane leads to global warming.
17. Ocean currents transport heat around the globe. Warm currents bring warmer air to coastal regions, making winters milder, while cold currents cool nearby land, affecting rainfall and fish populations. Disruptions in these currents can lead to extreme weather events.
18. Quantum computing allows scientists to process vast amounts of data more efficiently, improving climate models and weather predictions. It enables more accurate simulations of atmospheric and oceanic changes, helping researchers develop better climate mitigation strategies.
19. Changes in species distribution: As temperatures rise, many species are moving to cooler regions, such as higher altitudes or the poles, disrupting ecosystems.
Habitat loss: Rising sea levels, deforestation and extreme weather events are destroying natural habitats, making it harder for species to survive.
20. Possible causes include increased greenhouse gas emissions from industries and vehicles. Effects could include more heatwaves, rising sea levels and changes in local wildlife populations.
21. Slower currents could disrupt the transport of warm and cold water, leading to more extreme weather patterns, rising temperatures in some regions and harsher winters in others.
22. $0.2^{\circ}\text{C}/\text{decade} \times 5 \text{ decades} = 1.0^{\circ}\text{C}$ increase
Total increase = $1.1^{\circ}\text{C} + 1.0^{\circ}\text{C} = 2.1^{\circ}\text{C}$
23. Lower salinity makes seawater less dense, reducing the sinking of cold, salty water. This weakens deep ocean currents, potentially disrupting global climate patterns and causing extreme weather events.
24. $3.2 \text{ mm}/\text{year} \times 50 \text{ years} = 160 \text{ mm}$ (or 16 cm)
25. Extreme weather events: More frequent and severe hurricanes, droughts and heatwaves, causing destruction to communities and agriculture.
Food and water shortages: Rising temperatures will reduce crop yields and availability of fresh water, leading to food insecurity and possible conflicts over resources.
26. Ocean warming: Higher temperatures can lead to fish migrating to cooler waters, reducing population levels in the studied area.
Ocean acidification: Increased carbon dioxide absorption lowers the pH of seawater, harming marine organisms such as shellfish and corals, which many fish rely on for habitat.
Changes in ocean currents: Disruptions in deep ocean currents can reduce the availability of nutrients, affecting the food chain and leading to declining fish populations.

Chapter 5 – Physics

Activity 5.2.1

Answers will vary.

Activity 5.2.2

Displacement is the straight-line distance between the bee and the flower, including its direction, which is to the east (or to the right).

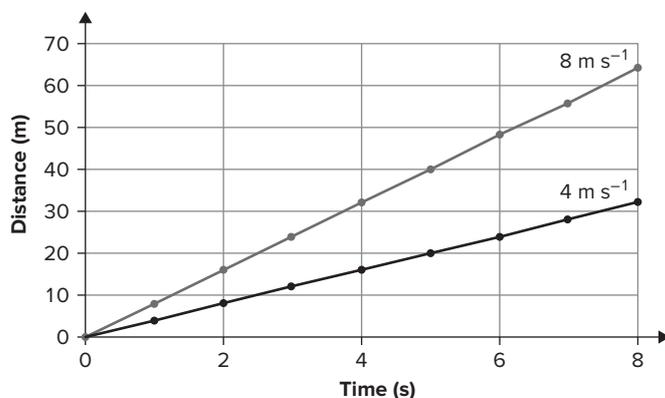
Distance is the total length of the curved path of the bee from its starting point to the flower.

Activity 5.3.1

1. Graph values will be (0,0), (1,8), (2,16), (3,24), (4,32), (5,40).

2. 8 m s^{-1}

3.



Activity 5.3.2

1. The object moves at a constant speed for the first 4 seconds. The speed is 7.5 m s^{-1} . The object is then stationary for 4 seconds. At the 8-second mark, it resumes moving at a constant speed of 5 m s^{-1} for a further 2 seconds.

2. Constant speed of 7.5 m s^{-1} for the first 4 seconds, rest for 4 seconds, then travel at 5 m s^{-1} for 2 seconds

$$3. \quad s = \frac{d}{t} = \frac{40}{10} = 4 \text{ m s}^{-1}$$

Activity 5.3.3

1. Walk at 2 m s^{-1} for 2 seconds, stop for 5 seconds, then walk back at 4 m s^{-1} .

2. 8 m

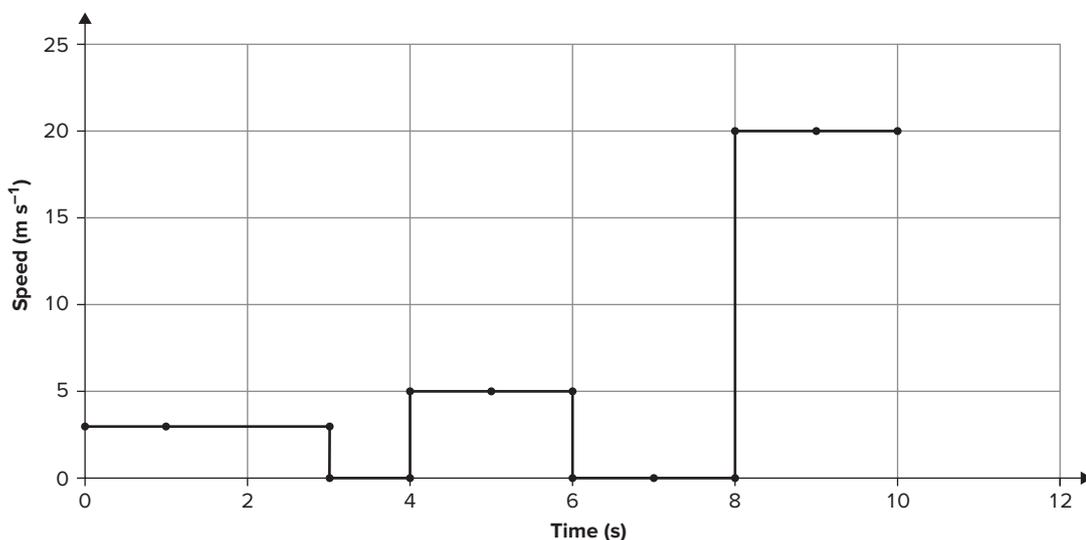
Activity 5.3.4

1.

Distance	Time	Speed
40 m	8.5 s	4.7 m s^{-1}
500 m	20 s	25 m s^{-1}
714 m	3.4 h	210 km h^{-1}
5 km	3 min	120 km s^{-1}

2. a. 6.4 m s^{-1}
 b. 0.2 cm s^{-1}
 c. 540 m s^{-1}
3. a. 120 m
 b. 119 m
4. a. 112 km h^{-1}
 b. 28 800 m
 c. 37 km h^{-1}
5. Travelled at 3 m s^{-1} for 3 s, then rested for 1 second, then travelled at 5 m s^{-1} for 2 seconds, then rested for 2 seconds, then travelled at 20 m s^{-1} for 2 seconds

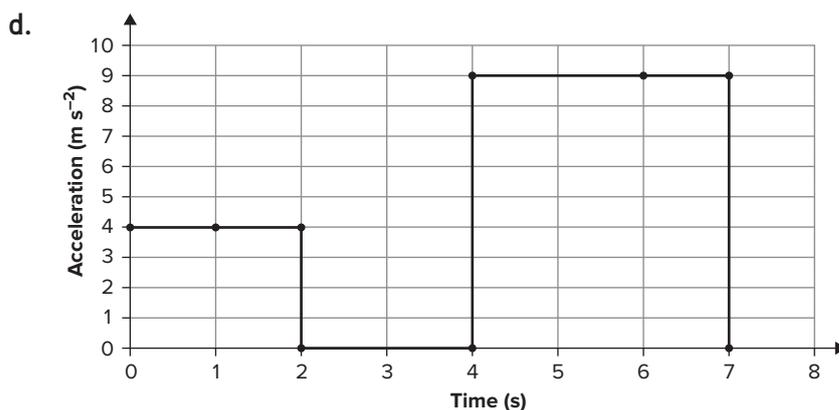
Activity 5.3.5



Activity 5.4.1

1. The athlete travels at a constant speed of 1 m s^{-1} for 4 seconds, stops for 4 seconds, then returns to their starting point in 2 seconds, travelling at 2 m s^{-1} .
2. a. The bird starts with a speed of 3 m s^{-1} but accelerates to 11 m s^{-1} by the 2-second mark, then travels at a constant speed between 2 and 4 seconds. The bird then accelerates over 3 seconds to a speed of 38 m s^{-1} , then holds that speed for 1 second.
 - b. Distance travelled = area under curve =

$$3 \times 2 + \frac{8}{2} + 11 \times 2 + 3 \times 11 + \frac{27 \times 3}{2} + 38 = 6 + 4 + 22 + 33 + 40.5 + 38 = 143.5 \text{ m}$$
 - c. Acceleration first sector = $\frac{11 - 3}{2} = 4 \text{ m s}^{-2}$
 Acceleration second and fourth sectors = 0
 Acceleration third sector = $\frac{38 - 11}{3} = 9 \text{ m s}^{-2}$



3. An athlete competing in the 100-metre sprint is unlikely to be accelerating for a high percentage of the race. They will accelerate during the first 2 seconds as they go from rest to their race speed of about 10 m s^{-1} . They will travel to the finish line at a fairly constant velocity, which means acceleration is zero. Once they pass the finish line, they usually need to decelerate quickly to avoid hitting the fence at the end of the track.
4. Cheetah acceleration = $\frac{26 - 0}{3} = 8.67 \text{ m s}^{-2}$. Car acceleration = $\frac{44 - 0}{6.2} = 7.1 \text{ m s}^{-2}$
The cheetah is accelerating faster than the car.

5.

Time (s)	Velocity (m s^{-1})
1	12
2	24
3	36
4	48
5	60
6	72
7	84
8	96

Revision questions

- Newton's second law ($F = ma$) – the greater the mass, the lower the acceleration.
 - Newton's first law – an object in motion (a passenger) will continue in the same motion unless a force acts on it.
 - Newton's third law – every force has an equal and opposite force. The air rushing out of the balloon pushes the balloon in the opposite direction
- The net force is $8 - 5 = 3 \text{ N}$ to the right. The box will accelerate in that direction.
- Newton's third law explains that the rifle exerts an opposite force on the soldier's shoulder to the bullet leaving the barrel.
- 1 s: 3 m s^{-1}
 - 2 s: 6 m s^{-1}
 - 3 s: 9 m s^{-1}
 - 4 s: 12 m s^{-1}
 - The speed is increasing by the same amount each second.

5. The more weight the horse carries, the greater the force required to travel with the same acceleration. ($F = ma$, where the mass is increased when a handicap is used.)
6. If the skater is maintaining a set pose, their speed will be relatively constant. There is a slight degree of friction to their skates over the ice, so they will slow a small amount each second. To either accelerate or stop, they need to change their position and apply a force of some type to the ice.
7. a. $a = \frac{F}{m} = \frac{550}{3.4} = 162 \text{ m s}^{-2}$
b. $F = ma = 12 \times 3.8 = 45.6 \text{ N}$
8. $F = ma = 75 \times 10 = 750 \text{ N}$
9. a. The mass is constant and will be the same on each planet.
b. Your weight on Mars will be less. The mass of the planet is less; therefore, the force of gravity it exerts will be less.

Chapter 6 – Chemistry

Activity 6.2.1

1. Protons and neutrons in the nucleus, electrons moving around the nucleus
2. 6 protons, 6 neutrons, 6 electrons
3. Electrons are much smaller than protons and neutrons. Neutrons have no charge, protons have positive charge and electrons have negative charge.
4. Each element has its own unique number of protons, which is different from carbon. The number of electrons equals the number of protons.

Activity 6.3.1

1. a. Superscript – atomic mass, subscript – atomic number
b. Potassium
c. 19 protons and 20 neutrons in the nucleus; 19 electrons around the nucleus (as 2,8,8,1 – explained in section 6.4)
2. Atoms contain *protons*, *neutrons* and *electrons*. Atoms have a small, central nucleus containing *protons* and *neutrons*, and the *electrons* are located in shells around the nucleus.
3. ${}_{92}^{238}\text{U}$
4. We know that the atom is mostly space. The plum pudding model does not show positive particles in a small nucleus with electrons circling around the nucleus.
5. a. The three isotopes have different numbers of neutrons. They are still magnesium because they each have 12 protons.
b. Yes – chemical properties of isotopes are usually identical.
c. It does not have 12 protons.
6. Silicon
7. Ne: 10 protons, 10 neutrons, 10 electrons in 2,8 configuration.
P: 15 protons, 16 neutrons, 15 electrons in 2,8,5 configuration.

Activity 6.4.1

Element	Symbol	Atomic number	Electron configuration
Hydrogen	H	1	1
Helium	He	2	2
Lithium	Li	3	2,1
Beryllium	Be	4	2,2
Boron	B	5	2,3
Carbon	C	6	2,4
Nitrogen	N	7	2,5
Oxygen	O	8	2,6
Fluorine	F	9	2,7
Neon	Ne	10	2,8
Sodium	Na	11	2,8,1
Magnesium	Mg	12	2,8,2
Aluminium	Al	13	2,8,3
Silicon	Si	14	2,8,4
Phosphorus	P	15	2,8,5
Sulfur	S	16	2,8,6
Chlorine	Cl	17	2,8,7
Argon	Ar	18	2,8,8
Potassium	K	19	2,8,8,1
Calcium	Ca	20	2,8,8,2 (not 2,8,10)

Activity 6.5.1

- To identify a metal impurity in a water supply (e.g. high levels of copper leaking into the water supply will produce a green colour in a flame)
- A flame test only works for a few metals and it can be difficult to distinguish between colours. Several metals produce a red flame and it is not easy to discern which metal caused it.
- Yellow
 - Lilac

Activity 6.5.2

- Lithium 2,1; sodium 2,8,1; potassium 2,8,8,1. Each group 1 element has 1 electron in the outer shell.
- Helium 2; neon 2,8; argon 2,8,8. Each group 18 element has a complete outer shell of 8 electrons.

Activity 6.5.3

- Nitrogen
 - Magnesium
 - Krypton
 - Iron
- Period 3, group 10
 - Period 4, group 3
- Groups: the number of outer shell electrons = group number for groups 1 and 2. For groups 13 to 18, the number of outer shell electrons = group number – 10
 - The period number = the number of electron shells in the element
- Period 2, group 13, boron
 - Period 3, group 14, sulfur
 - Period 4, group 1, potassium

Activity 6.6.1

- 2,8,3
 - Only 3 electrons in the outer shell
- Nickel, magnesium, lithium, potassium

3.

Property	Meaning	Why metals have this property
Ductile	Can be bent and beaten into a thinner shape	The layers of metal can slide past each other.
Conduct electricity? Yes	A current can pass through it	The outer-shell electrons are delocalised.
Lustrous	Light reflects from surface	No explanation required.
Relatively high melting and boiling points	Needs to be heated to a high temperature to melt	The bonds are strong.

Activity 6.7.1

Answers will vary.

Activity 6.7.2

1.

Atom	Atomic number	Electron configuration	Gain or lose electrons	Ion electron configuration	Cation or anion	Ion symbol and charge
Na	11	2,8,1	Lose	2,8	Cation	Na ⁺
K	19	2,8,8,1	Lose	2,8,8	Cation	K ⁺
Mg	12	2,8,2	Lose	2,8	Cation	Mg ²⁺
Cl	17	2,8,7	Gain	2,8,7	Anion	Cl ⁻
N	7	2,5	Gain	2,8	Anion	N ³⁻
B	5	2,3	Lose	2	Cation	B ³⁺
Al	13	2,8,3	Lose	2,8	Cation	Al ³⁺
F	9	2,7	Gain	2,8	Anion	F ⁻
Li	3	2,1	Lose	2	Cation	Li ⁺
Be	4	2,2	Lose	2	Cation	Be ²⁺
Ca	20	2,8,8,2	Lose	2,8,8	Cation	Ca ²⁺

2. The ion charge is easy to predict for some groups. Groups 1 and 2 have charges of 1+ and 2+. Groups 15, 16 and 17 will be 3-, 2- and 1-.

3. a. Mg 2,8,2; Cl 2,8,7

b. Two chlorine atoms accept an electron from a magnesium atom.

c. $\text{Mg}^{2+} + \text{Cl}^- \rightarrow \text{MgCl}_2$ (magnesium chloride)

4. a. Al 2,8,3; O 2,6

b. Two aluminium atoms accept six electrons from three oxygen atoms.

c. $2\text{Al}^{3+} + 3\text{O}^{2-} \rightarrow \text{Al}_2\text{O}_3$ (aluminium oxide)

5.

Name	Formula	Name	Formula
Ammonium iodide	NH ₄ I	Ammonium sulfate	(NH ₄) ₂ SO ₄
Sodium sulfide	Na ₂ S	Sodium sulfite	Na ₂ SO ₃
Sodium sulfate	Na ₂ SO ₄	Magnesium hydroxide	Mg(OH) ₂
Silver carbonate	Ag ₂ CO ₃	Calcium nitride	Ca ₃ N ₂
Iron(II) chloride	FeCl ₂	Potassium carbonate	K ₂ CO ₃
Barium carbonate	BaCO ₃	Copper(I) iodide	CuI
Aluminium sulfate	Al ₂ (SO ₄) ₃	Aluminium bromide	AlBr ₃
Lithium nitride	LiN ₃	Sodium oxide	Na ₂ O
Strontium sulfide	SrS	Lead(II) hydroxide	Pb(OH) ₂

Formula	Name	Formula	Name
NaI	Sodium iodide	NaF	Sodium fluoride
CaF ₂	Calcium fluoride	Al(NO ₃) ₃	Aluminium nitrate
MgS	Magnesium sulfide	SnCl ₄	Tin chloride
AgI	Silver iodide	CuO	Copper oxide
(NH ₄) ₂ CO ₃	Ammonium carbonate	Ba ₃ N ₂	Barium nitride
NiSO ₄	Nickel sulfate	K ₂ S	Potassium sulfide
KNO ₃	Potassium nitrate	Ag ₃ N	Silver nitride
AlPO ₄	Aluminium phosphate	Ba(OH) ₂	Barium hydroxide
PbI ₂	Lead iodide	Fe(NO ₃) ₃	Iron nitrate

Activity 6.8.1

1. Sulfur and oxygen gas

Word equation	sulfur + oxygen → sulfur dioxide
Formula equation	$S + O_2 \rightarrow SO_2$
Balanced equation	$S (s) + O_2 (g) \rightarrow SO_2 (g)$

2. Magnesium and oxygen gas

Word equation	magnesium + oxygen → magnesium oxide
Formula equation	$Mg + O_2 \rightarrow MgO$
Balanced equation	$2Mg (s) + O_2 (g) \rightarrow 2MgO (s)$

3. Silver nitrate and sodium chloride solutions

Word equation	silver nitrate + sodium chloride → silver chloride + sodium nitrate
Formula equation	$AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$
Balanced equation	$AgNO_3 (aq) + NaCl (aq) \rightarrow AgCl (aq) + NaNO_3 (aq)$

4. Sulfuric acid (hydrogen sulfate) and sodium hydroxide

Word equation	sulfuric acid + sodium hydroxide → sodium sulfate + water
Formula equation	$H_2SO_4 + NaOH \rightarrow Na_2SO_4 + H_2O$
Balanced equation	$H_2SO_4 (l) + 2NaOH (s) \rightarrow Na_2SO_4 (aq) + 2H_2O (l)$

Activity 6.8.2

- Copper sulfate + magnesium hydroxide → magnesium sulfate + copper hydroxide
 $\text{CuSO}_4 + \text{Mg}(\text{OH})_2 \rightarrow \text{MgSO}_4 + \text{Cu}(\text{OH})_2$
- Potassium bromide + silver nitrate → potassium nitrate + silver bromide
 $\text{KBr} + \text{AgNO}_3 \rightarrow \text{KNO}_3 + \text{AgBr}$
- Sodium hydroxide + nitric acid (hydrogen nitrate) → sodium nitrate + water
 $2\text{NaOH} + \text{HNO}_3 \rightarrow \text{NaNO}_3 + \text{H}_2\text{O}$
- Sodium carbonate + calcium chloride → sodium chloride + calcium carbonate
 $\text{Na}_2\text{CO}_3 + \text{CaCl}_2 \rightarrow 2\text{NaCl} + \text{CaCO}_3$

Activity 6.8.3

- $\text{S} + \text{O}_2 \rightarrow \text{SO}_2$
 - $\text{H}_2 + \text{I}_2 \rightarrow 2\text{HI}$
 - $\text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3$
 - $2\text{C}_2\text{H}_6 + 7\text{O}_2 \rightarrow 4\text{CO}_2 + 6\text{H}_2\text{O}$
 - $4\text{Al} + 3\text{O}_2 \rightarrow 2\text{Al}_2\text{O}_3$
 - $4\text{Fe} + 3\text{S}_2 \rightarrow 2\text{Fe}_2\text{S}_3$
 - $\text{Ca} + 2\text{H}_2\text{O} \rightarrow \text{Ca}(\text{OH})_2 + \text{H}_2$
 - $4\text{NH}_3 + 5\text{O}_2 \rightarrow 4\text{NO} + 6\text{H}_2\text{O}$
- $\text{KCl} + \text{AgNO}_3 \rightarrow \text{KNO}_3 + \text{AgCl}(\text{s})$
 - $\text{CaI}_2 + 2\text{AgNO}_3 \rightarrow \text{Ca}(\text{NO}_3)_2 + 2\text{AgCl}(\text{s})$
 - $\text{HCl} + \text{NaOH} \rightarrow \text{NaCl} + \text{H}_2\text{O}$
 - $2\text{LiCl} + \text{Pb}(\text{NO}_3)_2 \rightarrow 2\text{LiNO}_3 + \text{PbCl}_2(\text{s})$
 - $4\text{Al}(\text{s}) + 3\text{O}_2 \rightarrow 2\text{Al}_2\text{O}_3$

Activity 6.8.4

- Titanium: 4 times heavier than carbon, so 48
 - Uranium: 238 times heavier than hydrogen, so 238
 - Antimony: 10 times heavier than carbon, so 120
 - Helium: a third of the mass of carbon, so 4
- Copper 63.5
 - Nickel 58.7
 - Strontium 87.6
 - Lead 207.2

3. a. CO_2 44
b. HNO_3 63
c. NaCl 58.5
d. HCl 36.5
e. LiOH 23.9
f. $\text{Cu}(\text{OH})_2$ 97.5

Revision questions

1. a. Og
b. Carbon at 3500°C
c. Silver
d. Rhodium
2. a. Possible answers: mercury, uranium, caesium, fluorine, lead
b. Possible answers: uranium, radium, thorium
c. Possible answers: lead, carbon, copper, sulfur and gold
3. a. Lead
b. Lithium
c. Carbon
d. Nitrogen
- 4–7. Answers will vary.
8. The colour of a firework reflects the metals present (e.g. a very red firework might have lithium chloride).
9. Valence electrons
10. Noble gases have complete outer shells, therefore they are unreactive. They were difficult to discover because they are colourless, rare and unreactive.
11. Melting points increase as you move down the group.
12. $2\text{K} + \text{CuCl}_2 \rightarrow \text{Cu} + 2\text{KCl}$
13. a. 1+
b. 2+
c. 3+
d. 2-
e. 1-
f. 2-
14. Ba_3Y_2
15. 2+
16. $\text{Fe}(\text{II})\text{SO}_4$, $\text{Fe}(\text{III})_2(\text{SO}_4)_3$

17. a. KI
- b. High melting point, hard and brittle
- c. Potassium and potassium iodide are both solids and both conduct electricity as liquids. Potassium metal conducts as a solid and is ductile but potassium iodide as a solid does not conduct electricity and is not ductile.
18. a. Synthesis
- b. Precipitation
- c. Displacement
- d. Decomposition
- e. Decomposition
19. a. $\text{H}_2 + \text{Cl}_2 \rightarrow 2\text{HCl}$
- b. $2\text{HgO} \rightarrow 2\text{Hg} + \text{O}_2$
- c. $\text{Ca} + 2\text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 + \text{H}_2$
20. a. % C in $\text{CO}_2 = 27.3\%$
- b. % Na in $\text{NaCl} = 39.3\%$
- c. % N in $\text{NH}_3 = 82.4\%$
- d. %C in $\text{CH}_4 = 75\%$

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