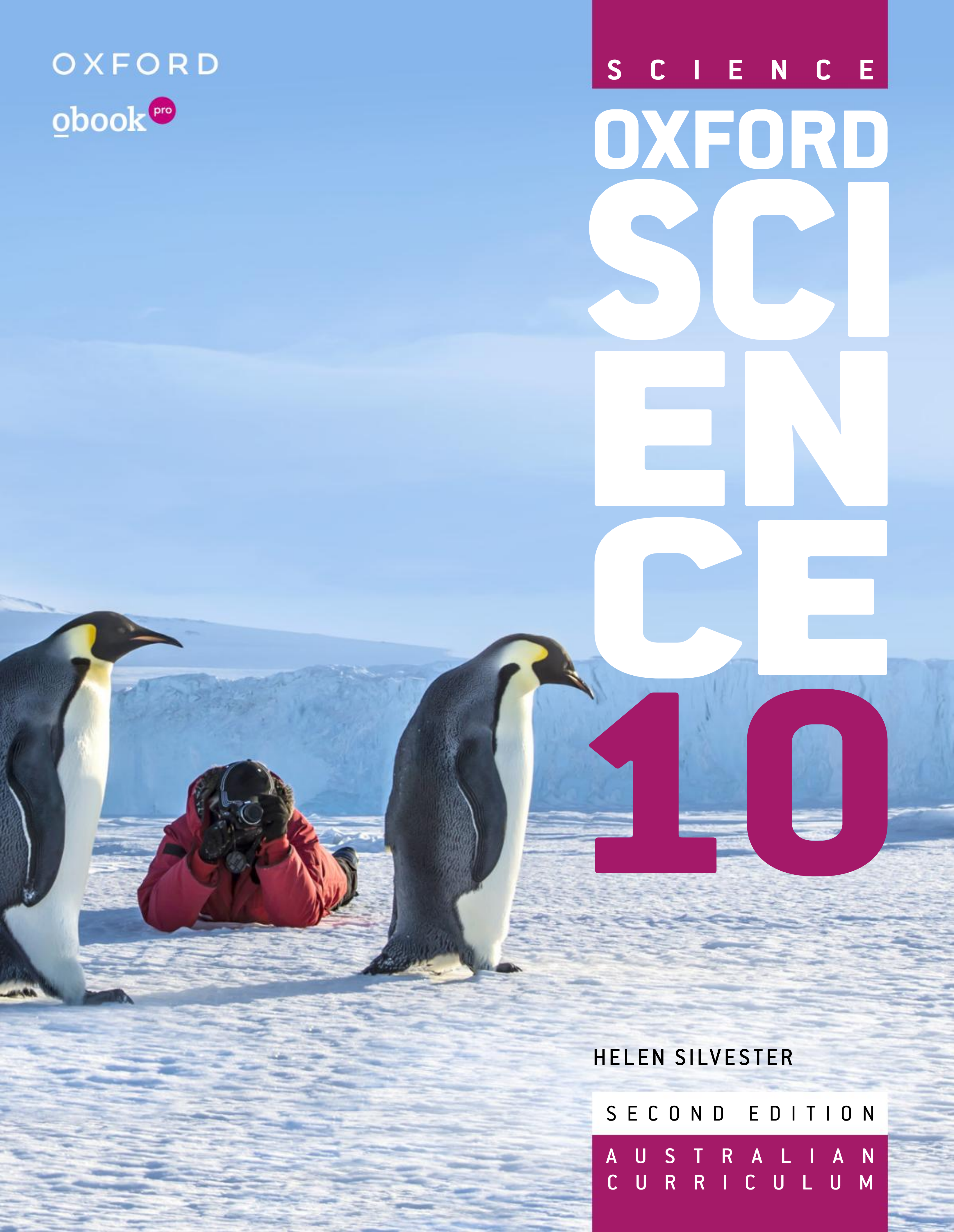

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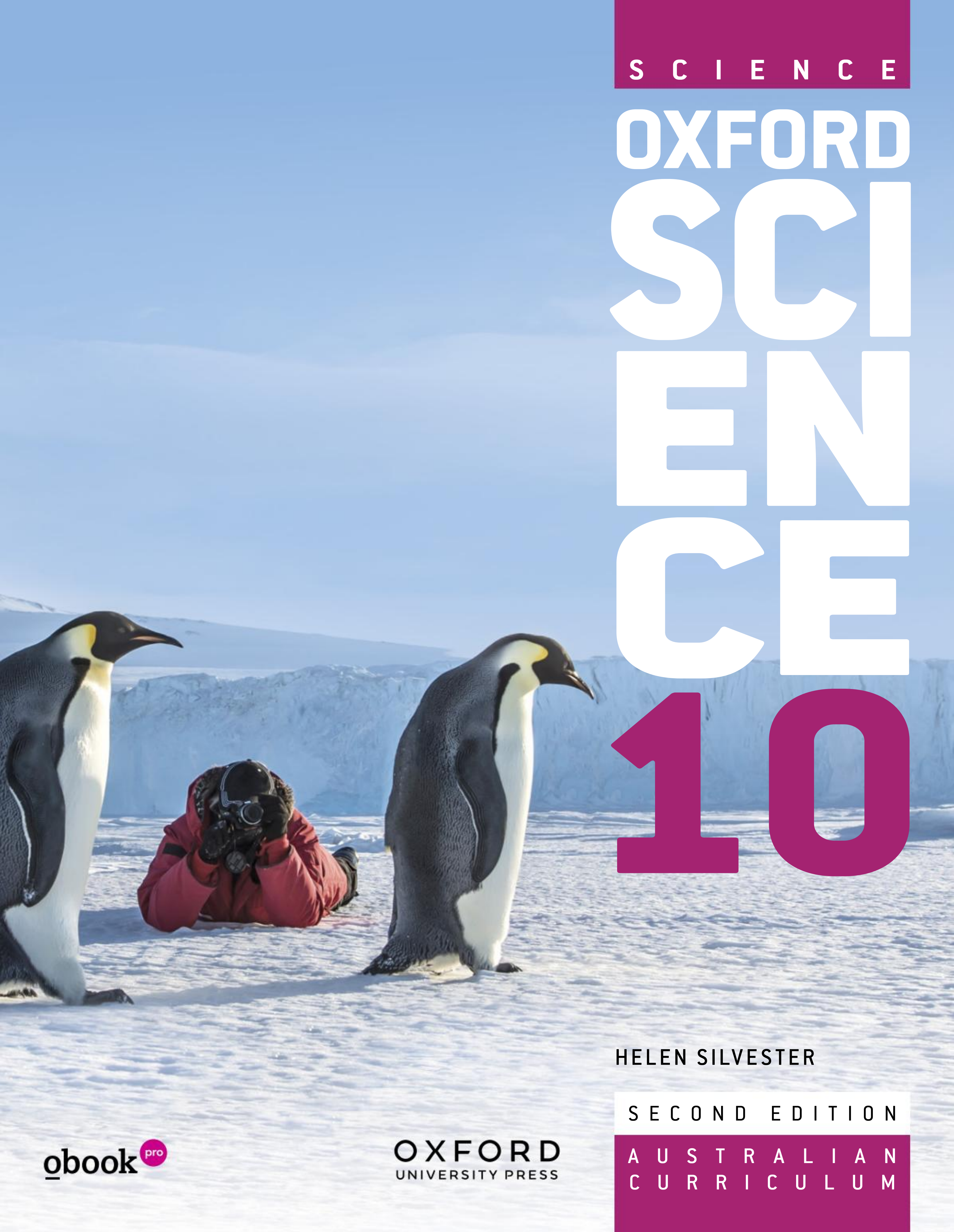

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OXFORD SCIENCE 10

1 Science toolkit
Scientists work collaboratively and individually to design experiments.

2 Genetics
Heritable characteristics are transmitted from one generation to the next in a process that involves genes and DNA.

3 Evolution
The theory of evolution by natural selection explains the diversity of living things on Earth and is supported by a range of scientific evidence. This theory has been developed over time.

4 Climate change
There are interactions and cycles within and between Earth's spheres. Global systems, including the carbon cycle, rely on these interactions involving the biosphere, lithosphere, hydrosphere and atmosphere.

5 The periodic table
The periodic table is used to classify and organise elements. The atomic structure and properties of elements are used to organise them in the periodic table. This system can be used to make predictions about the properties of elements.

6 Chemical reactions
Different types of reactions are used to produce a range of products and can occur at different rates. Different factors influence the rate of reactions.

7 The universe
The universe contains features including galaxies, stars and solar systems. The Big Bang theory can be used to explain the origin of the universe. This theory is supported by scientific evidence and has developed over time.

8 Motion
The relationships between force, mass and acceleration can be used to predict changes in the motion of objects.

9 Learning and memory
The brain coordinates learning and memory. Behaviours can be learned in specific ways, and the duration and capacity of memory can be improved.

10 Experiments

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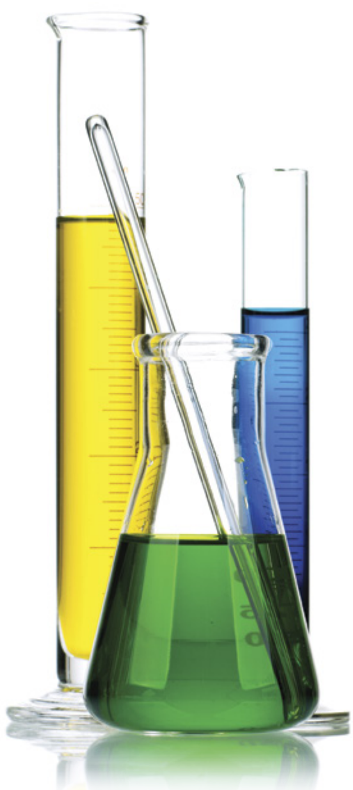
CONTENTS



INTRODUCING *OXFORD SCIENCE 7–10* *AUSTRALIAN CURRICULUM*

Oxford Science Australian Curriculum has been developed to meet the requirements of the *Australian Curriculum: Science* across Years 7–10. Taking a concept development approach, each double-page spread of Oxford Science represents **one concept**, **one topic** and **one lesson**. This new edition ensures students build science skills and cross-curriculum capabilities, paving a pathway for science success in the senior secondary years.

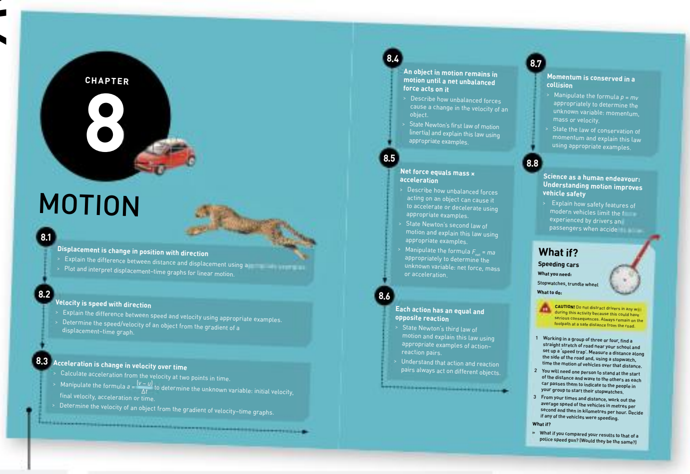
The series offers a completely integrated suite of print and digital resources to meet your needs, including:

> Student Book
> Student obook pro
> Teacher obook pro.

Key features of this Student Book

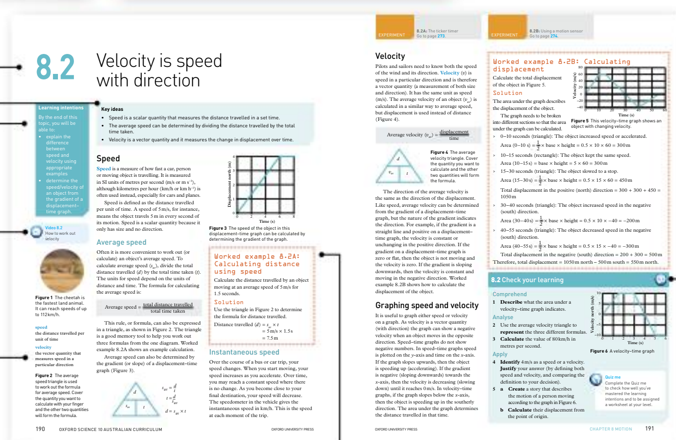
> This Student Book combines complete curriculum coverage with clear and engaging design.
> Each print Student Book comes with complete access to all the digital resources available on Student obook pro.

Focus on concept development



Reflect

- Students are encouraged to self-assess their learning against a set of success criteria in the Chapter checklist tables at the end of each chapter. If students do not feel confident about their learning, they are directed back to the relevant topic.



Chapter openers

- Every chapter begins with a clear learning pathway for students.

Concept statements

- Every topic begins with a concept statement that summarises the key concept of the topic in one sentence.

Learning intentions

- Learning intentions are clearly stated for every topic.

Key ideas

- Key ideas are summarised for each topic in succinct dot points.

Integrated links to engaging digital resources

- Where relevant, digital icons flag engaging resources that can be accessed via Student obook pro. These resources are directly integrated with the topic being covered.

Margin glossary terms

- Key terms are bolded in the body in blue text, with a glossary definition provided in the margin.

Worked examples

- Students are provided with step-by-step worked examples for mathematical problems and scientific concepts.

Check your learning

- Each topic finishes with a set of 'Check your learning' questions that are aligned to the learning intentions for the topic. Questions are phrased using bolded cognitive verbs which state what is expected of a student and prepares them for studying senior science subjects.

Focus on science inquiry skills and capabilities

Digital hotspots

Icons found in the student book link to digital resources accessible via the obook pro.

- Digital versions of the Check your learning and Chapter review questions
- Videos
- Digital quizzes
- Interactives

Science toolkit

- The Science toolkit is a standalone chapter that explicitly teaches important science inquiry skills and capabilities.

Science as a human endeavour

- 'Science as a human endeavour' topics explore real-world examples and case studies, allowing students to apply science understanding.

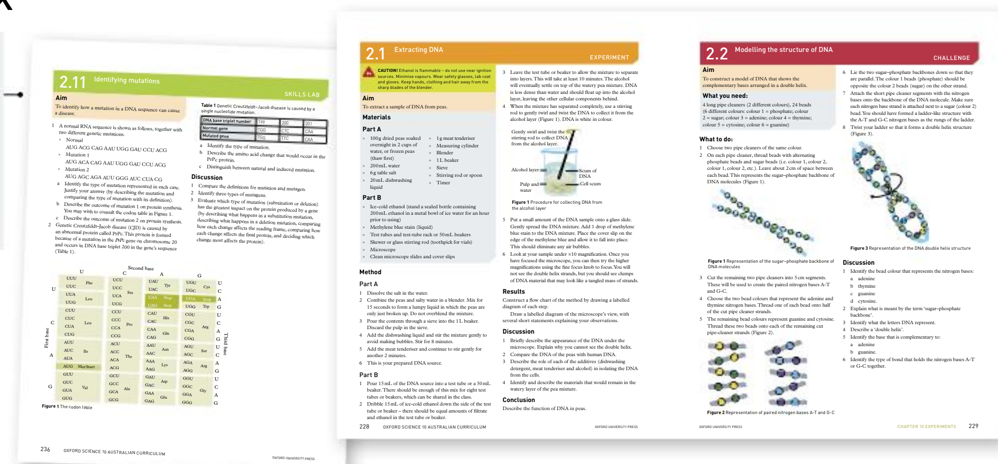
Test your skills and capabilities

- This section provides scaffolded opportunities for students to apply their science understanding while developing skills and capabilities.

Focus on practical work

Practical work appears at the back of the book

- All practical activities are organised in a chapter at the end of the book and signposted at the point of learning throughout each chapter.



Challenges, Skills labs and Experiments

- These activities provide students with opportunities to use problem-solving and critical thinking, and apply science inquiry skills.

Focus on STEAM

Integrated STEAM projects

- Take the hard work out of cross-curricular learning with engaging STEAM projects. Two fully integrated projects are included at the end of each book in the series, and are scaffolded and mapped to the Science, Maths and Humanities curricula. The same projects also feature in the corresponding Oxford Humanities and Oxford Maths series to assist cross-curricular learning.

Problem solving through design thinking

- Each STEAM project investigates a real-world problem that students are encouraged to problem solve using design thinking.

Full digital support

- Each STEAM project is supported by a wealth of digital resources, including student booklets (to scaffold students through the design-thinking process of each project), videos to support key concepts and skills, and implementation and assessment advice for teachers.

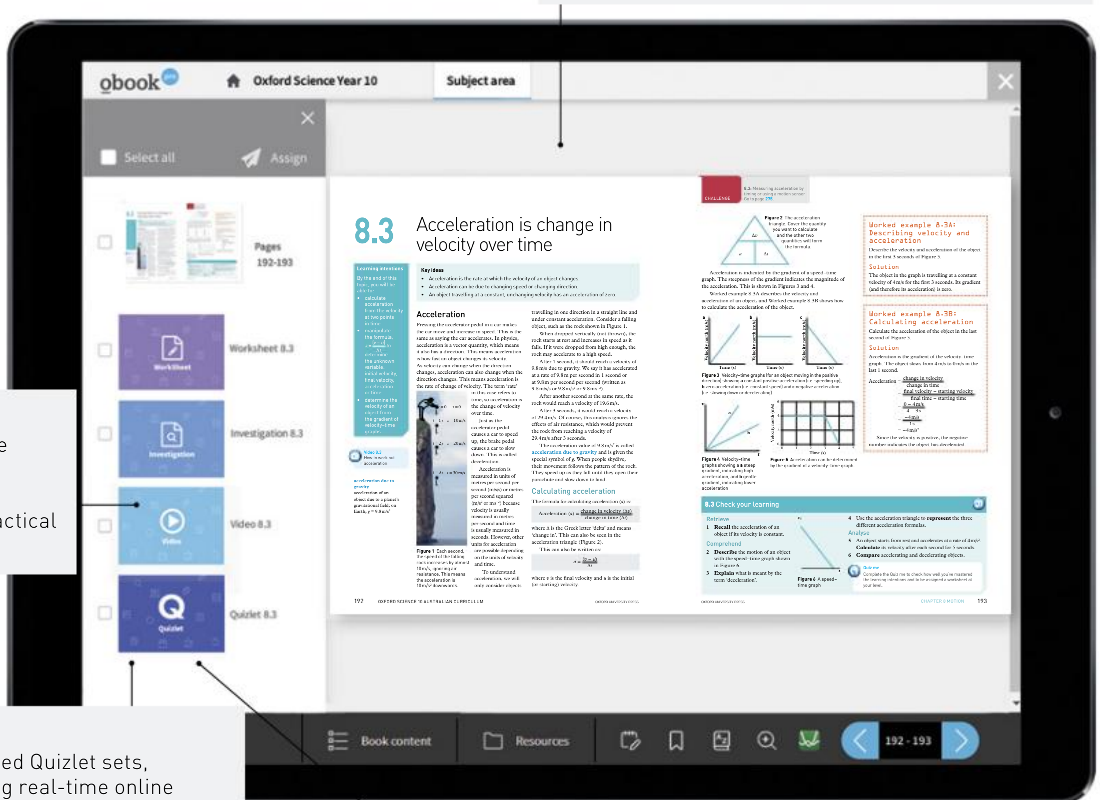
Key features of Student obook pro

- Student obook pro is a completely digital product delivered via Oxford's online learning platform, **Oxford Digital**.
- It offers a complete digital version of the Student Book with interactive note-taking, highlighting and bookmarking functionality, allowing students to revisit points of learning.
- A complete ePDF of the Student Book is also available for download for offline use and read-aloud functionality.

Focus on eLearning

Complete digital version of the Student Book

- This digital version of the Student Book is true to the print version, making it easy to navigate and transition between print and digital.



Videos

- Videos are available online to support understanding of concepts or key practical activities.

Quizlet

- Integrated Quizlet sets, including real-time online quizzes with live leaderboards, motivate students by providing interactive games that can be played solo or as a class. Quizlet can be used for revision or as a topic is introduced to keep students engaged.

Interactive quizzes

- Each topic in the Student Book is accompanied by an interactive assessment that can be used to consolidate concepts and skills.
- These interactive quizzes provide a mix of auto- and teacher-corrected questions, with students receiving instant feedback on achievement and progress. Students can also access all their online assessment results to track their own progress and reflect on their learning.

Benefits for students

- integrated *Australian Concise Oxford Dictionary* look-up feature
- targeted instructional videos for key concepts, practicals and worked examples
- interactive assessments to consolidate understanding
- integrated Quizlet sets, including real-time online quizzes with live leaderboards
- access to their online assessment results to track their own progress.

obook pro

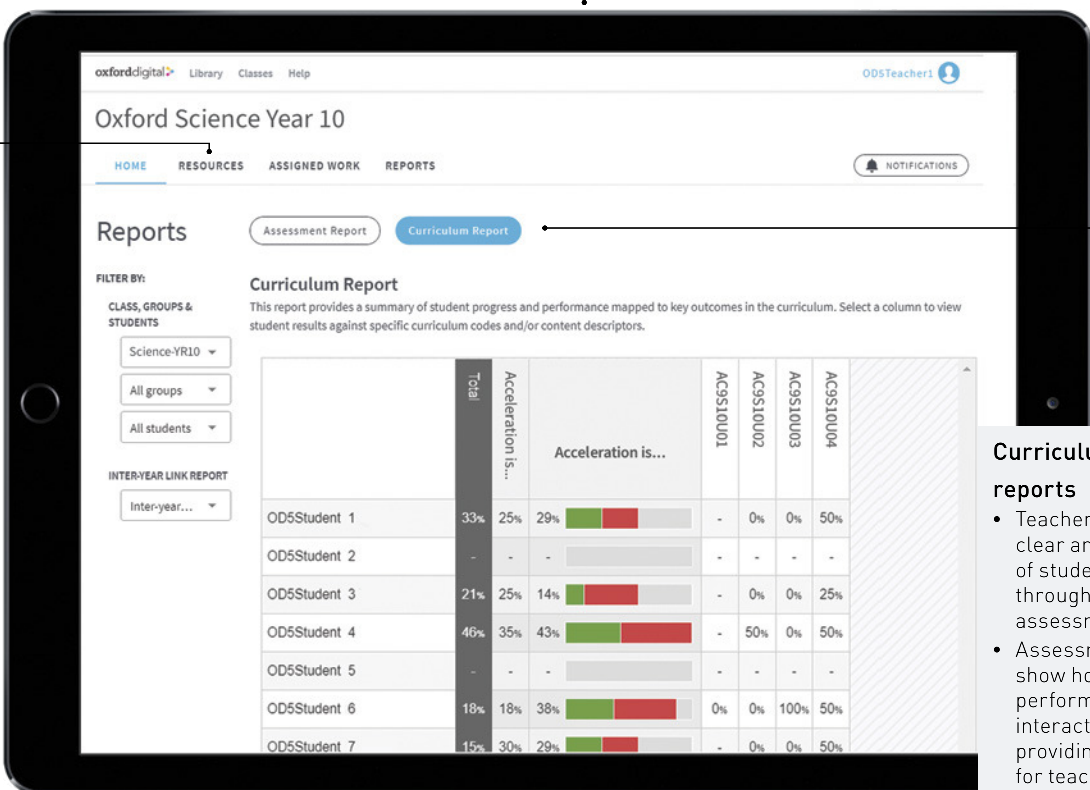
Key features of Teacher obook pro

- Teacher obook pro is a completely digital product delivered via **Oxford Digital**.
- Each chapter and topic of the Student Book is accompanied by full teaching support. Teaching programs are provided that clearly direct learning pathways throughout each chapter, including ideas for differentiation and practical activities.
- Teachers can use their Teacher obook pro to share notes and easily assign resources or assessments to students, including due dates and email notifications.

Focus on assessment and reporting

Complete teaching support

- Teaching support includes full lesson and assessment planning, ensuring there is more time to focus on students.



Curriculum and assessment reports

- Teachers are provided with clear and tangible evidence of student learning progress through curriculum and assessment reports.
- Assessment reports directly show how students are performing in each online interactive assessment, providing instant feedback for teachers about areas of understanding.
- Curriculum reports summarise student performance against specific curriculum content descriptions and curriculum codes.

Additional resources

- Each chapter of the Student Book is accompanied by additional worksheets and learning resources to help students progress.

Benefits for teachers

- In addition to online assessment, teachers have access to editable class tests that are provided at the conclusion of each chapter. These tests can be used as formative or summative assessment and can be edited to suit the class's learning outcomes.
- Teachers are provided with laboratory support through experiment answer guidance, laboratory technician notes and risk assessments to ensure safe learning experiences.

AUSTRALIAN CURRICULUM: SCIENCE 10 SCOPE AND SEQUENCE

YEAR 10 DESCRIPTION

In Year 10, students explore the biological, chemical, geological and astronomical evidence for different theories, such as the theory of natural selection and the Big Bang theory. Through investigating natural selection and processes of heredity they come to understand the evolutionary feedback mechanisms that ensure the continuity of life. They appreciate how energy drives the Earth system and how climate models simulate the flow of energy and matter within and between Earth's spheres. Students develop a more sophisticated understanding of atomic theory to understand patterns and relationships within the periodic table. They understand that motion and forces are related by applying physical laws and can be modelled mathematically. Students analyse and synthesise data from systems at multiple scales to develop evidence-based explanations for phenomena. They learn that all models involve assumptions and approximations, and that this can limit the reliability of predictions based on those models.

YEAR 10 CONTENT DESCRIPTIONS	
SCIENCE UNDERSTANDING	
Biological sciences	
Chapter 2	Explain the role of meiosis and mitosis and the function of chromosomes, DNA and genes in heredity and predict patterns of Mendelian inheritance (AC9S10U01)
Chapter 3	Use the theory of evolution by natural selection to explain past and present diversity and analyse the scientific evidence supporting the theory (AC9S10U02)
Earth and space sciences	
Chapter 7	Describe how the Big Bang theory models the origin and evolution of the universe and analyse the supporting evidence for the theory (AC9S10U03)
Chapter 4	Use models of energy flow between the geosphere, biosphere, hydrosphere and atmosphere to explain patterns of global climate change (AC9S10U04)
Physical sciences	
Chapter 8	Investigate Newton's laws of motion and quantitatively analyse the relationship between force, mass and acceleration of objects (AC9S10U05)
Chemical sciences	
Chapter 5	Explain how the structure and properties of atoms relate to the organisation of the elements in the periodic table (AC9S10U06)
Chapter 6	Identify patterns in synthesis, decomposition and displacement reactions and investigate the factors that affect reaction rates (AC9S10U07)
SCIENCE AS A HUMAN ENDEAVOUR	
Nature and development of science	
All chapters	Explain how scientific knowledge is validated and refined, including the role of publication and peer review (AC9S10H01)
All chapters	Investigate how advances in technologies enable advances in science, and how science has contributed to developments in technologies and engineering (AC9S10H02)
Use and influence of science	
All chapters	Analyse the key factors that contribute to science knowledge and practices being adopted more broadly by society (AC9S10H03)
All chapters	Examine how the values and needs of society influence the focus of scientific research (AC9S10H04)

SCIENCE INQUIRY	
Questioning and predicting	
All chapters	Develop investigable questions, reasoned predictions and hypotheses to test relationships and develop explanatory models (AC9S10I01)
Planning and conducting	
All chapters	Plan and conduct valid, reproducible investigations to answer questions and test hypotheses, including identifying and controlling for possible sources of error and, as appropriate, developing and following risk assessments, considering ethical issues, and addressing key considerations regarding heritage sites and artefacts on Country/Place (AC9S10I02)
All chapters	Select and use equipment to generate and record data with precision to obtain useful sample sizes and replicable data, using digital tools as appropriate (AC9S10I03)
Processing, modelling and analysing	
All chapters	Select and construct appropriate representations, including tables, graphs, descriptive statistics, models and mathematical relationships, to organise and process data and information (AC9S10I04)
All chapters	Analyse and connect a variety of data and information to identify and explain patterns, trends, relationships and anomalies (AC9S10I05)
Evaluating	
All chapters	Assess the validity and reproducibility of methods and evaluate the validity of conclusions and claims, including by identifying assumptions, conflicting evidence and areas of uncertainty (AC9S10I06)
All chapters	Construct arguments based on analysis of a variety of evidence to support conclusions or evaluate claims, and consider any ethical issues and cultural protocols associated with accessing, using or citing secondary data or information (AC9S10I07)
Communicating	
All chapters	Write and create texts to communicate ideas, findings and arguments effectively for identified purposes and audiences, including selection of appropriate content, language and text features, using digital tools as appropriate (AC9S10I08)

YEAR 10 ACHIEVEMENT STANDARD
By the end of Year 10, students explain the processes that underpin heredity and genetic diversity and describe the evidence supporting the theory of evolution by natural selection. They sequence key events in the origin and evolution of the universe and describe the supporting evidence for the Big Bang theory. They describe trends in patterns of global climate change and identify causal factors. They explain how Newton's laws describe motion and apply them to predict motion of objects in a system. They explain patterns and trends in the periodic table and predict the products of reactions and the effect of changing reactant and reaction conditions. Students analyse the importance of publication and peer review in the development of scientific knowledge and analyse the relationship between science, technologies and engineering. They analyse the key factors that influence interactions between science and society. Students plan and conduct safe, valid and reproducible investigations to test relationships or develop explanatory models. They explain how they have addressed any ethical and intercultural considerations when generating or using primary and secondary data. They select equipment and use it efficiently to generate and record appropriate sample sizes and replicable data with precision. They select and construct effective representations to organise, process and summarise data and information. They analyse and connect a variety of data and information to identify and explain patterns, trends, relationships and anomalies. They evaluate the validity and reproducibility of methods, and the validity of conclusions and claims. They construct logical arguments based on analysis of a variety of evidence to support conclusions and evaluate claims. They select and use content, language and text features effectively to achieve their purpose when communicating their ideas, findings and arguments to diverse audiences.

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CHAPTER

1

SCIENCE TOOLKIT

1.1

There are many types of scientific investigations

> Operationalise a question.
> Form a hypothesis.
> Explain how to plan and conduct a scientific investigation.
> Describe what a logbook is and how to use it.

1.2

Scientists communicate using scientific language

> Explain how scientists communicate when writing reports for different audiences.

1.3

Experiments must be controlled

> Define independent, dependent, controlled and confounding variables.
> Describe valid experiments, reliable experiments and control groups.

1.4

Data can be analysed

> Describe how bias can affect the design of an experiment and the analysis of data.
> Explain how graphs can be used to present and analyse data.

1.5

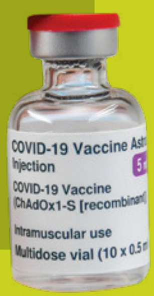
Clinical testing uses the scientific method

> Identify and explain the five stages of developing a new vaccine.

1.6

Science as a human endeavour: Scientific investigations must be ethical

> Describe deontological and consequentialist approaches to ethics.
> Apply ethical approaches to practices in science.



1.7

Cognitive verbs identify the tasks in a question

> Recognise the cognitive verb in a question.
> Understand the different tasks involved for different cognitive verbs.

What if?

Yeast reactions

What you need:

Active yeast suspension in warm water, 3 per cent hydrogen peroxide solution, test tube in a rack, measuring cylinder, 2 plastic pipettes, dishwashing detergent

What to do:

1 Use the measuring cylinder to measure 2 mL of hydrogen peroxide. Pour the hydrogen peroxide into the test tube.

2 Add one drop of dishwashing detergent to the test tube.

3 Use the plastic pipette to mix the yeast suspension thoroughly.

4 Add three drops of the yeast suspension to the test tube.

5 Measure the height of the bubbles made from the gas produced by the catalysed reaction.

What if?

» What if more yeast suspension was added?
» What if the hydrogen peroxide solution was diluted with water?
» What if the yeast mixture was put on ice?
» What if the yeast mixture was boiled before it was added to the hydrogen peroxide?

1.1 There are many types of scientific investigations

Learning intentions

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

- operationalise a question
- form a hypothesis
- explain how to plan and conduct a scientific investigation
- describe what a logbook is and how to use it.

Figure 1 Scientists might ask, 'How did the universe start?' To investigate this, they need to also ask questions that can be tested and measured.

Key ideas

- Types of scientific investigation include case studies, modelling or simulations, quantitative analysis and controlled experiments.
- Scientists record their research and data in a logbook.

Science is a way of asking and answering questions about the biological, chemical, physical and technological worlds. It allows us to explore the unknown and use our knowledge to solve problems.

Questioning and predicting

All scientific investigations start by asking a question. There are many different types of questions that can be asked. Questions can be big (such as 'How did the universe start?') or they can be small (such as 'What will happen if acid is mixed with metal?').

Big questions often need to be broken down into a series of small questions that can be answered over time (Figure 1). For example, the question 'How did the universe start?' could be broken down into these questions:

> What is a universe?
> What makes up our universe?
> What is the state of our current universe?
> How is our universe changing?
> Can we measure these changes?
> Have these changes always occurred?
> What is causing these changes?

Each question can then be broken down into something that is measurable. This is called **operationalising** the question.

Independent variable	IF 6 drops of yeast suspension (instead of 3 drops) was added to 2 mL of hydrogen peroxide
Dependent variable	THEN twice as much gas would be produced in the same time
Possible explanation	BECAUSE increasing the amount of catalyst will increase the rate of a reaction.

Figure 2 A possible hypothesis for the example question

Scientists need to ask specifically how they will test and measure their question.

For example, the question 'What if more yeast was added to hydrogen peroxide?' will need to consider the amount the yeast solution will be increased by. So, an operationalised question for this would be 'What if 6 drops of yeast extract was added to 2 mL of hydrogen peroxide?'

Forming a hypothesis

Once the question is testable, the scientist can predict the outcome of the test and state the reason for their prediction. These things are included in a hypothesis. The easiest hypothesis to use is an 'If … then … because …' statement.

For example, the hypothesis for the previous question could be as shown in Figure 2.

This hypothesis can now be investigated.

Planning and conducting

There are many ways to investigate science. The type of investigation used is called the **methodology**. This is different to a method (the step-by-step procedure of an investigation). The methodology that a scientist uses will depend on the type of question and the equipment that can be used.

Case studies

A case study is a detailed investigation of a real life or hypothetical activity, event or problem. It looks at all the causes or contributing factors involved at the beginning and describes what happened during the event, as well as the outcomes and consequences. The case study will also analyse the data and provide recommendations for the future. An example is a case study of an environment, where all the factors that contributed to a change in the environment (including the motivations of humans) are discussed.

Figure 3 The Commonwealth Scientific and Industrial Research Organisation (CSIRO) completed a detailed study of the Mitchell catchment and used the data to evaluate soil and water resources and identify and evaluate water capture and storage options.

Figure 4 Quantitative analysis of pH in soil is important for plant or crop growth.

It may include a detailed description of how the environment changed as well as the short- and long-term consequences of the change.

Modelling or simulations

Many scientific investigations involve constructing a physical or mathematical model or simulation of an object or a change. These models can be used to predict what will happen if something changes. In this year's science classes, you will complete examples of models or simulations, including modelling genetic inheritance and evolution, the properties of alloys, the effects of a carbon sink, and the laws of energy and motion.

Quantitative analysis

Scientists use quantitative analysis to calculate a number or relative amount of a substance. High-technology equipment is usually used in the analysis of samples. For example, chemists may want to calculate the pH in soil (Figure 4), and physicists may want to calculate the amount of dark matter in the universe.

In your science classes this year, you will use quantitative analysis to determine the age of an unknown sample, the amount of acid in a sample, the amount of phosphorus in a detergent, the distance to the Sun and the acceleration of a falling object.

Controlled experiments

Experiments investigate the relationship between an independent variable (the variable that is deliberately changed during an experiment) and the dependent variable (the variable that is observed to determine if it is changed by the independent variable). To determine the relationship between the independent variable and dependent variable, all of the remaining factors or variables must be maintained or controlled (Topic 1.3) so they do not influence the results.

Using a logbook

All scientists will record their research and data in a logbook. Logbooks can be paper based or computer based (these are regularly backed up). Logbooks should contain your name, address and the name of your school on the front. This is to make sure that if it becomes lost, it can be returned. The first page of your logbook should be used as a contents page where you can record the name of each investigation and its page number.

Before you start each investigation, record the name of the investigation and the date at the top of the page. This is to make sure that you will not forget the details of the investigation when you are writing a formal report or studying for your test or exam (Figure 5).

operationalising
a way to break a large science question into smaller measurable questions

methodology
the rationale (why) and approach (how) used by a scientist to investigate a scientific question

Figure 5 It's important to keep a detailed logbook during scientific investigations.

1.1 Check your learning

Retrieve

1 **Define** what it means to 'operationalise a question'. Give an example to support your definition.

Comprehend

2 **Explain** the purpose of using a simulation in science.

Analyse

3 **Compare** a quantitative analysis and a controlled experiment.

4 **Contrast** a methodology and a method.

Apply

5 A student wanted to demonstrate that heating a chemical reaction will cause it to happen faster. They wanted to test it using a dissolvable Alka-Seltzer tablet.

a **Create** an operationalised question for this investigation.

b **Construct** a hypothesis for this investigation.

c **Identify** which methodology the student should use.

6 **Create** a method for the experiment described in question 5.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

1.2 Scientists communicate using scientific language

Learning intentions

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

- explain how scientists communicate when writing reports for different audiences.

unbiased
impartial and free from preconceived ideas

objective
uninfluenced by personal opinions and interests

Key ideas

- Scientific communication requires the author to modify their language to suit the audience.

Like all forms of communication, the way we communicate in science depends on the audience. If the audience does not know the key words or concepts that you are discussing, then you will need to use simple pictures, models and language so that they can understand what you are trying to say. For example, two physicists may say, 'Potential energy was added to the rubber band', whereas a teacher may explain that, 'The rubber band was stretched'.

When writing reports, scientists also avoid using the first person ('I', 'we', 'me', 'you', 'us', etc.). All science is supposed to be **unbiased** and **objective**.

When the first person is used, it introduces the idea that humans can make mistakes.

Scientists usually use past tense when they write a report because they are describing something they have already completed. If results were described in present tense (the now) or future tense (the later on), then the listener would not be sure if the experiment was finished.

Some examples showing the differences between scientific language and common language are given in Table 1.

Table 1 Examples showing differences between scientific language and common language

Scientific language	Common language
The equipment was set up.	I set up the equipment.
The mass of the beaker was measured.	We weighed the beaker on the scales.
The beakers were heated to 50 degrees Celsius. (Past tense)	Heat the beakers to 50 degrees Celsius. (Present or future instruction)
The two trolleys were pulled apart. (Past tense)	Pull the two trolleys apart. (Present or future instruction)
The metal was malleable.	The metal could be bent into any shape.
At 6:15 am a single magpie sitting on a protruding tree branch called loudly for 30 seconds.	I think it was a magpie that sang the warbling song that woke me up in the morning.
The mass of the sodium bicarbonate was identified as a possible random error.	We could have improved the experiment if we were more organised and measured the amount of bicarb properly.

Figure 1 When writing reports, it is important to be unbiased and objective.

Writing a scientific report

Scientists write reports so that their experiment and results can be reviewed by their science-trained colleagues or peers. As both the writer and reader are science trained, these reports will contain many terms that have particular meanings. For example, the word 'significant' can mean 'important' when used by a person in the street. But to a scientist, the word 'significant' means that a result is 'not due to chance'. This means that the words in a scientific report need to be carefully chosen.

All scientific reports have common sections and headings. Table 2 explains each section that you will need to include in your scientific reports.

Table 2 Sections of a scientific report

Section	Description
Title	• A statement that includes the independent variable and the dependent variable.
Introduction	• A summary of any previous experiments that you have completed. • A description of the key concepts being examined and how they are related to your hypothesis.
Aim	• A statement of what you are trying to achieve in the experiment.
Hypothesis	• A prediction of how the independent variable will affect the dependent variable and the reason that supports the outcome. • If … <how the independent variable will change> … then … <how the dependent variable will change> … because … <reason for the change>.
Method	• A list of the materials, containing the concentrations and brands, should be included in the method. • The method should contain step-by-step instructions or a brief description (in past tense) that would enable someone to repeat the experiment. • Relevant labelled diagrams should be included where necessary.
Results	• The data should be presented in a table, graph or diagram. • A written summary of the results (stating facts without conclusions) should also be included.
Discussion	• This section should analyse the results by: › describing the relevant science concepts that occurred in the results › drawing conclusions from the results › comparing the conclusions to the hypothesis › describing how the results could apply in the real world.
Conclusion	• The conclusion should answer the aim of the experiment by: › comparing the conclusions to the aim › describing the limitations of the experiment (by describing situations where these results would not apply) › describing a possible next experiment that could occur to confirm or extend the conclusions.
References	• Any sources that you used to research the scientific concepts or definitions should be included here. • There are different ways to write a reference. Check which style is preferred by your school. • Most scientific communications use APA Style (American Psychological Association Style). For example: Silvester, H. (2023). *Oxford Science 10 Australian Curriculum* (2nd ed.). Oxford University Press.

1.2 Check your learning

Retrieve

1 **Identify** what should be included in the discussion section of a scientific report.

Comprehend

2 **Explain** why scientists avoid using the first person to describe the results of an experiment.

3 Rewrite the following statements using scientific communication.

  a I measured the speed of a skateboard.

  b The acid made lots of bubbles appear on the side of the metal.

  c When I put my hand in the water, it felt very cold. I think it was 15 degrees.

Analyse

4 **Contrast** the common meaning and the scientific meaning of the word 'significant'.

5 **Compare** the information that is written in the results and discussion sections.

Quiz me

Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

1.3 Experiments must be controlled

Learning intentions

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

- define independent, dependent, controlled and confounding variables
- describe valid experiments, reliable experiments and control groups.

Key ideas

- Experiments must be valid and reliable.
- Controlled experiments need to have control groups and may have positive and negative controls.

controlled variables
variables that remain unchanged during an experiment

independent variable
a variable (factor) that is changed in an experiment

dependent variable
a variable in an experiment that may change as a result of changes to the independent variable

confounding variable
a variable that impacts both the independent and dependent variables

valid
when the design of the experiment will produce a result that answers the scientific question

reliability
when an experiment can be repeated to produce the same results

repeatable
when an experiment can be repeated by the same scientist using the same materials

One of the most important parts of a scientific experiment is identifying all the different variables that affect the outcome of the experiment.

Any experiment will have many different factors or variables that will change the result. For example, an experiment that tests how to improve the growth of a plant will be affected by these variables: type of soil, amount of water, amount of sunlight, temperature of the environment, amount of air, and concentration of different gases in the air. A good experiment will keep all these variables the same, or **controlled**, except for one.

The **independent variable** is the only variable that is deliberately changed by the experimenter. In the example of the plant, the experimenter could keep the same soil, the same temperature, the same sunlight and the same air for all plants. The only thing that may change is the amount of water that the plants receive. Then the experimenter will know if the amount of water causes a change in the **dependent variable**. The dependent variable is the variable that is measured at the end of the experiment and is 'dependent' on any change in the independent variable.

Confounding variables are a third type of variable that impact both the independent and the dependent variables. For example, weather is a confounding variable in an experiment examining the relationship between sunburn and number of ice creams sold. While it might appear as if there is a direct correlation between the level of sunburn in individuals and number of ice creams sold, one variable does not cause the other. Instead, the confounding variable is the weather and amount of sunlight which causes the changes in the other two variables.

Valid experiments

The dependent variable must be carefully selected to make sure the experiment is **valid**. An experiment is valid if it measures what it claims to measure. The scientific validity can be checked by asking three questions.

> Does the experiment relate to what happens in the real world?
> Does the experiment measure a dependent variable that is relevant to the aim?
> Does the experiment control all the other factors that might affect the outcome?

For example, if an experimenter wants to test the growth of the plant, then they need to consider what they mean. Growth can mean the height of the plant, the number of leaves, the size of the leaves, the length of the roots, or the number of roots. A valid experiment would identify which of these dependent variables would apply in the real world and would not be affected by the other factors (such as how tightly packed the soil may be).

Reliable experiments

The **reliability** of a science experiment is dependent on the ability to repeat the experiment with the same scientist and same materials (**repeatable**) or with another scientist in another laboratory (**reproducible**) and achieve the same results. For an experiment to be reliable, all the variables that can affect the dependent variable need to have been identified and controlled for.

Control groups

Controlled experiments keep all the variables the same except for the independent variable. If the independent variable is changed, then it needs to be compared to a **control group**.

The control group is a second group of organisms, chemical reactions or physical conditions for which the independent variable has not been changed.

In a biology experiment investigating the effect of amount of water on plants, the independent variable is the amount of water. The control group and the experiment group would contain identical plants, with the same soil, temperature, sunlight and air conditions. The control group would then receive a standard amount of water while the experiment group receives a different amount of water.

Figure 1 Experiments to determine the effectiveness of increased sleep on exam results require matching participants' ages, sexes, food intake, amount of exercise, amount of sleep and general health. Having similar characteristics in each group reduces the number of variables when comparing their results.

In chemistry, a control group might be a set of chemical reactions that occur at a standard temperature, while the experiment group's reactions occur at an increased temperature. In physics, an experiment group of model cars might have an added mass. In psychology, the control and experiment groups must contain the same number of people of the same ages and general health. They should differ only in regard to the independent variable being tested.

Positive control

The **positive control** is an individual test that makes sure a positive outcome is possible. For example, in an experiment to determine whether soap will kill bacteria, a positive control would be to test that the original bacteria are alive.

Negative control

A **negative control** is an individual test to check that the different materials will not affect the dependent variable. For example, in a chemical reaction where an indicator changes colour to show the production of the product, a negative control would be to add a reactant to the indicator to check that it does not cause a colour change (a negative reaction) before the experimental reaction.

reproducible
when the experiment can be repeated by another scientist in another laboratory

control group
a group of organisms, chemical reactions or physical conditions that can be compared to the group that has had the independent variable changed

positive control
an individual test that checks that a positive result is possible in an experiment

negative control
an individual test that checks that a negative result is possible in an experiment

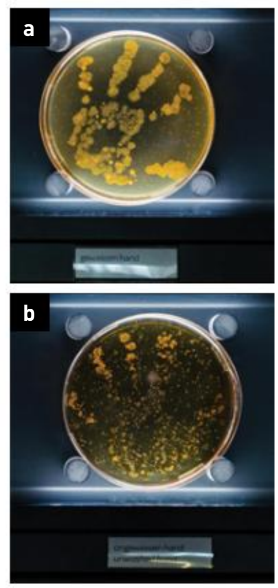


Figure 2 When testing the effectiveness of soap in killing bacteria, **a** the positive control will have bacteria without soap, whereas **b** the negative control will test the soap with no bacteria.

1.3 Check your learning

Retrieve

1 **Define** the terms 'valid' and 'reliable'.

Comprehend

2 **Explain** why a control group should have participants with similar or comparable characteristics to those of the experiment group.

Analyse

3 **Identify** the variables that need to be controlled in an experiment that tests the following hypothesis. **Describe** how you could control each variable.

If the speed of a car was increased from 60 km/h to 80 km/h, then the distance taken to stop will increase from 27 m to 36 m, because the car will travel further before the driver reacts and the braking distance will also increase.

4 **Identify** a positive control and a negative control for an experiment where an electric circuit was set up to determine whether a crystal was able to conduct electricity.

5 **Contrast** repeatable experiments and reproducible experiments.

Apply

6 Your class is investigating whether adding coffee grounds to soil helps a plant grow faster. One of your classmates suggests adding tea leaves to the soil of a plant as a negative control. **Evaluate** this statement (by defining a negative control and comparing the definition to the student's suggestion, and deciding whether adding tea leaves would act as a negative control).

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

1.4 Data can be analysed

Key ideas
- Bias can affect the design of an experiment or the analysis of data.
- Graphs can be used to present data.
- The mean, median and mode can be used to mathematically analyse data.

Learning intentions

By the end of this topic, you will be able to:
- describe how bias can affect the design of an experiment and the analysis of data
- explain how graphs can be used to present and analyse data.

primary data
data collected by the person writing the report

secondary data
data collected by someone else

confirmation bias
when a scientist selects a method that will support the outcome they want

sampling bias
a bias where a group of test subjects do not represent the larger sample group

There are two types of data that you will examine in science this year: primary data and secondary data. **Primary data** is data that you collect from your own experiments. This data relies on the careful planning of the experiment to make sure it is a valid experiment that produces reliable results. The second form of data is collected by other people. This data is called **secondary data**.

When analysing secondary data, it is important to ask a series of questions. These questions might be as simple as:
> Is the data trustworthy?
> Where did the data come from?
> Why did the person collect the data?
> Is the data unbiased?

Bias

If a person is biased, it means they have already made a decision about a person or outcome. In science, bias can cause an observer to only notice the information that they expect to occur and to avoid or refuse to acknowledge data that is unexpected. Because biased observations only tell one side of a story, it can sometimes cause inaccurate data and leave a false impression. There are many ways bias can affect a scientific investigation.

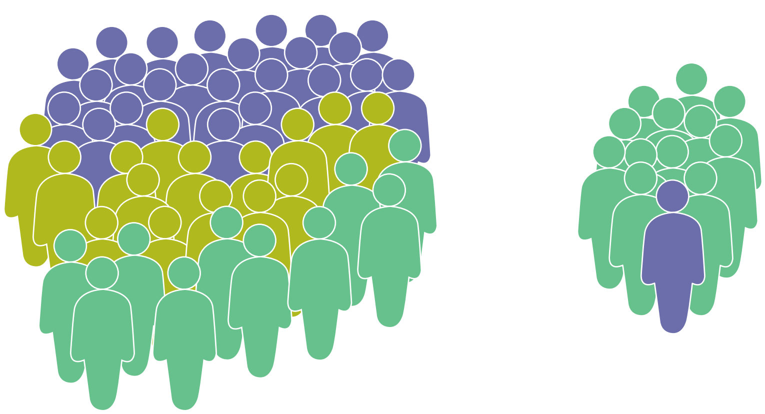


Figure 1 Sampling bias exists when the population of the sample doesn't reflect the actual population.

Confirmation bias

When a researcher has a hypothesis that they are certain is correct, they may shape their investigation so that the data supports the hypothesis. This is known as **confirmation bias**; it involves favouring information that 'confirms' a hypothesis. An example of this occurred in the early 1900s when French scientist Rene Blondlot announced that he had observed a new type of radiation 'glow' called N-rays. He claimed he saw these N-rays released when electricity was passed through particular crystals. Blondlot was so convinced that the N-rays existed, he continued to see them even when an American scientist secretly removed the crystal before a demonstration. Other French scientists also continued to 'see' the glow around crystals for several years because they were convinced that the rays existed.

Sampling bias

When discussing experiment methodology, a sample refers to the people or objects tested in an experiment. The people or objects chosen to be part of a sample should represent the population being studied.

Sampling bias occurs when an experiment tests a small group of subjects (either people or objects) that do not properly represent the larger group (Figure 1). This has been seen most recently during pre-election surveys where people are asked who they will vote for via landline phone surveys in city regions. These surveys often miss people who are not home during the day or who do not have a landline phone because they only use their mobile phones. This means the predictions of who will win an election can be biased because the sample only represents people who own landline phones.

Channelling bias

When scientists want to test the effectiveness of a new drug, they will carefully select a large group of people and divide them into two smaller groups.

When selecting which person will be placed into each group, it is tempting for the scientist to place or 'channel' the people most affected by a condition into the group that will receive the treatment and the people who are least affected into the non-treatment group. But this can affect the outcome of the trial.

Instead, the two groups should be **randomised** (randomly assigned to a group), and both groups should appear to receive the same treatment. This can be done by giving both groups a pill to take at the same time each day. One group will have the new drug in the pill, while the control group will be given a placebo.

A **placebo** is a substance or treatment that is designed to have no effect; for example, a sugar pill. Some people can be so convinced that the treatment will work that a placebo will make them feel better. In one experiment, a group of patients with osteoarthritis of the knee underwent a placebo operation instead of receiving the real procedure. These patients reported feeling less pain as a result of the fake procedure. When participants do not know if they are receiving the real treatment or a placebo, it is called a randomised **blind study**.

Although a blind study is useful, the doctors treating the participants might also behave differently towards a patient if they know the patient is receiving treatment or a placebo. To avoid this, sometimes the treating doctors are not told which treatment the patient is being given. In these tests, only the scientists know the outcome and can decode which group received the treatment. When there are two layers of people who do not know who received the treatment until it is over, this is called a randomised **double-blind study**.

Processing data

There are a variety of tools that can be used to analyse the data of an experiment. One important way is to draw an appropriate graph of the data. All graphs should have:

> the independent variable on the horizontal *x*-axis
> the dependent variable on the vertical *y*-axis
> a descriptive title.

The type of graph you can use will vary according to the type of data. Continuous data can have any value including decimals or fractions.

Discrete data can only have certain values or names. For example, height (… 1.67 m, 1.68 m …) is continuous data. Colours, categories or types are discrete data.

Line graphs are used when both the independent variable and the dependent variable are continuous data (Figure 2).

Scatter plots are used when both the independent variable and the dependent variable are continuous and may not be connected by a line. Occasionally a line of best fit can be used to show the trend or direction of the relationship. A line of best fit is a straight line drawn through a group of data points, and it can show the positive or negative relationship (correlation) between two variables (Figure 3).

randomised
when people or objects are selected at random

placebo
a substance or treatment that is designed to have no effect

blind study
when the participants do not know if they are receiving the treatment or a placebo

double-blind study
when neither the participants nor the treating doctors know if they are receiving the treatment or a placebo

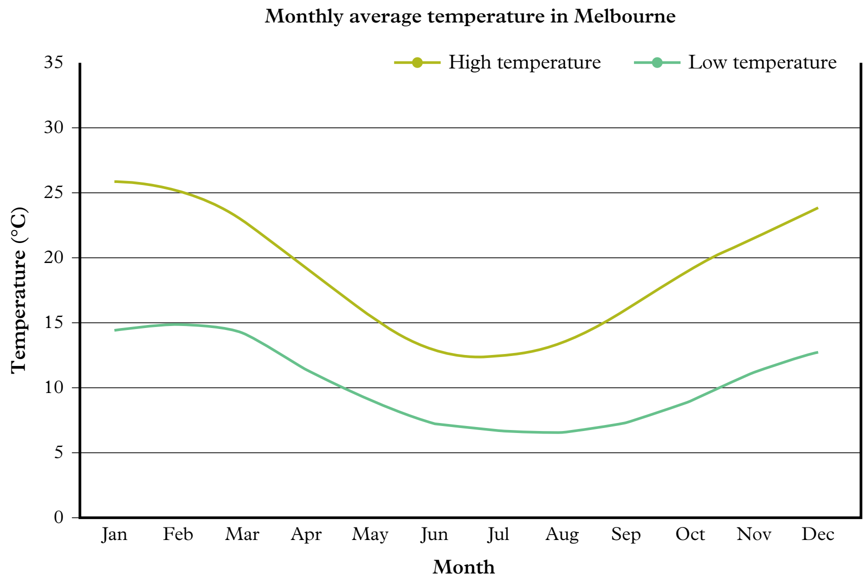


Figure 2 A line graph plots continuous data. In this graph, two data sets are included and are represented by different colours to make it clearer to read.

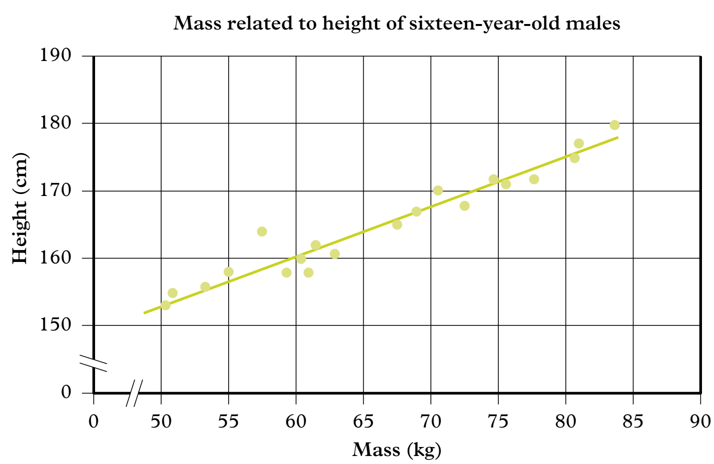


Figure 3 A scatter plot with a line of best fit

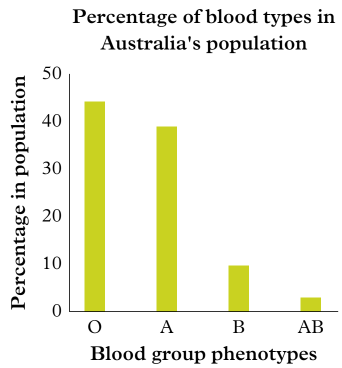


Figure 4 A column graph is used to represent discrete data.

Column graphs are used when either the independent variable or the dependent variable has discrete data (Figure 4).

Analysing numerical data

There are many different ways to use mathematics to represent the data. The average of the data set can be found in a number of ways (outlined in Table 1). Worked example 1.4 shows how to find the average of a data set.

Table 1 Ways to measure the 'average' of a data set

Measure	Description
Mean	• The expected or average value of a data set. • It is calculated by the formula: $\text{Mean} = \frac{\text{Sum of all values}}{\text{The number of values}}$
Median	• The middle value of the data. • It is calculated by placing all the values in order from lowest to highest and then selecting the value in the middle.
Mode	• The most common value in the set of data. • It is calculated by tallying how many times each number appears. The number that appears most often is the mode.

Worked example 1.4: Calculating mean, median and mode

Calculate **a** the mean, **b** the median and **c** the mode for the following times taken for a car to travel 100 m.

278 seconds, 167 seconds, 180 seconds, 208 seconds, 3 minutes

Solution

a Mean: To calculate the mean, all values must be in the same unit (seconds).

The data should therefore be: 278 seconds, 167 seconds, 180 seconds, 208 seconds, 180 seconds.

$$\begin{aligned}\text{Mean} &= \frac{\text{Sum of all values}}{\text{The number of values}}\\ &= \frac{278 + 167 + 180 + 208 + 180}{5}\\ &= \frac{1013}{5}\\ &= 202.6 \text{ seconds}\end{aligned}$$

As all values have three significant figures, the answer should also have three significant figures.

202.6 seconds should be rounded up to 203 seconds.

Therefore, the mean is 203 seconds.

b Median: To calculate the median, all the values must be placed in increasing order.

167 seconds, 180 seconds, 180 seconds, 208 seconds, 278 seconds

The median value is the middle number, which is 180 seconds.

c Mode: The mode is the most common number in the data set.

The mode value is 180 seconds.

Uncertainties in data

There are many different variables that can affect the outcome of an experiment. Something as simple as measuring the mass of an object on scales can change if someone breathes on the scales, or if a person generates a small breeze by quickly walking past. These small unpredictable variations in measurements are called **random errors**. Random errors can be reduced if the measurements or experiments are repeated.

Another error that can occur is a **systematic error**. These errors occur when there is an error in the equipment that is used (such as scales that constantly measure the wrong mass) or in the way the experiment is completed.

Repeating the experiment will not remove these errors. Instead, checking the accuracy of the scales with a known weight (Figure 5) or carefully checking that there are no other variables in the method that will affect the outcome will minimise these errors.

Figure 5 Checking the accuracy of scales will minimise errors in data.

random error
when an unpredictable variation in measurement occurs, resulting in an outlier result

systematic error
a repetitive error that is not removed by repeating the experiment

1.4 Check your learning

Retrieve

1 **Define** the term 'bias'.

2 **Define** the term 'placebo'.

Comprehend

3 **Explain** how a blind study or double-blind study can be used to control variables in an investigation.

Analyse

4 **Compare** a blind study and a double-blind study.

5 **Contrast** random errors and systematic errors.

6 A student measured the amount of hydrogen gas produced from an acid and metal reaction. They repeated the experiment five times to make sure the experiment was reliable. The amount of gas collected in each attempt is shown in Table 2.
Calculate the mean, median and mode for the hydrogen gas produced.

Table 2 The amount of gas produced from an acid and metal reaction

Attempt	Amount of hydrogen gas (mL^3)
1	1.68
2	2.54
3	2.05
4	1.69
5	2.05

Apply

7 **Discuss** how a scientist can avoid confirmation bias when designing an experiment to test the effectiveness of adding phosphorus to soil to improve plant growth.

Figure 6 Does adding phosphorus to soil improve plant growth?

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

1.5 Clinical testing uses the scientific method

Learning intentions

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

- identify and explain the five stages of developing a new vaccine.

Key ideas

- All drugs and vaccines must be tested before they are approved by the Therapeutic Goods Administration in Australia.
- Clinical testing on humans is part of the testing procedure.

antigen
a molecule that will cause the body's immune system to react

informed consent
a decision that is made by a person who has had the procedure and possible effects explained to them

Figure 1 During the first phase of clinical trials, the vaccine is tested on a small number of adults.

The COVID-19 pandemic began in 2019 and caused major disruptions across the world. As a result, there was renewed interest in the importance of science and the scientific method, especially in relation to the rapid development of vaccines.

Vaccines are a way of warning the body's immune system to watch for a particular molecule called an **antigen**. Antigens trigger our body's immune response to fight infection. Most vaccines contain a copy of the antigen, either individually or on the surface of an inactive virus. A few new vaccines contain a copy of special genetic material (mRNA; messenger ribonucleic acid) that allows the body's own cells to make the antigen that warns the immune system.

All new vaccines must go through the same five-stage development cycle.

Stage 1: Exploratory stage

This stage of vaccine development involves basic laboratory research to identify and produce copies of the appropriate antigen molecule. Like a 'wanted' poster, the antigen is used to warn the immune system to watch for the agent that causes the disease. The antigen molecule may also need to be placed on the surface of the inactive virus. This exploratory stage can last 2–4 years and depends on the number of researchers involved and the funding requirements of the laboratory.

Stage 2: Pre-clinical stage

During this stage, the vaccine antigen will be tested on groups of cells in the laboratory or in animal subjects such as mice or monkeys. These tests allow researchers to test how effective the antigen is at warning the immune system and to check that the antigen will not harm the organisms receiving the vaccine.

This stage usually lasts 1–2 years due to the costs involved. Most vaccines fail at this point.

Stage 3: Clinical development stage

This stage involves testing the vaccine on humans who have given their **informed consent**. (They understand what is going to happen and the possible side effects and agree to take part.) Three phases of trials must be completed as part of the clinical development process. The scientific method is most obvious during the clinical development trials.

Phase I

The first phase of clinical trials involves the vaccine being tested on a small number of adults (usually adult males) to determine how their immune systems will react. Females are usually not included, to prevent the possibility of a woman undergoing the trial treatment without realising that she is pregnant. The trials take place over several days and start with very small doses before increasing the dose. The participants are carefully monitored to make sure their bodies do not over-react to the vaccine. These trials may be un-blinded (meaning the patients know whether they are receiving a placebo or the real vaccine).

Phase II

In this phase of the vaccine trial, a larger group of several hundred people are treated with different doses, schedules and methods of delivery. These trials are randomised to different adult age groups and different sexes, and these trials always include a placebo group. Pregnant women, children or people with pre-existing conditions are not included in these trials. These trials may also be un-blinded.

Phase III

Vaccines that pass phase II are then tested on groups of thousands to tens of thousands of people. These tests are randomised and double blind. This means the participants and the doctors or nurses injecting the participants do not know whether the treatment is the vaccine or the placebo (either saline or an unrelated safe vaccine). This phase is to test for possible rare side effects that may still occur in healthy people. This stage is designed to test the following:

> Will the participant be protected from the disease's symptoms?
> Will the participant be protected from becoming infected?
> Will the participant produce an immune response?

Stage 4: Regulatory review stage

If a vaccine is shown to be successful during the clinical testing stage, the vaccine company will provide all its data to the Therapeutic Goods Administration (TGA) for a regulatory review and approval. The data is equivalent to a peer review to ensure that the scientific method had been correctly followed. The TGA must also approve the method of manufacturing.

Stage 5: Manufacturing and quality control

Before vaccines can be administered, the manufacturing process must produce a pure, sterile antigen. Most vaccines contain a mixture of substances including the important antigen, an adjuvant (an ingredient to strengthen the body's immune response), preservatives (to prevent bacteria from growing), sugars or oils to stabilise the vaccine, and a solution to dilute the vaccine. Each batch of vaccine needs to be tested to make sure that the manufacturing process is safe.

Fast tracking the process

During 2020, the COVID-19 vaccine approval process was fast-tracked by checking the vaccine manufacturing process while the phase III trials were still being conducted.

The University of Oxford and AstraZeneca vaccine was one of the first vaccines that went through this process (Figure 3). This vaccine was shown to be highly effective when two doses were given 12 weeks apart. This vaccine passed the first two stages of the clinical trials without any difficulties.

However, an error occurred during the phase III trial. Some of the volunteers (all under 55 years of age) received a half dose in the first injection as a result of an error in the concentration of antigen in the manufacturing process. Although a half dose was found to be more effective than the full dose of the vaccine, the phase III trial still needed to be repeated because the control group was no longer matched to the test group. Review by the regulatory authorities suggested that the small number of people who received the half dose first (2741) could not be effectively compared to those who received the full dose first (8895). Any differences in participants being resistant to the symptoms of the disease could be due to the statistical effects rather than the effectiveness of the vaccine.

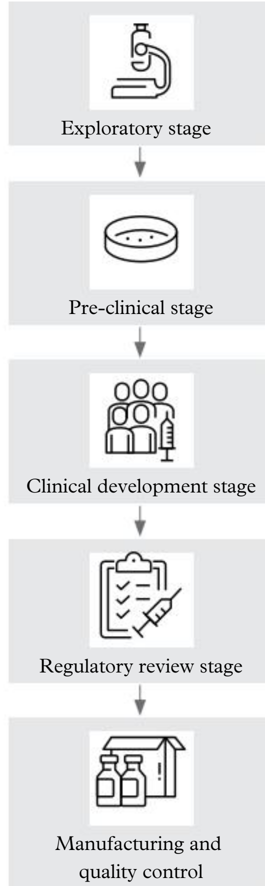


Figure 2 The stages for developing a vaccine

Figure 3 The University of Oxford and AstraZeneca vaccine for COVID-19

1.5 Check your learning

Retrieve

1 **Identify** the regulatory body that is responsible for approving drugs for use in Australia.

2 **Identify** what could be used as a placebo in a vaccine trial.

Comprehend

3 **Describe** how a vaccine works.

4 **Explain** why double-blind studies must be used in the final stage of clinical testing.

5 Use the example of the University of Oxford and AstraZeneca vaccine to **explain** why a control group must match the age and health of the test group.

Apply

6 **Discuss** the importance of 'informed consent' in drug and vaccine trials.

7 **Evaluate** the ethics of not including female participants in vaccine trials. **Discuss** the benefits and consequences of this.

Quiz me

Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

//SCIENCE AS A HUMAN ENDEAVOUR//

1.6 Scientific investigations must be ethical

Learning intentions

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

- describe deontological and consequentialist approaches to ethics
- apply ethical approaches to practices in science.

Ethics are principles that help us make decisions. There are different frameworks for thinking about ethics. For example, consequentialist ethics considers the consequences of an action. Deontological ethics considers duties or rules when making a decision. These approaches can be used to help us decide the right course of action when the answer might otherwise be unclear.

Science does not always answer questions. Sometimes the study of science can cause many more questions to be asked. An example of this is the invention of dynamite.

Alfred Nobel was a scientist who worked with the highly explosive nitroglycerine. Because of an accident in his laboratory, he experimented on ways to make the nitroglycerine safer so that it could be used in blasting rock and drilling tunnels to build a railroad. He patented this method in 1866. As a pacifist, he was horrified when his invention was used in wars. As a result, he used the wealth that was generated from his invention to set up the most important prize in science (and literature, peace, economics, etc.): the Nobel Prize. Although this might sound like a happy ending, there were many ethical questions raised by Nobel's research.

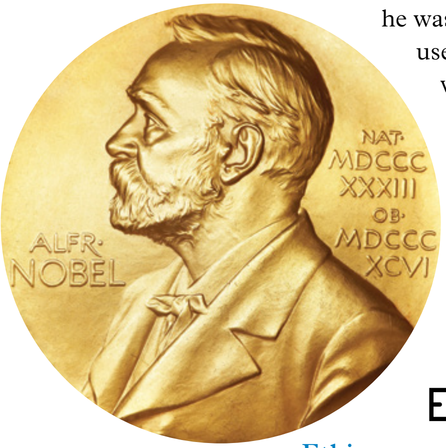


Figure 1 Nobel Prizes are awarded to people who have contributed greatly to the benefit of humankind.

cultural norm
the expectation that you should behave according to the values of the people around you

ethics
a set of principles that provide guidance to determine what is morally right and wrong

Ethics

Ethics are a set of principles that provide a way to think when making decisions. Sometimes when you make a decision, you use the rules that are written down, such as the school rules or the laws of the government. Other times you use the rules that are not written down. Some rules are set according to what is normal to the people around you. For example, the unwritten rules in your science classroom may be different to the rules in a physical education class. When playing sport, it might be normal to yell to a team member, whereas yelling in a science classroom is not normal. Neither of these rules are written down; however, everyone in the class will know them and behave accordingly. The expectation that you should behave according to the values of those around you is called the **cultural norm**.

The cultural norm in the study of science has traditionally led scientists to ask and answer questions. It is only recently that scientists have started to ask, 'Even though we can, should we?'

Ethical approaches

When answering the question 'Should we?', scientists can use a variety of ethical approaches. Two of the most common approaches are consequentialist ethics and deontological ethics.

CONSEQUENTIALIST ETHICS

The consequentialist approach to ethics considers the consequences of an action in order to decide whether an action is good or bad. This approach can also be described as 'the end justifies the means'.

If this approach was used by Alfred Nobel, he might have considered that his 'invention' was bad, because it had been used to kill many people, and that the science should therefore not have been investigated. Alternatively, if the consequence was setting up the Nobel Prize that led to increased recognition of science and scientists, and the promotion of peace, then the overall action could be considered good.

DEONTOLOGICAL ETHICS

In contrast, the deontological approach to ethics considers each action taken according to a set of rules or duties. If an individual did the 'right thing' at the time, then ethically it is 'good' despite the outcome.

Using this approach, Alfred Nobel did the ethically right thing because he wanted to stop people becoming hurt by unstable nitroglycerine. The consequences of this decision are not as important when using this approach.

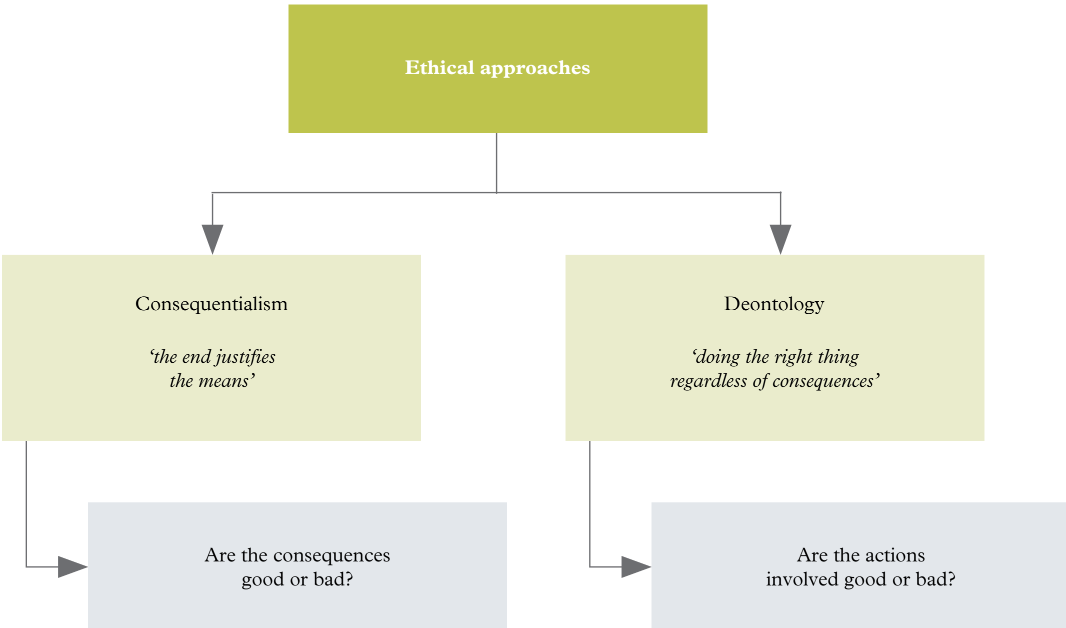


Figure 2 A consequentialist approach to ethics considers the consequences. A deontological approach considers duties and rules.

1.6 Test your skills and capabilities

Applying ethics

Using different ethical approaches can lead to different opinions about what is right and wrong. When this occurs, there is not always a single correct answer to the ethical dilemma. Instead, the consequentialist and deontological approaches can be used to understand the reasons for the different opinions and to provide a common base to discuss the ethical decision that each person would make.

1 **Consider** seven ethical problems that occur in science (see the following list). For each problem:

- use consequentialist ethics to **identify** the issue
- use deontological ethics to **describe** the issue
- **identify** any conflicts between the two approaches
- **describe** the decision you would make
- **explain** the reasons for your decision.

Is it ethical to:

a dissect humans post-mortem to determine the cause of their death

b test vaccines on animals to determine the safety of the vaccines

c test new drugs on humans to determine the safety of the drugs

d use foetal cell lines in the development of vaccines

e dissect animals in science classes

f develop new flexible plastic moulds (to make ceramic false teeth) that do not degrade

g use First Nations peoples knowledge to develop a commercial product without their permission?

1.7 Cognitive verbs identify the tasks in a question

Learning intentions

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

- recognise the cognitive verb in a question
- understand the different tasks involved for different cognitive verbs.

Key ideas

- Cognitive verbs are instructive words that require specific types of mental processes to perform set tasks.
- Cognitive verbs can be grouped into categories based on the level of cognition required to perform the task.

cognitive verb
a doing word that requires you to perform a specific thinking task

cognition
mental processes that are involved in acquiring, storing, manipulating and retrieving information

Cognitive verbs

Cognitive verbs are instructive words that require specific types of mental processing or '**cognition**' to perform set tasks. For example, the word 'explain' is a cognitive verb because it requires you to first recall what you understand about something and then reframe that understanding into clearer succinct terms. Cognitive verbs are often used in questions which means you will encounter a variety of different cognitive verbs in school as you learn new information and undertake assessments.

Familiarising yourself with different cognitive verbs and the tasks and thinking processes behind them can help you determine how to best respond to a question. An understanding of cognitive verbs can be the difference between achieving partial or full marks on an important exam or assessment question. Common cognitive verbs and the task/s associated with them are given in Table 1.

Some cognitive verbs require multiple or more complex cognitive processes than others. For example, if you were asked to *name* the two fruits in Figure 2, you may instantly recall 'apple' and 'orange'. However, if you were asked to *compare* the two fruits, you would also need to consider the two fruits and identify at least one similarity and one difference between them. In this sense, 'compare' involves more cognitive processes than 'name'.

Table 1 shows four different categories of thinking processes that can be used to categorise cognitive verbs. These are retrieve, comprehend, analyse, and apply. When learning new information, a 'retrieve' question will often come before an 'apply' question. This is because a retrieve-type question relies on you to recall information which is one type of mental process. However, an apply-type question requires you to not only recall information but also to interpret that information and determine how it can be used for a specific situation. Answering questions in order of increasing cognitive processes can support the way you acquire and understand new information.

Figure 1 Familiarising yourself with different cognitive verbs can help you answer questions and improve your learning.

Figure 2 Two healthy fruits

Table 1 Common cognitive verbs and their tasks

Cognitive verb	Task	Category
Define	give the meaning of a word	**Retrieve** – Recall information from permanent memory.
Identify	recognise and state a distinguishing factor or feature	
Name	provide the correct term or noun	
Recall	present remembered ideas, facts or experiences	
Use	operate or put into effect	
Select	pick out	
Describe	give an account of a situation, event, pattern or process, or of the characteristics or features of something	**Comprehend** – Activate and transfer knowledge from your permanent memory to your working memory.
Explain	make an idea or situation plain or clear by describing it in more detail or revealing relevant facts	
Summarise	give a brief statement of a general theme or major point/s; present ideas and information in fewer words and in sequence	
Calculate	determine or find (e.g. a number, answer) by using mathematical processes	**Analyse** – Use your reasoning to go beyond what was directly taught.
Categorise	place in or assign to a particular class or group	
Classify	arrange, distribute or order in classes or categories according to shared qualities or characteristics	
Compare	display recognition of similarities and differences and recognise the significance of these similarities and differences	
Contrast	give an account of the differences between two or more items or situations	
Distinguish	recognise as distinct or different; note points of difference between	
Interpret	use knowledge and understanding to recognise trends and draw conclusions from given information	
Create	reorganise or put elements together into a new pattern or structure	**Apply** – Use your knowledge in specific situations.
Discuss	examine by argument; sift the considerations for and against; talk or write about a topic	
Evaluate	examine and determine the merit, value or significance of something	
Elaborate	investigate, inspect or scrutinise	
Justify	give reasons or evidence to support an answer, response or conclusion	
Predict	give an expected result of an upcoming action or event	

1.7 Check your learning

Retrieve

1 **Define** the term ‘cognitive verb’.

2 **Identify** the cognitive verb that requires you to ‘display recognition of similarities and differences and recognise the significance of these similarities and differences’ and **identify** the category of thinking processes the verb belongs to.

Comprehend

3 **Explain** in your own words what is required to correctly answer:

- **a** an ‘evaluate’ question
- **b** a ‘justify’ question
- **c** a ‘predict’ question.

Analyse

4 **Compare** the terms ‘contrast’ and ‘distinguish’.

Apply

5 After conducting an experiment on how temperature affects the plant growth of corn and beet plants, a student was asked to ‘discuss which plant would be more suitable to grow in a hot environment’. Their response was, ‘The corn would be more suitable to grow in a hot environment’. **Evaluate** whether the student has correctly answered the question.

Quiz me

Complete the Quiz me to check how well you’ve mastered the learning intentions and to be assigned a worksheet at your level.

CHAPTER 1 REVIEW

SCIENCE TOOLKIT

Retrieve

1 **Identify** the section of a written report that contains the analysis of data.
- A method
- B results
- C discussion
- D conclusion

2 A double-blind study occurs when:
- A neither the patient nor the treating doctor knows if the patient is receiving the placebo
- B the patient does not know if they are receiving the placebo
- C a placebo is used on test animals
- D a placebo is being used.

3 **Identify** which of the following could be used to describe deontological ethics.
- A survival of the fittest
- B the end justifies the means
- C a rules-based approach
- D a common good approach

4 **Define** the term 'confirmation bias'.

5 **Define** the terms 'independent variable' and 'dependent variable'.

6 **Define** the term 'ethics'.

Comprehend

7 **Identify** and **describe** three different types of bias that can occur in scientific investigations.

8 **Describe** how a vaccine protects a person from becoming sick from a disease.

9 **Explain** why a placebo may be used in a clinical study.

10 **Explain** the term 'confounding variable' and provide an example.

11 **Describe** the three phases of a clinical trial for drugs or vaccines.

12 Use an example to **explain** the term 'cultural norm' (by defining the term, describing an example and comparing the example to the definition).

13 **Explain** what is meant by the term 'valid experiment' (by defining valid experiment and describing the factors that affect the validity of an experiment).

14 **Describe** how the selection of people for a sports team could be randomised (by defining 'randomisation' and describing how it can be used to select people for the team).

15 Year 12 exams must be marked by someone who does not know the student. Use your knowledge of bias to **explain** the purpose of this rule.

Analyse

16 A customer wrote the following review on a restaurant's website.

'The food was excellent, and the atmosphere was amazing. Our chef is the best chef in town.'

Identify what feature of the review might suggest that the person who wrote it might be biased.

17 A scientist wanted to investigate if the angle of a ramp affected the time it took for a ball to reach the bottom of the ramp. **Identify** the independent variable and the dependent variable for this experiment.

18 **Classify** each of the following cognitive verbs into the category (retrieve, comprehend, analyse, apply) they belong to.
- a summarise
- b select
- c define
- d compare
- e discuss

19 **Calculate** the mean, median and mode for the following values. (Express your answers in significant figures.)

14.0, 19.76, 33.1, 26.187, 105.7, 59.0, 73.97

20 **Compare** consequentialist ethics and deontological ethics (by defining both terms, describing their similarities and describing their differences).

21 **Contrast** methodology and method (by defining both terms and emphasising how they are different).

22 **Compare** the methodologies of modelling and case studies.

Apply

23 A manufacturer claimed that their antibacterial wash killed 99% of all bacteria.
- a **Rewrite** this claim as an operationalised question.
- b **Construct** a hypothesis for this question.
- c **Identify** a methodology that could be used to test this hypothesis.

d **Identify** the independent variable and the dependent variable for this investigation.

e **Identify** three variables that you will need to control in this experiment.

f **Describe** a negative control and a positive control that you will need to use in this experiment.

g **Describe** the method you will use for this investigation and **justify** why you have selected the method.

Figure 1 It is important to check manufacturers' claims before purchasing products.

24 **Identify** a potential random error and a systematic error for the investigation you designed in question 23. **Discuss** how you could minimise these errors.

25 A consumer scientist wanted to test the effect of a lotion for treating acne. At first, they tested the lotion on a group of 20 teenagers, all aged 15 years old, but then they decided to conduct some more tests on 100 14-year-olds. **Suggest** how to improve the reliability of this experiment (by defining 'reliability', identifying one way the experiment is not reliable and describing how this can be improved).

26 A scientist set up an experiment that had seven samples from a control group and seven samples from a treatment group. There are two possible ways to measure the samples:

> Method A: In a random order.

> Method B: Alternating the control group and the treatment group.

Evaluate which method would be the most appropriate to avoid bias (by describing the way the scientist could be affected by bias in each method and deciding which method would have the least bias).

27 **Create** a mind map that identifies the links between each of the glossary terms used in this chapter.

Social and ethical thinking

28 ClassDojo is a popular online tool that allows a teacher to record what occurs in the classroom. This can include students' marks, behaviour and current activities. This information is then converted into a ranking that is shared with the students and parents. The schools and teachers that use this tool claim that it improves the classroom environment by providing feedback to students and parents. Use two ethical approaches to **evaluate** this online tool (by defining both ethical approaches, using each approach to identify and explain the key ethical issues in the online tool, and deciding which ethical approach is similar to your values).

29 A scientist wanted to test whether a particular drug was effective in preventing Alzheimer's disease. The scientist recruited a series of volunteers who had just been diagnosed with the disease and compared them to a control group of volunteers with no family history of Alzheimer's disease. **Propose** how the scientist should modify this experiment to prevent bias in the test.

Critical and creative thinking

30 A new vegetarian dog food claims to give improved coat condition within two weeks. **Propose** how you would evaluate this claim.

Figure 2 Can vegetarian dog food improve coat condition within two weeks?

Research

31 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

» Causation versus correlation

The terms 'causation' and 'correlation' can seem like they are very similar. If the independent variable increases at the same rate as the dependent variable, then the two variables are described as positively correlated. This does not mean that the independent variable causes the change in the dependent variable.

- Define the terms 'causation' and 'correlation'.
- Compare the two terms.
- Describe an example where a positive correlation does not mean one factor causes the other to change.
- Describe one example of causation.

» Pharmaceutical bias

Some pharmaceutical companies sponsor medical conferences in exotic locations around the world. They may pay for doctors' flights, accommodation and food during the conference.

- Explain why some doctors may refuse to attend these conferences.
- Explain how attendance at these conferences could affect the care of a patient.
- Describe one way a pharmaceutical company could promote their product without causing bias.

Figure 3 What issues could arise from a pharmaceutical company sponsoring a medical conference?

» Ethical machines

Quantum computers use quantum circuits that are based on qubits. These circuits are enabling computers to learn from data and to make decisions based on this data. These decisions can include deciding the diagnosis and treatment of diseases in a hospital and deciding if a criminal is guilty and how long they should spend in jail. One of the difficulties of this machine learning is the type of data that should be used to teach the machine.

- Identify and describe the ways machine learning is used to make decisions.
- Identify the possible biases that could be entered into the quantum computer with the data.
- Explain how each bias would affect the decisions made.
- Use the different ethical approaches to discuss the advantages and disadvantages of using machine learning for these decisions.

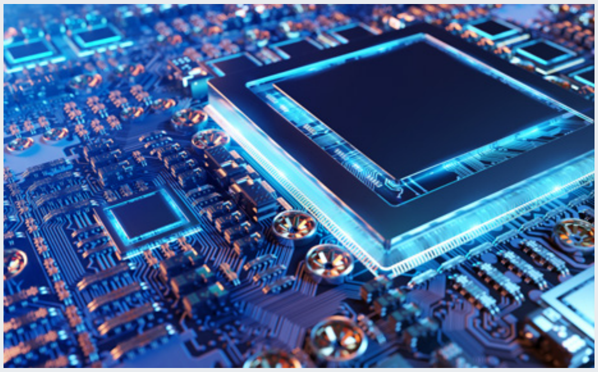


Figure 4 Quantum computers use circuits that allow the computer to use data to learn and improve functionality.

Chapter checklist

Now that you have completed this chapter, reflect on your ability to do the following.

	I can do this.	I cannot do this yet.
• Operationalise a question. • Form a hypothesis. • Explain how to plan and conduct a scientific investigation. • Describe what a logbook is and how to use it.	☐	☐ Go back to Topic 1.1 'There are many types of scientific investigations'. Page 4
• Explain how scientists communicate when writing reports for different audiences.	☐	☐ Go back to Topic 1.2 'Scientists communicate using scientific language'. Page 6
• Define independent, dependent, controlled and confounding variables. • Describe valid experiments, reliable experiments and control groups.	☐	☐ Go back to Topic 1.3 'Experiments must be controlled'. Page 8
• Describe how bias can affect the design of an experiment and the analysis of data. • Explain how graphs can be used to present and analyse data.	☐	☐ Go back to Topic 1.4 'Data can be analysed'. Page 10
• Identify and explain the five stages of developing a new vaccine.	☐	☐ Go back to Topic 1.5 'Clinical testing uses the scientific method'. Page 14
• Describe deontological and consequentialist approaches to ethics. • Apply ethical approaches to practices in science.	☐	☐ Go back to Topic 1.6 'Science as a human endeavour: Scientific investigations must be ethical'. Page 16
• Recognise the cognitive verb in a question. • Understand the different tasks involved for different cognitive verbs.	☐	☐ Go back to Topic 1.7 'Cognitive verbs identify the tasks in a question'. Page 18

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Play a Quizlet game to test your knowledge.

Chapter quiz
Check your understanding of this chapter with the chapter review quiz.

CHAPTER

2 GENETICS

2.1 Science as a human endeavour: Scientists review the research of other scientists

- Explain the principles of segregation and independent assortment.
- Describe the contributions of different scientists, including Franklin and Watson and Crick's research on DNA.

2.2 DNA consists of a sugar–phosphate backbone and complementary nitrogen bases

- Describe the structure of a nucleotide.
- Explain the importance of DNA being able to make copies of itself and carry information.

2.3 Chromosomes carry genetic information in the form of genes

- Define the terms 'DNA', 'gene' and 'chromosome' and explain the relationship between them.
- Interpret a human karyotype.

2.4 DNA holds the code for building proteins

- Explain the role of DNA and RNA in the processes of transcription and translation.

2.5 Mitosis forms new somatic cells

- Describe the stages of mitosis.
- Explain how and why a cell undergoes apoptosis.

2.6 Meiosis forms gamete cells

- Describe the stages of meiosis I and meiosis II.

2.7 Alleles can produce dominant or recessive traits

- Explain how combinations of dominant and recessive alleles produce different genotypes and phenotypes in individuals.
- Predict genotypic and phenotypic ratios of a monohybrid cross using Punnett squares.

2.8 Alleles for blood group traits co-dominate

- Describe the different genotypes and phenotypes of human blood groups.
- Explain the function of different blood groups and Rhesus markers and their importance.
- Predict the inheritance of co-dominant traits using Punnett squares.

2.9 Alleles on the sex chromosomes produce sex-linked traits

- Identify a trait as one of the four patterns of inheritance (autosomal dominant, autosomal recessive, X-linked dominant and X-linked recessive).
- Explain how and why sex-linked traits are inherited differently in males and females.
- Describe how different sex-linked traits such as haemophilia and red–green colour blindness are inherited.

2.10 Inheritance of traits can be shown on pedigrees

- Analyse and interpret pedigrees to determine if a trait is dominant, recessive, autosomal or sex-linked.
- Analyse and interpret pedigrees to predict whether an individual will inherit a disease.

2.11 Mutations are changes in the DNA sequence

- Distinguish between genetic and chromosomal mutations.
- Explain how substitution and frameshift mutations alter nucleotide and amino acid sequences of a protein.

2.12 Science as a human endeavour: Genes can be tested

- Describe the purpose of genetic screening and testing.
- Provide examples of diseases that are screened for.

2.13 Science as a human endeavour: Genes can be manipulated

- Explain the human need for selected GMOs to be produced.
- Outline how a desirable gene can be inserted into a plant cell.

2.14 Science as a human endeavour: Genetic engineering is used in medicine

- Outline the process of gene cloning.
- Explain how gene therapy can be used for medical treatment.
- Describe the different types of stem cells and their uses in medicine.

What if?

Genetic chance

What you need:

Coin (or plastic counter with 'Heads' written on one side and 'Tails' written on the other)

What to do:

1. Toss the coin (or counter) five times and record the results in a table.
2. Predict how many heads or tails will land for the next five tosses.

What if?

» What if heads represented the chance of having a daughter and tails represented the chance of having a son? (Would this change the outcome?)

» What if heads represented the chance of having red hair and tails represented the chance of having black hair?

» What if you had a coin with two heads (for red hair)?

2.1 Scientists review the research of other scientists

Learning intentions

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

- explain the principles of segregation and independent assortment
- describe the contributions of different scientists, including Franklin and Watson and Crick's research on DNA.

Figure 1 Gregor Johann Mendel, 1822–1884, is known as the father of genetics.

gene
basic unit of genetic material passed on from parents to offspring

Scientific understanding is constantly being reviewed and refined. Sometimes scientists collaborate and sometimes scientific teams 'compete' to make discoveries first. The scientific understanding of genes and DNA is no exception.

Gregor Mendel

Gregor Mendel was an Austrian monk and scientist (Figure 1). He is known as the 'father of genetics' because he was the first person to make accurate conclusions about how genetic information is passed from parents to offspring. Mendel loved experimenting with peas – and he did many experiments in his garden.

Before Mendel (in the early 1800s), it was thought that children inherited a mixture of characteristics from both their parents, resulting in a mixture of looks, in the same way that mixing red and yellow paint produces orange paint. It was thought that you could not separate the pure red or yellow forms again. Mendel discovered that the different 'factors' could be separated again.

Mendel observed the inheritance of different characteristics in pea plants, such as seed colour, pod shape and height (Figure 2). From his observations he accurately concluded that 'factors' (now called genes) existed in pairs, one from each parent. Genes control the characteristics of the cells, and therefore the characteristics of each person.

The importance of Mendel's research was not realised at the time, even by Mendel himself. When he sent his research to Charles Darwin (responsible for the theory of evolution), the letter remained unopened until after Darwin's death. It wasn't until the early 1900s when three other scientists repeated Mendel's experiments that he was given credit for the two key principles of genetics: segregation and independent assortment.

PRINCIPLE OF SEGREGATION

Traits or characteristics of living things exist in pairs of factors. These factors must become separated or segregated before they can be passed on to offspring. Every organism inherits one set of factors from their mother and one set from their father.

PRINCIPLE OF INDEPENDENT ASSORTMENT

The inheritance of one set of factors from one parent is independent from the inheritance of other factors. So, just because you inherit one factor (e.g. blue eyes) from your mother, that does not mean you inherit all other factors from her (e.g. her blonde hair and small nose). Factors are usually inherited independently from each other.

For almost 70 years after Mendel's death, the identity and chemical structure of these factors remained unknown. Today we know the factors as genes made up of DNA.

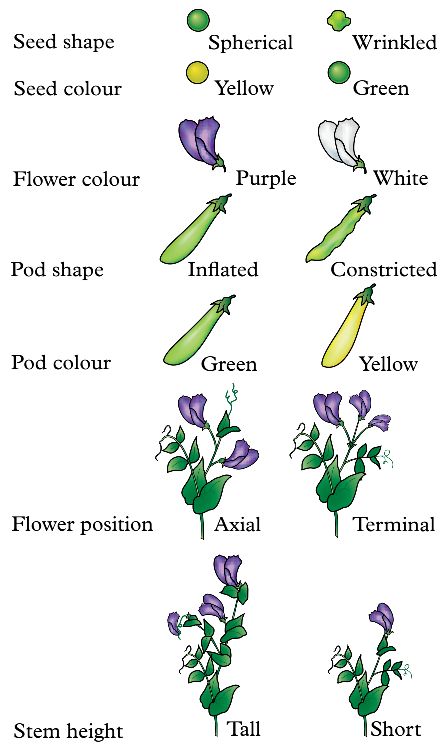


Figure 2 The seven traits, or characteristics, of pea plants studied by Mendel

EXPERIMENT
2.1: Extracting DNA
Go to page 228.

Watson and Crick's double helix discovery

James Watson was a young chemist from the United States who went to the University of Cambridge, in the United Kingdom. There he met Francis Crick, an English physicist (Figure 3). Watson and Crick were theoretical scientists. This meant they did not complete any experiments themselves. Instead, they used the experimental results from other scientists (Linus Pauling, Erwin Chargaff and Rosalind Franklin) to develop their own models and theories. They worked as a team to unravel the secret of the structure of **DNA (deoxyribonucleic acid)**, which they identified as a double helix (two-stranded spiral) in 1953.

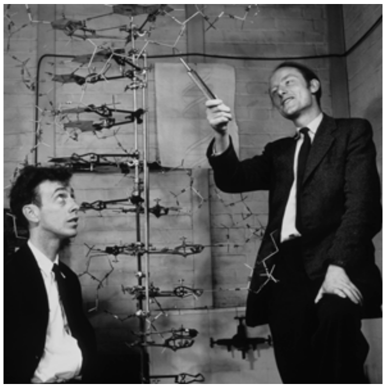


Figure 3 James Watson and Francis Crick with their DNA model

Rosalind Franklin

Rosalind Franklin had wanted to study science since the age of 15 and eventually earned her doctorate in physical chemistry at the University of Cambridge in 1945 (Figure 4).

In 1951, she began work in John Randall's laboratory at King's College in London. When Franklin started work in Randall's laboratory, Maurice Wilkins (another scientist working on DNA) was away. When Randall gave Franklin responsibility for part of the DNA project, no one had worked on it for months. When Wilkins returned, he misunderstood her role, treating her as though she were a technical assistant. His mistake was not surprising given the situation for women at the university at the time. Only males were allowed in the university dining rooms, and after hours Franklin's colleagues went to men-only pubs.

Between 1951 and 1953, Franklin was able to improve the quality of the photographs she took of DNA crystals. While she was out of the laboratory, Wilkins showed Watson photograph 51, one of Franklin's best crystallographic images of DNA (Figure 5). When Watson saw the picture, he was able to imagine the structure of DNA that he and Crick had been working on. They quickly completed their model and published the result in the journal *Nature*. Franklin's work appeared as a supporting article in the same issue of the journal.

Figure 4 Rosalind Franklin

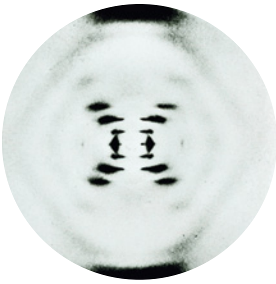


Figure 5 Photograph 51: the X-ray crystallography image of DNA taken by Rosalind Franklin

DNA (deoxyribonucleic acid)
a molecule that contains all the instructions for every job performed by the cell; this information can be passed from one generation to the next

2.1 Test your skills and capabilities

Acknowledging the work of others

Plagiarism involves presenting someone else's ideas or work as your own. It can be as obvious as directly copying, or it can include taking their ideas and using them in a very similar manner. In the art or fashion industries, it could be copying the style of a painting or dress. In the science world, it can involve using someone else's results without acknowledging their contribution. If a student or a person employed at a university is found to have committed plagiarism, they can be expelled or sacked.

Wilkins showed Franklin's results to Watson and Crick without her knowledge. Watson and Crick then used her photo to create and publish their DNA model without acknowledging Franklin's contribution.

1 **Evaluate** one of the following ethical issues that arises from this discovery by:
  > describing the ethical approach you are using (e.g. consequentialist or deontological)
  > describing the issue from the point of view of Franklin
  > describing the issue from the point of view of Wilkins, Watson and Crick
  > deciding which view has greater importance.

a Should Wilkins have shown Watson and Crick photograph 51?

b Franklin was considered a brilliant scientist and a kind-hearted woman; however, she is also described as short tempered and stubborn. Some of her fellow scientists (including Wilkins) found her difficult to work with. If Franklin had been given a choice, should she have shared her results with other scientists?

c Should all scientists share their results with each other? If so, then how should the work be acknowledged? Provide reasoning to justify your answer.

2.2 DNA consists of a sugar–phosphate backbone and complementary nitrogen bases

Learning intentions

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

- describe the structure of a nucleotide
- explain the importance of DNA being able to make copies of itself and carry information.

Key ideas

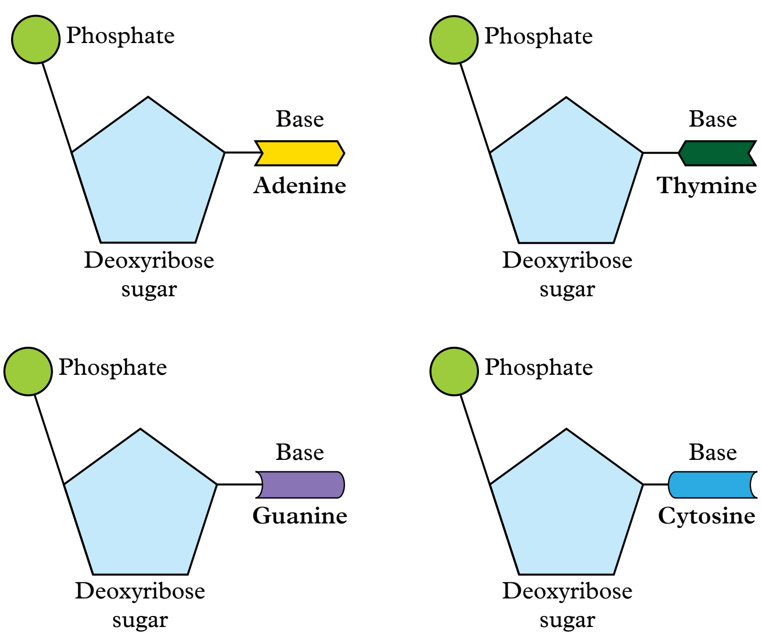
- Genes are made of a chemical called deoxyribonucleic acid (DNA).
- The DNA molecule consists of two long, thin strands of complementary nucleotides that are held together by hydrogen bonds.
- DNA is a double-helix shape.

nucleotide
a subunit of a nucleic acid

Your DNA blueprint

DNA is like a blueprint, or set of plans, for every structure and function in an organism. It contains a code unique to each individual that can be passed from parents to children, generation after generation, with little or no change. Every cell in your body (except red blood cells) contains the same identical DNA molecules. The DNA in your body is 99.9 per cent identical to the person next to you. It is only very small differences in the code that give your hair, eyes and skin their unique colour and texture. Understanding of the structure of DNA allows us to explain the similarities and differences that exist between and within species.

Figure 1 Nucleotides: the building blocks or subunits of DNA



Structure of a nucleotide

Each DNA strand is like a necklace of beads. The individual 'beads' are called **nucleotides**. These are the subunits or building blocks of DNA (Figure 1).

A nucleotide is a complex molecule composed of three smaller parts:

> a nitrogen base (sometimes just called a 'base')
> a sugar molecule (deoxyribose)
> a phosphate molecule.

In DNA there are four different types of nitrogen bases:

> adenine (A)
> guanine (G)
> cytosine (C)
> thymine (T).

These four nitrogen bases are what defines the four different nucleotides (or 'beads') that make up the DNA.

Structure of a polynucleotide chain

When nucleotides (or 'beads') join together, they form a long polynucleotide chain called a nucleic acid. DNA is a nucleic acid.

The nucleotide 'beads' in the long nucleic chain are joined together by their sugar and phosphate groups. The sugar of one nucleotide is joined to the phosphate of the next nucleotide. This forms a sugar–phosphate backbone, like the sides of a ladder (Figure 2).

Double helix

The sugar–phosphate backbone of one nucleic acid chain is attracted to a second nucleic acid chain, creating a ladder-like structure.

CHALLENGE
2.2: Modelling the structure of DNA
Go to page **229**.

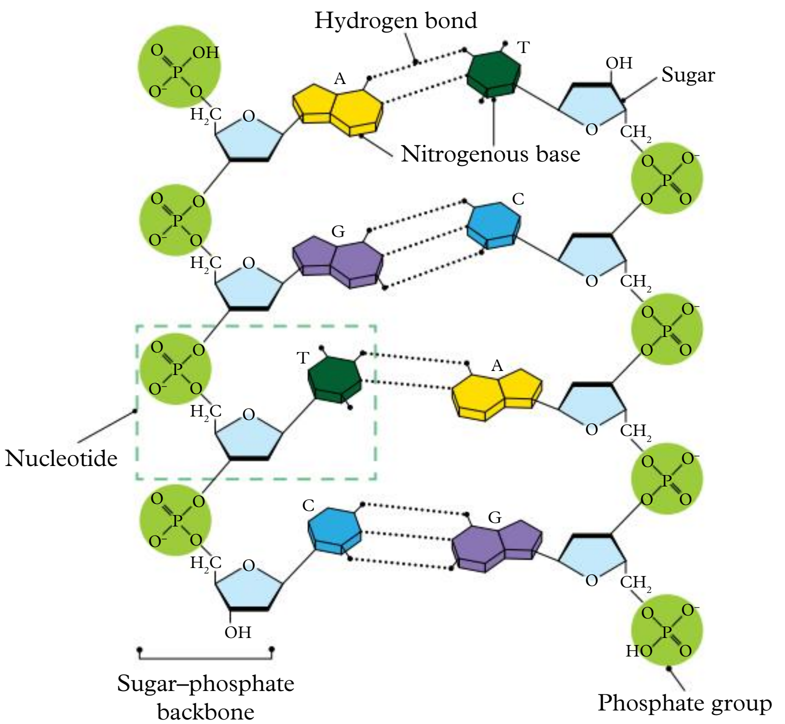


Figure 2 Nucleic acids such as DNA are made of a chain of nucleotides joined together through a sugar–phosphate backbone.

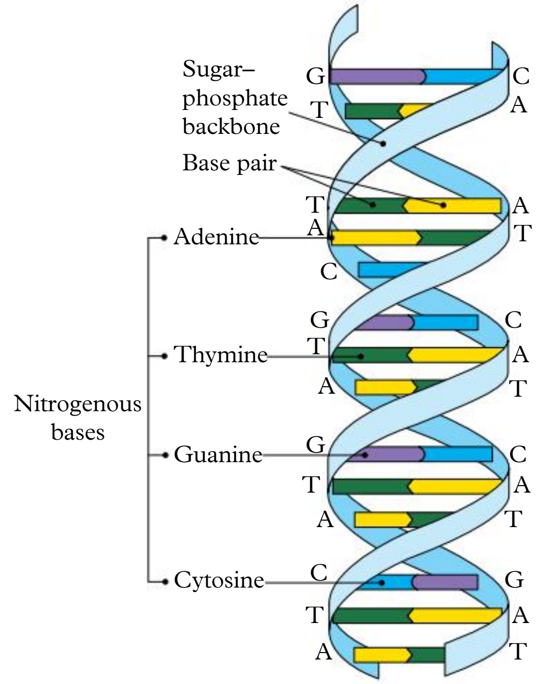


Figure 4 The DNA double helix. If you picture the DNA molecule as a twisted ladder, the sides are sugar and phosphate molecules and the rungs are pairs of nitrogen bases.

The 'rungs' of the ladder are made up of **hydrogen bonds** (relatively weak bonds) between the nitrogen bases. A large nitrogen base (adenine or guanine) is always bonded to a small nitrogen base (thymine or cytosine) because this gives the correct amount of space between the strands.

The four different types of nitrogen bases link in a specific way: adenine (A) always pairs with thymine (T) and cytosine (C) always pairs with guanine (G) (Figure 3). These base pairs (G-C and A-T) are called **complementary bases** or complementary base pairs. This means that one nucleic acid strand will be complementary to the other strand.

The two nucleic acid strands then wind into a double helix – the twisted ladder (Figure 4).

DNA molecules have two vital properties.

- DNA can make copies of itself: if two strands unwind, each strand can be used to make a new DNA molecule.
- DNA can carry information: the order of bases along a strand is a code for making proteins.

G	C	C	C	A	T	A	A	T
|	|	|	|	|	|	|	|	|
C	G	G	G	T	A	T	T	A

Figure 3 DNA bases always pair as guanine with cytosine and thymine with adenine.

hydrogen bond
a type of weak chemical bond between two groups of atoms; the bond between two nitrogen bases in the DNA helix

complementary base
a nucleotide base that pairs with its partner nucleotide on the alternative DNA strand; adenine pairs with thymine, cytosine pairs with guanine

2.2 Check your learning

Retrieve

1 **Define** the term 'nucleotide'.

Comprehend

2 **Explain** how nucleotides join together to form polynucleotides.

3 **Explain** how two polynucleotides can twist helically around each other to form a double helix of DNA.

4 **Describe** the part of the DNA molecule that varies. **Identify** the part that remains constant.

5 **Describe** how the order of the bases on one polynucleotide chain determines the order of the bases on the other chain.

Analyse

6 **Identify** the complementary DNA sequence to GTTAGCCAGT.

Apply

7 David recorded the following answer as the complementary DNA sequence for question 6: TGACCGATTG.
Discuss why David's answer is incorrect. **Identify** where he has gone wrong.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

2.3 Chromosomes carry genetic information in the form of genes

Learning intentions

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

- define the terms 'DNA', 'gene' and 'chromosome' and explain the relationship between them
- interpret a human karyotype.

Key ideas

- Each cell in your body (except red blood cells) contains 46 chromosomes.
- Chromosomes can be arranged from largest to smallest to form a karyotype.
- Females have two X chromosomes; males have an X and a Y chromosome.
- Genes are sections of DNA that have a function.
- DNA cannot leave the nucleus of a cell.

Video 2.3
Chromosomes

chromosome
the form of DNA that is tightly wound around proteins before replication

karyotype
a way of representing a complete set of chromosomes, arranged in pairs, in order of decreasing size

Chromosomes and genes

Inside the nucleus of a cell are the chromosomes. **Chromosomes** are made up of DNA molecules tightly wound around proteins.

There are 46 chromosomes in a human nucleus: 23 of them come from the mother and 23 from the father. Along the length of each chromosome, in specific positions, are the genes.

Chromosomes can be organised into pairs according to length and banding patterns. Pairs of matching chromosomes are called homologous. A picture of all the homologous chromosomes in a cell, arranged from largest to smallest, is called a **karyotype** (Figure 1).

How we relate chromosomes to DNA

DNA is found inside a cell's nucleus, and looks a little like a pile of wool. By the time a cell is ready to divide, the DNA has copied itself and the chromosomes can clearly be seen under a microscope.

A simple equation to understand the relationship between DNA and chromosomes is:

A single chromosome = a molecule of DNA (a DNA helix)

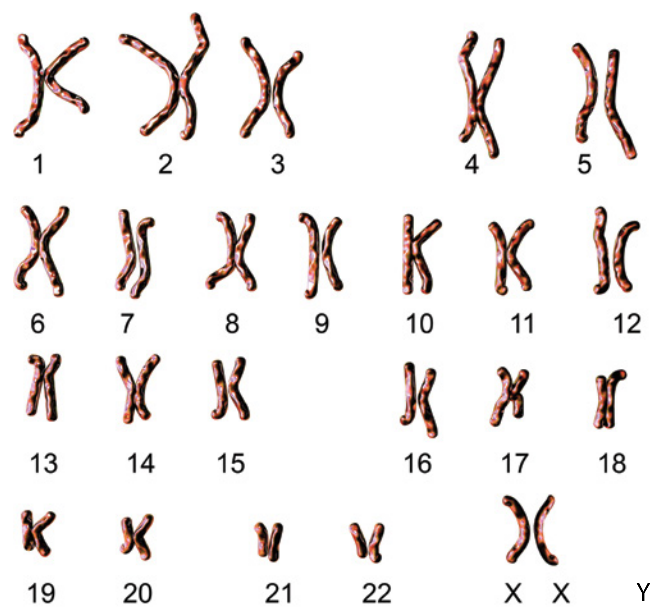


Figure 1 Pairs of chromosomes are often referred to by numbers according to their size – the largest pair is number 1. The last two chromosomes determine the sex of an individual. Human females have two X chromosomes, and males have one X and one Y chromosome. This karyotype is from a female (XX).

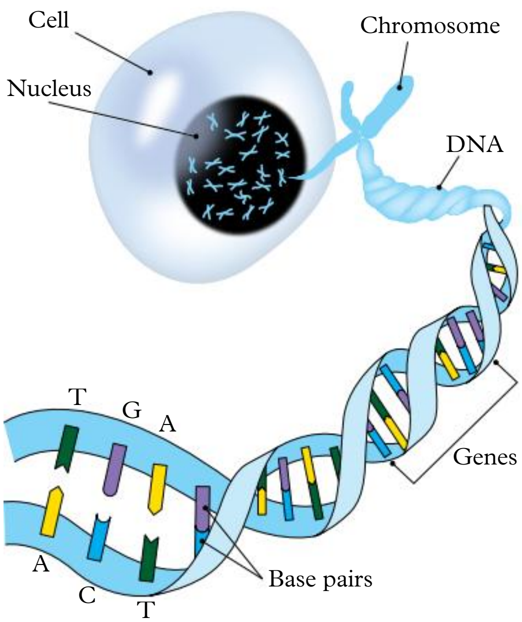


Figure 2 The relationship between DNA and chromosomes

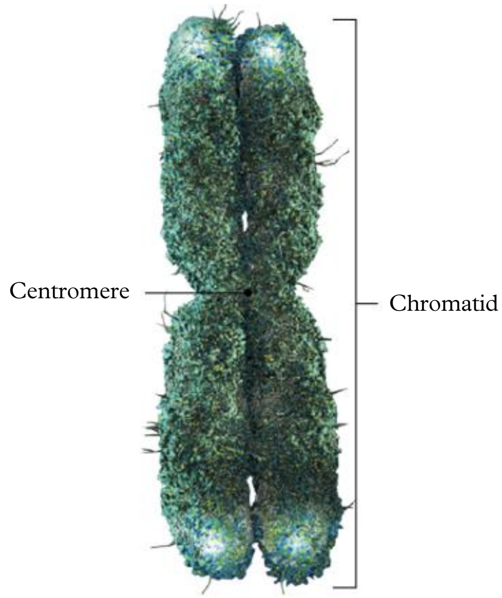


Figure 3 An X-shaped chromosome is made up of sister chromatids joined at the centromere.

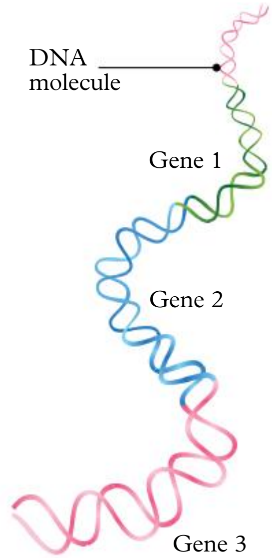


Figure 4 The relationship between DNA and genes

Chromosomes may be a single helix or a pair joined at the centromere (a duplicated chromosome). The two joined strands are identical to each other. They form during DNA replication so that two identical copies are produced. Each strand of a duplicated chromosome is called a **chromatid**. The two chromatids are joined at the centromere (Figure 3).

If the DNA in a single chromosome was unwound, it would be 5 cm long. With 46 chromosomes in the average human cell, this means all the unravelled DNA in a single cell would be approximately 2 m long! The DNA fits inside the cell because the DNA molecules are tightly wound around small proteins called histones. These histones stack tightly together and only unwind when the instructions they carry are needed by the cell.

How we relate genes to DNA

DNA in chromosomes consists of sections, and each section is a gene (Figure 4). Some genes have 250 nucleotide 'beads', whereas other genes have over 2 million nucleotide 'beads'. The order of the nucleotides (with the nitrogen bases A, T, G or C) in each gene contains information for one characteristic or trait. For example, a gene may have information for making the pigment melanin, which gives our skin colour. Another gene may have the information for making keratin for hair and nails. So a chromosome, which contains many genes, is like a sentence with a lot of words (genes) made up of alphabet letters (nucleotides).

2.3 Check your learning

Retrieve

1 **Identify** the number of chromosomes in each of your cells.

2 **Define** the term 'karyotype'.

3 **State** the names of the nitrogen bases that are represented by the letters A, T, G and C.

4 **Identify** the nitrogen bases that are complementary to A, T, G and C.

Comprehend

5 **Describe** how DNA is like a string of beads.

Analyse

6 **Compare** DNA, chromosomes and genes.

Apply

7 This topic compared the structure of chromosomes, genes and nucleotides to sentences, words and letters. **Evaluate** this comparison (by comparing the similarities and differences between each group of terms and deciding if there are more similarities than differences).

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

chromatid
one side of the X-shaped chromosome that contains a double helix of DNA

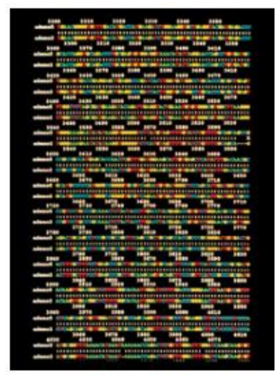


Figure 5 The sequence of bases on DNA is the coding system for life. The sequence of bases shown here comes from the DNA in adenovirus types 5 and 2. These viruses cause a range of illnesses, including colds, sore throats and diarrhoea.

2.4 DNA holds the code for building proteins

Learning intentions

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

- explain the role of DNA and RNA in the processes of transcription and translation.

Key ideas

- Transcription is the process of copying genetic information from DNA into mRNA.
- Translation is the process of decoding mRNA to form a protein.

genetic code
the sequence of nucleotides in DNA, inherited from parent organisms

Genetic code

One major feature of DNA is its ability to replicate itself; another feature is its ability to carry the genetic coding system for making proteins. The order of the nucleotides on the DNA strands is the **genetic code** for an organism.

The genetic code has the instructions to make a protein (Figure 1). Some proteins (such as collagen) provide support for cells in the body. Other proteins are enzymes that help us digest food and speed up the chemical reactions of our metabolism.

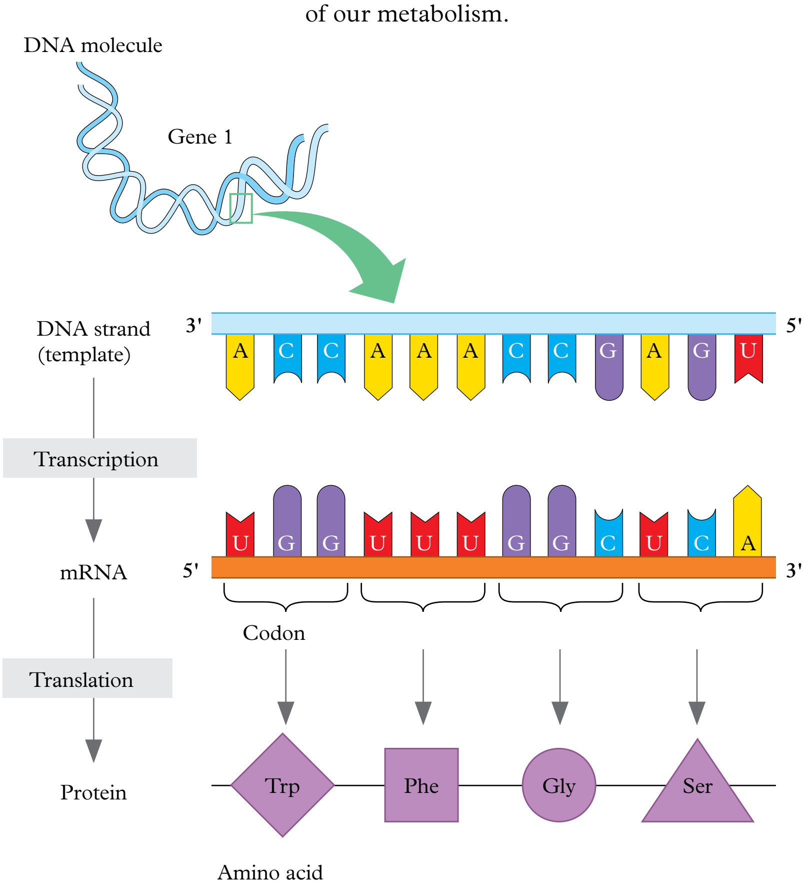


Figure 1 Protein synthesis. A complementary strand of mRNA is made (G-C and A-U). The mRNA leaves the nucleus and is used to form a protein. (Trp = tryptophan; Phe = phenylalanine; Gly = glycine; Ser = serine)

How genes make protein

To make protein, the DNA molecule unwinds and one strand acts as a pattern or template to form a molecule of messenger RNA (mRNA, messenger ribonucleic acid; Figure 2).

RNA

RNA contains a ribose sugar, unlike DNA which has a deoxygenated ribose sugar. The nitrogen bases of RNA are adenine, cytosine, guanine and uracil (not thymine). Messenger RNA (mRNA) plays a key role in protein synthesis. mRNA acts like a photocopy of the original DNA blueprint.

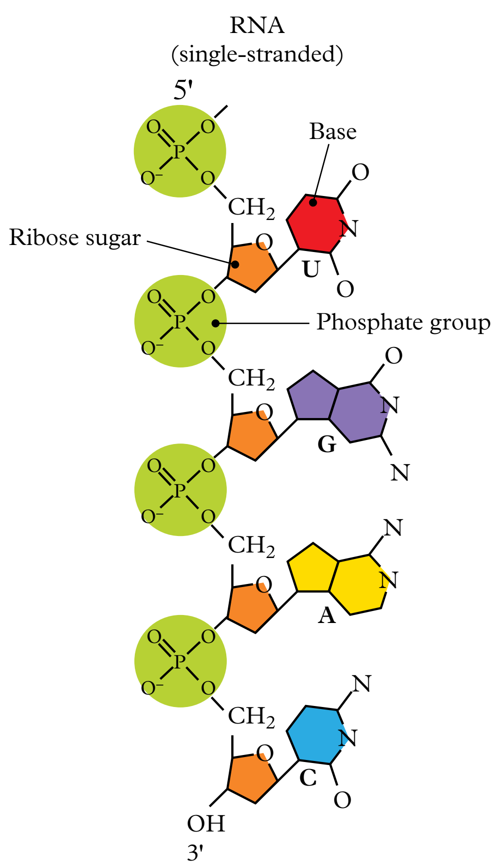


Figure 2 The structure of RNA

SKILLS LAB
2.4: Making protein
Go to page **230**.

Transcription

The process of making an mRNA copy from a DNA strand is called **transcription**. Transcription takes place in the nucleus and involves a number of stages.

1 DNA is 'unzipped', unwinding the two strands.
2 An enzyme called RNA polymerase moves along the exposed gene on the DNA strand. As it goes, it joins together free RNA nucleotides (C, G, A, U), which form the strand of mRNA. The mRNA nucleotides are complementary to the DNA nucleotides.
3 The RNA polymerase detaches once the mRNA strand is complete. The two DNA strands re-join.

transcription
the process of copying the DNA that makes up a gene to messenger RNA

Translation

The next process of forming a protein from RNA is called **translation**.

Unlike DNA, mRNA can leave the nucleus and attach to a ribosome in the cytoplasm. The mRNA now 'tells' the ribosome the order in which to connect the amino acids that will make up a protein.

The nitrogen bases on the mRNA are read in groups of three called **codons**. Each codon corresponds to a single amino acid.

Amino acids are brought to the ribosome by another type of RNA called transfer RNA, or tRNA. The amino acids join in a chain according to the order specified by the sequence of codons in the mRNA. Eventually the amino acids form a long chain, which becomes the final protein (Figure 3).

translation
the formation of a protein from RNA; occurs on a ribosome

codon
a group of three nucleotides on mRNA

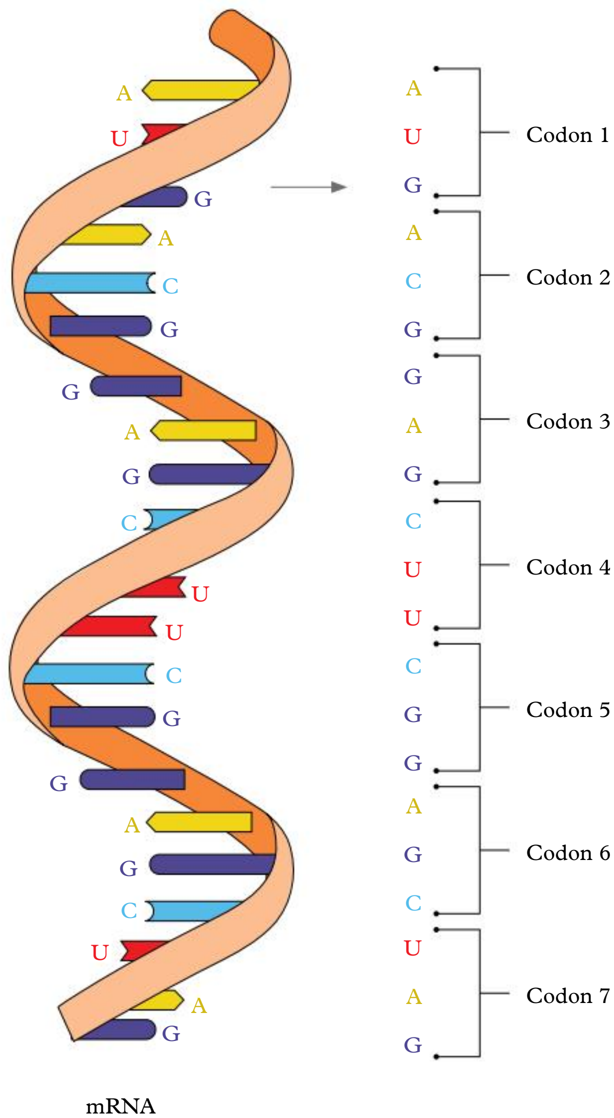


Figure 3 Each codon codes for a specific amino acid. Proteins are made up of long chains of amino acids.

2.4 Check your learning

Comprehend

1 **Describe** the process of translation in your own words.
2 **Explain** the role that mRNA plays in the conversion of DNA information into protein.

Analyse

3 **Compare** the features of DNA and RNA. (You may like to draw a Venn diagram for this task.)
4 **Contrast** transcription and translation.
5 **Identify** the mRNA sequence for the template DNA sequence GTTAGCCAGT. (Remember to pair uracil with adenine.)

Apply

6 The human body can make 10 of the 20 amino acids that it needs to survive. **Discuss** why it is important to eat a balanced diet that includes protein.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

2.5 Mitosis forms new somatic cells

Learning intentions

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

- describe the stages of mitosis
- explain how and why a cell undergoes apoptosis.

Key ideas

- Most of the cells in your body are somatic cells (all except sperm and egg cells).
- Somatic cells are diploid, which means they carry two sets of genetic material – one from the mother and one from the father.
- Mitosis is the division of the genetic material to produce two genetically identical nuclei.

Interactive 2.5
Mitosis

Mitosis is cell division that does not change the number of chromosomes

Every organism needs to grow and repair damage throughout its lifetime. This means cells need to reproduce. **Somatic cells** are all the cells in the body except for the egg and sperm cells (which are called gametes). When somatic cells reproduce, they undergo a process called **mitosis**.

Mitosis is a part of cell division where one parent nuclei divides to form two genetically identical daughter nuclei. Once the nuclei have divided, the rest of the cell will divide into two in a process called **cytokinesis**. In humans, this means the parent cells have 46 chromosomes and the daughter cells each have 46 chromosomes or 23 pairs of chromosomes. Each set of 23 chromosomes comes from a parent (23 from the mother and 23 from the father). When a cell has two complete sets of chromosomes, they are described as **diploid**.

Cell division is essential for an organism to grow or to repair damage. In humans, intestine cells replace themselves every 4 days, skin cells every 3 weeks and bones every 7–10 years. This means the body is constantly undergoing mitosis and cytokinesis.

Most of the time, cells are not dividing and are in the phase called **interphase** (Figures 1 and 2). During this phase, the cells do everyday processes such as making proteins. Cells will only start mitosis when new cells are needed. Before mitosis begins, the cell must make new copies of DNA.

somatic cells
the body cells except gametes (egg and sperm)

mitosis
the process of cell division that results in genetically identical daughter cells; allows growth and repair

cytokinesis
the splitting of a replicating cell into two cells

diploid
containing two complete sets of chromosomes

interphase
a phase of cell life where normal functioning occurs

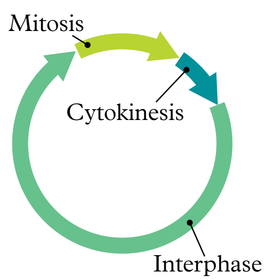


Figure 1 The cell cycle; cells spend most of their life in interphase, when normal cell functioning occurs.

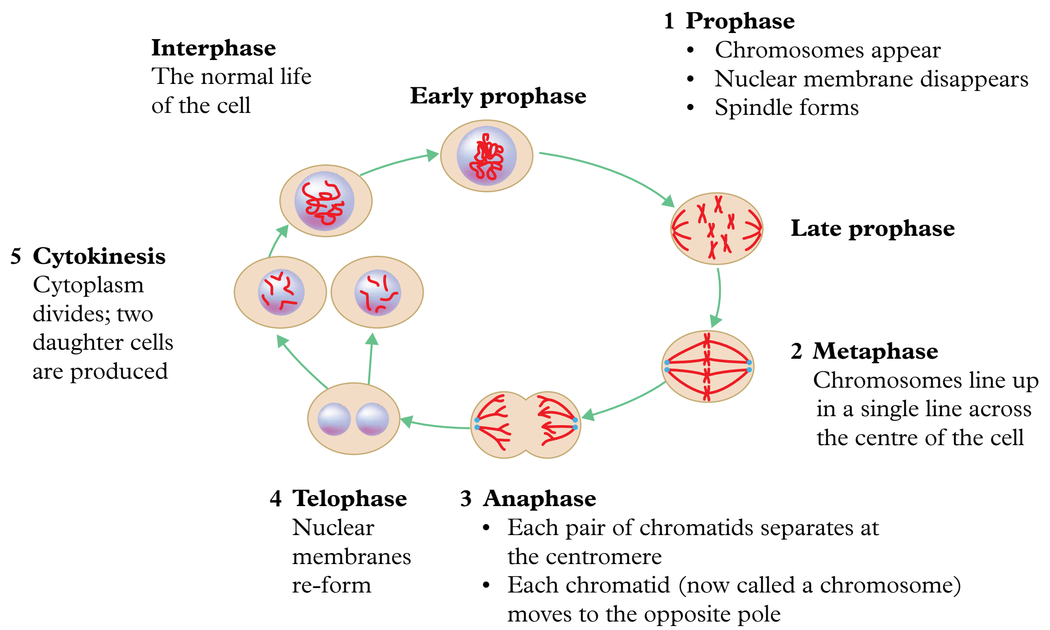


Figure 2 Interphase and the phases of mitosis and cytokinesis

SKILLS LAB
2.5: Cell division in action
Go to page 231.

This doubles the single chromosomes to duplicated chromosomes, connected at the centromere. When the cell undergoes mitosis, the duplicated chromosomes separate and each of the daughter cells will receive a genetically identical copy of each chromosome.

Cancer: Mitosis out of control

The rate of mitosis in a cell needs to be carefully controlled. Cells do not survive indefinitely in an organism. The death of a cell is carefully programmed into a cell's DNA. All cells are constantly checking to make sure that everything is running normally.

If any errors occur, then the cell will undergo programmed cell death, called **apoptosis**. This checking for errors is especially important during mitosis. Before the cell enters prophase or telophase, the DNA is carefully checked to make sure there are two complete sets of unaltered chromosomes.

Sometimes the DNA of a cell can become damaged. This may be due to radiation, viruses or chemicals called mutagens. If this damage is not detected, then the cell may start undergoing continual cycles of mitosis without apoptosis. This is one of the key characteristics of cancer cells.

apoptosis
programmed cell death

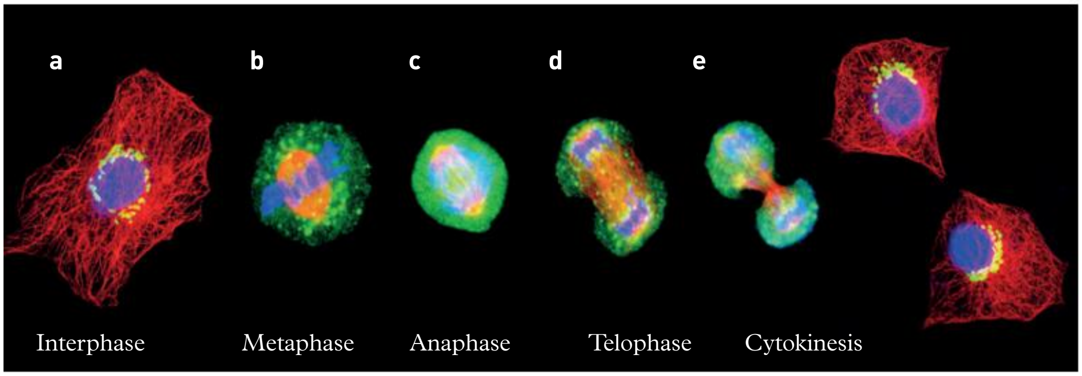


Figure 3 These animal cells are undergoing mitosis. They have been stained with a fluorescent stain to show the separation of DNA. **a** The cell is at the end of interphase. **b** The blue chromosomes line up along the middle of the cell and attach to the yellow spindle during metaphase. **c** Yellow spindles are contracting and separating two chromatids at the centromere during anaphase. **d** The nuclear membrane re-forms around the two sets of DNA in telophase. **e** Cytokinesis occurs when the plasma membrane divides in two.

2.5 Check your learning

Retrieve

1 **Recall** the phase where most cells spend most of their time.

Comprehend

2 **Explain** why cells need to undergo mitosis.
3 **Describe** what happens in each phase of mitosis.

Analyse

4 A cell that is about to undergo mitosis must double its amount of DNA. **Consider** why this needs to occur.
5 **Contrast** mitosis and cytokinesis.
6 **Identify** each of the stages of mitosis that is happening in Figure 4.

Apply

7 **Develop** a story of a chromosome as it undergoes mitotic division. **Describe** how it replicates, remains attached at the centromere until anaphase, and says its final goodbye during cytokinesis.
8 Use your understanding of mitosis to **evaluate** the following claim: 'Interphase has nothing to do with mitosis.'

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

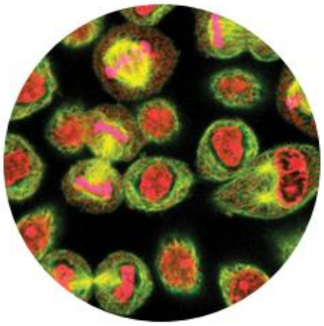


Figure 4 Stages of mitosis

2.6 Meiosis forms gamete cells

Learning intentions

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

- describe the stages of meiosis I and meiosis II.

Key ideas

- A gamete is a sex cell (egg or sperm) that has half the genetic material of the parent cell.
- Meiosis is the process of cell division that produces haploid gametes.
- Two haploid gametes combine to produce the first diploid cell of a new organism.

Meiosis is cell division in which the number of chromosomes is halved

Half of the genetic material in each of your cells comes from your mother, and the other half comes from your father. Have you ever wondered how the genetic material in one of your parent's cells divided in half?

A gamete is a sex cell. In animals, the male gamete is a sperm and the female gamete is an ovum. In flowering plants, the male gamete is contained in a pollen grain and the female gamete is located in the flower's ovary. The male and female gametes of a species join to form the first cell of the new offspring.

Gametes differ from all other body cells because they contain half the number of chromosomes of somatic cells – they are **haploid**.

meiosis
the process that results in the formation of gametes with half the genetic material of the parent cell

haploid
containing one complete set of chromosomes in each cell; an example is gametes

Most somatic cells in your body contain 46 chromosomes arranged in pairs (two sets of 23 chromosomes, or $2n$). They are diploid. Gametes (egg and sperm) in humans have 23 chromosomes (n) (Figure 1). When the egg and sperm combine at fertilisation, a diploid somatic cell is produced (Figure 3) – one set of 23 chromosomes comes from the mother and one set of 23 chromosomes comes from the father. In this way, all children are similar, but not identical, to their parents.

Meiosis is the type of cell division that occurs when gametes are being made from their parent cells. It is sometimes called reduction division and occurs in two stages, known as meiosis I and meiosis II (Figure 4). Before meiosis can occur, the single chromosomes must copy the DNA to form duplicated chromosomes. Once this occurs, the first stage of meiosis can begin.

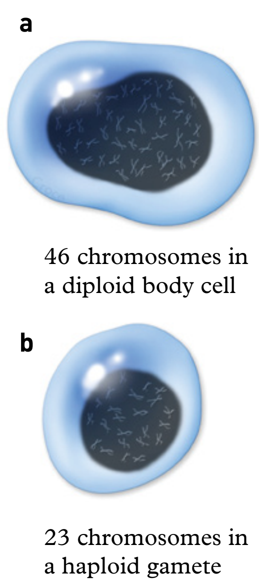


Figure 1 **a** A diploid body cell and **b** a haploid gamete

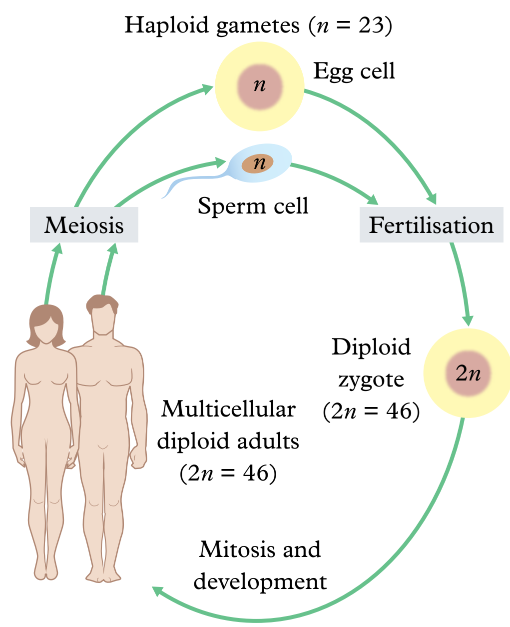
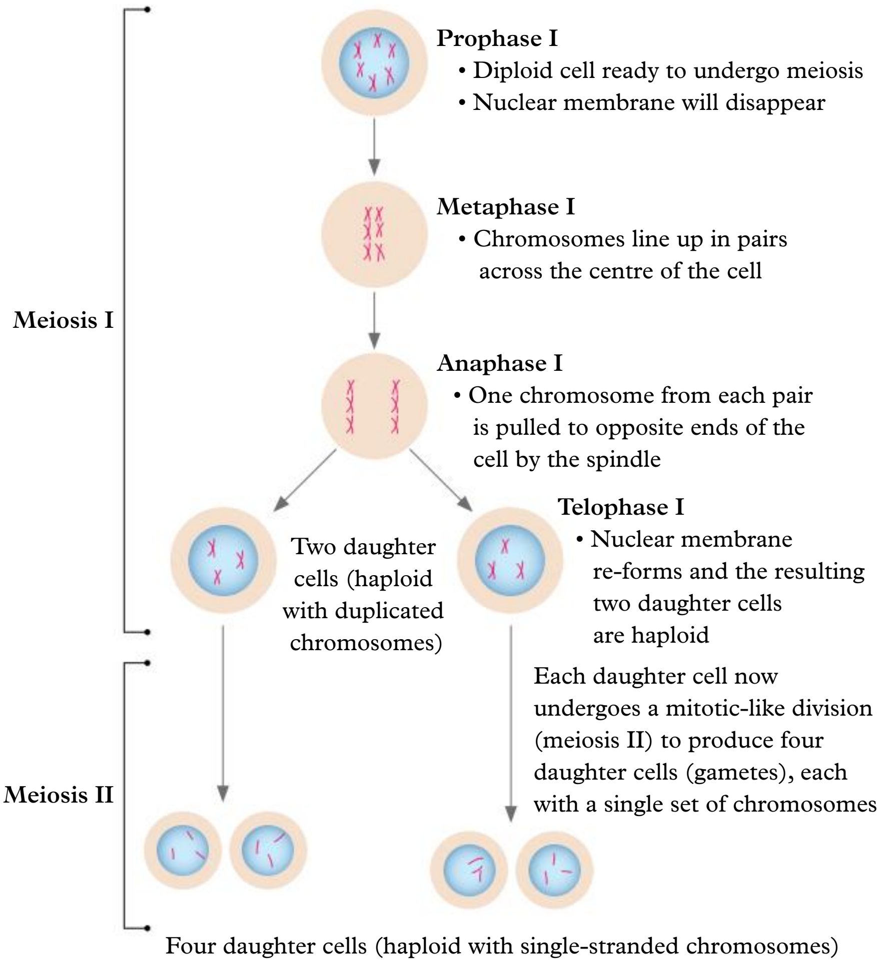


Figure 2 The human life cycle, involving mitosis and meiosis

CHALLENGE
2.6: Modelling meiosis
Go to page **232**.



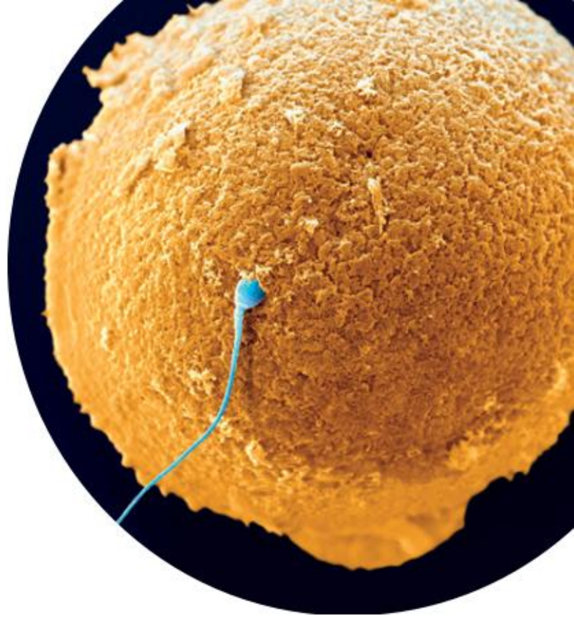


Figure 3 When a haploid sperm cell (*n*) fertilises a haploid egg cell (*n*), a diploid somatic cell (2*n*) is formed.

Figure 4 Meiosis consists of two rounds of each phase: prophase, metaphase, anaphase and telophase. If a gamete is fertilised, the chromosomes of the zygote will become diploid again so that the zygote can grow (by mitosis) into an embryo.

2.6 Check your learning

Comprehend

1 We all started from a single cell, a zygote, which then grew into an embryo. **Explain** how meiosis and mitosis allow the formation of a zygote and its growth into an embryo.

2 **Explain** why the offspring of sexually reproducing organisms are not identical to their parents.

3 **Explain** why it is essential that the number of chromosomes is halved during meiosis.

Analyse

4 **Compare** a haploid cell and a diploid cell.

5 Prepare a table **comparing** mitosis and meiosis.

6 Interphase is the 'normal' life stage of the cell – the phase between one mitotic division and the next. Interphase also occurs before meiotic divisions. **Identify** the number of chromosomes present at each phase of meiosis shown in Figure 4.

7 The chromosomes in Figure 5 are separating at the centromere. **Identify** the phase of meiosis that the cell is undergoing.

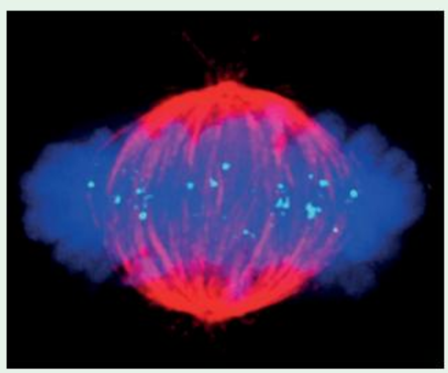


Figure 5 Each stage of meiosis includes prophase, metaphase, anaphase and telophase.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

2.7 Alleles can produce dominant or recessive traits

Learning intentions

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

- explain how combinations of dominant and recessive alleles produce different genotypes and phenotypes in individuals
- predict genotypic and phenotypic ratios of a monohybrid cross using Punnett squares.

Key ideas

- Genes can have different versions (alleles) at the same location of a chromosome.
- The unique combination of alleles for a gene inherited from parents is called the genotype of the organism.
- Homozygous individuals have two identical alleles; heterozygous individuals have two different alleles.
- A dominant trait only needs a single allele present to appear in the phenotype.
- Recessive traits need two copies of the allele to appear in the phenotype.
- A person who is heterozygous for a recessive trait is said to be a carrier for the trait.

Interactive 2.7
Punnett squares

Video 2.7
Using Punnett squares

allele
a version of a gene; a person inherits two alleles for each gene, one coming from each parent

homozygous
having two identical alleles for a particular trait

heterozygous
having two different alleles for a particular trait; a carrier for a recessive trait

dominant trait
a characteristic that needs only one copy of an allele to appear in the physical appearance of an organism

recessive trait
a characteristic that is only expressed in the phenotype when two identical alleles are inherited

Alleles

Have you ever wondered why some people look so much like their mother or father? Each cell in your body contains two sets of chromosomes – one from your mother and one from your father. If your mother has blue eyes, then you may inherit the gene for blue eyes from her. If your father has brown eyes, then you may inherit the gene for brown eyes from him. Each version of a gene (e.g. for eye colour) at the same position (or loci) of a chromosome is called an **allele**.

If a person has two identical alleles for a trait or characteristic, they are said to be **homozygous** for that trait. If a person has two different alleles for the same trait (e.g. a blue eye allele and a brown eye allele), they are **heterozygous** for the trait (Figure 1).

If someone is heterozygous for eye colour, then the colour of their eyes is determined by which version is dominant. **Dominant traits** only need one copy of the allele to be visible in the appearance of the individual. Dominant traits are usually represented by capital letters. For example, brown eyes is a dominant trait and is often given the symbol 'B'.

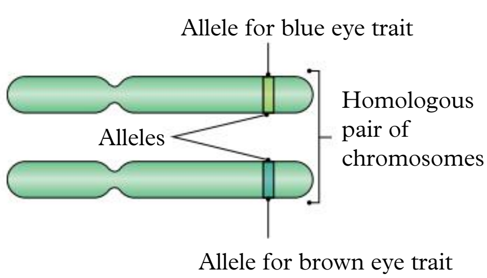


Figure 1 A heterozygous pair of chromosomes

Other traits are called **recessive traits**. These traits can only be seen if there are two identical copies (homozygous) of the allele present. The alleles for recessive traits are represented by lower-case letters. For example, blue eyes is a recessive trait and is often given the symbol 'b'.

Therefore, a person with blue eyes must have two alleles for blue eyes (bb). In contrast, a person with brown eyes could be homozygous (BB) or heterozygous (Bb) for the trait. A brown-eyed individual who is heterozygous for the trait is sometimes called a **carrier** for the blue eye trait. They have one allele for blue eyes, but the trait cannot be seen in their appearance.

The combination of allelic symbols that a person has for a trait (e.g. BB, Bb or bb) is called their **genotype**.

Nature versus nurture

For over a century, scientists have puzzled over whether the genetic material you inherit (nature) or the environment in which you are raised (nurture) is more important in determining your characteristics. For example, genetically identical hydrangeas that produce pink flowers in alkaline soil and blue flowers in acidic soil suggest that nurture is more important. However, the growth of the stem, flowers and leaves is a result of the genes in the plant.

EXPERIMENT

2.7: Zazzle genetics
Go to page 233.

Phenotype is the physical expression of a trait or characteristic that results from the genetic make-up of the organism and is influenced by the environment. An example is how tall you will grow. You inherit a series of genes from your parents that will determine your growth potential, but if you don't get enough food when you are growing, then you will not reach your full height.

Monohybrid cross

Some traits, such as the ability to roll your tongue, are controlled by only one gene. This single gene has two alleles: one for rolling your tongue (the dominant trait, R) and one for non-tongue-rolling (the recessive trait, r).

Worked example 2.7: Using Punnett squares

A man who is heterozygous for brown hair has a child with a woman who has the recessive trait of red hair. Calculate the probability of the child having red hair.

Solution

First the symbols for hair colour need to be selected.

Red hair is a recessive trait = r (lower-case letter)

The letter chosen for the dominant trait must be a capital letter (same gene, different allele).

Brown hair = R

Father (heterozygous) = Rr

		Father's alleles	
		R	**r**
Mother's alleles	r	Rr	rr
	r	Rr	rr

Mother has the recessive trait (homozygous) = rr

Then a Punnett square can be constructed.

The children's possible genotypes are 2 Rr : 2 rr.

The children's possible phenotypes are 2 brown hair : 2 red hair.

Therefore, the child has an equal (50 per cent) chance of having red hair.

Parents' phenotype	Homozygous non-tongue-roller	x	Heterozygous tongue-roller
Parents' genotype	rr	x	Rr
Parents' gametes	r r	x	R r

F_1 genotype (offspring)

Punnett square

		Father's alleles	
		R	**r**
Mother's alleles	r	Rr	rr
	r	Rr	rr

F_1 phenotype 50% tongue-rollers
50% non-tongue-rollers

Figure 2 The ability to roll your tongue is inherited.

We can examine how this single trait is passed on by using a **Punnett square** (Figure 2). In a Punnett square, the parents' genes are listed across the top and down the side. The remaining boxes are filled by combining the letters of each parent. This shows the possible genotypes the children could inherit. From the genotypes, the possible phenotypes of the children can be predicted. Worked example 2.7 shows how to use a Punnett square to predict the possible genotypes and phenotypes of offspring.

carrier
a person who has the allele for a recessive trait that does not show in their phenotype

genotype
the combination of alleles for a particular trait

phenotype
the physical characteristics that result from an interaction between the genotype and the environment

Punnett square
a diagram used to predict the outcome of breeding organisms

2.7 Check your learning

Retrieve

1 **Define** the term 'carrier'.

Analyse

2 Dimples (D) is dominant to no dimples (d). **Identify** the genotypes for individuals who:
   a are homozygous for dimples
   b are heterozygous for dimples
   c have no dimples.

3 The trait for blue eyes is recessive to the trait for brown eyes.
   a **Calculate** the chances of two blue-eyed parents having a brown-eyed child.
   b **Calculate** the chances of two brown-eyed parents having a blue-eyed child.

Apply

4 If the children of a right-handed man and a left-handed woman are all right-handed, **identify** whether left-handedness is a dominant or recessive trait. **Justify** your answer (by defining dominant and recessive traits, describing an example of each type of inheritance, and deciding which type of inheritance is most likely).

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

2.8 Alleles for blood group traits co-dominate

Learning intentions

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

- describe the different genotypes and phenotypes of human blood groups
- explain the function of different blood groups and Rhesus markers and their importance
- predict the inheritance of co-dominant traits using Punnett squares.

Key ideas

- The gene for blood type can make protein enzymes that make sugar molecules (A or B) on the surface of a red blood cell.
- The allele symbols for this gene can be expressed together.
- Other genes can produce the Rhesus protein.

Blood types

Some genotypes are more complex and involve more alleles. This is the case when determining your blood group. When stating your blood group, two components are usually referred to – a letter grouping (ABO) and whether you are Rhesus positive or negative. Rhesus protein molecules are present on the surface of the red blood cells of 80 per cent of people. These people are said to be Rhesus positive. If the Rhesus molecule is not present, these people are said to be Rhesus negative.

There are four other types of blood groupings. Table 1 shows the proportion of Australians who fall into each of these four groups.

People who have blood group A have red blood cells that display a special sugar molecule A on the surface of their red blood cells. People who are blood group B display sugar molecule B on their red blood cells. Group AB people display both molecules A and B, and people in blood group O have neither sugar molecule. The gene for each of these traits produces an enzyme (a protein) that makes the specific red blood cell sugar molecule (Figure 1).

It is important to know your blood group because mixing different types of blood can cause clots to form that block blood vessels. A person who is transfused with the wrong type of blood can die.

ABO blood grouping is determined by a different gene from Rhesus grouping, so the inheritance of each component must be investigated separately. Three alleles determine the ABO blood group (Table 2). Depending on which of these three alleles you inherit from your parents, your blood group may be different from that of your parents or your siblings.

The I^A and I^B alleles are described as **co-dominant**. The symbol for a co-dominant trait is given the symbol of a capital letter with a superscript. Co-dominant traits are expressed equally together, rather than one being dominant over the other. This means a person with the genotype I^AI^B will make the enzymes for sugar A and sugar B. This will give a person the blood type AB. However, both of these alleles are completely dominant over the recessive trait of the O blood type (i). This means a person with the genotype I^Ai or I^AI^A will make sugar molecule A and therefore have blood type A. A person with the genotype I^Bi or I^BI^B will make sugar molecule B and have blood type B. Worked example 2.8 shows how to use a Punnett square to predict the inheritance of co-dominant traits.

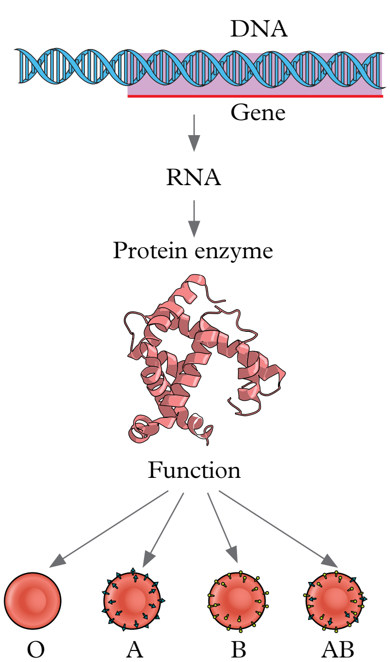


Figure 1 Genes for blood type produce an enzyme that makes a sugar (A or B) on the surface of a red blood cell.

co-dominant
two different alleles that can both appear in the phenotype at the same time; both can appear with a single allele

Table 1 Blood groupings in Australia

Blood group (phenotype)	Frequency in Australian population (%)	Frequency in Australian population of Rhesus positive (%)	Frequency in Australian population of Rhesus negative (%)
O	49	40	9
A	38	31	7
B	10	8	2
AB	3	2	1

EXPERIMENT

2.8: Blood typing experiment
Go to page 234.

Table 2 Blood group alleles

Trait	Allele symbol	Function
Dominant trait	I^A	Produces an enzyme that forms an A sugar on red blood cells.
Dominant trait	I^B	Produces an enzyme that forms a B sugar on red blood cells.
Recessive trait	i	Results in a non-functioning enzyme. No specific sugar on the surface of red blood cells.

Worked example 2.8: Using Punnett squares for co-dominant traits

A couple, Greg (blood group A) and Ellie (blood group B), decide to have a child. If both their individual mothers were blood group O, calculate the possibility of their child being blood type O.

Solution

First calculate the phenotype and then the genotype of each parent (Figure 2).

Greg's blood group is A. This means there are two possibilities for his genotype: I^AI^A or I^Ai.

If Greg's mother was blood group O, then Greg could have only inherited the alleles for the recessive trait (i) from his mother and so he must be heterozygous (I^Ai).

By applying the same process to Ellie, it can be determined that she is I^Bi.

This information can be used to construct a Punnett square, as shown in Figure 2.

The four possibilities for the ABO blood group for Greg and Ellie's child are:

Genotypic ratio: 1 I^AI^B : 1 I^Ai: 1 I^Bi : 1 ii

Phenotypic ratio: 1 AB : 1 A : 1 B : 1 O

This means that Greg and Ellie's child has a 1 in 4 (25%) chance of being blood type O.

	Greg		Ellie
Parents' phenotype	Blood type A	x	Blood type B
Parents' genotype	I^Ai	x	I^Bi
Parents' gametes	I^Ai	x	I^Bi
F_1 genotype (offspring)	Punnett square		

		Ellie's alleles	
		I^B	i
Greg's alleles	I^A	I^AI^B	I^Ai
	i	I^Bi	ii

Figure 2 A Punnett square showing the inheritance of genes for the ABO blood type

2.8 Check your learning

Retrieve

1 From Table 1, **identify** the blood group in Australia that is the:

a most common

b least common.

Comprehend

2 Complete Table 3 to **summarise** the possible genotypes that combine to produce each blood group phenotype and the sugars displayed.

Table 3 The genotype and AB sugars found in different blood types

Blood group (phenotype)	Possible genotypes	Sugars displayed on a red blood cell
O		
A		
B		
AB		

Analyse

3 **Consider** two parents who are both blood group O. **Identify** the blood groups their children could have.

4 Vinda is homozygous for blood group A. Julie is heterozygous for blood group B. Use a Punnett square to **calculate** the possible genotype(s) and blood group(s) for a child of Vinda and Julie.

5 **Construct** an appropriate graph to present the type of data presented in Table 1.

a **Analyse** the data in the graph and **describe** any pattern you identify in terms of independent and dependent variables.

b Does the pattern you identified in part **a** represent correlation or causation? **Justify** your response.

Quiz me

Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

2.9 Alleles on the sex chromosomes produce sex-linked traits

Learning intentions

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

- identify a trait as one of the four patterns of inheritance (autosomal dominant, autosomal recessive, X-linked dominant and X-linked recessive)
- explain how and why sex-linked traits are inherited differently in males and females
- describe how different sex-linked traits such as haemophilia and red–green colour blindness are inherited.

Key ideas

- Sex chromosomes are chromosomes that determine the sex of an organism.
- Human females have two X chromosomes and human males have an X and a Y chromosome.
- Fathers pass an X chromosome to each daughter and a Y chromosome to each son; mothers pass one X chromosome to each of their children.
- Autosomes are non-sex chromosomes.

Sex chromosomes

Humans have 22 pairs of chromosomes that are not sex chromosomes, called **autosomes**. The twenty-third pair of chromosomes are the chromosomes that determine the sex of the offspring (**sex chromosomes**). The genotype for the sex chromosomes in a female is XX and the genotype for a male is XY. These chromosomes contain the genes with information for sexual traits.

The X chromosome is larger than the Y chromosome (Figure 1). In addition to carrying genes for sexual characteristics, it contains information for non-sexual characteristics, such as blood clotting and red–green colour vision. Traits (and the genes that determine them) that are carried on a sex chromosome are said to be sex linked.

Males show deficiencies in these genes more commonly than females because they only have one X chromosome. Females have two X chromosomes and therefore are more likely to have a copy of the effective working allele.

In general, when investigating the pattern of inheritance for a particular trait (characteristic), it is useful to consider each trait as one of the following four types (see also Table 1):

> autosomal dominant
> autosomal recessive
> X-linked dominant
> X-linked recessive.

autosome
a chromosome that does not determine the sex of an organism

sex chromosome
a chromosome that determines the sex of an organism

Figure 1 The X chromosome (left) is much larger than the Y chromosome (right) and carries more genetic information.

Figure 2 Most sex-linked genes are situated on the X chromosome. There are only a few Y-linked genes in humans. In rats, spontaneous high blood pressure is linked to the Y chromosome, so only male rats experience spontaneous high blood pressure.

EXPERIMENT

2.9: Colour-blindness inheritance
Go to page **235**.

Figure 3 A male gets his X chromosome from his mother and his Y chromosome from his father. A female gets one of her X chromosomes from her mother and the other X chromosome from her father.

Table 1 The four patterns of inheritance

	Dominant	Recessive
Autosomal	• Males and females are affected equally over a large sample size. • Affected offspring have at least one affected parent (i.e. it does not skip a generation).	• Males and females are affected equally over a large sample size. • Affected offspring may have unaffected parents (i.e. parents may be carriers).
X-linked	• Generally, more females than males are affected. • Affected offspring have at least one affected parent (i.e. it does not skip a generation). • An affected father will pass the trait to all daughters, but not to any sons. • An affected mother has a 50% chance of passing the trait to any son or daughter.	• Generally, more males than females are affected; females are carriers. • Affected offspring may have unaffected parents (men cannot be carriers, but women may be). • A carrier mother has a 50% chance of passing the trait on to each son. • Daughters of an affected father will all be carriers.

Sex-linked conditions

Two conditions that are caused by defective sex-linked genes are red–green colour blindness and haemophilia.

Red–green colour blindness is an X-linked recessive trait. This means the red–green colour-blindness allele is found on the X chromosome, and the trait only appears if no 'normal' alleles for this gene are present. The colour receptors in the retina of the eye are controlled by a gene on the X chromosome.

When the gene is defective, the colour receptors do not function properly and the person cannot distinguish red from green (Figure 4). Approximately 8 per cent of males and less than 1 per cent of females have red–green colour blindness. It is very rare for a female to have two defective alleles, but not as rare for them to be 'carriers' (heterozygous) of the defective allele.

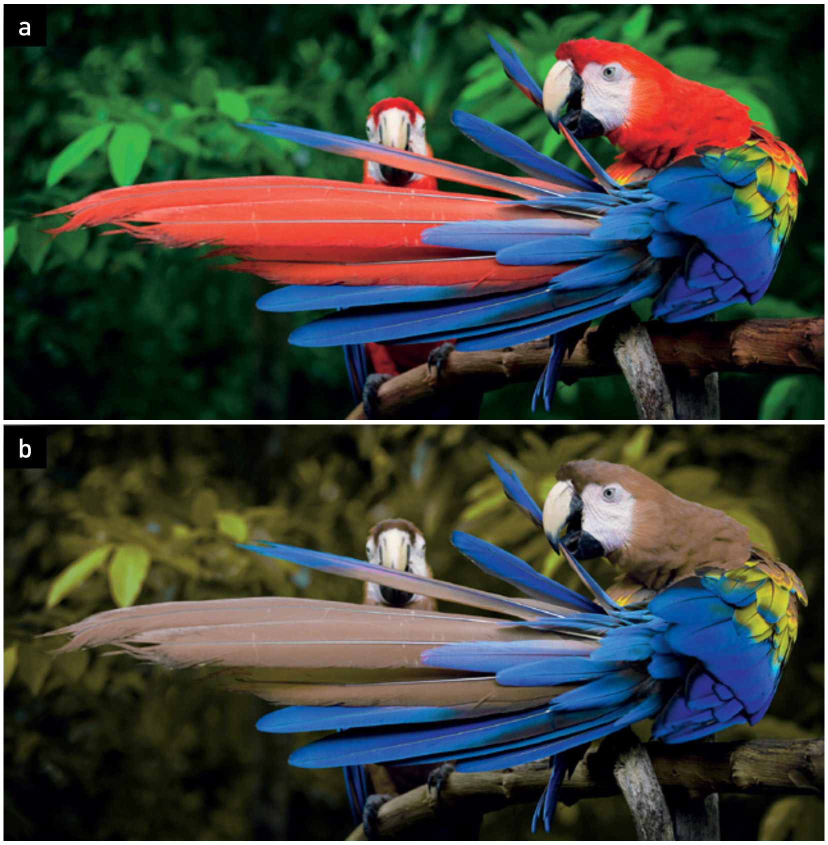


Figure 4 A person with colour blindness will have a very different view of the world. **a** A person with normal vision can see all the colours of these parrots. **b** A person with colour blindness cannot see the red and green feathers.

Figure 5 Queen Victoria's granddaughter Alexandra, her husband, Nicholas II (the last Tsar of Russia), and their son, Alexei, who suffered from haemophilia

Haemophilia is a disease that prevents the blood from clotting. This occurs when the X-linked gene that controls one of the clotting factors is defective. Even a small injury to a person with haemophilia can result in prolonged bleeding. It is possible to treat this disease today because the clotting factors can be produced from donated blood or made in the laboratory. These clotting factors are given by injection.

In the past, there was no treatment for haemophilia. Queen Victoria, Queen of the United Kingdom, appears to have had a spontaneous mutation in the gene on the X chromosome for making a blood clotting factor. She passed this defective gene on to some members of her family. When her male descendants inherited their only X chromosome with the 'defective' allele from her, they often died prematurely.

Queen Victoria's granddaughter Alexandra was a carrier of the haemophilia gene. She married the last Tsar of Russia, Nicholas II, with whom she had four unaffected daughters and a son, Alexei, with haemophilia (Figure 5).

Alexei's disease caused great stress to the family. Alexandra even consulted the monk Rasputin to pray over him, but there was no reliable treatment for haemophilia in the early twentieth century.

Communicating sex-linkage

When writing genotypes for sex-linked crosses, it is important to show the allele as being attached to either the X or the Y chromosome because the gender of the offspring is important in determining phenotype.

For example, in colour blindness, using X for normal and X^c for colour blindness, the genotype for a colour-blind female is X^cX^c, the genotype of a carrier female is XX^c and the genotype for a colour-blind male is X^cY. For haemophilia, we can use X^H and X^h to represent the normal allele and the allele for haemophilia, respectively (Figure 6).

Key: H = normal allele and h = allele for haemophilia

Queen Victoria X^HX^h x X^HY Albert

↓

Carrier daughter X^HX^h x X^HY Her husband

↓

Alexandra X^HX^h (carrier granddaughter) x X^HY Nicholas II (last Tsar of Russia)

↓

Alexei X^hY (haemophiliac son)

Figure 6 Genotypes in the family tree of Queen Victoria leading to Alexei

2.9 Check your learning

For the following questions, assume that the sex-linked gene is X-linked and recessive.

Comprehend

1 **Explain** why a defect in a sex-linked gene affects males more than females.

Analyse

2 A man and a woman, both of whom had normal sight, had three children: two boys and a girl. One of the boys had normal sight and the other was red–green colour blind. The girl had normal sight. **Calculate** the genotypes for this family.

3 The girl from the family in question 2 married a normal-sighted man and had a son who was colour-blind. **Calculate** the genotypes for this family.

4 The colour-blind son from the family in question 3 married a normal-sighted woman and had a son with normal sight and a colour-blind daughter. **Calculate** their genotypes.

5 **Calculate** the probability that the four girls in the family of the last Russian Tsar were carriers of the allele for haemophilia.

6 If a man has a mutated gene on his Y chromosome, **identify** which grandparent he inherited it from.

Apply

7 **Describe** who will be affected by a Y-linked gene. **Justify** your answer (by describing the sex chromosomes of males and females, and describing who would be affected by a gene on the Y chromosome).

8 Tortoiseshell cats have fur coats that are a combination of orange and black. The gene for hair colour is found on the X chromosome.

   a **Explain** why all tortoiseshell cats are female. Use diagrams to **justify** your answer.

   b **Identify** the coat colour of the offspring of a tortoiseshell cat and a black cat.

Quiz me

Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

Figure 7 A tortoiseshell cat

2.10 Inheritance of traits can be shown on pedigrees

Learning intentions

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

- analyse and interpret pedigrees to determine if a trait is dominant, recessive, autosomal or sex-linked
- analyse and interpret pedigrees to predict whether an individual will inherit a disease.

Interactive 2.10
Pedigrees

pedigree
a chart showing the phenotypes for an individual and their ancestors, usually over several generations; also known as a family tree diagram

Key ideas

- Pedigrees are a visual way to show the inheritance pattern of a trait.
- Circles represent females and squares represent males.
- Shaded symbols represent individuals who express the trait.
- Recessive traits may skip a generation.
- Once a dominant trait disappears from a family line, it will not reappear.

Kinship systems

Although each of your parents contributed to your genotype, the genotypes of other family members (e.g. grandparents, aunts and uncles) can all be important in explaining who you are.

They can provide an indication of potential recessive traits that may affect your health if you inherited two copies of the alleles (one from each parent). Understanding the way recessive traits can accumulate if small groups intermarry is the basis of many European laws that forbid the marriage of siblings (brother and sister).

First Nations peoples in Australia have demonstrated an understanding of traits and inheritance without the use of the advanced technologies that are now available to geneticists. Despite living thousands of kilometres away from Gregor Mendel, First Nations peoples had observed how some recessive traits and illnesses could be inherited in the children of related parents.

This resulted in the development of kinship systems that can be used to identify relatives in the mother's or father's line. Across mainland Australia, a 'skin name' can identify relatedness and roles in society. It can also determine who is and who is not allowed to marry.

Pedigree construction and analysis

Inheritance of characteristics is today often traced through families using family tree diagrams or **pedigrees**. There are specific symbols used in constructing pedigrees (Figure 1).

> Males are represented by squares and females by circles.

> A marriage or de facto relationship is shown by a horizontal line; a vertical line leads to the offspring.

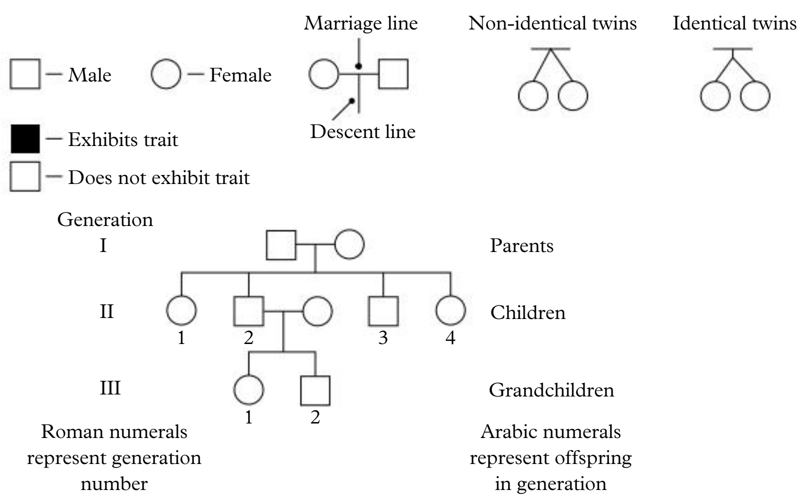


Figure 1 Some symbols used in family tree diagrams

- The characteristic being studied is shown by shading.
- Generation numbers are represented by Roman numerals and individuals are represented by Arabic numerals.

When analysing a pedigree to determine whether a trait is dominant or recessive, the following rules apply.

- If neither parent has a characteristic and some of their offspring have it, then the characteristic is recessive (i.e. both parents are carrying the allele for the recessive trait but it is not shown in their phenotype).
- If both parents have a characteristic and some of their children have it, then the characteristic is dominant (i.e. both parents are heterozygous).
- If both parents have a characteristic and it is recessive, then all of their children will have that characteristic because only recessive alleles could be inherited by offspring. If both parents have a characteristic and none of their children have it, then the characteristic is dominant because it would require two heterozygous parents to produce offspring that do not inherit the characteristic.

In the pedigree in Figure 2, red hair is recessive because individual II2 and his partner do not have red hair but some of their children have it. They are both carrying the allele for red hair, but not expressing it. They both contribute their allele for red hair to some of their offspring.

In the pedigree shown in Figure 3, tongue rolling is dominant. This is because individual II1 and her partner can roll their tongues, and some of their offspring can and some cannot. The parents are both heterozygous for tongue rolling.

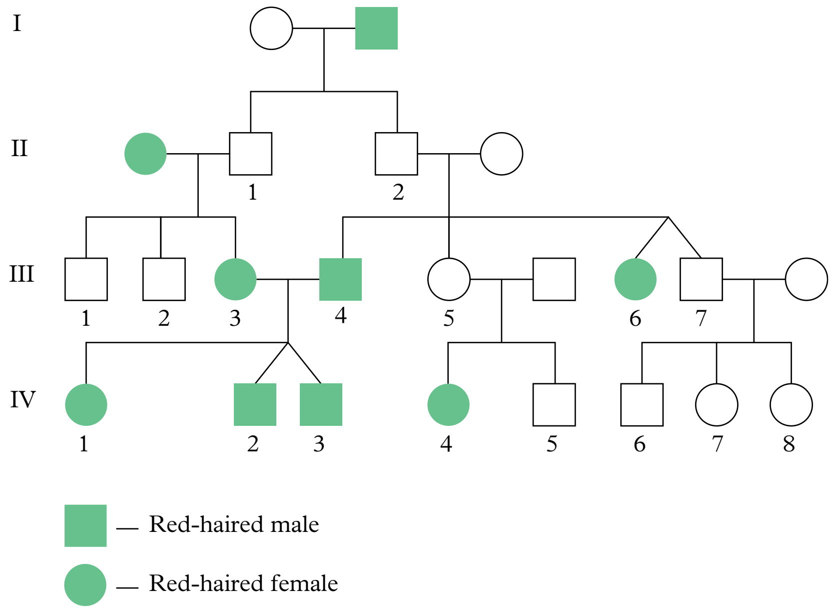


Figure 2 A pedigree for red hair

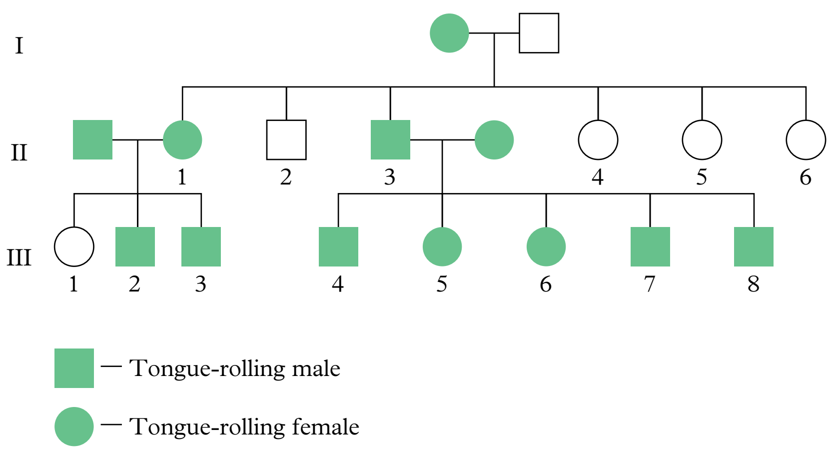


Figure 3 A pedigree for tongue rolling

Analysing pedigrees

Pedigrees can be analysed to determine whether an individual will inherit a disease. There is a series of questions you should ask when determining the inheritance pattern from a pedigree.

1. Are more males than females affected by the trait?
   If YES, go to 2. If NO, go to 3.
2. Do all daughters of affected males have the trait?
   YES – Sex-linked dominant. NO, go to 4.
3. Do all affected children have an affected parent?
   YES – Autosomal dominant. NO, go to 5.
4. Has a carrier mother passed it on to half/some of her sons?
   YES – Sex-linked recessive.
5. Do affected children have unaffected parents?
   YES – Autosomal recessive.

achondroplasia
a genetic (inherited) disorder of bone growth resulting in abnormally short stature and short limbs

Figure 4 Achondroplasia is the most common form of dwarfism.

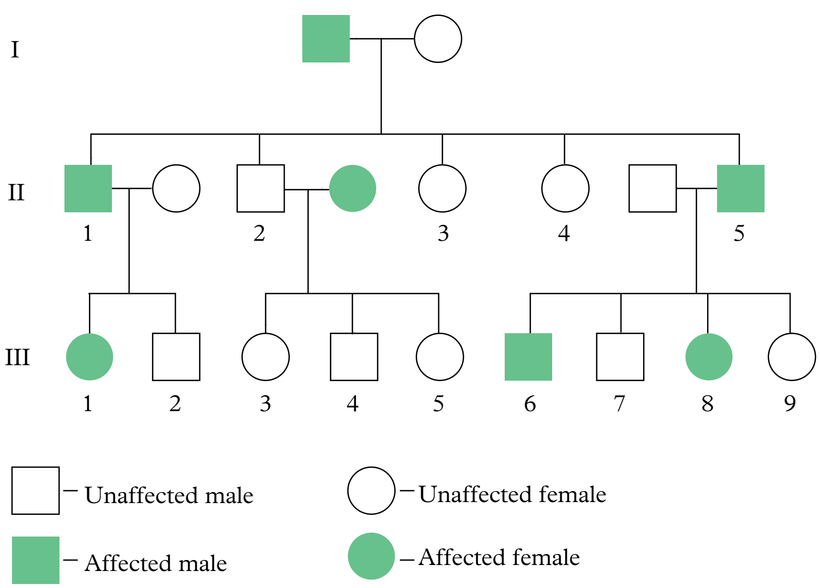


Figure 5 The pedigree chart of a family affected by achondroplasia – some of the children are unaffected.

Dwarfism

Achondroplasia is the most common form of dwarfism (Figure 4) and is inherited as an autosomal dominant trait (although spontaneous mutations can also arise with no prior family history). The gene is located on chromosome 4, and it controls the production of a protein that responds to a growth factor hormone. If this gene is not functioning (affected allele), a person will not produce the protein. This means they will not be able to respond to the growth factor and will have a short stature. People with achondroplasia have normal intelligence and lead independent and productive lives, despite their medical problems.

Because the trait is dominant, people affected by achondroplasia have at least one affected parent (Figure 5). If one parent is affected, there is a 50 per cent chance of the children being affected.

2.10 Check your learning

Comprehend

1 **Represent** the following with a pedigree symbol.

- a a female with a trait
- b a male without a trait
- c non-identical male and female twins without a trait.

Apply

2 Some people have ear lobes that hang free and some people's ear lobes are attached. Natalie has attached ear lobes, but both Natalie's parents and her brother, Daniel, have free-hanging ear lobes as shown in the pedigree (Figure 6).

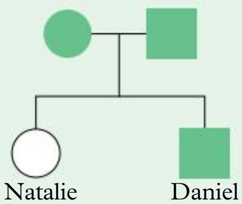


Figure 6 A pedigree showing inheritance of ear lobes

- a **Identify** whether the characteristic of free-hanging ear lobes is a dominant trait or a recessive trait. **Justify** your answer (by describing each of the rules that apply to the pedigree).
- b Use suitable symbols to **represent** the alleles for the ear lobe gene, and then **determine** the genotypes of:
  - i Natalie
  - ii Natalie's parents.
- c **Identify** the possible genotypes for Daniel.

3 A particular X-linked disease causes weakening of the muscles and loss of coordination. This often leads to death in childhood. A pedigree for this disease is shown in Figure 7.

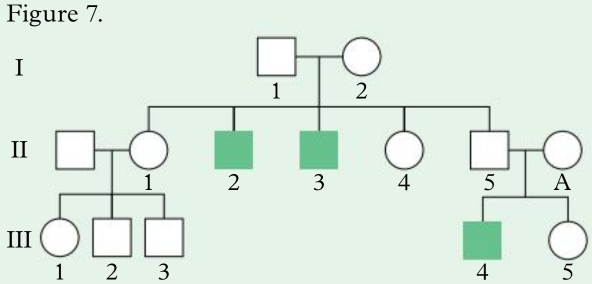


Figure 7 A pedigree showing the inheritance of an X-linked disease

- a Use this pedigree and suitable symbols to **demonstrate** the genotype of individuals I1, I2 and II5. **Determine** the genotype of individual A.
- b **Identify** one carrier in the pedigree shown in Figure 7.

4 **Evaluate** Figure 8.

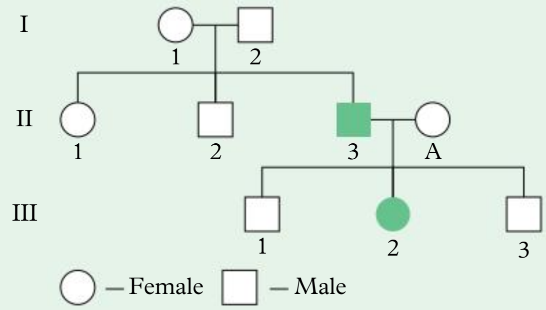


Figure 8 A pedigree indicating the inheritance of a trait

- a In this family pedigree, **identify** the characteristic indicated by shading as dominant or recessive. **Justify** your answer.
- b If R represents the allele for the dominant trait and r represents the allele for the recessive trait, **determine** the genotypes of individuals I1, I2 and person A.
- c If A and her partner had another child, **calculate** the chance of the child having the characteristic indicated by shading. Show your working.

5 The pedigrees in Figure 9 show the inheritance of two genetic disorders (vision defects and limb defects) in the same family.

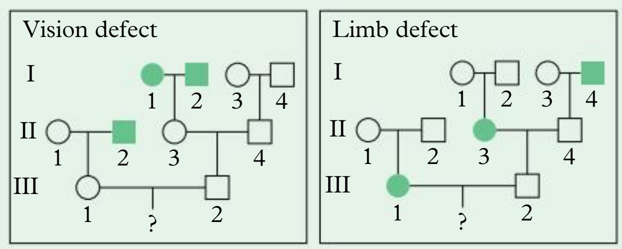


Figure 9 Pedigrees for the inheritance of vision defects and limb defects

- a **Identify** the allele responsible for the vision defect as dominant or recessive. **Justify** your answer.
- b **Identify** the allele responsible for the limb defect as dominant or recessive. **Justify** your answer.

Quiz me

Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

2.11 Mutations are changes in the DNA sequence

Learning intentions

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

- distinguish between genetic and chromosomal mutations
- explain how substitution and frameshift mutations alter nucleotide and amino acid sequences of a protein.

Key ideas

- Mutagens such as chemicals, UV light and cigarette smoke can cause permanent changes in the sequence of nucleotides that make up DNA.
- Genetic mutations can involve substituting one nucleotide for another, or deleting or adding a nucleotide.
- Chromosomal mutations result from the centromere failing to separate (non-disjunction) during meiosis.

Mutations and mutagens

A **mutation** is a change in the sequence or amount of the genetic material (DNA) that can be passed on to daughter cells. Therefore, a mutation is a permanent change in the DNA, and it may be in one gene or in a number of genes (part or all of a chromosome).

If the change is in a single gene, then it is called a genetic mutation; if it affects most of a chromosome, it is called a chromosomal mutation.

Before a new cell can be produced, the three billion nucleotides need to be copied. Although the aim of copying the DNA is to keep the order of nucleotides the same, occasional errors can occur. The order of nucleotide nitrogen bases in the DNA is critical – a tiny change in the sequence changes the order of amino acids in the protein being made, which, in turn, may affect how the protein functions. On many occasions, these changes can be corrected by the cell or they do not cause a change in an important part of the protein that is produced by the gene.

A single nucleotide mutation many thousands of years ago prevented the production of brown pigment in eyes. As a result, blue eyes developed in humans. The mutation gave humans a new allele. However, some mutations are deadly, because they cause a cell to rapidly reproduce and never die (cancer).

Natural mutations occur at a continuous low rate. However, environmental factors called **mutagens** can increase the frequency of mutations. Mutagens include chemicals, radiation and ultraviolet (UV) light (Figure 1).

Genetic mutations

There are two types of single nucleotide (point) mutation:

> substitution mutations
> frameshift mutations.

A **substitution mutation** occurs when one nucleotide base substitutes for another. As the genetic code is read in groups of three (called triplets), this may or may not have an effect on the final protein. This is best shown using the sentence:

THE CAT ATE THE RAT AND RAN FAR

If there was a substitution mutation in this sentence, it might read:

THE CA**R** ATE THE RAT AND RAN FAR

In this case, the sixth letter, T, was substituted by R. In DNA it might be a G substituted for A. This small change will be passed on to the RNA but may not affect the order of amino acids in a protein.

Sickle cell anaemia is an example of a substitution mutation that does affect the final protein.

mutation
a permanent change in the sequence or amount of DNA

mutagen
a chemical or physical agent that causes a change in genetic material such as DNA

substitution mutation
a form of mutation where one nucleotide is substituted for another; may or may not result in a deformed protein

Radiation	Chemicals	UV light
• Ionises biochemical compounds in cells, forming free radicals • The free radicals cause damage to DNA and proteins (e.g. breakages in chromosomes)	• Some chemicals insert into DNA instead of bases (i.e. they substitute for bases) • Other chemicals insert between bases, causing problems when the DNA replicates	• Causes thymines that are close together on a DNA polynucleotide chain to bind together, forming 'thymine dimers'. This causes problems during DNA replication

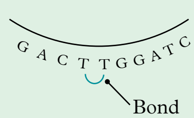


Figure 1 The effect of mutagens

SKILLS LAB

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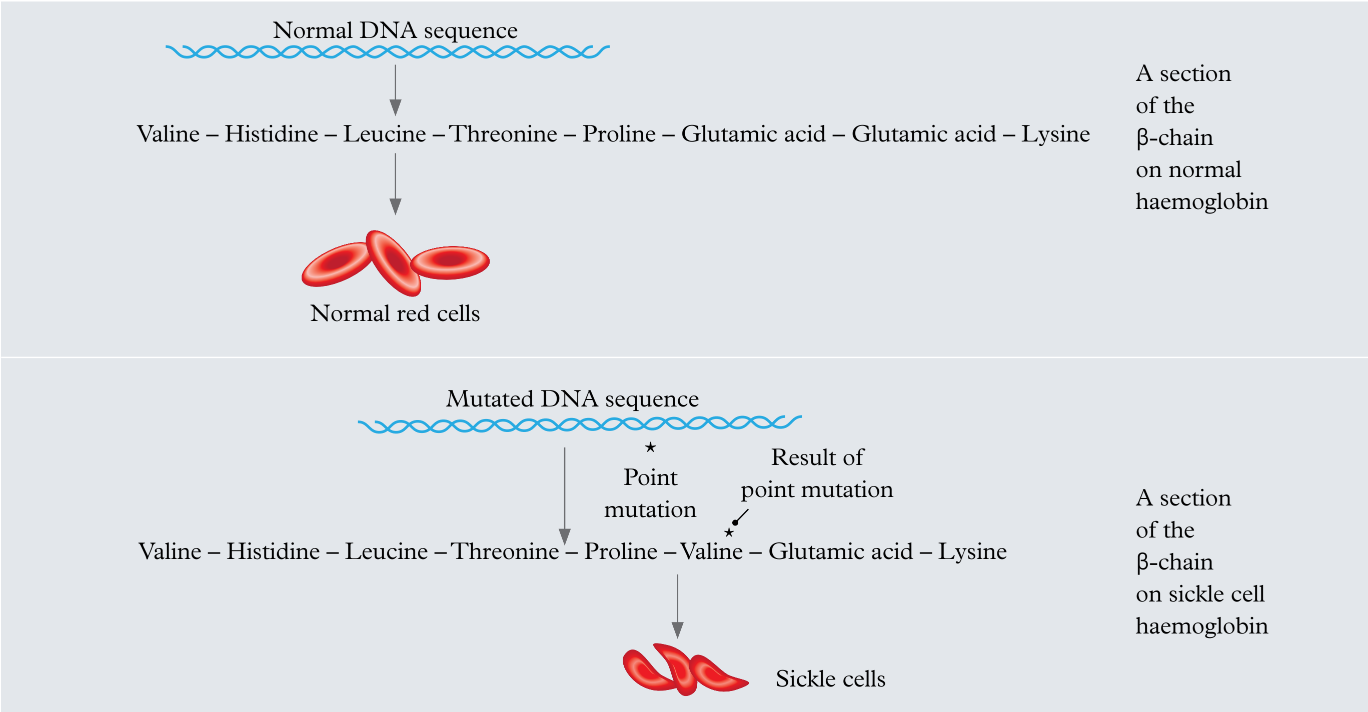


Figure 2 Haemoglobin and sickle cell anaemia – an example of the effects of a point mutation

The gene that makes part of the haemoglobin molecule, which carries oxygen around the body, substitutes an adenine (A) for a thymine (T), so the code in the DNA sequence reads CAC instead of CTC. As a result, the codon on the RNA reads GUG instead of GAG. This makes the matching amino acid valine rather than glutamic acid. This means the protein haemoglobin that is produced is sticky and deformed, which doesn't carry oxygen as effectively (Figure 2). People with sickle cell anaemia can feel tired, and the sticky haemoglobin deforms the red blood cells, making them a sickle shape.

A deletion or an addition can have a large impact on how the genetic code (groups of three nucleotides) is read. Adding or removing one letter shuffles all the groups of three nucleotides.

A deletion of the sixth letter (T) in the example sentence results in the triplet code becoming:

THE CAA TET HER ATA NDR ANF AR

An addition of an extra R results in the triplet code becoming:

THE CAR TAT ETH ERA TAN DRA NFA R

These are both **frameshift mutations** because the group-of-three reading frame has been shifted along the DNA strand.

Frameshift mutations have more damaging effects than substitution mutations because they change the entire reading frame of the DNA and RNA, producing a very different protein.

frameshift mutation
a type of mutation in which a nucleotide is added or deleted, causing a shift in the reading frame of codons; usually results in a deformed protein

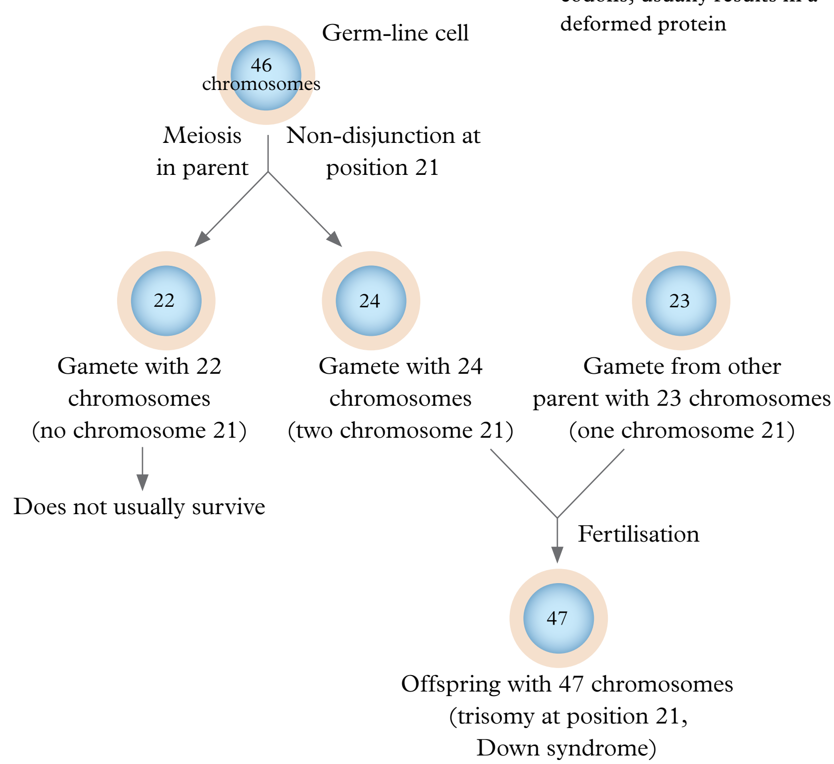


Figure 3 Changes in chromosome numbers due to non-disjunction

If the RNA sequence reads UAC after the mutation, then this is a 'stop codon' and the protein synthesis will stop at that location, resulting in a shorter molecule that is unable to be useful. Frameshift mutations will always cause a damaged protein.

Mutations involving chromosome number

This type of mutation is usually the result of **non-disjunction** – the failure of a chromosome pair to separate at the centromere in meiosis.

non-disjunction
the failure of one or more chromosomes to separate during meiosis; can result in an abnormal number of chromosomes in the daughter cells

In such cases, one of the daughter cells (gametes) will have too many chromosomes and the other will have too few chromosomes (Figure 3). If an abnormal gamete is fertilised, the offspring will have either too many or too few chromosomes.

Down syndrome is the result of non-disjunction in chromosome pair 21 during the formation of the gametes in one parent. A person with Down syndrome has three copies (trisomy) of chromosome 21 (Figures 4 and 5).

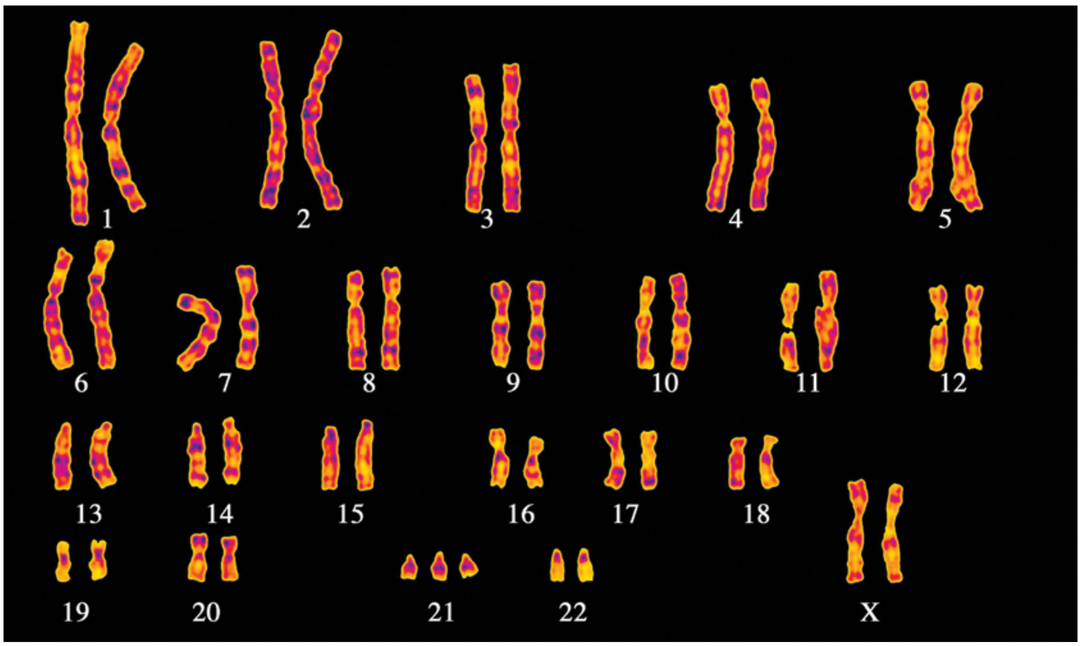


Figure 4 Individuals with Down syndrome have three copies of chromosome 21.

Figure 5 This girl has Down syndrome, which is a result of non-disjunction of chromosome 21.

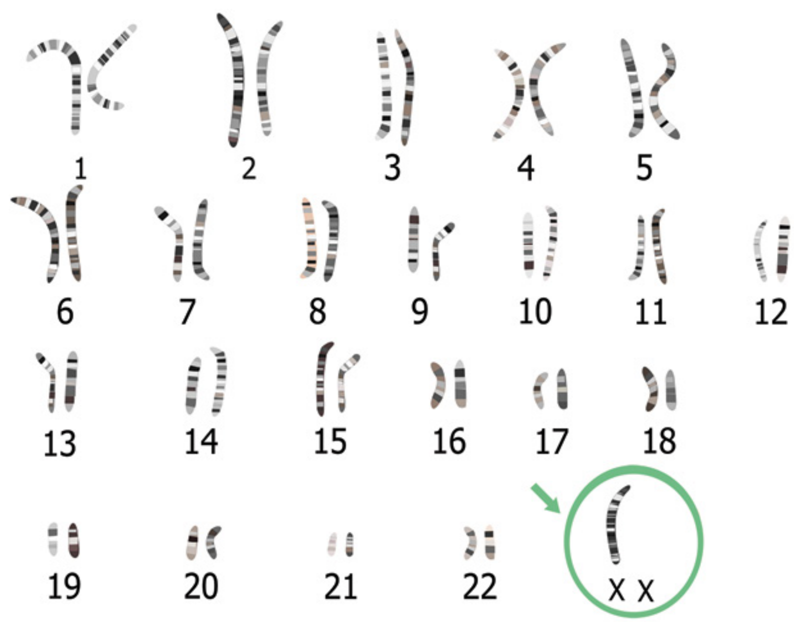


Figure 6 Turner syndrome is a result of non-disjunction of the X chromosome.

Non-disjunction in sex chromosomes

Non-disjunction can also occur with the sex chromosomes X and Y. This can result in a variety of syndromes.

Females with Turner syndrome have only one X chromosome (Figure 6). Turner syndrome can appear in many different ways, and it is not always apparent from the person's physical appearance. Symptoms can include shorter than average height, infertility, extra webbing on the neck, swollen hands and feet, diabetes and many other difficulties. Turner syndrome does not normally affect intellectual ability.

Males with Klinefelter syndrome have an extra X chromosome, giving them a total of 47 chromosomes (Figure 7). This can affect their fertility, muscle development and intellectual ability. Many of these individuals will be undiagnosed. Approximately 1 in 660 males are affected.

Cri du chat syndrome

Cri du chat syndrome is caused by missing portions of chromosome 5 (Figure 8). Both males and females can be affected. Symptoms include having a high-pitched cry (similar to that of a cat) as a baby. People with Cri du chat syndrome are slow to grow, and they often have a small head and intellectual difficulties. Their fingers or toes can sometimes be fused together.

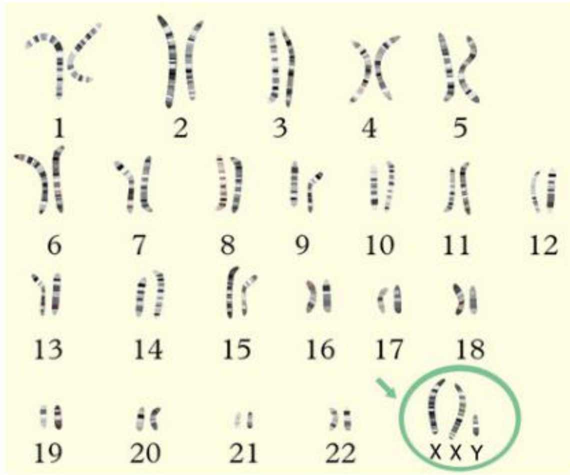


Figure 7 Males with Klinefelter syndrome have an extra X chromosome.

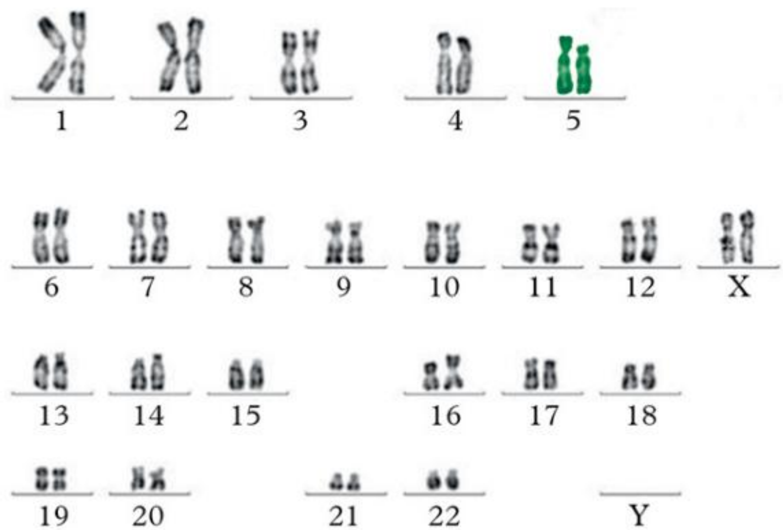


Figure 8 Cri du chat syndrome occurs when part of chromosome 5 is missing.

2.11 Check your learning

Retrieve

1 **Define** the term 'mutation'.

Comprehend

2 **Define** the term 'mutagen'. **Describe** one example of a mutagen and how it acts to cause mutations.

3 **Define** the term 'trisomy'. **Describe** an example of a trisomy in humans.

4 **Describe** a frameshift mutation.

5 **Ilustrate** a series of diagrams that represent non-disjunction occurring in meiosis.

Analyse

6 **Compare** the causes of Turner syndrome and Down syndrome.

Apply

7 **Evaluate** whether a mutation can be advantageous (by defining the term 'mutation', describing an example of a mutation that helps an organism to survive, and deciding whether mutations can be advantageous).

8 **Propose** how you would test whether a male had Klinefelter syndrome.

Quiz me

Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

//SCIENCE AS A HUMAN ENDEAVOUR//

2.12 Genes can be tested

Learning intentions

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

- describe the purpose of genetic screening and testing
- provide examples of diseases that are screened for.

Mutations in genes can be identified by using probes, short sections of complementary nucleotides that can bind to mutated alleles. If the mutated allele is TAA CAG TAT, the probe will be ATT GTC ATA. The complementary nucleotides of the probe will bind to the mutated allele and can help identify individuals at increased risk of developing diseases.

Genetic screening and testing

Genetic testing is carried out on people who are known to be at risk of a particular genetic disease or condition. This is usually evident from an individual's family history. The genetic material of a person at risk is obtained through a blood sample. DNA from the white blood cells (red blood cells do not have a nucleus) is isolated and replicated. Special probes act like a stain that sticks to specific genes in the chromosomes, identifying the particular allele that is present in people at risk of the trait.

Genetic screening refers to testing a large number of people within the community even if they do not have any family history of genetic disease.

Genetic screening and testing services currently available in Australia include:

> **maternal serum screening (MSS)** – offered to all pregnant women for the detection of Down syndrome and neural tube defects

> **newborn screening** – the screening of all newborn babies for genetic diseases, including phenylketonuria (PKU), hypothyroidism and cystic fibrosis (Figure 1)

> **early detection and predictive testing for adults** – the screening of adults to detect existing disease, those who have a high chance of the disease or those who are carriers with a reproductive genetic risk.

maternal serum screening (MSS)
the genetic testing of fetal DNA found in the mother's blood

newborn screening
the testing of chromosomes in a baby's white blood cells for the presence of a genetic disease

early detection and predictive testing for adults
the testing of chromosomes for the presence of alleles that increase the probability of cancers forming

Genetic screening allows individuals to be diagnosed early, before the symptoms of the disease appear. These individuals can then be treated, preventing the worst symptoms from appearing and even preventing death.

Figure 1 A blood sample is collected from a newborn infant to screen for phenylketonuria – a disease that affects the way the body breaks down proteins.

Genetic screening can also be used to prevent genetic diseases from being passed on to the next generation. While this prevents future children from suffering, it sometimes involves some very difficult decisions. For example, individuals who are carriers of genetic mutations must decide whether to have children, who may suffer from the disease. Genetic screening also raises the following questions. What are the risks of the tests and are people prepared to take them? Who should be screened, and for what? What is the impact of false positives? What options are available if it's not good news?

Genetic counsellors can help clarify the situation, but they cannot make the decision for the people involved. Instead, they help the individuals make their own decisions.

The collection, storage and potential use of genetic information raises many ethical questions, including who should access the information and the possible misuse of such information.

Sex, Down Syndrome Tests

***The Weekend West* November 7 – 8, 2015, p.17**

BY CATHY O' LEARY, MEDICAL EDITOR

A growing number of pregnant women in WA are having a simple blood test that can pick up signs of Down syndrome and the baby's sex as early as 10 weeks.

Doctors say demand has gone 'crazy' in WA for non-invasive prenatal testing (NIPT), which costs more than $400 but is more accurate than the blood test used in traditional prenatal screening. Women found to be at low risk of Down syndrome by the test could avoid having invasive procedures such as amniocentesis, which increases the risk of miscarriage.

Instead of testing cells from the foetus or the placenta, NIPT picks up traces of foetal DNA circulating in the mother's blood. Because there is an option to screen for sex-linked chromosomes, it can also show the gender of the foetus.

Some ethics experts are worried that detecting the gender early on could make it easier for couples who want a child of a particular sex to terminate the pregnancy.

Prenatal screening is usually aimed at women at higher risk of Down syndrome, such as those aged over 35, but even low-risk women are having the newer test, despite it not having any Medicare or private health insurance rebate. It cost $1400 when it became available in Australia three years ago but it is now as low as $420. While it is not a diagnostic test, it is 99 per cent accurate and has a very low false positive rate. A WA survey of high-risk pregnant women presented at the Royal Australian and New Zealand College of Radiologists scientific meeting in Adelaide yesterday showed most preferred it.

Obstetric radiologist Emmeline Lee, from Western Ultrasound for Women, said there had been a huge uptake in WA. 'The market has gone crazy,' she said. 'Even though we were cautious about offering it only to high-risk women, we're seeing low-risk women wanting it as an extra layer of security.'

Professor Peter O'Leary from Curtin University's Faculty of Health Sciences, said there was a push to have the test publicly funded but he believed it should be limited to 20 per cent of women at higher risk.

What is NIPT?

- Non-invasive prenatal testing is a new way to screen for genetic abnormalities.
- Unlike invasive tests such as amniocentesis and chorionic villus sampling (CVS) that collect cells from the foetus or the placenta, NIPT uses traces of foetal DNA in the mother's blood.
- It can be done from 10 weeks and is 99 per cent accurate at detecting Down syndrome.
- Costs between $420 and $900.
- Samples have to be sent to the Eastern states, with results usually within a week.
- A 12-week ultrasound should still be done to check for structural abnormalities.
- It is not a diagnostic test, so women who test positive need to have it confirmed by amniocentesis or CVS.

2.12 Test your skills and capabilities

Describing ethical issues

There are many ethical and legal issues raised by genetic testing.

1 Select one of the issues listed below, and use an ethical approach to **evaluate** the issue by:

> describing the people affected by the issue (including individuals, their family, and medical, personal and societal costs)

> describing how they are affected

> describing the ethical approach you will use (consequentialist or deontological)

> using the ethical approach to describe the issue

> describing an alternative view that could be used by someone else

> describing the decision you would make if faced by the issue.

a A pregnant woman who is at high risk of having a child with a painful genetic disease refuses to have a prenatal genetic test.

b An employer insists on a person having a genetic test before they will be employed.

c A health insurance company demands a copy of the results of a previous genetic test before they will insure the person.

d A couple expecting a child with a non-painful genetic disease ask for your advice about terminating the pregnancy.

//SCIENCE AS A HUMAN ENDEAVOUR//

2.13 Genes can be manipulated

Learning intentions

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

- explain the human need for selected GMOs to be produced
- outline how a desirable gene can be inserted into a plant cell.

genetically modified organism (GMO)
an organism that has had its DNA changed in a laboratory

transgenic organism
an organism that has a gene from another organism inserted into its own chromosomes

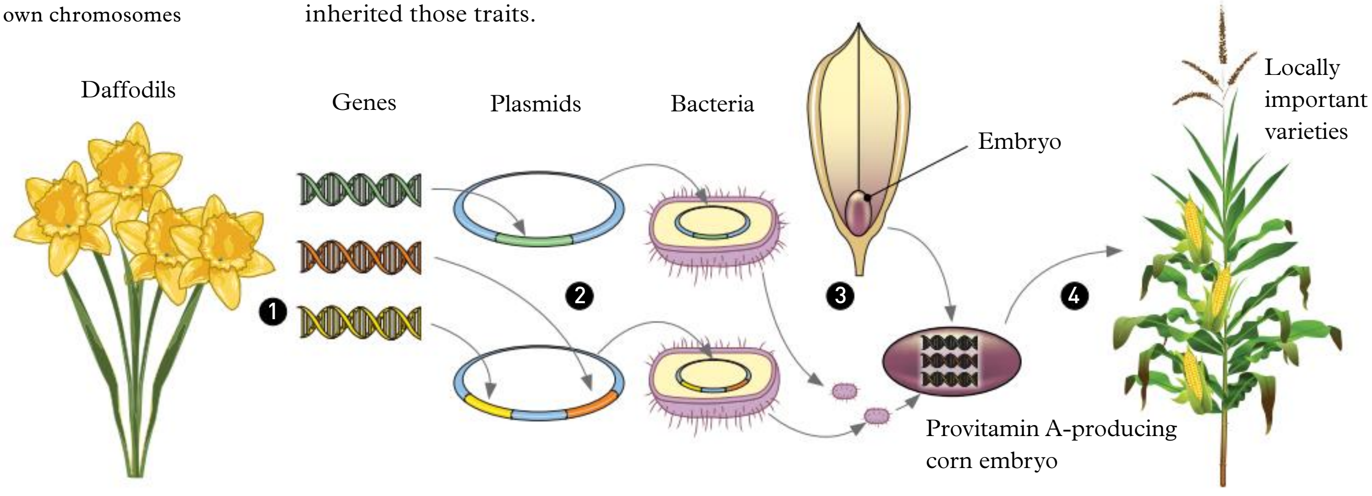
The genetic material of all organisms is made of the same four nucleotides A, T, C and G. The only difference is their order in the DNA. Understanding the nature of DNA led to the question 'Can we change it?'

Genetically modified organisms

Genetically modified organisms (GMOs) have had their DNA changed or modified in the laboratory. This can be done by changing the nucleotides to stop genes making protein or to add new genes into an organism's genetic material to improve certain traits, such as increased resistance to herbicides or improved nutritional content. Traditionally, breeders would select breeding organisms who had the desired traits and hope that the offspring inherited those traits.

Today, genetic engineering can create plants with the exact desired trait very rapidly and with great accuracy. For example, geneticists can remove a gene for drought tolerance from one plant and insert that gene into a different plant. The new genetically modified (GM) plant will now be able to survive a drought. Not only can genes from one plant be transferred into another plant, but genes from non-plant organisms can also be used. **Transgenic organisms** are those that contain a foreign gene inserted from another organism, usually a different species.

Agriculture has been significantly affected by the introduction of transgenic animals and genetically modified crops and foods (GM foods), including plants that are resistant to herbicides and pesticides. There are also 'pharm' plants and animals that produce pharmaceutical proteins required by humans.



1. The gene that produces vitamin A is isolated from a daffodil.
2. This gene is added into a plasmid, which is a small loop of DNA that acts as a vector transporting the gene into a bacterial cell.
3. The bacterial cells containing the plasmid are added to the embryonic corn plant.
4. The transgenic corn plant grows. The introduced genes produce high levels of vitamin A.

Figure 1 Scientists can grow transgenic corn that produces high levels of vitamin A.

Engineering crops to resist disease means that farmers can use less pesticide and herbicide when growing them. Reducing the amount of pesticide and herbicide reduces production costs and environmental pollution.

Figure 1 shows the process of introducing a gene from a daffodil into corn. Examples of plants that have been genetically engineered are shown in Figures 2–4.

GMO issues

GM crops can pose a threat to biodiversity because they replace a number of natural varieties of plants with one variety: the genetically engineered plant. This can generate a monoculture, decreasing the diversity of other plants and animals (i.e. biodiversity) in the growing area.

The organic food movement is completely against the principle of GM foods, and public debate into the benefits and dangers of such foods is likely to continue well into the future. Some people believe that GM foods pose health risks, although there is no clear evidence for or against this. Like the DNA and proteins that exist in all food that we eat, the introduced genes and proteins are digested in our stomach and intestines.

One criticism of GM foods is the potential for accidental gene transfer to other species. GM plants may also contaminate non-GM plants of the same species; for example, when wind blows the pollen from one farm to another nearby. This may also contribute to pest insects developing resistance to the pesticide and insecticide. This means the GM plants that have the pesticide and herbicide resistance may then become vulnerable to the resistant pests.

Video 2.13A A genetically superior bee

Video 2.13B Genetically modified salmon

Figure 2 Transgenic variety of cotton that is pest resistant. Genes (that make a protein toxic to insect pests) from the bacterium *Bacillus thuringiensis* have been introduced into the DNA of this plant. The protein is called Bt (*Bacillus thuringiensis*) toxin and the plants are Bt plants. The toxin only becomes active in the alkaline environment of the insect gut, whereas in vertebrate animals it is destroyed by the acid in the stomach.

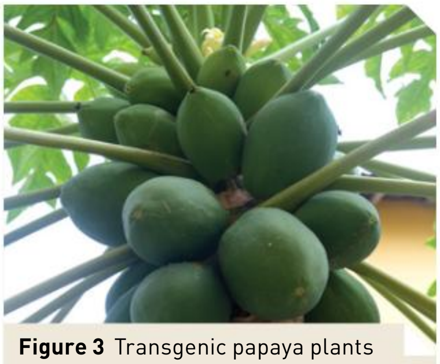


Figure 3 Transgenic papaya plants in Hawaii are resistant to the ring spot virus. Genetically engineering papaya has saved the industry. The technology has also been exported to other countries where ring spot virus is damaging papaya plants.

Figure 4 Golden rice has had genes inserted from daffodils. These genes control the production of a chemical that is converted into vitamin A, making this rice much richer in vitamin A than non-transgenic rice. Without adequate amounts of vitamin A, people's eyesight can be severely impaired, even leading to blindness. Many people in South-East Asia, a large rice-consuming area of the world, are blind or have severe sight problems due to vitamin A deficiency. Therefore, this high-nutrition rice is most valuable in parts of Asia.

2.13 Test your skills and capabilities

Evaluating claims

'Since the introduction of GMOs in America in 1996, there has been an increase in chronic illness, food allergies, autism and digestive problems.'

1 **Evaluate** this claim from a health blog by:
- contrasting correlation and causation
- identifying an example of this contrast in the statement
- identifying the reason why the author may have made this statement
- defining the term 'bias' and discussing the bias in the statement.

//SCIENCE AS A HUMAN ENDEAVOUR//

2.14 Genetic engineering is used in medicine

Learning intentions

By the end of this topic, you will be able to:
- outline the process of gene cloning
- explain how gene therapy can be used for medical treatment
- describe the different types of stem cells and their uses in medicine.

Video 2.14 Genetically modified humans

genetic engineering the deliberate engineering of change in the DNA of an organism

gene cloning the production of identical copies of a gene

gene therapy inserting a new healthy allele into an organism to treat a genetic disease

Genetic engineering has been used to change the genetic code of animals, to make medicines and to treat people with genetic diseases.

Gene cloning

Before a gene can be used in medicines, an exact copy needs to be made. This exact genetic copy is called a clone. The process of making multiple copies of a gene is called **gene cloning**.

Once the copies of the gene are produced, they can be inserted into bacteria. An example of this is the production of insulin (used to treat diabetes). The human gene for insulin was cloned and inserted into a fast-growing bacteria (Figure 1). The bacteria used the gene to produce multiple copies of the human insulin protein, which was purified and used to treat a person with diabetes. Because it is human insulin made from the human gene, this production method avoids the complications caused when insulin is made from pig or sheep genes.

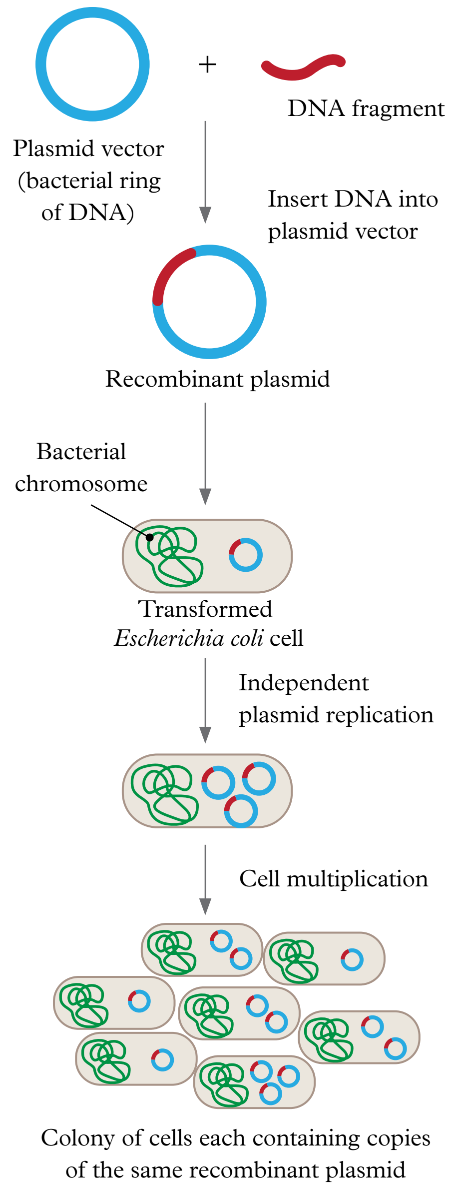


Figure 1 Gene cloning

Gene therapy

Some people are born with a defective gene that affects the health of their body. **Gene therapy** involves inserting a healthy replacement gene into the chromosomes of an individual with a defective gene. Gene therapy that inserts a new gene into body cells (somatic cells) can be therapeutic only. This means that the new gene cannot be passed on to the next generation. At present, gene therapy targeting germ-line cells (cells destined to become gametes) is not legal in Australia.

Despite initial setbacks, gene therapy has been quite successful in the treatment of cystic fibrosis (CF). Patients with CF have a deficiency in a gene that controls the production of a protein that regulates the movement of chloride ions across cell membranes. A major symptom of CF is the accumulation of a thick mucus that can damage lung tissue.

This reduces the lifespan of patients significantly. Medical scientists have been able to clone the healthy gene in bacteria. The purified gene is then attached to a carrier molecule called a vector. The vector in this case is a harmless virus, and it is added via a spray through the nose of patients.

CHALLENGE
2.14: Edible genetic engineering
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The virus enters many of the lung cells and inserts the healthy gene into the DNA in the nucleus. When the lung cells divide, the new cells contain the healthy gene (Figure 2).

Stem cells and ethics

Stem cells are undifferentiated cells that can differentiate (mature) into many different types of specialised cells, such as muscle, nerve, liver and blood cells. There are two types of stem cells. Pluripotent embryonic stem cells (obtained from embryos) can develop into most cell types in the body, whereas multipotent adult stem cells can only develop into certain cell types in the body.

There are many ethical issues associated with the use of embryonic stem cells. The establishment of a stem cell line involves the artificial creation of an embryo solely for the purpose of collecting stem cells. This process results in the destruction of the embryo. At present, such procedures are illegal in Australia. The only embryos that are used for research are those classed as 'excess embryos', that is, those originally created for use in in-vitro fertilisation (IVF). However, some people consider the use of these excess embryos to be unethical. They regard the embryos as potential life and their use in research as depriving life to these embryos.

Most recently, scientists have been able to reverse the differentiation process and turn multipotent adult stem cells back into pluripotent stem cells (like the embryo cells).

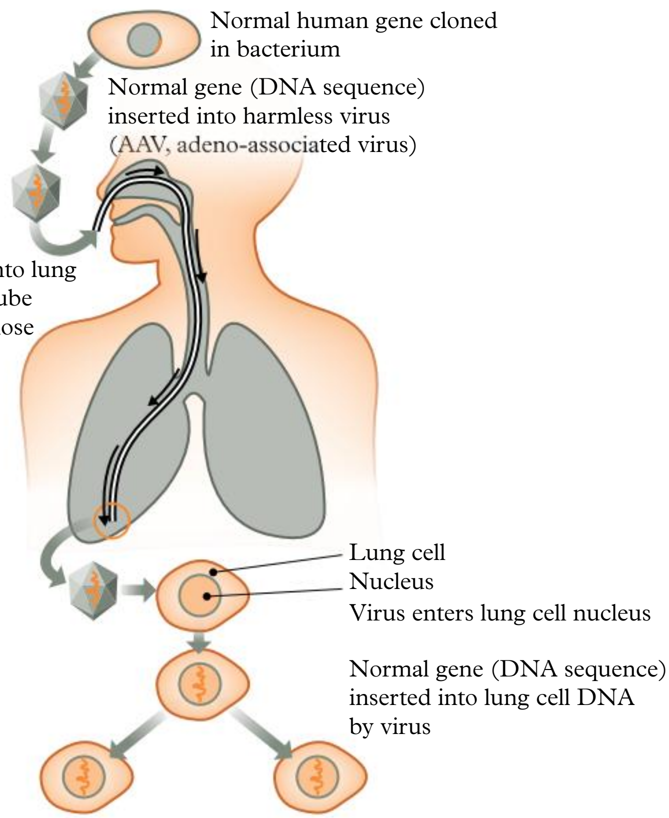

Figure 2 Gene therapy for cystic fibrosis

These cells are called induced pluripotent stem cells. In the future, induced pluripotent stem cells may be used to treat a variety of diseases, including cancer, multiple sclerosis (MS), Parkinson's disease, motor neurone disease and spinal cord injuries.

stem cell
a cell that can produce different types of cells; adult stem cells can produce a limited number of cell types (e.g. skin stem cells), whereas embryonic stem cells can produce many types of cells

2.14 Test your skills and capabilities

Evaluating ethics

A new form of gene therapy has recently been developed for the treatment of cancer. CAR T-cells (chimeric antigen receptor T-cells) are formed when a cancer patient's immune cells (T-cells) are removed and provided with genes that will allow them to fight the patient's cancer. These treated T-cells are placed back into the patient where they will find and kill the cancer cells. This new form of gene therapy is very expensive (usually starting at $500 000 for a single treatment). The ethical dilemma arises when considering the effectiveness of spending the money to treat one person, or to treat the many thousands of people who are sick due to poverty.

1 **Evaluate** the ethical dilemma presented when deciding whether to treat a 20-year-old cancer patient with CAR T-cells by:
 - describing the people affected by the issue (including individuals, their family, and medical, personal and societal costs)
 - describing how they are affected
 - describing the ethical approach you will use (consequentialist or deontological)
 - using the ethical approach to describe the issue
 - describing an alternative view that could be used by someone else
 - describing the decision you would make if you had to make the choice.

CHAPTER 2 REVIEW

GENETICS

Retrieve

1 **Identify** which is not a smaller part of all DNA nucleotides.

A deoxyribose
B nitrogen base
C adenine
D phosphate molecule

2 **Identify** the missing phrases in the following sentence. Mutations are _________ and mutagens are __________.

A changes in the gene carried through DNA; a substance that causes permanent change
B changes in the chromosomes; a substance that causes permanent change
C a substance that causes permanent change; changes in the chromosomes
D a change in the genetic structure; substances that cause temporary change

3 **Recall** the definition of 'pedigree'.

A a cross that shows inheritance
B a diagram to show the inheritance pattern of a trait
C a particular breed of species
D a plot of chromosomes.

4 **Recall** the two vital properties DNA molecules have:

A DNA can carry information; DNA is organised in pairs
B DNA can make copies of itself; DNA can carry information
C DNA contains ribose sugar; DNA can make copies of itself
D DNA can leave the nucleus and attach to a ribosome; DNA is a nucleic acid.

5 **Identify** the missing phrases in the following sentence. Mitosis is ___________ and meiosis is ___________.

A a change in the sequence of the genetic material (DNA); part of a cell division where one parent nucleus divides to form two genetically identical daughter nuclei
B cell division in which the number of chromosomes is halved; the manipulation of the nucleotides to stop genes making protein
C the failure of a chromosome pair to separate at the centromere; the type of cell division that occurs when gametes are being made
D part of a cell division where one parent nucleus divides to form two genetically identical daughter nuclei; cell division in which the number of chromosomes is halved.

6 **Identify** which of the following is not a function of mitosis.

A replenishing the epithelial cells of the small intestine that are shed daily
B forming new red blood cells to replace those that are worn out
C forming cells for sexual reproduction
D repairing cuts and abrasions of the skin

7 **Identify** the four nitrogen bases found in DNA.

8 **Define** the term 'monohybrid cross'.

9 **Define** the following terms.

a GMO
b transgenic organism

10 **Recall** why it is important to know your blood group.

Comprehend

11 Use the terms 'gametes' and 'fertilisation' to **explain** how DNA is transferred from one generation to the next.

12 **Describe** Mendel's conclusions from his work on breeding peas.

13 **Explain** what is meant by the following formula:

Phenotype = genotype + environment

14 **Explain** the process of:

a gene cloning
b gene therapy.

15 **Describe** the sort of information that can be determined from the pedigree shown in Figure 1.

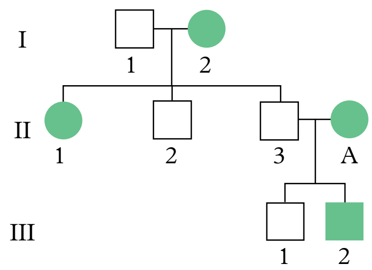

Figure 1 A pedigree

16 **Explain** why large-scale genetic screening programs reduce the prevalence of genetic diseases.

17 Gene therapy has been proposed as a treatment for a young boy suffering from Duchenne muscular dystrophy, a degenerative disorder of the muscles. **Describe** three factors that should be considered by the boy's health team prior to treatment.

Analyse

18 If a gene contains 600 nucleotide bases, **calculate** the number of amino acids that would be incorporated into the resulting protein. (HINT: 3 nucleotides = 1 codon = 1 amino acid.)

19 **Compare** a chromosome and a molecule of DNA.

20 **Contrast** the structure or function of DNA and RNA.

21 Use words and/or diagrams to **contrast**:

a a nitrogen base and a codon
b diploid and haploid.

22 **Contrast** the following pairs of terms.
  a autosome and sex chromosome
  b gene and allele
  c heterozygous and homozygous

23 **Contrast** the information provided by a chromosome and a gene.

24 If both parents have achondroplasia, **calculate** the chances of their children being unaffected.

25 **Consider** the Punnett square in Figure 2, which shows the inheritance for green (G) or yellow (g) pea colour in pea plants.

		Parent 1	
		G	g
Parent 2	G	GG	Gg
	g	Gg	gg

Figure 2 The inheritance of pea colours can be predicted with a Punnett square.

  a **Identify** the genotype and phenotype of Parent 1 and Parent 2.
  b **Calculate** the chances of Parents 1 and 2 producing offspring with green peas.
  c **Calculate** the chances of Parents 1 and 2 producing offspring with yellow peas.
  d **Explain** how you know one of the traits in the Punnett square is dominant.

Apply

26 A newborn baby shows distinct facial abnormalities. A karyotype (Figure 3) was prepared to determine whether there were any chromosomal abnormalities.

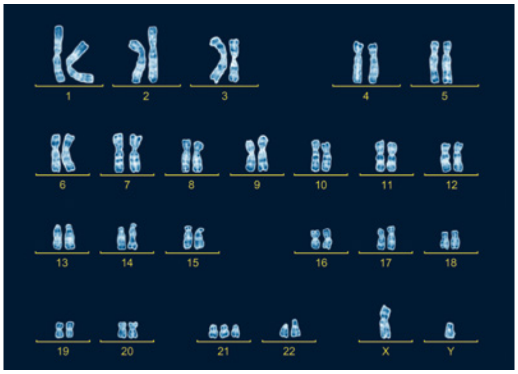

Figure 3 The newborn baby's karyotype

  a **Identify** the total number of chromosomes shown.
  b **Determine** if the child is male or female. **Justify** your answer (by describing the sex chromosomes present in a male and a female and comparing the descriptions to the karyotype, and deciding if the baby is male or female).
  c As the geneticist, **discuss** what you could tell the parents about their baby.

27 Wavy hair in humans is dominant to straight hair. A wavy-haired man and a straight-haired woman have two children. The first child has wavy hair and the second child has straight hair. **Determine** the genotype of all four individuals and use suitable symbols to **justify** your answer.

28 **Explain** whether the blood group of the first child in a family will affect that of the second child. **Justify** your answer (by describing the law of independent assortment, describing how this applies to the alleles of blood groups, and describing whether previous children affect the law).

29 A student wants to check whether her grey cat is heterozygous or homozygous for coat colour. Assuming breeding was ethical and time efficient, **describe** how the student could mate her cat to **determine** whether the cat is heterozygous or homozygous for coat colour. (HINT: Grey colour is a dominant trait.)

Social and ethical thinking

30 The debate around embryonic stem cells is heated. **Investigate** the advantages and disadvantages of using embryonic stem cells to test vaccinations. **Describe** how governments have intervened in this area. Select one ethical approach to **decide** if embryonic stem cells should be used.

31 Scientists have discovered dozens of genes that are believed to influence our athletic ability. In the lead up to the 2022 Winter Olympics, China announced that it would use genetic testing to assess the athletic potential of its athletes. This involved analysing blood samples of potential athletes for the presence of alleles believed to control athletic ability. In contrast, the Australian Institute of Sport has warned against genetic testing for athletic talent, especially in children. Select one ethical approach to **evaluate** this use of genetic testing.

32 Phenylketonuria is an autosomal recessive genetic disorder. It results in the lack of production of an enzyme that is needed to convert the amino acid phenylalanine to the amino acid tyrosine. A diet low in phenylalanine and high in tyrosine is prescribed to people with phenylketonuria to avoid problems with brain development. Every child born in Australia is now screened for phenylketonuria within weeks of birth. **Discuss** the benefits of such genetic screening.

Critical and creative thinking

33 Select a genetic disease and **create** a pamphlet for display in the reception area of a doctor's surgery. The pamphlet should outline information about the cause of the disease (genetic or chromosomal abnormality), pattern(s) of inheritance, the frequency of the disease in the population, diagnosis, symptoms and treatment.

34 **Create** a brochure that promotes the benefits of purchasing organic and non-GM foods. Alternatively, produce a brochure promoting the benefits of GM foods.

35 **Create** a teaching resource that could be used to teach a Year 7 student about the process of cell division.

Research

36 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

» Stem cell survival technique

Australian scientists have found a way to keep muscle stem cells alive so they can regenerate damaged tissue around them.

- » Explain why this technique is important.
- » Describe the technique used to keep the stem cells alive.
- » Describe the immediate uses of this technique.

» A shrinking Y chromosome

The Y chromosome has been losing genes over the course of time so that it is now only a fraction of the size of the X chromosome.

- » Describe how the Y chromosome has changed over time.
- » Describe the future of the Y chromosome.
- » Describe the impact on humans if the Y chromosome were to disappear.

» Cloning

An understanding of how cells replicate has allowed scientists to clone animals.

- » Define the term 'clone'.
- » Identify three animal clones that have been developed since Dolly the sheep in 1997.
- » Evaluate the benefits of cloning (by describing the advantages and disadvantages of cloning animals, comparing the costs of cloning and the benefits of cloning, and deciding if the cost is equivalent to the benefits).

» DNA barcodes

A single cell in a human can contain 3 billion pairs of nucleotides. Other organisms can contain even longer lengths of DNA in a cell. This can make it difficult to compare the DNA between different organisms. To make this easier, scientists use DNA barcoding to quickly identify commonalities.

- » Investigate what DNA barcoding is.
- » Explain why scientists may use this process.
- » Explain how fast computers have been used to compare the DNA sequence data sets in research.
- » Explain how it has been used to understand the cause of some genetic diseases.

Chapter checklist

Now that you have completed this chapter, reflect on your ability to do the following.

	I can do this.	I cannot do this yet.
• Explain the principles of segregation and independent assortment. • Describe the contributions of different scientists, including Franklin and Watson and Crick's research on DNA.	☐	☐ Go back to Topic 2.1 'Science as a human endeavour: Scientists review the research of other scientists'. Page 26
• Describe the structure of a nucleotide. • Explain the importance of DNA being able to make copies of itself and carry information.	☐	☐ Go back to Topic 2.2 'DNA consists of a sugar–phosphate backbone and complementary nitrogen bases'. Page 28
• Define the terms 'DNA', 'gene' and 'chromosome' and explain the relationship between them. • Interpret a human karyotype.	☐	☐ Go back to Topic 2.3 'Chromosomes carry genetic information in the form of genes'. Page 30
• Explain the role of DNA and RNA in the processes of transcription and translation.	☐	☐ Go back to Topic 2.4 'DNA holds the code for building proteins'. Page 32

• Describe the stages of mitosis. • Explain how and why a cell undergoes apoptosis.	☐	☐	Go back to Topic 2.5 'Mitosis forms new somatic cells'. Page 34
• Describe the stages of meiosis I and meiosis II.	☐	☐	Go back to Topic 2.6 'Meiosis forms gamete cells'. Page 36
• Explain how combinations of dominant and recessive alleles produce different genotypes and phenotypes in individuals. • Predict genotypic and phenotypic ratios of a monohybrid cross using Punnett squares.	☐	☐	Go back to Topic 2.7 'Alleles can produce dominant or recessive traits'. Page 38
• Describe the different genotypes and phenotypes of human blood groups. • Explain the function of different blood groups and Rhesus markers and their importance. • Predict the inheritance of co-dominant traits using Punnett squares.	☐	☐	Go back to Topic 2.8 'Alleles for blood group traits co-dominate'. Page 40
• Identify a trait as one of the four patterns of inheritance (autosomal dominant, autosomal recessive, X-linked dominant and X-linked recessive). • Explain how and why sex-linked traits are inherited differently in males and females. • Describe how different sex-linked traits such as haemophilia and red–green colour blindness are inherited.	☐	☐	Go back to Topic 2.9 'Alleles on the sex chromosomes produce sex-linked traits'. Page 42
• Analyse and interpret pedigrees to determine if a trait is dominant, recessive, autosomal or sex-linked. • Analyse and interpret pedigrees to predict whether an individual will inherit a disease.	☐	☐	Go back to Topic 2.10 'Inheritance of traits can be shown on pedigrees'. Page 46
• Distinguish between genetic and chromosomal mutations. • Explain how substitution and frameshift mutations alter nucleotide and amino acid sequences of a protein.	☐	☐	Go back to Topic 2.11 'Mutations are changes in the DNA sequence'. Page 50
• Describe the purpose of genetic screening and testing. • Provide examples of diseases that are screened for.	☐	☐	Go back to Topic 2.12 'Science as a human endeavour: Genes can be tested'. Page 54
• Explain the human need for selected GMOs to be produced. • Outline how a desirable gene can be inserted into a plant cell.	☐	☐	Go back to Topic 2.13 'Science as a human endeavour: Genes can be manipulated'. Page 56
• Outline the process of gene cloning. • Explain how gene therapy can be used for medical treatment. • Describe the different types of stem cells and their uses in medicine.	☐	☐	Go back to Topic 2.14 'Science as a human endeavour: Genetic engineering is used in medicine'. Page 58

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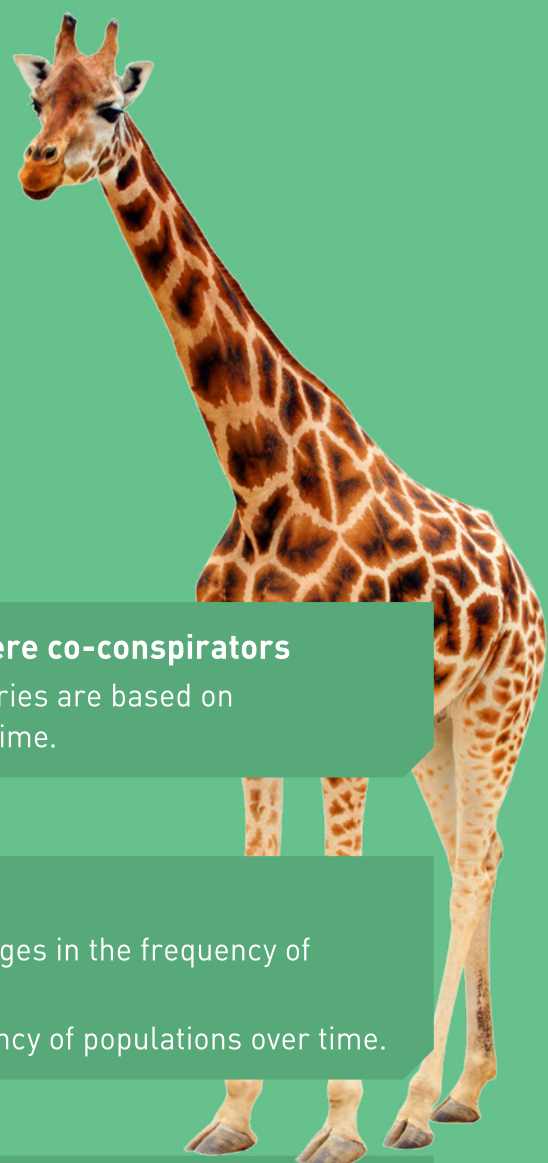
Quizlet
Play a Quizlet game to test your knowledge.

Chapter quiz
Check your understanding of this chapter with the chapter review quiz.

CHAPTER

3



EVOLUTION

3.1 Science as a human endeavour: Darwin and Wallace were co-conspirators

> Use evolution as an example to explain how scientific theories are based on substantiated evidence that is contested and refined over time.

3.2 Natural selection is the mechanism of evolution

> Describe how natural selection results in permanent changes in the frequency of alleles in a population.

> Discuss how selection pressures change the allele frequency of populations over time.

3.3 Different selection pressures cause divergence. Similar selection pressures cause convergence

> Explain how different selection pressures can cause divergence and the formation of new species (speciation).

> Explain how similar selection pressures can cause convergence.

3.4

Fossils provide evidence of evolution

> Explain how the existence of fossils provides evidence to support the processes of evolution.
> Describe how fossils are dated using relative and absolute dating techniques.

3.5

Multiple forms of evidence support evolution

> Explain how continental drift provides a well-supported explanation for the geological isolation of species that eventually results in divergent evolution.
> Identify vestigial structures and explain how they are interpreted as evidence of an ancestral heritage in which these structures once performed other tasks.

3.6

DNA and proteins provide chemical evidence for evolution

> Explain how mutations can cause small differences that can accumulate over time.
> Explain how scientists use the differences in DNA sequences to compare evolutionary relationships between species.

3.7

Humans artificially select traits

> Describe how the breeding of an organism with desirable traits has led to domestication.
> Explain how the misuse of antibiotics has led to the evolution of super-bacteria such as MRSA.

3.8

Science as a human endeavour: Natural selection affects the frequency of alleles

> Explain how malaria is a selection pressure for the sickle cell anaemia allele.
> Describe how the process of natural selection can result in an increase in the frequency of the sickle cell allele in malaria prone regions.

What if?

Lolly selection

What you need:

Range of eating utensils (e.g. spoons, forks, chopsticks or straws), lollies

CAUTION! Make sure you check for food allergies and avoid using lollies that present a risk of anaphylaxis.

What to do:

1 This is a whole-class activity. Each group of students has a different type of eating utensil, such as spoons, forks, straws or chopsticks. Each group has the same mix of lollies.

2 Using only the tool provided, try to collect as many of the lollies as possible into a bowl.

What if:

» What if there were more spoons? (Would some lollies be collected more quickly/slowly?)

» What if only hard-boiled lollies were available? (Which utensil would collect the most lollies?)

» What if straws were the only utensil available? (What type of lolly could they be used for?)

//SCIENCE AS A HUMAN ENDEAVOUR//

3.1 Darwin and Wallace were co-conspirators

Learning intentions

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

- use evolution as an example to explain how scientific theories are based on substantiated evidence that is contested and refined over time.

Video 3.1 Galapagos

Scientific theories are explanations of the natural world that are based on well-substantiated evidence. These theories are contested and refined over time through a process of review by the scientific community. The statement 'organisms change in response to environmental pressures' is an observation. Natural selection as the mechanism of evolution, as proposed by Charles Darwin and Alfred Wallace, is a scientific theory that has 200 years of reproducible experimental evidence supporting it.

Figure 1 These layers of rock are an indication of different time periods. Pale layers can sometimes represent volcanic ash released during an eruption.

Before evolutionary theory

The generally accepted belief for many thousands of years was that life was 'created' by gods. Even events such as volcanic eruptions and earthquakes were considered to be expressions of the emotions of the gods. Societies could have one or more gods, which could be human or animal-like in appearance.

There was little thought given to whether organisms changed over time. The idea of extinction was not proposed until the 1790s, when William Smith uncovered fossils while analysing the geology of a mine in England. Fossils were already known to be the remains of living organisms, but Smith identified organisms that had never been seen before and was able to 'date' them by the layer of rock in which they were found (Figure 1). This later became known as relative dating.

Georges Cuvier, a French zoologist, collected and examined many fossils. He concluded that many of the animals represented were remains of species now extinct. Mary Anning collected and sold fossils to support her family and was the first person to discover a 5 m *Ichthyosaurus* fossil. Because women were not allowed to join scientific societies, the fossils she sold were claimed as discoveries by men.

Early evolutionary theory

Evolutionary theories were all proposed without any knowledge or understanding of DNA and genetic inheritance – making the following accounts even more remarkable.

LAMARCKIAN THEORY

One of the first documented theories of evolution was by Jean-Baptiste de Lamarck, a French naturalist. Lamarck believed in evolutionary change – that organisms change over time due to changing environmental conditions. He is best known for his hypothesis of inheritance of acquired characteristics, which was first presented in 1801. In this hypothesis, Lamarck proposed that if an organism changes during its lifetime in order to adapt to its environment, those changes are passed on to its offspring. This is how he explained the long necks of giraffes (Figure 2). The giraffes needed to stretch their necks to reach food in the tops of the trees. Because their necks were strong, their children were born with long and strong necks.

There are many problems with Lamarck's hypothesis. For example, Lamarck's hypothesis implied that a man who had lost his arm would have children with weak or deformed arms. This was obviously not the case. August Weismann finally provided scientific evidence when he cut the tails off 22 generations of mice, continually allowing them to breed with each other. Unsurprisingly, all their offspring were born with tails.

CHARLES DARWIN

Charles Darwin was well educated and had been exposed to the sciences from an early age through his father and grandfather, who were both physicians. Darwin had also read the works of Lamarck. In 1832, the young 23-year-old set sail on a 5-year world cruise as the unpaid naturalist on the HMS *Beagle*.

During the final stages of the voyage, the ship visited the Galapagos Islands, about 1000km off the coast of South America. Here, Darwin made his most significant observations.

Darwin and his helpers collected specimens, trying to obtain at least one of each species. Among the specimens collected were 13 finches, all of which looked very much alike, including the structure of their beaks, the form of their bodies and their plumage. Yet each specimen represented a new species and most had been found on different islands.

In his journal, Darwin noted that these birds were strikingly similar to those found on the mainland of South America.

Figure 2 Lamarck believed that giraffes stretched their necks to reach food and that their offspring, and later generations, inherited the resulting stretched long necks.

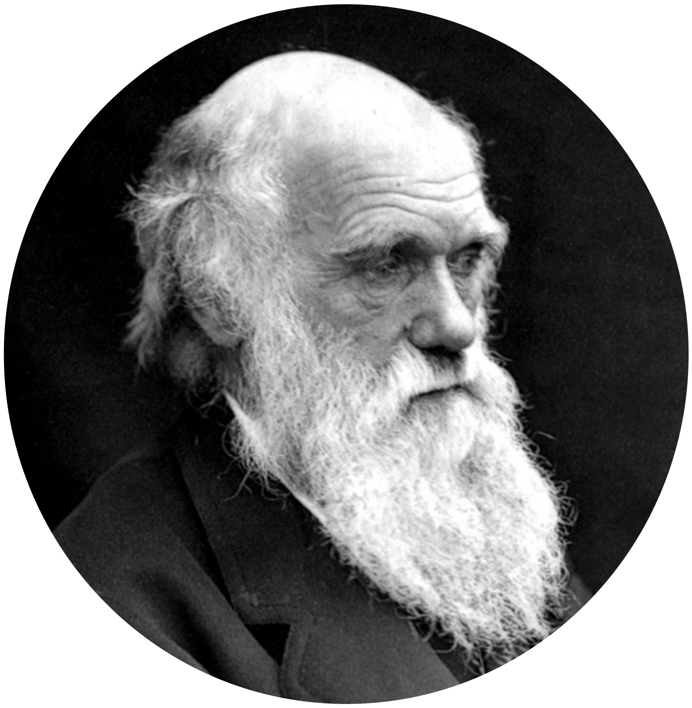


Figure 3 Charles Darwin's theory of evolution was a departure from the traditional view of Creation and attracted much public interest and criticism.

He wondered why the different populations looked so similar, if new and different beings had been placed on the islands at the time of Creation.

Figure 4 On the Galapagos Islands, tortoises' shells vary in shape according to habitat.

The dry, volcanic Galapagos Islands archipelago is also home to different species of tortoise. Darwin noted that the different types of tortoise had different-shaped shells (Figure 4). Tortoises that live on dry islands, such as Hood Island, have shells that are raised at the front so they can reach up for vegetation. In contrast, tortoises that live on islands with dense vegetation have low domed shells to help them push through the shrubbery.

When he returned to England, Darwin became aware that humans have selectively bred pigeons and racehorses for more than 10 000 years by choosing breeding partners for animals and other organisms in an effort to 'select' for certain traits in their offspring. Over many generations, the 'wild' traits are often lost and the species is considered 'domesticated'.

Darwin then wondered how 'selection' occurred in nature. Thomas Malthus's paper, *An Essay on the Principle of Population*, gave Darwin the insight he needed.

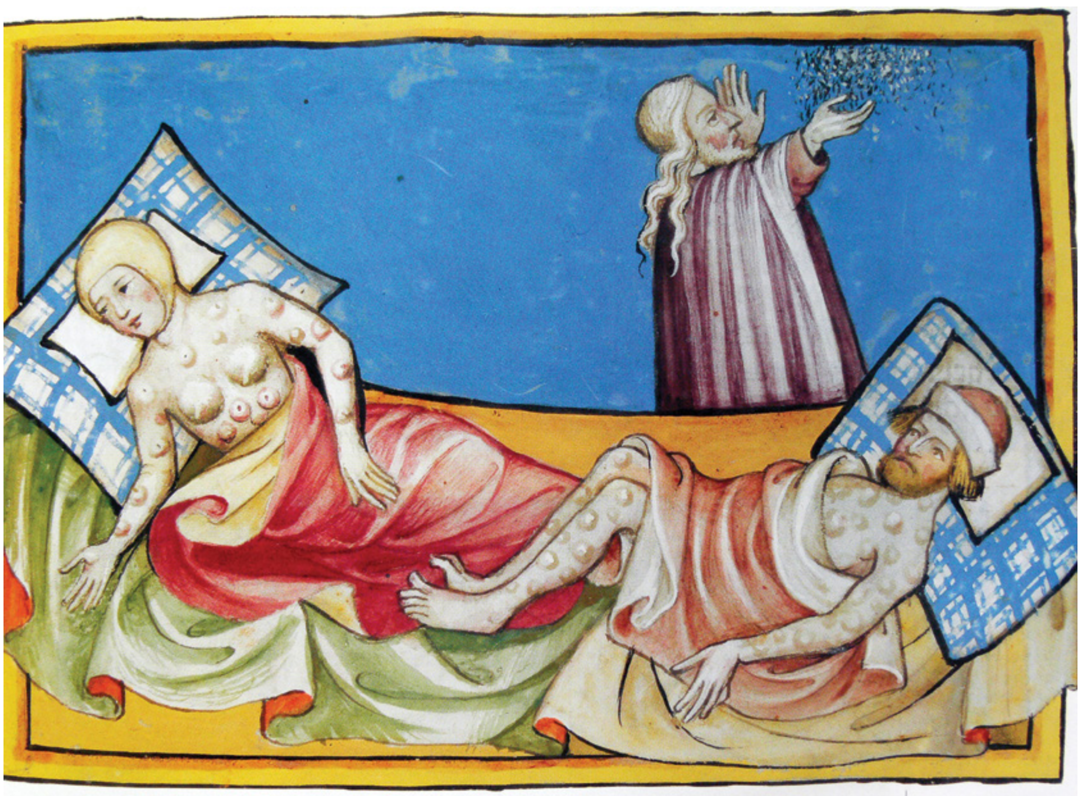


Figure 5 Was the plague simply nature's way of keeping the human population in check?

Malthus argued in his paper that the human race would completely overrun the Earth if it was not held in check by war, famine and disease, such as the plague, or 'Black Death', in the fourteenth century (Figure 5). Darwin concluded from this that, under changing circumstances, favourable variations would tend to be preserved and unfavourable ones would be destroyed.

At last Darwin had a hypothesis to test. But it would take another 20 years of painstaking hard work discussing dog and horse breeding with farmers, and conducting experiments with pigeon breeding and barnacles, before he was convinced that his hypothesis had enough support to be developed into a theory.

ALFRED RUSSEL WALLACE

Alfred Russel Wallace (1823–1913) was a naturalist working at the same time as Darwin. Wallace collected specimens from tropical regions, particularly the Malay Archipelago, which is now Malaysia and Indonesia. Wallace collected thousands of insects, shells and bird skins, as well as mammal and reptile specimens, many of which were new species to science at the time. One of his best-known discoveries was Wallace's golden birdwing butterfly.

During his time in the Malay Archipelago, Wallace proposed the theory of natural selection as the mechanism of evolution. In 1858, he wrote a series of letters to Darwin outlining his idea. Darwin and his friends were worried about who should get the credit for the two theories, which were essentially identical.

They decided to read Wallace's letter and Darwin's paper, one after the other, at the Royal Linnaean Society of London. We now associate Darwin with the theory of evolution because, in 1859, Darwin followed the papers with his book *On the Origin of Species by Means of Natural Selection*.

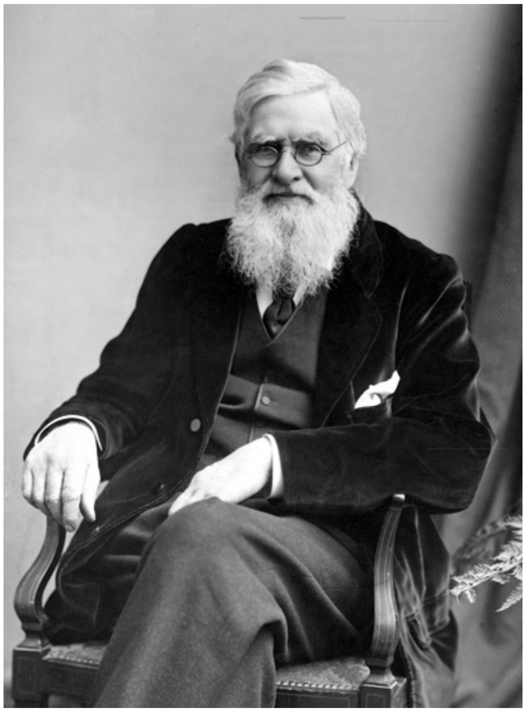


Figure 6 Alfred Russel Wallace formed the same theory as Darwin and at the same time. Wallace's work was conducted in Asia, whereas most of Darwin's observations were made in South America. Darwin had the advantage of a wealthy family that could assist him in being published. Perhaps this is why Darwin receives all the credit.

3.1 Test your skills and capabilities

Refining science theories

Although Charles Darwin is credited with the theory of evolution, he built upon the ideas of other scientists, including Jean-Baptiste de Lamarck, Georges Cuvier, Alfred Russel Wallace and August Weismann.

1 **Evaluate** who should receive credit for the theory of evolution by:
   > drawing a timeline of the scientists and their contributions to the theory of evolution
   > comparing (the similarities and differences between) Lamarck's theory and Darwin's theory
   > discussing the importance of August Weismann's experiment
   > comparing the different approaches of Darwin and Wallace
   > deciding which scientists made significant contributions to the theory of evolution.

3.2 Natural selection is the mechanism of evolution

Learning intentions

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

- describe how natural selection results in permanent changes in the frequency of alleles in a population
- discuss how selection pressures change the allele frequency of populations over time.

Key ideas

- Evolution is the permanent change in the number of alleles in a population due to natural selection.
- Natural selection is the process where selection pressures select for or against a trait or characteristic so that a species becomes better suited to its environment.
- All scientists make observations of the world around them; they then use these observations and reasoning to make a conclusion (an inference).

biodiversity
the variety of life; the different plants, animals and microorganisms and the ecosystems they live in

gene pool
all the genes or alleles in a population

selection pressure
the environmental factors that affect an organism's ability to survive

Observations and inferences

Although scientists knew that living organisms changed over time, how the change occurred was first described by Charles Darwin and Alfred Wallace. They did this through a series of observations.

1. Members of a species are often different from each other.
2. There are always more children than parents.
3. The size of a population does not change.
4. Some offspring do not survive (survival of the fittest).
5. Offspring look like their parents.

These five observations led Darwin to make three key inferences.

1. There is a struggle to survive, in which some organisms die.
2. The organisms that die are not chosen at random – those individuals that are most suited to their environment survive.
3. Those individuals that survive pass their favourable traits on to their children.

Variations in populations

Natural selection cannot occur unless there is **biodiversity** in a population. A biodiverse population has many different types of traits, from camouflage colour to the ability to sense and defend against predators. Some species will even have traits that allow them to survive in different temperatures. But where does this variation come from?

Figure 1 These Siberian huskies have different versions, or alleles, of the gene for eye colour.

Much of the variation between individuals is due to genetic differences that can be inherited – something Darwin and his contemporaries observed but did not understand.

Individuals of the same population generally have the same number and types of genes but different alleles (variations of the genes). For example, all humans will have the gene for eye colour, but the alleles they have for this gene may be blue, brown or even hazel. New alleles arise because of small changes in the DNA sequence. Some mutations are not obvious in the appearance of an organism. Other mutations cause variations in the physical appearance (phenotype) of the individual. For example, it was a single mutation about 6000–10 000 years ago that resulted in one of our ancestors having blue eyes.

All the different types of genes in the entire population can be thought of as a **gene pool** – a pool of genetic information. The gene pool includes all the alleles for all the genes in the population. New alleles arise through changes (or mutations) in the DNA that makes up the genes.

A mutation may give an individual an advantage, making them better able to survive than others of their population. This means they have a greater chance of mating and passing their genetic advantage on to their offspring.

Selection pressures cause some of these new variations to survive and others to die. Selection pressures include any environmental factor affecting an organism's chance of survival. For example, it may be an advantage to be able to survive in hot weather, or to escape a predator by running fast. If an organism is suited to its environment, then it is able to mate and produce offspring.

EXPERIMENT

3.2: What if the habitat of bean prey was changed?
Go to page **238**.

The offspring will have the same survival characteristics (and the corresponding alleles) as their parent. This gradually changes the frequency of alleles in the gene pool. This process of selecting for or against a characteristic so that the species will be better suited to its environment is called **natural selection**.

Allele frequencies

The frequency of an allele is how common that allele is within a population. The allele frequency is affected by environmental conditions. If the environmental conditions are favourable, then more of that allele will appear in the next generation.

An example of this is the ability of First Nations peoples in Western Australia to avoid the damaging effects of high temperatures. It is thought that a single mutation in a gene (creating a new allele) changes how their bodies react to high temperatures. In hot weather, their bodies do not increase metabolic activity, reducing the extra heat that is usually generated. This ability is also useful during an infection, as it can prevent the development of high fevers. It also provides a selection advantage in the extreme heat of the inland areas of Australia. This survival advantage means they are more likely to survive and have children with the same alleles. This increases the number of individuals with the same alleles and increases the frequency of the allele in the population.

Evolution is the permanent change in the frequency of alleles in a population due to natural selection.

Mutating moths

Figure 2 Dark-coloured moths of the species *Biston betularia* increased in numbers when air pollution killed lichen on trees. Lighter-coloured moths (such as the one on the right side of the image) became more visible to predators and were selected against.

In the 1950s, scientists in England documented changes in the colour of the moth species *Biston betularia*. These moths range in colour from light grey to nearly black. During the day, the moths rest on tree trunks. In unpolluted areas, tree trunks are covered with light-grey lichens, against which lighter moths are well camouflaged. In areas with severe air pollution, lichens cannot survive, so tree trunks are lichen-free and dark, exposing lighter moths to predation from birds.

It seemed to researchers that, as areas became more polluted, dark moths increased in frequency. This is often described as selection pressure. The darker-coloured bark allowed the dark moths to survive (be selected for), and caused the lighter moths to be eaten (be selected against). Natural selection was increasing the frequency of the allele for dark colour in the population. This was selection pressure in favour of the 'dark' colour allele.

In 1952, strict pollution controls were introduced in England, the lichens returned, and the tree trunks became mostly free of soot. Predictably, selection pressures started to operate in the reverse direction. In areas where pollution levels decreased, light moths were selected for and dark moths were selected against. The frequency of dark moths decreased.

Other examples of directional selection include the evolution of pesticide-resistant insects and antibiotic-resistant bacteria. In these cases, our use of chemicals (i.e. pesticides or antibiotics) has selected for variants that are resistant to the chemicals.

natural selection
when the natural environment selects for or against a physical characteristic

evolution
the gradual change in the genetic material of a population of organisms over a long period of time

3.2 Check your learning

Comprehend

1 Variation in individuals can occur in different ways, but there is only one way in which new alleles can arise. **Describe** the process that can result in new alleles.

2 **Describe** the selection pressures that caused the allelic frequency of light-grey moths to decrease in England in the 1950s.

3 In your own words, **describe** the mechanism by which natural selection can influence the frequency of alleles in a population.

4 **Explain** why natural selection cannot increase or decrease the frequency of some mutations in a population.

Analyse

5 Darwin made a series of inferences based on observations he made over 20 years. **Connect** each of Darwin's observations with the appropriate inference he made.

Apply

6 **Create** a diagram that illustrates the process of natural selection of the moths in England.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

3.3 Different selection pressures cause divergence. Similar selection pressures cause convergence

Learning intentions

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

- explain how different selection pressures can cause divergence and the formation of new species (speciation)
- explain how similar selection pressures can cause convergence.

Key ideas

- Speciation is the formation of a new species that cannot reproduce with other species.
- Allopatric speciation can occur when a permanent barrier separates a population and prevents gene flow.
- Divergence occurs when one population becomes two new species.
- Convergence occurs when two different species become more physically similar due to similar selection pressures.

speciation
the process that results in the formation of a new species

adaptation
a characteristic or behaviour of a species that allows it to survive and reproduce more effectively

gene flow
the flow of genes from one generation to the next, or from one population to the next, as different families or groups in the population choose partners and mate

isolation
the division of a population into two groups

diverge
in relation to two species: to become more different over time due to different selection pressures, possibly becoming reproductively isolated

homologous structure
structure that is similar in different species, because those species evolved from a common ancestor, but do not necessarily have the same function now; an example is forelimbs in different mammal species

A species is a group of organisms who are able to breed with each other in natural conditions to produce offspring that are viable (alive) and fertile (able to have children of their own).

The process of forming a new species is called **speciation**.

Speciation

When a variation within a species is favoured by the environmental conditions, it is referred to as an **adaptation**. Variations within a species provide 'options' for the species when environmental conditions change. Although individual organisms may be wiped out, some members of the population with the favourable adaptation survive and continue the species' gene pool.

Along the way, entire species may become extinct and new species will emerge. New species can increase the biodiversity of the environment.

Under normal conditions, genes in a given population are exchanged through breeding. This means the genes will flow from one generation to the next as families or groups in the population choose partners and mate. This is called **gene flow**. But the gene flow is interrupted if the population becomes divided into two groups; this is called **isolation**. If there is no exchange of genes between the two groups, then they may begin to look and behave differently from each other.

Over time, different selection pressures occur in the two groups. Different characteristics are selected for. Given enough time for evolution to occur, the two populations may become so different that they are incapable of interbreeding should they ever come together again. The two populations become reproductively isolated and therefore are different species (speciation). The two species have **diverged**.

Allopatric speciation is one of the most common ways species become different or diverge. In this type of speciation, a permanent barrier such as canyons, rivers, roads or oceans separates a population of organisms, allowing different mutations and selection pressures to change the allelic frequencies until they are different species.

Even though populations diverge and become different species, they retain some characteristics in common. These characteristics, such as forelimbs, may be used for different purposes because the selection pressures have changed. Common structures that are found in different species often have a similar pattern but a different function. These structures are known as **homologous structures**. The most commonly discussed homologous structure is the pentadactyl limb – the pattern of limb bones in all groups of tetrapods (four-legged vertebrates) that ends in five digits (Figure 1). This structure is found in the fins of certain fossil fishes from which the first amphibians are thought to have evolved.

EXPERIMENT
3.3: Divergent and convergent evolution of big beaks and small beaks
Go to page **239**.

All tetrapods have the same basic structure of the pentadactyl limb.

These commonalities indicate that these organisms originated from a common ancestor. But, during the course of evolution, mutations and different selection pressures modified these structures and they are now used for different purposes.

Analogous structures are structures in organisms that perform the same function but are structurally different (suggesting no recent common ancestor). For example, a dolphin (mammal) and a shark (fish) have the same environmental selection pressures. Although these species do not share a recent common ancestor, they both need to move through water fast enough to catch fish and escape predators. As a result, they both have a streamlined body with fins and a tail. This is an example of **convergent evolution**. The wings of birds and butterflies are also analogous structures (Figure 2).

analogous structures
structures in organisms of different species that have the same function but are structurally different, because they evolved independently; for example, wings in birds and bats

convergent evolution
the process whereby unrelated organisms evolve to have similar characteristics as a result of adapting to similar environments

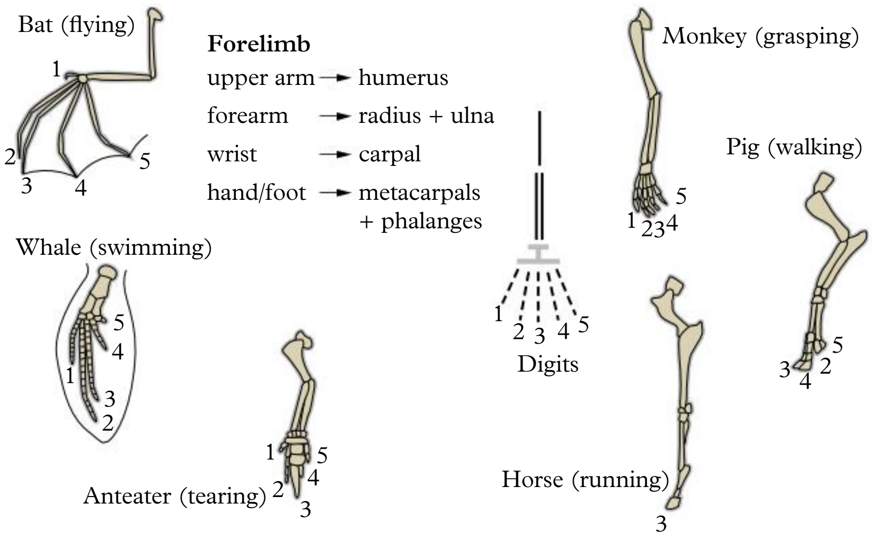


Figure 1 The homologous forelimbs of different mammals show the same basic structure, with a single upper bone, two lower limb bones, small wrist or ankle bones and five digits that are adapted to different uses.

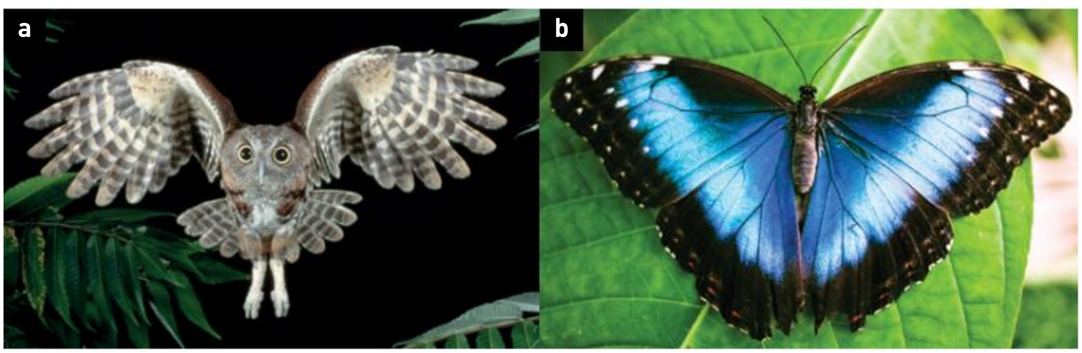


Figure 2 The wings of **a** a bird and the wings of **b** a butterfly are analogous structures: they perform the same function but have significantly different structures.

3.3 Check your learning

Retrieve

1 **Define** the term 'homologous structure'.
2 **Identify** an example of an analogous structure.
3 **Define** the term 'speciation'.

Comprehend

4 Use an example to **describe** how a permanent barrier could create a new species.
5 **Describe** how gene flow influences the process of speciation.

Analyse

6 **Contrast** an individual organism adapting to the environment, and the adaptation of a species.

Apply

7 **Discuss** how the land ancestors of dolphins evolved to become the streamlined mammals we see now.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

3.4 Fossils provide evidence of evolution

Learning intentions

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

- explain how the existence of fossils provides evidence to support the processes of evolution
- describe how fossils are dated using relative and absolute dating techniques.

Key ideas

- Fossils are remains or traces of an organism that once existed.
- Transitional fossils are intermediary fossils that have traits of both the ancestral organism and the more recent organism.
- Relative dating determines the relative order in which the fossilised remains were buried; older fossils are found in deeper layers than more recent fossils.
- Absolute dating uses the amount of radioactivity remaining in the rock surrounding the fossil to determine its age.

fossil
the remains or traces of an organism that existed in the past

fossilisation
the process of an organism becoming a fossil

transitional fossil
a fossil or an organism that shows an intermediate state between an ancestral form and its descendants; also known as a 'missing link'

relative dating
a method of determining the age of an object relative to events that occurred before and after

absolute dating
a method of determining the age of a fossil, by measuring the amount of radioactivity remaining in the rock surrounding the fossil

half-life
the time it takes the radioactivity in a substance to decrease by half

Evolution

Support for any theory, including evolution, requires evidence from a range of sources that all point towards the same explanation. Early evidence for evolution came from the discovery of fossils that identified extinct species. A species is extinct when there are no living members of the species left. The discovery of many unknown types of plants and animal fossils reinforced the fact that life forms change with changing environmental pressures – even if that simply means that many die and only few survive.

What are fossils?

Fossils are the remains or traces, such as footprints, imprints or coprolite (fossilised faeces), of organisms from a past geological age embedded in rocks or other substances by natural processes.

Fossilisation requires the organism, or its traces, to be buried away from oxygen quickly so that weathering and total decomposition do not occur. Skeletal structures or other hard parts of organisms that resist weathering are slower to decompose and therefore are more likely to form fossils.

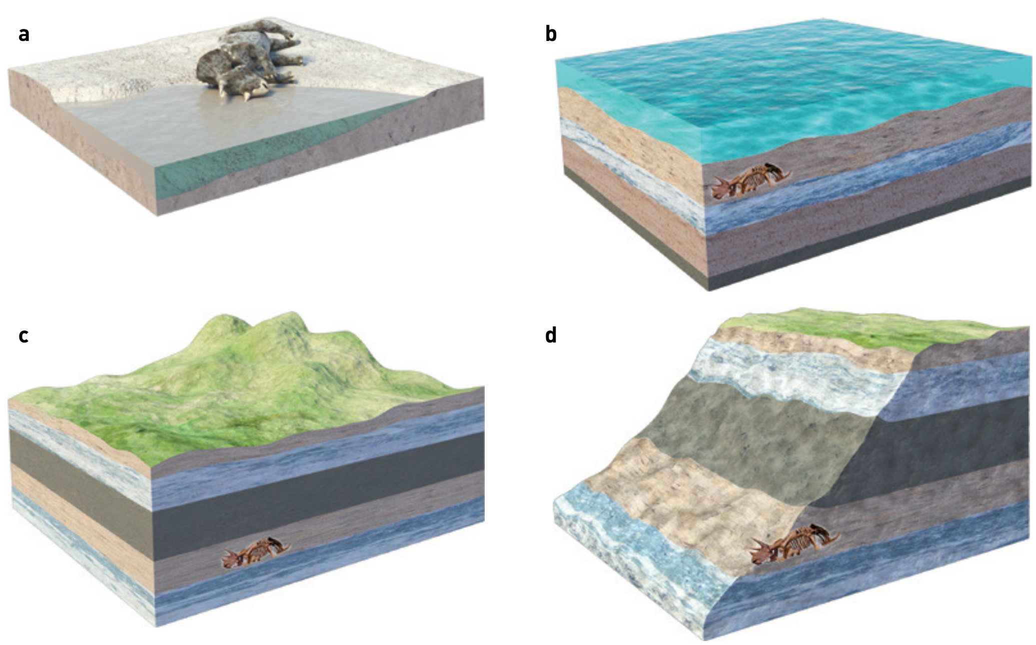


Figure 1 Formation of a fossil. **a** and **b** If an organism dies near water, it has a greater chance of being covered by sediment. The sediment protects the body from predators and weathering. **c** Over millions of years, more sediment is deposited, replacing the remains so they are transformed gradually into sedimentary rock. **d** Years of geological movement, weathering and erosion may eventually expose the fossil.

These are the most common form of fossilised remains. Figure 1 shows how the process of fossilisation occurs.

Transitional fossils

Darwin's theory suggests that life originated in the sea, crawled onto land and then took to the skies or grew fur. The evidence that links these stages is in the form of **transitional fossils**, which are sometimes referred to as 'missing links'. Transitional fossils will often display some characteristics of two different species.

When Darwin first published his theory, he stressed that the lack of transitional fossils was the largest obstacle to his theory because, at that time, very little was known about the fossil record. Since then, many excellent examples of transitional fossils have been found, such as *Archaeopteryx* (Figure 2), which was discovered in the Solnhofen area of Germany just 2 years after Darwin's work was published. *Archaeopteryx* is the earliest and most primitive bird.

Dating fossils

It is possible to find out how a particular group of organisms evolved by arranging its fossil records in a chronological (time) sequence. **Relative dating** can provide approximate dates for most fossils because fossils are found in sedimentary rock. Sedimentary rock is formed by layers (or strata) of silt or mud on top of each other (Figure 3). Over time, the layer containing the fossil is buried deeper under the surface. The deeper the layer, the older the rock. Each layer acts as a time capsule that contains fossils that lived during that period. Older fossils are buried deeper than younger fossils.

Advances in our understanding of matter have led to technologies that can provide more accurate time frames for fossils. **Absolute dating** relies on the level of radioactivity in the fossil. Every living organism maintains a constant low level of radiation. When an organism dies, the amount of radioactivity starts decreasing. The time it takes for half the radioactivity to decrease is called the **half-life**. In one half-life, there is a 50 per cent decrease in the initial radioactivity level. In the second half-life, the remaining radioactivity decreases by half again, leaving only 25 per cent of the starting radioactivity level. This will continue until only very small levels of radioactivity are left.

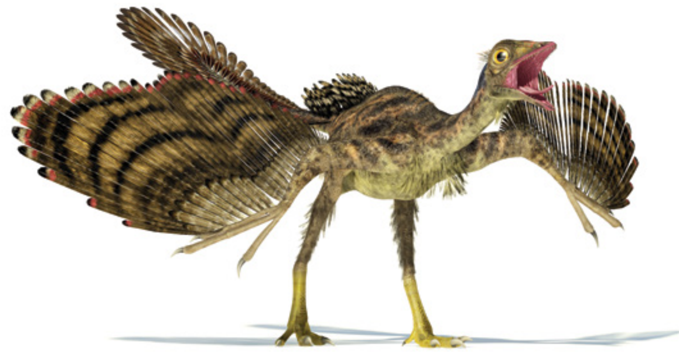


Figure 2 *Archaeopteryx* is an important transitional fossil. It displays a number of features common to both birds (hollow wishbone and feathers) and reptiles (teeth, flat sternum/breastbone, three claws on the end of its wings and a long bony tail).

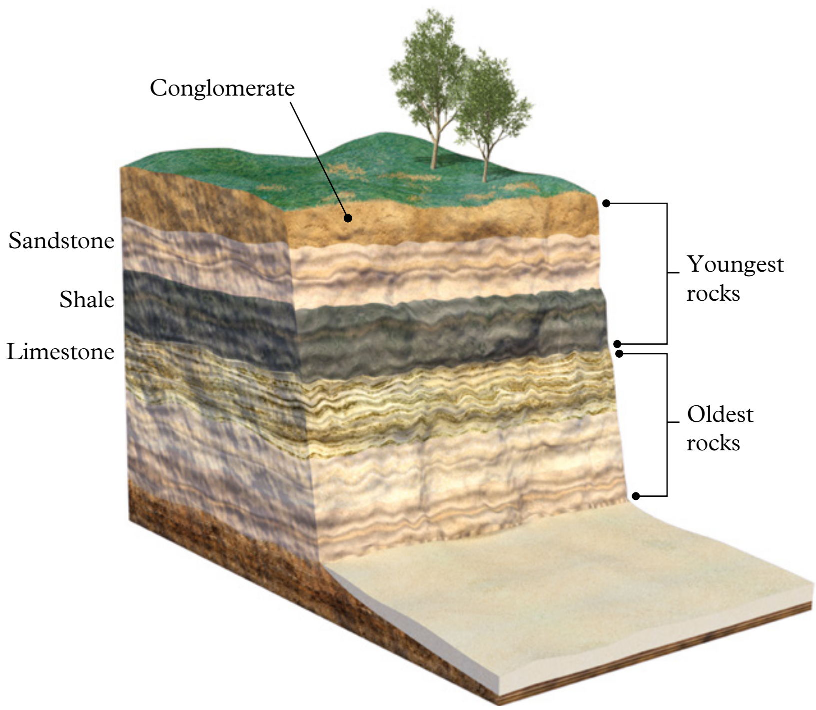
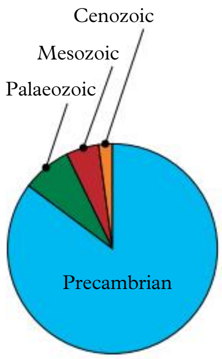


Figure 3 Relative dating is used to work out the age of rocks and fossils. Older rocks are found below younger rocks.

Figure 4 This fossil of *Triceratops horridus* is 65 million years old.

If scientists know the length of an element's half-life, they can determine how many half-lives have passed by measuring the amount of radioactivity.

Therefore, they can determine the age of the fossil or rock. Worked example 3.4 illustrates how to calculate the number of half-lives that have passed in a fossil.



This pie chart shows the relative duration of the four eras.

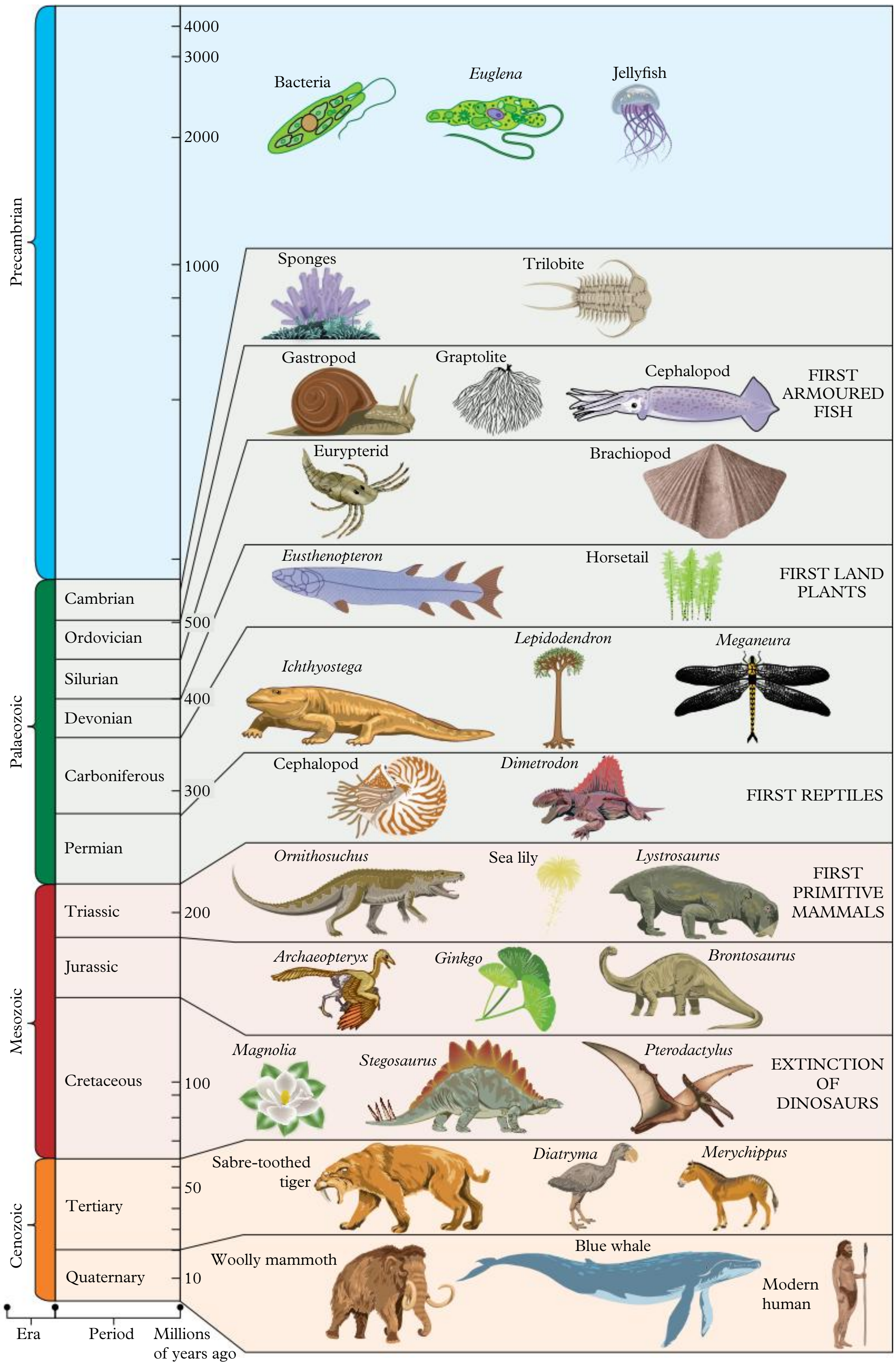


Figure 5 The history of living things (mya = million years ago), as determined by palaeontology (the study of fossils)

EXPERIMENT

3.4: Popcorn dating
Go to page **240**.

Worked example 3.4: Calculating half-lives

A fossilised piece of coral was found at a beach in Beaumaris, Melbourne. Scientists at the Melbourne Museum determined that the fossil has $\frac{1}{8}$ of radioactive carbon-14 remaining.

a Calculate the number of half-lives that have passed in the fossil.

b If 1 half-life = 5000 years, calculate the age of the fossil.

Solution

a After 1 half-life, $\frac{1}{2}$ of the radioactive material will remain.

After 2 half-lives, $\frac{1}{4}$ of the radioactive material will remain $\left(\frac{1}{2} \times \frac{1}{2}\right)$.

After 3 half-lives, $\frac{1}{8}$ of the radioactive material will remain $\left(\frac{1}{2} \times \frac{1}{4}\right)$.

Therefore, 3 half-lives have passed.

b If 1 half-life = 5000 years, 3 half-lives = 15 000 years. The fossil is 15 000 years old.

Living fossils

According to fossil records, some modern species of plants and animals are almost identical to species that lived in ancient geological ages. **Living fossils** are plants or animals that have not changed their shape or way of living for thousands or even millions of years. This means the selection pressures for these organisms have not changed and therefore there has been no pressure for the organism to change.

Trace fossils

Not all fossils are bones. Occasionally, other forms of evidence for living things can be found. Footprints in mud can become permanent indentations when the mud becomes stone. Faeces (or poo) can become buried and form a fossilised coprolite. Plants can leave a leafy imprint. All of these forms of evidence are called trace fossils.

living fossil
an existing species of ancient lineage that has remained unchanged in form for a very long time

3.4 Check your learning

Retrieve

1 **Define** the term 'transitional fossil'.

Comprehend

2 **Describe** the process of relative dating a fossil.

3 Living fossils have remained relatively unchanged, often for millions of years, while around them other species have adapted or become extinct. **Explain** why some species are able to remain unchanged for such a long period.

Analyse

4 A fossil of a giant 7 cm long mega shark tooth (*Carcharocles angustidens*) was found on the beach of Jan Juc. The age of the fossil could be determined using absolute dating. If the amount of hafnium-182 (half-life ~ 8 million years) remaining had decreased from 100 per cent to 12.5 per cent, **calculate** the age of the tooth.

5 **Contrast** relative dating and absolute dating.

Apply

6 **Evaluate** whether the theory of evolution will ever become fact (by contrasting the scientific terms 'theory' and 'fact', and deciding whether the theory of evolution could become a fact).

7 Fossils were found at four locations (Figure 6). Use relative dating to **determine** which location had the oldest fossils.

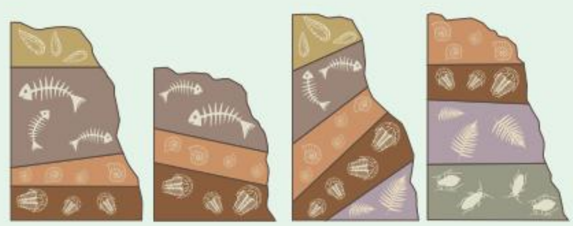


Figure 6 Fossils found at four different locations

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

3.5 Multiple forms of evidence support evolution

Learning intentions

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

- explain how continental drift provides a well-supported explanation for the geological isolation of species that eventually results in divergent evolution
- identify vestigial structures and explain how they are interpreted as evidence of an ancestral heritage in which these structures once performed other tasks.

Key ideas

- Biogeography is the study of how the continents move across the Earth and how this directly affects the location of organisms.
- When continents collide, species can spread, and when continents separate, the new species move with them.
- The study of how genetic material affects the development of embryos (embryological studies) is a new and growing field of study.

Biogeography

At the beginning of the seventeenth century, the English philosopher Francis Bacon noted that the east coast of South America and the west coast of Africa looked as though they could fit together like pieces of a jigsaw (Figure 1). Since then, our knowledge of the structure of the Earth has developed, and the theory of **continental drift** through plate tectonics continues to be supported by observations of various phenomena across the planet. It is now thought that at one time all the continents were connected in a single land mass – Pangaea (Figure 2). This supercontinent then broke into two to form Gondwana in the south and Laurasia north of the equator. Over long periods of time, the two land masses drifted apart and re-joined to form the continents that we now know. During this drift of land masses, populations of organisms were separated, forming new diverged species.

Video 3.5
Horses and rhinos share an ancestor

continental drift
the continuous movement of the continents over time

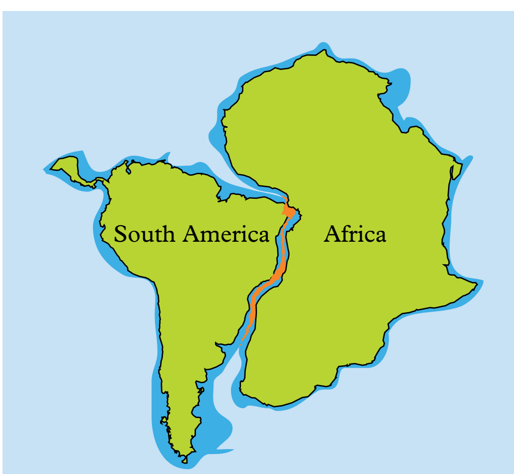


Figure 1 The jigsaw fit of Africa and South America supports the theory of continental drift.

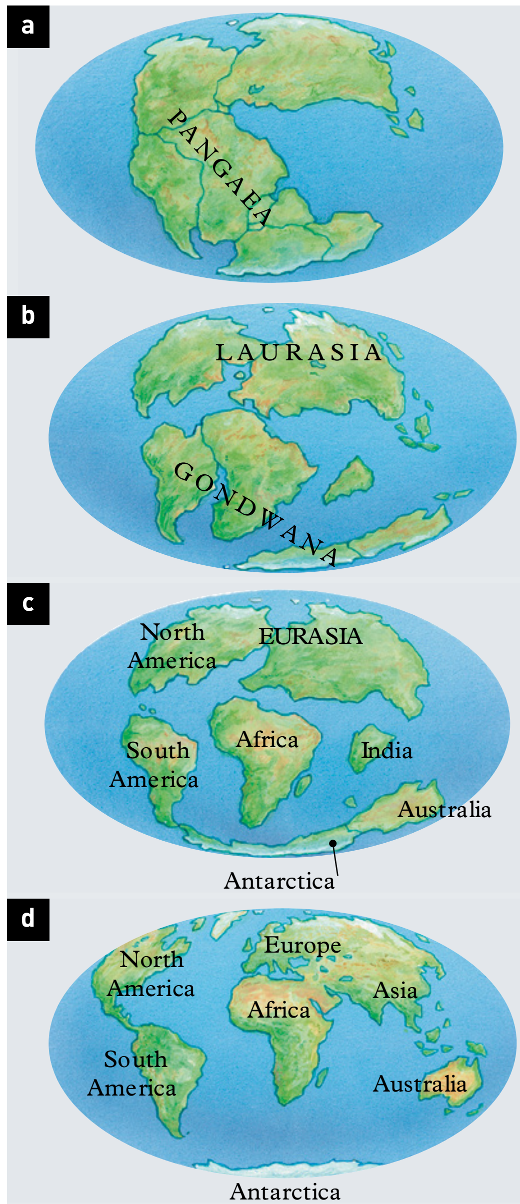


Figure 2 How the continents have drifted: **a** 220 million years ago; **b** 135 million years ago; **c** 65 million years ago; and **d** today

This theory of continental drift is supported by identical fossils buried on the land masses that used to be joined. An example of this is fossilised pollen that has been found in Antarctica, India and Australia (Figure 3). Although animals that could fly or swim could travel from continent to continent, continental drift is the only convincing explanation for the distribution of the plant pollen.

Continental drift provides a well-supported explanation for the geographical isolation of species that eventually results in speciation – divergent evolution. Groups of similar species, such as the ratites (flightless birds), and the existence of marsupials on several continents, can be explained by biogeography (Figures 3 and 4). 'Coincidence' is simply not a scientific explanation.

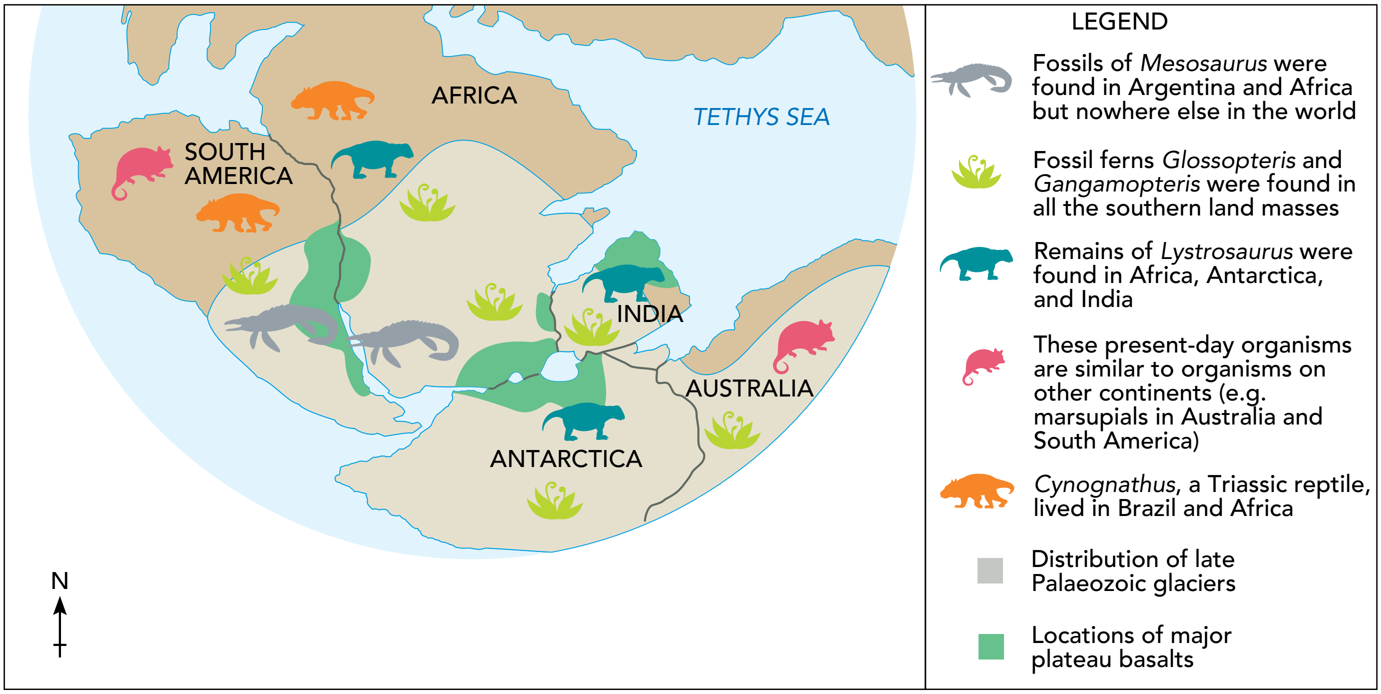


Figure 3 Evidence for the existence of the supercontinent Gondwana is provided by the similarity of fossils on different continents.

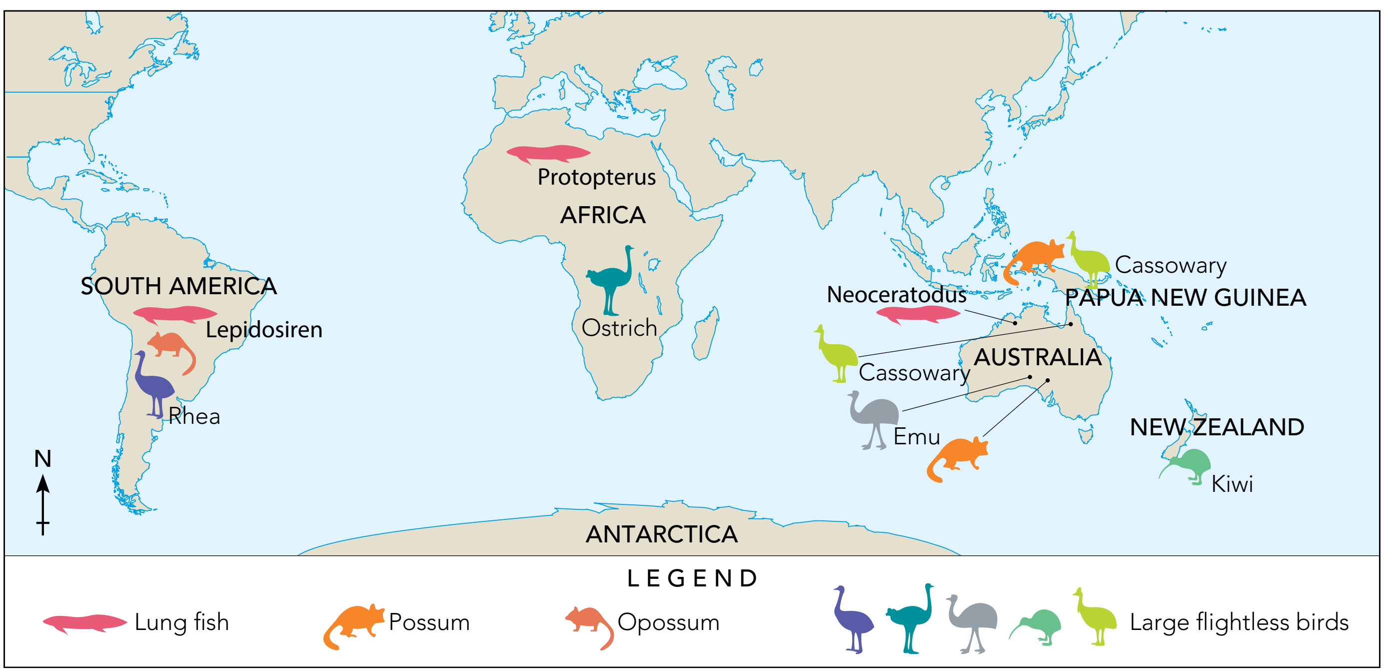


Figure 4 Similar lungfish are found in South America, Africa and Australia. Similar marsupials are found in South America and Australia.

vestigial structure
a structure in an organism that no longer has an obvious purpose

Vestigial structures

Vestigial structures are structures that no longer have a function in organisms. They have puzzled naturalists throughout history and were noted long before Darwin first proposed the concept of evolution from a common ancestor (also called common descent). We now understand that individual organisms contain, within their bodies, evidence of their histories. Some structures within the organisms would have once been useful; however, their function has since been replaced so they are no longer needed. If the structures are not selected against (it is not harmful to keep them), then there is no reason for the structure to disappear. This means the non-functioning structure stays inside the organism. Examples of this include the tiny wings of a cassowary and the hindlimb buds of many snake species, which still carry vestigial pelvises hidden beneath their skin (Figure 5). These structures are not needed, but they still exist because they were once important.

Vestigial structures are now interpreted as evidence of an ancestral heritage in which these structures once performed other tasks. The wings of a cassowary are a reminder that a distant relative of this organism once used its wings to fly. Similarly, snakes evolved from a four-legged ancestor. Humans, too, carry the evolutionary baggage of our ancestry.

The ancestors of humans are known to have been herbivorous, and molar teeth are required for chewing and grinding plant material. More than 90 per cent of all adult humans develop third molars (otherwise known as 'wisdom teeth').

Usually these teeth never erupt from the gums, and in one-third of all individuals they are malformed and impacted. These useless teeth can cause significant pain and an increased risk of injury, and they may result in illness if they are not removed.

Analysing embryos

Scientists have noticed that, although adult vertebrates have certain differences, many embryos demonstrate similarities during the early stages of development. For example, a chicken and a human are very different when fully formed, but chicken embryos are very similar to human embryos (Figure 6). Even reptile embryos are similar to human embryos. Embryos may also show many interesting features that are not seen in the fully developed animal. As the embryo develops, it goes through a variety of stages. Many of these stages show homologous structures with different species.

If the various life forms developed independently, we could think that their embryonic development would be different and consider what the organism would look like when it was fully developed.

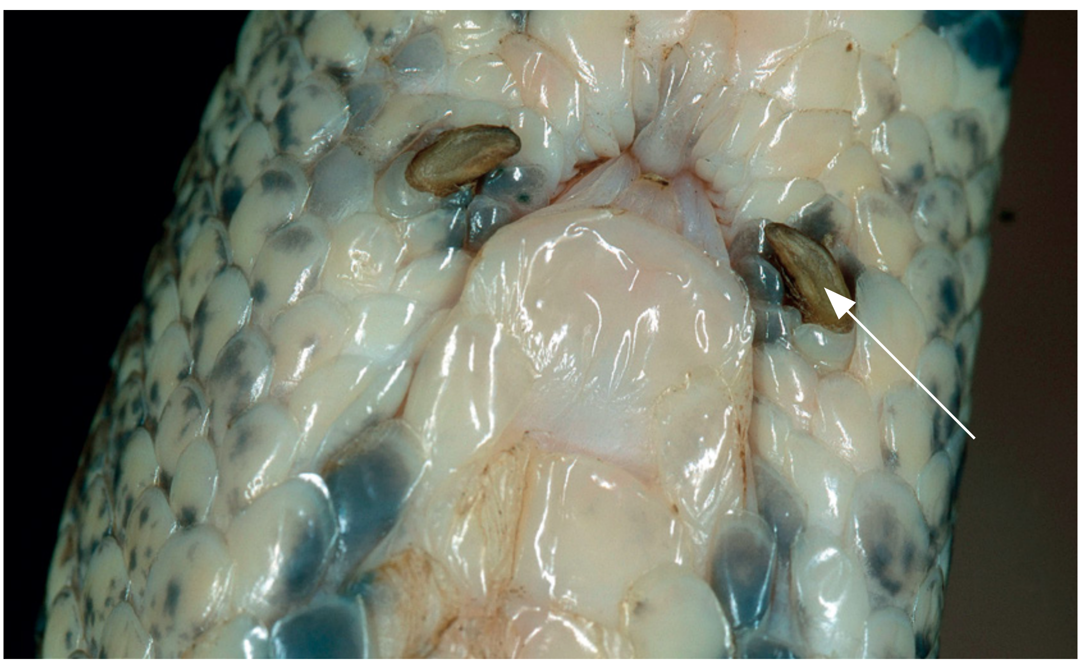


Figure 5 The rear legs on a snake (as shown by the arrow) are an example of a vestigial structure.

It would make more sense for a horse to develop a hoof directly rather than first develop five finger-like digits that are then modified into a hoof.

The embryological similarities are explained by inferring that these organisms all had a common ancestry with common genes. Whales start developing teeth embryonically because they evolved from ancestors that had the genes for teeth. Human embryos develop gill-like structures and tails during their early development because they have the genes for these structures. These genes get turned up or down or 'switched off' during later stages of development. For example, the gene for a bat's fingers becomes 'supercharged' during embryological development so that the fingers start growing faster than the rest of the body (Figure 7). This makes the fingers of the bat extra-long compared to the rest of its body. The long fingers then develop into support structures in the bat's wing. These similar structures, coded by similar genes, provide further evidence supporting evolution.

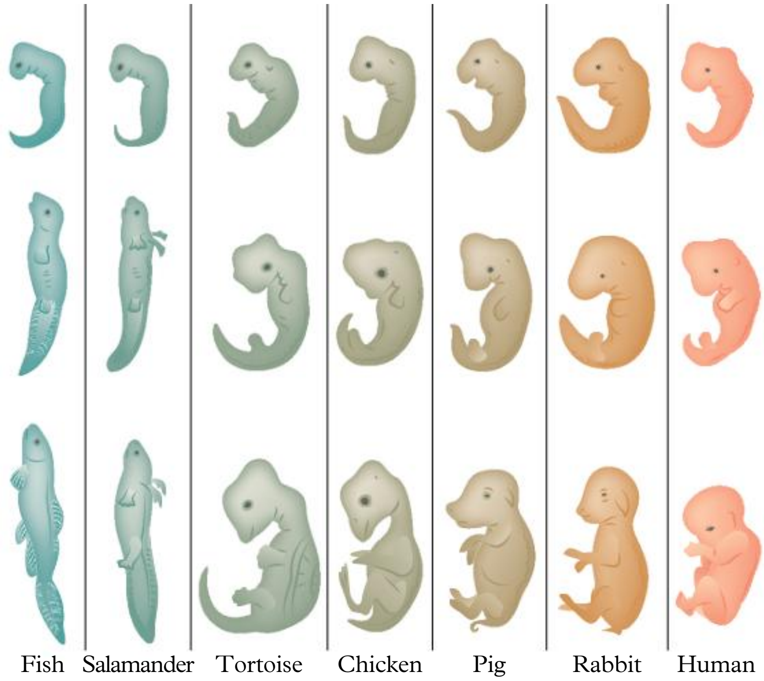


Figure 6 Common structures in the early stage of embryonic development of vertebrates indicate the existence of common genes.

Figure 7 As an embryo, the 'finger genes' of the bat become more active. As a result, the bat's fingers grow much faster than the fingers of other embryos.

3.5 Check your learning

Comprehend

1 The frogs in Australia show their closest evolutionary relationships to frogs in Africa and South America. **Explain** how this is possible.

2 **Explain** how the presence of vestigial structures supports the theory of evolution.

3 **Explain** why human embryos temporarily develop gill-like structures.

4 **Describe** how the gene that forms fingers changes to form the wings on a bat.

5 Geologists are identifying ancient magnetic rocks that suggest magnetic north has moved over millions of years. **Explain** how this information could be used to support the theory of continental drift and the theory of evolution.

Apply

6 Jemima thinks that if native Australian marsupials were found in North America, this would support the theory of continental drift. **Evaluate** her claim (by describing two reasons that support her claim, describing two reasons that refute her claim, and deciding which reasons are most convincing).

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

3.6 DNA and proteins provide chemical evidence for evolution

Learning intentions

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

- explain how mutations can cause small differences that can accumulate over time
- explain how scientists use the differences in DNA sequences to compare evolutionary relationships between species.

Key ideas

- The basic structure of DNA and proteins is identical for all species on Earth.
- Small differences in the sequences of amino acids in proteins and nucleotides in DNA can be used to determine the evolutionary relationship between species.
- The more differences in the nucleotide sequence between organisms, the more time has passed since they shared a common ancestor, and the greater the evolutionary distance between the species.

evolutionary relationship
the way in which two species or populations are related with respect to their evolutionary descent

protein
a chain of amino acids; an essential part of cells

amino acids
small molecules that make up proteins

Comparing DNA

The best evidence in support of evolutionary theory comes from a study of gene sequences. The order of nucleotides in DNA in chimpanzees and humans is 97 per cent identical. Millions of years in the past, humans and chimpanzees shared a common ancestor. A separation in the population of ancestors allowed mutations (permanent changes in the order of DNA nucleotides) to accumulate. This accumulation of mutations eventually caused the 3 per cent difference in the DNA sequence that resulted in the formation of humans and chimpanzees.

Comparing the order of the nucleotides in DNA allows scientists to compare the **evolutionary relationship** between different species. If the theory of evolution is supported, then species that share a common ancestor will have inherited that ancestor's DNA sequence. Any mutations will cause slight differences between the species. The more alike the two DNA sequences are, the more closely related the two species are. The more differences in their DNA sequences, the more time has passed since the two species had a common ancestor and the less related they are now (Figure 2).

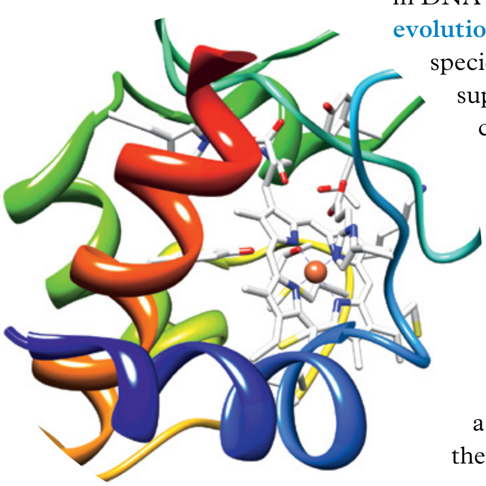


Figure 1 There are many different sequences of amino acids that could make a functional cytochrome c molecule.

Comparing amino acids in proteins

The order of the nucleotides in DNA contains the recipe for the production of proteins. When the DNA changes due to mutation, it can cause changes in the protein it produces. **Proteins** are like long necklaces made up of a series of beads. The beads are called **amino acids**. DNA provides the instructions for the order of the amino acid beads. Proteins range in size from approximately 50 amino acids to thousands of amino acids and are among the most important chemicals in life. They can be enzymes that control chemical reactions, or hormones, the chemical messengers in the body. The characteristics of a protein are determined by the order or sequence of amino acids.

The same type of proteins in different species can be very much alike. Cytochrome c is one such example. Several types of cytochrome c proteins are found among different vertebrates and invertebrates (Table 1).

Comparing the sequence of amino acids in a protein can show the evolutionary relationship between different species. Before a species diverges, the organisms will have exactly the same protein with an identical sequence of amino acids. When the two species diverge, the number of mutations gradually accumulates. This may not affect the structure or function of the protein, but it can change a few amino acids in the long chain. The more time that passes, the more the changes to the amino acid sequence can accumulate. Therefore, the more similar the proteins, the more closely related the species. This means organisms with similar proteins share a very recent common ancestor.

EXPERIMENT

3.6: Who is my cousin?
Go to page **241**.

Table 1 The sequence of amino acids that make up cytochrome c protein in different animals

Human	Val	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Ile
Chicken	Val	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Val
Lungfish	Val	Glu	Lys	Gly	Lys	Lys	Val	Phe	Val
Fly	Val	Glu	Lys	Gly	Lys	Lys	Leu	Phe	Val

Note: Val = valine; Glu = glutamic acid; Lys = lysine; Gly = glycine; Ile = isoleucine; Phe = phenylalanine.

phylogenetic tree
a branching tree-like diagram showing relationships between different taxonomic groups

Phylogenetic trees

Before scientists were able to compare proteins and DNA, they examined the structures of organisms to determine whether they were related. The difficulty with this is that some organisms, such as dolphins and sharks, look very similar because of convergent evolution.

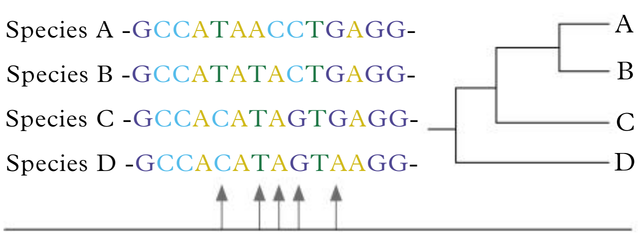


Figure 2 Comparing the DNA sequences allows scientists to determine the evolutionary relationship between different species. Species A is most closely related to B. Species D is the most distant relative of A. A phylogenetic tree for the four species is shown on the right.

Currently, scientists use the differences in DNA sequences to compare the evolutionary relationship.

One way of showing how closely related different organisms are is through a **phylogenetic tree** (Figure 2). Comparing the DNA sequences between humans, chimpanzees and gorillas shows that humans are more closely related to chimpanzees than to gorillas. This means that humans and chimpanzees are drawn closer together on the phylogenetic tree.

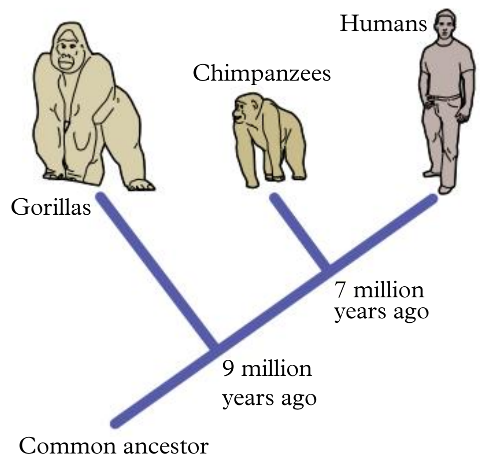


Figure 3 Gene sequencing has shown that humans, gorillas and chimpanzees all evolved from a common ancestor.

3.6 Check your learning

Retrieve

1 **Identify** the smaller (bead-like) structures that make up proteins.

2 **Identify** the cause of gradual changes to the sequence of nucleotides in DNA.

Comprehend

3 Cytochrome c is of interest to biologists studying evolution. **Explain** how the study of cytochrome c protein can contribute to the evidence of evolution (by explaining how DNA contributes to the sequence of amino acids in a protein, explaining how mutations affect the sequence of amino acids, and explaining the relationship between common ancestors and diverged species).

4 **Explain** how DNA sequencing supports the concept of evolution from a common ancestor.

Apply

5 Table 1 shows a small section of the cytochrome c molecule for humans, chickens, lungfish and flies. **Identify** the species that shows the greatest similarity to humans. **Justify** your answer (by explaining the relationship between DNA mutations and amino acid sequences, identifying the animal with the least difference, and explaining how this is an indication of evolutionary relationships).

6 Use the phylogenetic tree in Figure 4 to **determine** which species is most closely related to species A.

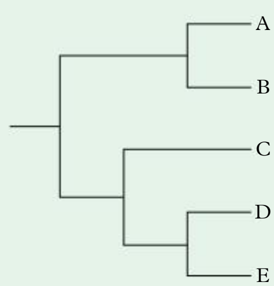


Figure 4 A phylogenetic tree

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

3.7 Humans artificially select traits

Learning intentions

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

- describe how the breeding of an organism with desirable traits has led to domestication
- explain how the misuse of antibiotics has led to the evolution of super-bacteria such as MRSA.

Key ideas

- Artificial selection occurs when humans breed organisms that have desirable traits.
- Rapid regrowth through binary fission or horizontal transfer has led to an increase in some bacteria such as methicillin-resistant *Staphylococcus aureus* (MRSA).

Selective breeding

Humans have practised selective breeding for more than 10000 years. When many human populations moved from the hunter–gatherer way of life to more permanent settled communities, they captured and tamed wildlife for their own purposes. Wild sheep grew wool in winter climates to keep warm. During the warmer summer months, they shed their wool in large clumps. Early humans chose the wild sheep that produced the most wool and bred from them. A random mutation caused the wool to grow all year round. These sheep were selected by breeders over many generations. After thousands of years, the sheep became unable to shed their wool. This means these once wild animals became more reliant on humans removing their wool to survive (Figure 1). Over many generations, the 'wild' traits were lost and the species was considered 'domesticated'.

Figure 1 Some animals have become so dependent on humans that they struggle to survive in natural conditions. Sheep now rely on humans to remove their wool.

a

b

Figure 2 **a** Modern bulldog and **b** the bulldog 200 years ago. Over the last 200 years, breeders of British bulldogs have selected dogs with large flat faces. This has resulted in many birthing difficulties for female dogs. Up to 90 per cent of bulldogs are born by caesarean. The flat faces also make the dogs more prone to breathing difficulties.

Artificial selection

The process of humans selecting for or against a particular characteristic or trait is called **artificial selection**. Unlike natural selection, artificial selection does not make the organism more suited to the environment. This is most evident in our pets. Many breeds (or subspecies) of dogs result from certain traits being selected by breeders. These purebred dogs can have very similar genetics, which can result in damaging recessive characteristics appearing (Figure 2).

Evolution of super-bacteria

Humans can also influence the evolution of bacteria. One of the deadliest species of bacteria in hospitals is methicillin-resistant *Staphylococcus aureus* (MRSA or Golden Staph). These bacteria have arisen as a result of humans overusing antibiotics.

Figure 3 Another example of artificial selection, bubble-eye goldfish can have problems with buoyancy, which affects their ability to swim.

artificial selection
when humans breed organisms that have desirable traits, increasing the likelihood of that trait occurring in the next generation

CHALLENGE
3.7: Selective breeding of dogs
Go to page **242**.

Figure 4 Selected for its hairless coat, the sphynx cat was recognised as a new breed in 2008.

Staphylococcus aureus is normally found on the skin and in the noses and throats of many individuals in the population. Antibiotics prevent these bacterial cells from repairing or producing new cell walls, causing the cells to die rather than reproduce. In some populations, random mutations caused some *Staphylococcus aureus* cells to be unaffected by antibiotics. These bacteria became resistant.

When a person has a bacterial infection, a doctor will often prescribe an antibiotic. If there is a single bacterium present that is able to resist the antibiotic for a short time, then it will survive longer than the rest of the bacteria. If the person feels better and stops taking the antibiotic, that partially resistant bacteria will start reproducing again through a process called **binary fission**. This makes the person sick again, so they take the rest of the antibiotics. Once again the partially resistant bacteria slows its growth, but this time another random mutation causes a fully resistant bacteria to start growing. This bacterium is not affected by the antibiotic and can easily spread to other patients in a hospital.

MRSA is such a bacterium. The misuse of antibiotics by humans selected the bacteria for its resistance (Figure 5).

Some bacteria do not have to wait for a random mutation to develop resistance to antibiotics. Sometimes the gene for antibiotic resistance can be transferred from one bacteria to another in a process called **horizontal transfer**. Because bacteria reproduce so quickly, they evolve very quickly.

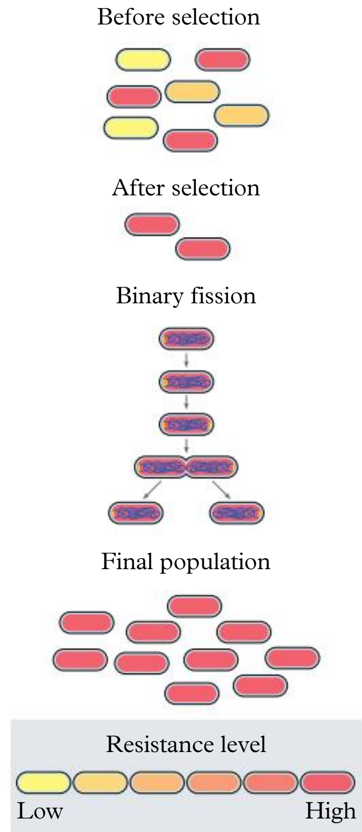


Figure 5 The frequent use of antibiotics allows for the selection of bacteria that are resistant to antibiotics. This increases the allelic frequency of resistance.

horizontal transfer the transfer of genetic material (usually containing antibiotic resistance) from a bacterium to another bacterium that is not its offspring

binary fission a form of asexual reproduction used by bacteria; the splitting of a parent cell into two equal daughter cells

3.7 Check your learning

Retrieve

1 **Define** the term 'selective breeding'.

2 **Identify** an example of how selective breeding was used to produce a domesticated animal.

3 **Define** the term 'MRSA'.

Comprehend

4 **Explain** how misusing antibiotics can contribute to the existence of MRSA.

Analyse

5 **Compare** selective breeding and natural selection.

Apply

6 A student claimed that artificial selection has interfered with nature. **Evaluate** their claim (by describing two reasons that support their claim, describing two reasons that refute their claim, and deciding which reasons are most convincing).

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

//SCIENCE AS A HUMAN ENDEAVOUR//

3.8 Natural selection affects the frequency of alleles

Learning intentions

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

- explain how malaria is a selection pressure for the sickle cell anaemia allele
- describe how the process of natural selection can result in an increase in the frequency of the sickle cell allele in malaria prone regions.

Sickle cell anaemia is a disease that affects the structure and function of red blood cells. While few people in Australia have sickle cell anaemia, it is much more common in countries that have the mosquito-borne disease malaria.

Sickle cell anaemia

Sickle cell anaemia is a genetic disease that causes swelling of the hands and feet, fatigue and pain. It is an autosomal recessive disease (see Chapter 2) that affects the haemoglobin protein found in red blood cells. The haemoglobin protein is made from four genes found on chromosome 11. It is responsible for carrying oxygen around the body. Most people have normal versions (or alleles) of the haemoglobin genes, but some people have a mutated allele, which causes the haemoglobin to clump together (Figures 1, 2 and 3). A single copy of the mutated allele will not affect the quality of a person's life. However, two copies of the mutated allele will cause all the haemoglobin to clump together and the red blood cells to become shaped like a sickle (a curved cutting instrument).

These sickle-shaped cells can become stuck in the blood vessels, causing strokes or damaging the joints and organs of the body. People suffering sickle cell anaemia must be treated regularly to prevent infections. Thirty years ago, sufferers would die by the age of 20. Today, life expectancy is approximately 55 years.

Figure 1 A person with sickle cell anaemia has crescent-shaped red blood cells (left) that are unable to effectively transport oxygen around the body.

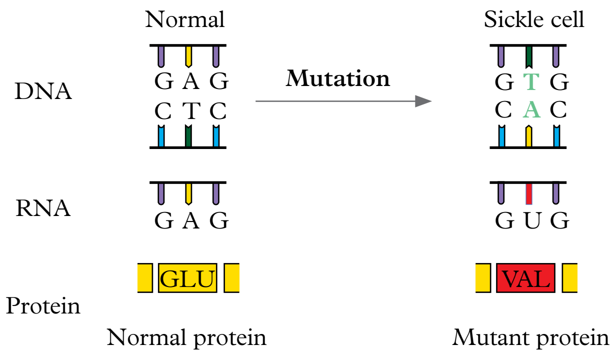


Figure 2 A mutation in the nucleotide sequence causes a change in the amino acid sequence at a DNA level.

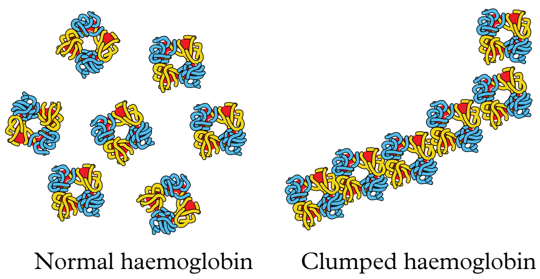


Figure 3 A change in the amino acid sequence causes the haemoglobin to clump together at the protein level.

EXPERIMENT

3.8: Selecting for sickle cell anaemia
Go to page **243**.

Selection pressures

The rate of sickle cell anaemia is very low in Australia. It is thought that only 5 per cent of the world's population is a carrier for sickle cell anaemia. This means they have one copy of the sickle cell allele and one copy of a normal haemoglobin allele. However, in countries such as Africa the rate of carriers for sickle cell anaemia is closer to 25 per cent (Figure 4). This is because a person who is a carrier for sickle cell anaemia is protected from contracting malaria (an infectious disease that is contracted through mosquito bites). This means that people who:

- are not carriers of the allele for sickle cell anaemia are at risk of catching malaria and dying
- are carriers of the sickle cell allele do not get sickle cell anaemia or malaria
- have two copies of the sickle cell allele have sickle cell disease and may die young.

Malaria is the selection pressure that selects for the sickle cell carriers.

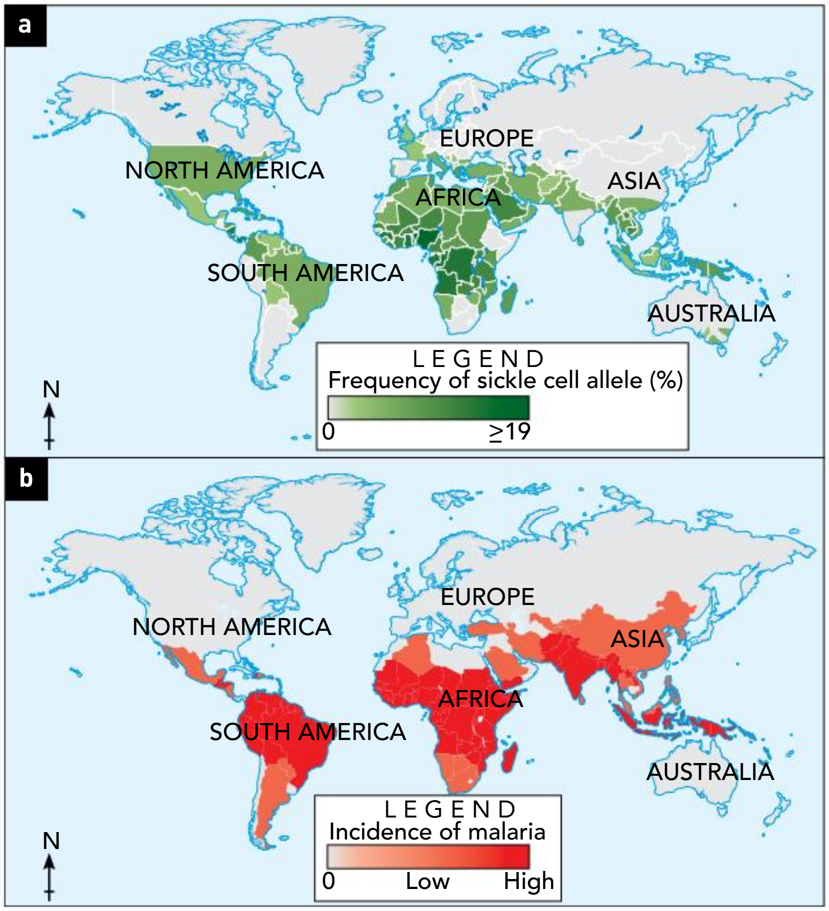


Figure 4 There is a strong correlation between **a** countries that have a high number of carriers for the sickle cell anaemia allele and **b** countries that have a high incidence of malaria.

3.8 Test your skills and capabilities

Scientific needs and values

Red blood cells are formed from stem cells in the bone marrow. If there are two alleles for the sickle cell 'sticky' haemoglobin, the stem cell will produce sickle-shaped red blood cells.

In 2019, scientists removed the bone marrow stem cells from a patient with sickle cell anaemia and replaced the mutated alleles with healthy copies of the genes.

1 **Consider** the potential effect of this process on the evolution of the human species by:
   - describing the effect that replacing the sickle cell alleles will have on the patient
   - describing the effect that replacing the sickle cell alleles will have on the offspring of the patient
   - describing how the patient and their future offspring will be affected by malaria.

Although the genetic manipulation of somatic (body) cells has been trialled for the last 10 years, there is a moratorium (a temporary ban) on the manipulation of the human genome in human gametes (eggs and sperm).

2 **Evaluate** the reasons for this moratorium by:
   - describing how a genetically modified somatic cell will affect a patient
   - describing how a genetically modified somatic cell will affect the offspring of the patient
   - describing how a genetically modified gamete cell will affect a patient
   - describing how a genetically modified gamete cell will affect the offspring of the patient
   - contrasting the effect of a genetically modified somatic cell or gamete on future generations
   - explaining the reason for the moratorium on human genetic manipulation in gametes.

CHAPTER 3 REVIEW

EVOLUTION

Retrieve

1 **Identify** which evolutionary theory proposed that organisms acquired inherited characteristics.
  A Darwinism
  B Lamarckian theory
  C Wallace's theory
  D natural selection

2 **Recall** the term that is used to describe a single population that is divided by a permanent barrier and diverges into new species.
  A reproductive isolation
  B speciation
  C allopatric speciation
  D convergence

3 Relative dating is used to work out the age of rocks. **Identify** which layer is likely the oldest of the layers in Figure 1.
  A Layer 1
  B Layer 2
  C Layer 3
  D Layer 4

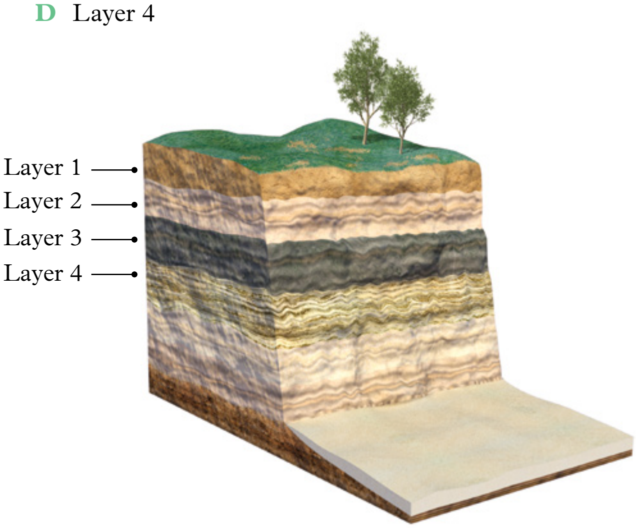


Figure 1 Layers of rock

4 **Define** the term 'natural selection' and **identify** the four essential factors for this process.

5 **Define** the term 'gene pool'.

6 **Identify** the professional title for a person who studies the fossil record and geological time periods.

7 *Archaeopteryx* had features of both birds and lizards. **Identify** the term that is applied to fossils that shows the evolutionary progression between two very different forms.

Comprehend

8 **Explain** the difference between incorrectly suggesting an organism has evolved and correctly suggesting that a population of organisms has evolved.

9 **Describe** Gondwana.

10 The layering of sedimentary rocks is useful in relative dating. **Explain** the basic principle of comparative dating.

11 **Explain** precisely how fossils provide evidence for evolution.

12 **Explain** why a vestigial structure, once it has been reduced to a certain size, may not disappear altogether.

13 **Explain** how the study of DNA sequences helps in our understanding of evolution.

14 Use examples to **illustrate** the two critical deductions that Darwin made – the struggle for existence and the survival of the fittest.

Analyse

15 **Contrast** a hypothesis and a theory.

16 **Contrast** 'transitional fossil' and 'living fossil'.

17 **Compare** the terms 'allopatric speciation' and 'gene flow'.

18 **Compare** the terms 'diversity' and 'evolution'.

Apply

19 *Callistemon* (bottlebrushes) are unusual because their stems (branches) do not terminate in flowers. Instead, the stem keeps growing out past the old flower. Consequently, a mature plant may contain the ripe seeds of numerous years in its branches. **Suggest** how this adaptive feature enabled *Callistemon* to exploit the current Australian environment.

Figure 2 *Callistemon* flowers

20 The tortoises of the Galapagos Islands either have a domed shell and a short neck (on islands with significant rainfall) or a shell with the front flared up and a long neck (on islands that are more arid). The tortoises feed on prickly pear cactus. On islands with no tortoises, the prickly pear plant is low and spreading, but on islands with long-necked tortoises, the prickly pear plant is tall and has harder spines protecting it.

a **Explain** why the tortoises have two very different phenotypes.

b **Describe** how the tortoises that originally reached the islands could resemble any of the tortoises that live there today.

c Using the terms 'variation' and 'survival of the fittest', **discuss** why the prickly pear plant is so different on islands with long-necked tortoises compared with those plants growing elsewhere.

d **Identify** the type of speciation that is occurring on these islands.

Figure 3 Tortoises on different Galapagos Islands have unique features.

21 Only two species of native non-marine mammals (both bats) existed in New Zealand before the Polynesians introduced rats and dogs 1500 years ago. This unusually small number of mammal species, along with New Zealand's separation from Gondwana 60–80 million years ago, has led many to speculate on which land-mass mammals originally evolved. The earliest known mammal-like fossil remains are over 160 million years old. Consider this information to **determine** if mammals were likely to have originated on Gondwana.

22 Megafauna are the large animal ancestors that lived in Australia thousands of years ago. One of these was the *Diprotodon*, an early ancestor to wombats and koalas. In 2016, archaeologists discovered a front leg bone of the *Diprotodon* at the Warratyi rock shelter in the Flinders Ranges in South Australia.

a If the amount of carbon-14 (with a half-life of 5700 years) remaining in the sample was 1/128, **calculate** the age of the leg bone.

b As a large animal (3500 kg), it became extinct at the same time as many other Australian megafauna. One of the causes is thought to be extreme drought conditions. **Discuss** how drought conditions could act as a selection pressure.

Social and ethical thinking

23 Through selective breeding, humans are able to bring about changes in the gene pool of a population. **Discuss** the various scenarios in which this has occurred in the past and may occur now and in the future. **Describe** three examples of human intervention being positive and three examples of detrimental intervention. **Justify** your decisions.

Critical and creative thinking

24 **Investigate** the various explanations for changes in the natural world before evolutionary theories. Select one example and present your findings and analysis to the class in an appropriate and interesting format.

25 The theories of Lamarck and Darwin are often compared and contrasted in the form of cartoon strips. **Create** a three-part cartoon strip for each theory that clearly identifies the similarities and differences between these theories.

26 **Evaluate** the strengths and weaknesses of the various forms of evidence that support evolution.

Research

27 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

» Darwin and the Galapagos Islands

Much of Darwin's theory developed while he was visiting the Galapagos Islands.

- » Identify which new species Darwin found there.
- » Describe what was so unique about these species.
- » Describe how Darwin's findings helped him to develop his ideas.
- » Explain what was unique about the Galapagos Islands that helped Darwin develop his theories.

» Eugenics and racism

Eugenics, the use of genetics and evolution to 'improve' the human race, gained popularity in the early 1900s. It led to deliberate sterilisation of some individuals in the United States, the Holocaust in Germany and the White Australia policy.

- Research the person who coined the term 'eugenics'.
- Select one of the examples provided and explain how misconceptions of heredity and evolution led to the development of the governmental policies and societal attitudes.

Figure 4 The White Australia Policy was one of several inhumane and profoundly hurtful policies based on a misconception of heredity and evolution.

» Modern-day evidence for evolution

There is evidence of current populations evolving by natural selection all around us. Investigate one of the following topics and see whether you can find evidence of evolution by natural selection occurring today.

- Explain how controlled breeding can modify organisms.
- Explain how the number of predators can affect the evolution of bright colouration.
- Explain how natural selection leads to pesticide resistance.

Figure 5 *Myzus persicae* (green peach aphid) is resistant to multiple pesticides and a problem for Australian farmers.

» Climate change and natural selection

Climate scientists predict that the average temperature of the Earth will increase by 2 degrees Celsius over the next 100 years.

- Explain how this climate change will affect species on Earth.
- Describe the species you think will be most affected. Explain what this species could do to avoid becoming extinct as a result of changing habitats.
- Explain if all species would be able to avoid the effects of climate change.
- Describe how a new species may evolve as a result of climate change.

Figure 6 Increased incidence of bushfires in Australia is one of the devastating effects of increasing global temperatures.

» Real-time evolution

Significant advances in our understanding of evolution by natural selection have been vital to the study of diseases and pests. Antibiotic resistance in bacteria and the tolerance to herbicides in crops and pesticides in general agriculture are monitored closely.

- Explain why these examples are important.
- Explain why they need close monitoring.
- Explain why these organisms demonstrate evolution at such a fast rate.

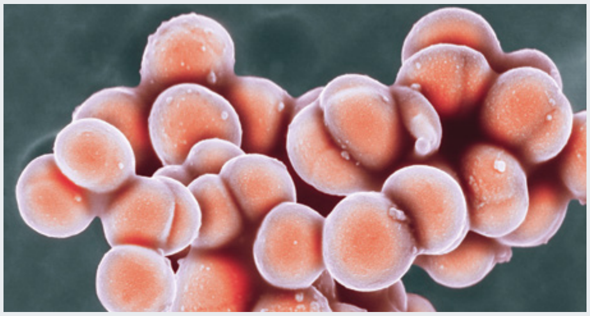


Figure 7 Scanning electron micrograph of methicillin resistant *Staphylococcus aureus* (MRSA)

Chapter checklist

Now that you have completed this chapter, reflect on your ability to do the following.

	I can do this.	I cannot do this yet.
• Use evolution as an example to explain how scientific theories are based on substantiated evidence that is contested and refined over time.	☐	☐ Go back to Topic 3.1 'Science as a human endeavour: Darwin and Wallace were co-conspirators'. Page 66
• Describe how natural selection results in permanent changes in the frequency of alleles in a population. • Discuss how selection pressures change the allele frequency of populations over time.	☐	☐ Go back to Topic 3.2 'Natural selection is the mechanism of evolution'. Page 70
• Explain how different selection pressures can cause divergence and the formation of new species (speciation). • Explain how similar selection pressures can cause convergence.	☐	☐ Go back to Topic 3.3 'Different selection pressures cause divergence. Similar selection pressures cause convergence'. Page 72
• Explain how the existence of fossils provides evidence to support the processes of evolution. • Describe how fossils are dated using relative and absolute dating techniques.	☐	☐ Go back to Topic 3.4 'Fossils provide evidence of evolution'. Page 74
• Explain how continental drift provides a well-supported explanation for the geographical isolation of species that eventually results in divergent evolution. • Identify vestigial structures and explain how they are interpreted as evidence of an ancestral heritage in which these structures once performed other tasks.	☐	☐ Go back to Topic 3.5 'Multiple forms of evidence support evolution'. Page 78
• Explain how mutations can cause small differences that can accumulate over time. • Explain how scientists use the differences in DNA sequences to compare evolutionary relationships between species.	☐	☐ Go back to Topic 3.6 'DNA and proteins provide chemical evidence for evolution'. Page 82
• Describe how the breeding of organisms with desirable traits has led to domestication. • Explain how the misuse of antibiotics has led to the evolution of super-bacteria such as MRSA.	☐	☐ Go back to Topic 3.7 'Humans artificially select traits'. Page 84
• Explain how malaria is a selection pressure for the sickle cell anaemia allele. • Describe how the process of natural selection can result in an increase in the frequency of the sickle cell allele in malaria-prone regions.	☐	☐ Go back to Topic 3.8 'Science as a human endeavour: Natural selection affects the frequency of alleles'. Page 86

Check your Student obook pro for these digital resources and more:

Quizlet
Play a Quizlet game to test your knowledge.

Chapter quiz
Check your understanding of this chapter with the chapter review quiz.

CHAPTER

4

CLIMATE CHANGE

4.1

Climate change is global

> Explain the difference between weather and climate.

> Explain how solar radiation influences the global climate system.

4.2

Climate change indicators include increased global temperatures, extreme weather, disease and species distribution

> Describe how increased greenhouse gases have resulted in increased global temperatures and extreme weather events.

> Describe how climate change has led to changes in disease and species distribution.

4.3

Deep ocean currents regulate global climate

> Explain how climate change models help make predictions about global climate trends.
> Describe how melting icecaps result from increased global temperatures and how this influences sea levels.
> Explain how deep ocean currents regulate global climate.

4.4

Science as a human endeavour: Climate change can be mitigated

> Compare climate mitigation and climate adaptation strategies.
> Describe how First Nations peoples have used ecological knowledge to reduce carbon dioxide in the atmosphere.

What if?

Greenhouse gases

What you need:

Two clear identical water bottles with labels removed, water, tape, scissors, two thermometers, two seltzer (effervescent) tablets, two lamps, a stopwatch, markers

What to do:

1. Fill both bottles so that they are a third full of water. Label one bottle 'CO_2' and the other 'control'.
2. Tape the top of the control bottle and poke a thermometer down through the tape so that it sits in the bottle without touching the water.
3. Drop the two seltzer tablets into the CO_2 bottle and quickly tape the top of the bottle. Poke a thermometer down through the tape so that it sits in the bottle without touching the water.
4. Immediately record the temperature of each bottle and then position the bottles so that each has a lamp shining directly on it.
5. Start the stopwatch and record the temperature of each bottle every 20 minutes for the next hour.

What if?

» What if four seltzer tablets were placed in the CO_2 bottle? (Would this increase or decrease the temperature of the bottle?)

4.1 Climate change is global

Key ideas
- Weather is the short-term changes in temperature, wind, rain, humidity and atmospheric pressure in a small region.
- Climate is a long-term measure of averages, variations and extremes in weather over large global areas.
- Solar radiation interacts with the atmosphere, ocean and land to affect the global climate system.

Learning intentions

By the end of this topic, you will be able to:
- explain the difference between weather and climate
- explain how solar radiation influences the global climate system.

Many systems in nature are balanced, from the regulation of the body to the carbon cycle of the Earth. When the balance is disrupted, it can cause a chain of reactions that can have long-term impacts. For thousands and thousands of years, there has been a balance between the geosphere (the rocks and minerals on the surface of the Earth), the biosphere (all living things), the hydrosphere (all the ice, water and vapour on the Earth) and the atmosphere (the layer of gases surrounding the Earth). These spheres act together to make the global climate one in which humans and other parts of the biosphere are able to survive. **Climate change** refers to change in the state of the global climate.

climate change
periodic change in the Earth's climate

weather
the temperature, humidity, rainfall and wind on particular days in a particular place

climate
the weather conditions at a particular place, averaged over a long period of time, based on the collection and analysis of large amounts of data

solar radiation
radiant electromagnetic energy from the Sun

Weather and climate systems

Weather reports tell you the temperature, humidity, rainfall and wind on particular days in a particular place. They provide a snapshot of day-to-day changes. **Climate** is concerned with longer periods of time and involves the collection and analysis of large amounts of data. You can use weather predictions to decide what to wear each day, whereas climate predictions may help farmers plan what types of crops to grow each year, governments to decide whether to invest in certain technologies or even households to decide whether they'll need to install an air conditioner.

Solar radiation

Light and thermal energy produced by the Sun is something that is often taken for granted. We have all felt the heat of a footpath or road on a hot day. This is due to the energy of **solar radiation** (shortwave, high-energy radiation) heating the rocks and minerals that form the geosphere under our feet. This includes everything from the molten rocks of the mantle to the peaks of the mountains of the Earth.

The amount of solar radiation released by the Sun varies by 0.1 per cent every 9–11 years (Figure 1a). The small variation has had no impact on the amount of solar radiation that reaches the top of Earth's atmosphere.

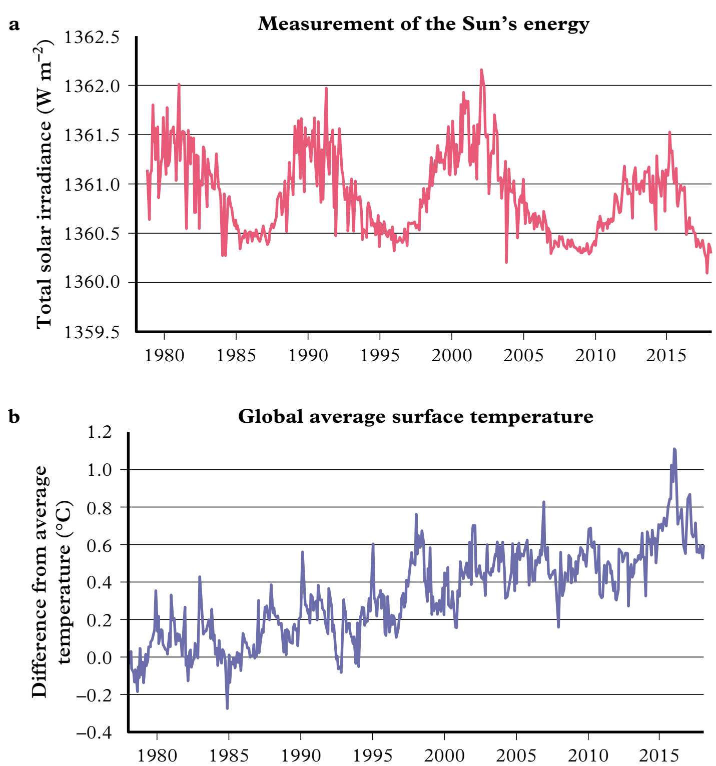


Figure 1 **a** The measurement of solar energy reaching the top of Earth's atmosphere, and **b** the global average surface temperature over time

CHALLENGE

4.1: Making a simple barometer
Go to page **244**.

This means that the variations in the energy released by the Sun are not the cause of the current increasing trend in global climate warming (Figure 1b).

Solar radiation that reaches the Earth's atmosphere is either absorbed or reflected into space. Seventy per cent of solar radiation is absorbed by the water and rocks that make up the Earth's surface (hydrosphere and geosphere). The absorbed energy causes the molecules that make up the rocks and water to increase their kinetic energy and vibrate faster which results in the increased temperature. This energy is then re-radiated as longwave, lower-energy wavelengths of infrared radiation (known as heat) into the gases in the air. The more solar radiation that is absorbed by the Earth, the hotter the surface becomes. This in turn heats the greenhouse gases in the atmosphere.

Some parts of the Earth will receive more solar radiation than other parts. At the North or South Pole, the energy from the Sun shines at an angle. As it travels through the atmosphere, some of it radiates back into space. Less energy is available to heat the Earth. Near the equator, the Sun spends more time directly overhead. This means more solar radiation is absorbed by the Earth's surface at the equator than at the poles where the Sun is at a steep angle (Figure 2). This is the reason that the temperature at the equator is higher than at the Earth's poles.

Areas of the Earth that experience long periods of solar radiation from the Sun have higher temperatures.

Regions near the equator are warmer than regions near the Earth's poles. Near the equator, the Earth is exposed to long periods of solar radiation because the equator faces the Sun all year. Because of this, the Earth's surface is heated intensely. The thermal energy in the rocks making up the geosphere heats the gases in the atmosphere. This can lead to higher temperatures lasting longer at the equator. This uneven heating of the geosphere and hydrosphere can affect the global atmosphere and ocean circulation patterns.

As the air heats up in a high pressure system, the particles in the air move faster and spread out to the outer regions as wind. In a low pressure system, the air in the centre has lower pressure than the surrounding areas. The air moves towards the centre and upwards, forming water vapour, clouds and rain. This means warm air near the equator rises into the upper atmosphere and colder air near the poles moves towards the equator to fill the space left by the warm air (Figure 3). The movement of air is better known as **wind**. The wind is the result of sideways or horizontal movements of air due to pressure differences.

The **Coriolis effect** is the influence of the Earth's rotation on the direction of air or water movement. The Coriolis effect of a spinning Earth can cause the winds to appear to move in a circular pattern across the Earth (Figure 4). The surface of the Earth can also interfere with the speed and direction of wind. Rough and mountainous terrain will slow wind and significantly change the wind's direction.

wind
the sideways movement of air as a result of lower-density warm air rising through the atmosphere

Coriolis effect
the influence of the Earth's rotation on the direction of movement of air or water

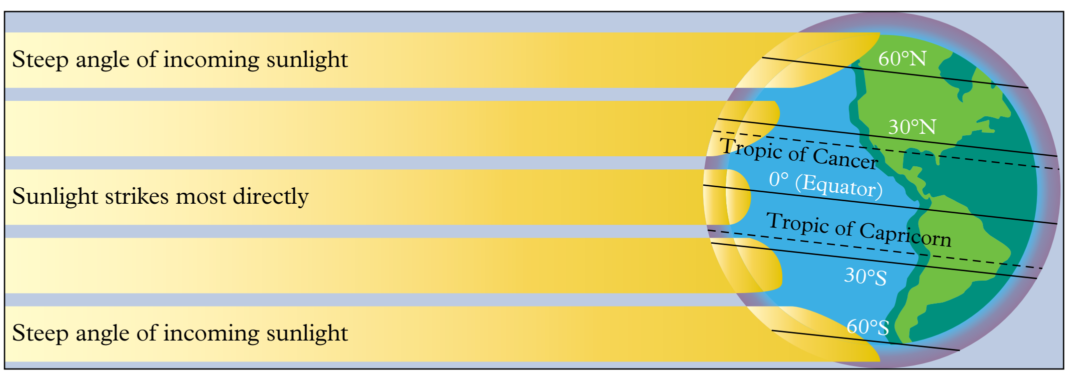


Figure 2 The angle of solar radiation (sunlight) can affect the amount of energy absorbed by the Earth's surface.

isobar
a line drawn on a weather map that joins places of equal air pressure

On a weather map, the air pressure differences caused by heated air are shown as **isobars**; the closer the isobars, the greater the difference in pressure and the stronger the wind. Regions of high and low pressure are shown on weather maps (Figure 5b). Low-pressure areas are frequently associated with clouds and precipitation and represented by an 'L'. High-pressure systems bring clear blue skies and are represented by an 'H'.

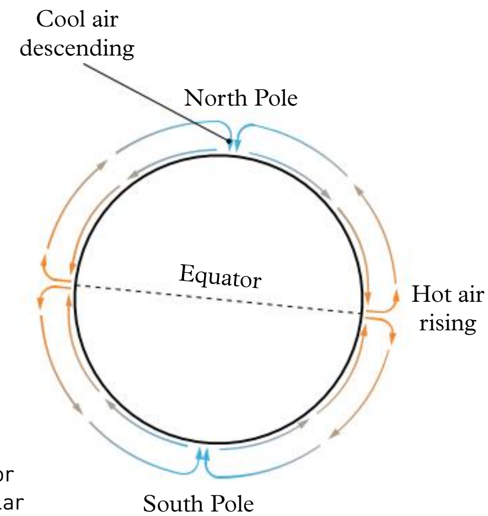


Figure 3 Movement of air at the equator and at the poles can result in the circular movements of air called cyclones.

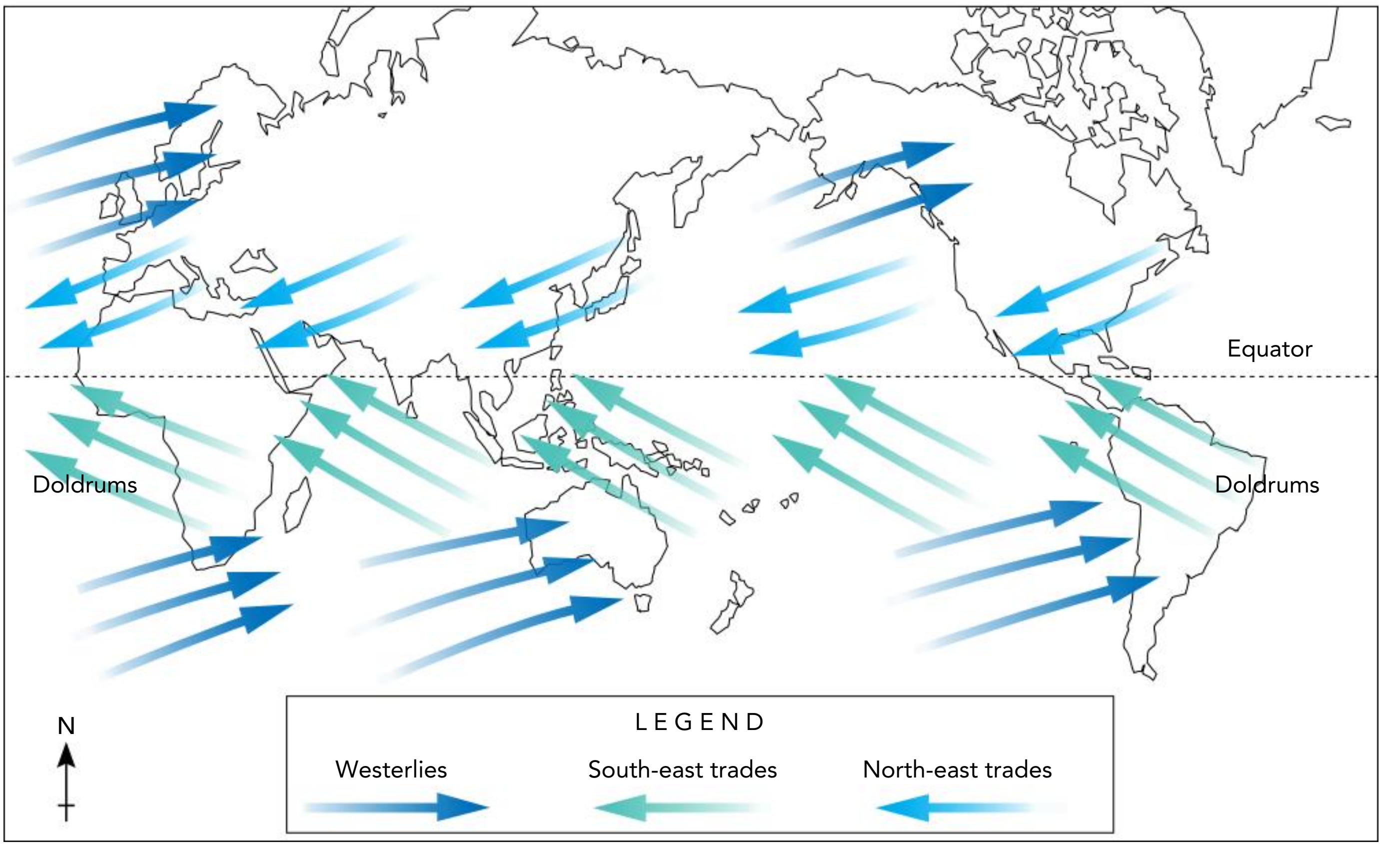


Figure 4 Wind patterns over the Earth; the Doldrums are areas of low pressure where winds tend to be very calm.

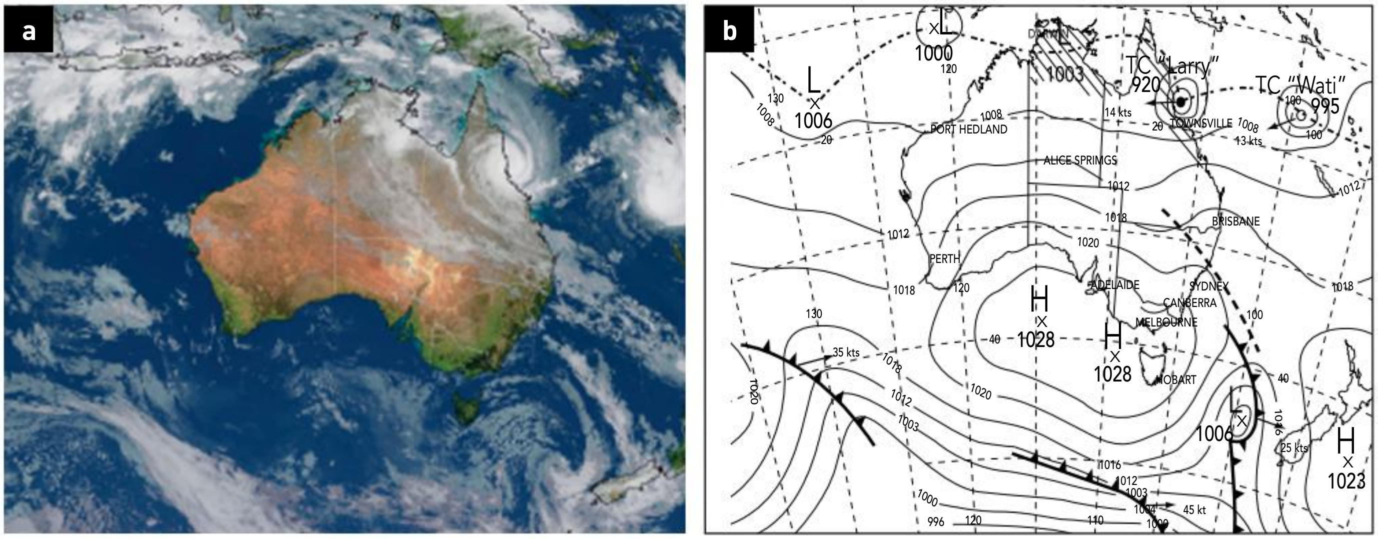


Figure 5 **a** A satellite image and **b** a weather map showing tropical Cyclone Larry as it crosses the Australian coast at Innisfail, just south of Cairns, in 2006

4.1 Check your learning

Retrieve

1 **Define** the term 'air pressure'.

Comprehend

2 **Describe** the relationship between winds and rising air.

3 **Explain** what happens to the pressure of the air when it is heated.

4 **Describe** the role of the Coriolis effect on global winds.

Analyse

5 **Compare** weather and climate.

6 **Compare** the wavelength and energy levels of solar radiation and infrared (heat) radiation.

Apply

7 Cyclones are more likely to occur close to the equator during the wet season. **Describe** what is meant by the term 'wet season' and **investigate** the climate conditions that contribute to the formation of a cyclone. **Create** a 2-minute video in which you are a meteorologist on the news who explains why the cyclone is forming.

Quiz me

Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

4.2 Climate change indicators include increased global temperatures, extreme weather, disease and species distribution

Learning intentions

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

- describe how increased greenhouse gases have resulted in increased global temperatures and extreme weather events
- describe how climate change has led to changes in disease and species distribution.

Key ideas

- Data is used to measure climate change.
- Climate change has caused increasing global temperatures and extreme weather events.
- Climate change has changed the distribution of diseases.
- Rapid changes in climate have changed and will continue to change species distribution.

greenhouse gas
an atmospheric gas able to absorb and emit solar energy causing a greenhouse effect

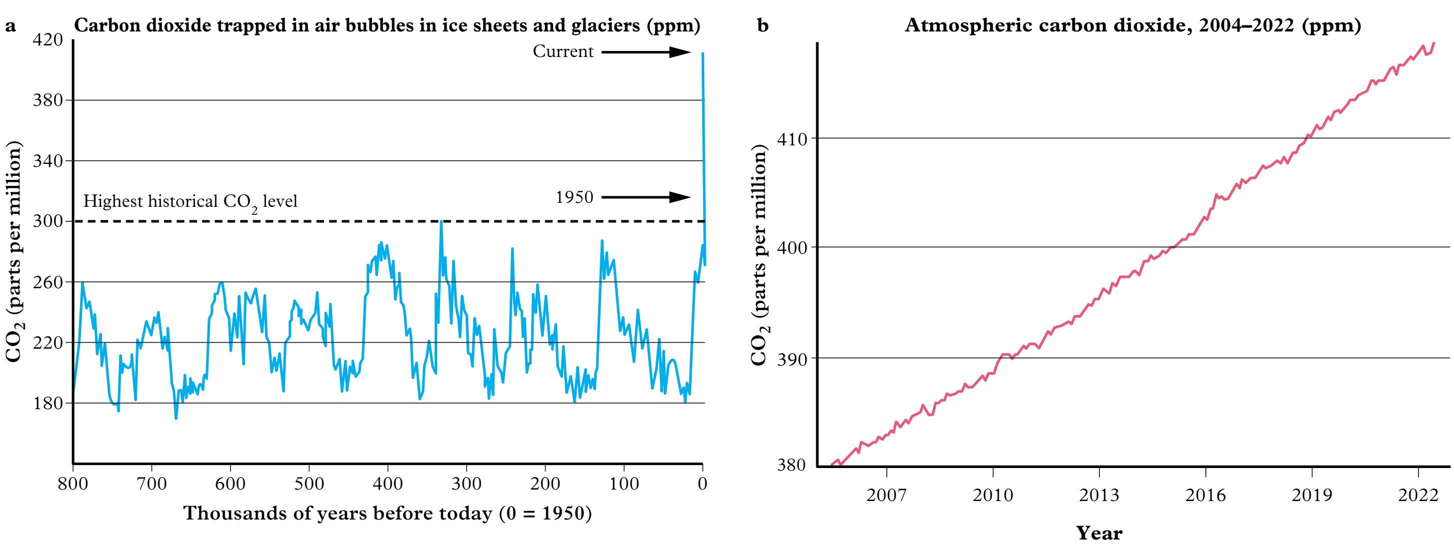
Greenhouse gases

The presence of a gaseous atmosphere allows the Earth to maintain a relatively constant environment in which life can survive. The Moon is not large enough to retain a full atmosphere. This means the Moon's temperatures can vary from 123°C when in sunlight to –153°C when it is turned away from the Sun.

Gases in the Earth's atmosphere (oxygen, nitrogen, hydrogen, carbon dioxide and methane) can reflect some of the heat from solar radiation during the day. These gases can also retain some of the heat so that the Earth's surface does not cool too much at night (similar to how a greenhouse retains heat for plants to grow).

Not all atmospheric gases are equal in their ability to retain heat. **Greenhouse gases** such as methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) absorb and emit solar radiation within the thermal infrared range. Atmospheric carbon dioxide has increased significantly because of human-related activities, such as burning fossil fuels and deforestation. The level of carbon dioxide has varied between 180 and 300 ppm (parts per million) over the past 800 years. The amount of carbon dioxide trapped in ice sheets and glaciers was used to obtain this data (Figure 1a). In 2022, the level of carbon dioxide reached a new high of 419 ppm which has contributed to the rise in average global temperatures (Figure 1b).

Figure 1 Trends in atmospheric carbon dioxide from **a** air bubbles trapped in ice sheets and glaciers, and **b** Mauna Observatory, Hawaii



CHALLENGE

4.2: Using computer simulations
Go to page **245**.

Rising temperatures

Increased atmospheric carbon dioxide from human activities has resulted in a rapid increase in the average global temperature. Figure 2 shows that the increase in average temperature is not evenly spread across the Earth. Temperatures might rise by 5°C in the North Pole but only increase by 1.5°C in Australia.

These average temperature changes might not seem large at first; however, they are quite drastic changes.

It only took a drop of 1–2°C to cause the Little Ice Age in the seventeenth century. This resulted in widespread crop failure, famine and disease. NASA has predicted that global warming of 1.5°C will cause deadly annual heatwaves, water stress in some countries, increased heavy rainfall and floods in other countries, reduced biodiversity, increased wildfires and melting of the polar icecaps.

Figure 4 The aftermath of a cyclone; the number of severe cyclones is increasing.

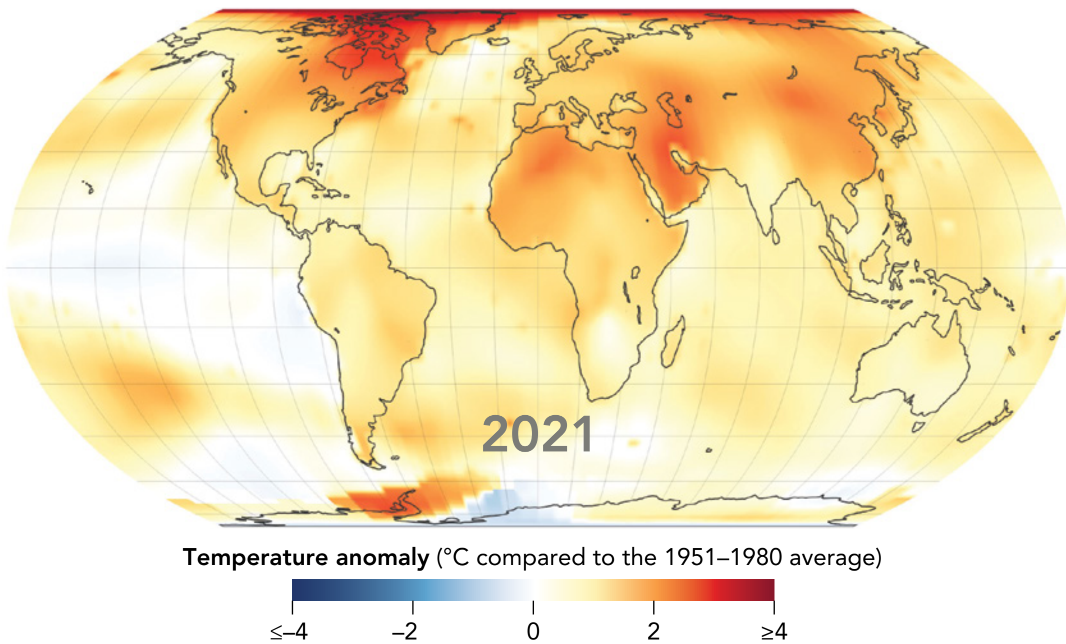


Figure 2 The average increase in global temperature compared to the 1951–1980 average

Extreme weather events

The number of extreme weather events around the world is increasing (Figure 3). Warmer oceans increase the amount of water vapour in the atmosphere and rapidly rising hot air causes stronger winds. Based on the current trend of rising global temperatures, scientists have predicted that storms will have greater maximum wind speeds and more sudden and extreme rainfall. More intense tropical cyclones will cause flooding, landslides and damage to buildings.

Worldwide, the number of cyclones reaching categories 4 or 5 has risen by 15 per cent over the past 20 years (Figure 4). With an increase in extreme weather events, we can expect to see an increase in the loss of human lives.

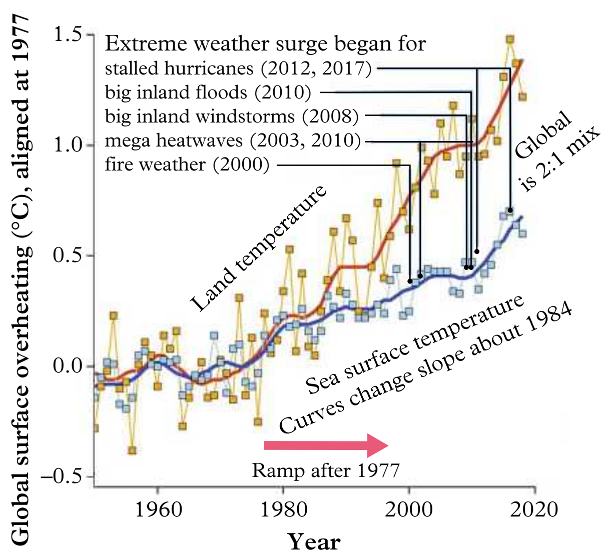


Figure 3 The number of extreme weather events has increased with the increased surface temperatures of the Earth and the sea. NASA GISTEMP V4 Foundation.org

Health and disease

Higher temperatures in summer have increased heat-related deaths. In 2022, the average global temperature was recorded to have risen by approximately 1.1°C. Heatwaves are now lasting longer causing people to become more dehydrated, placing more strain on their hearts and causing people to experience sleep deprivation.

These factors contributed to the deaths of 56 000 people during a heatwave in Russia in 2010.

Enhanced global warming is changing the climates in many areas. Some areas are becoming warmer and experiencing more rain. This can extend the zones for infectious diseases, such as dengue fever and malaria, which thrive in warm, moist conditions (Figure 5). In cities such as Beijing, China, stagnant weather conditions can trap both warm air and pollutants, leading to increased smog which results in serious respiratory problems contributing to increased deaths.

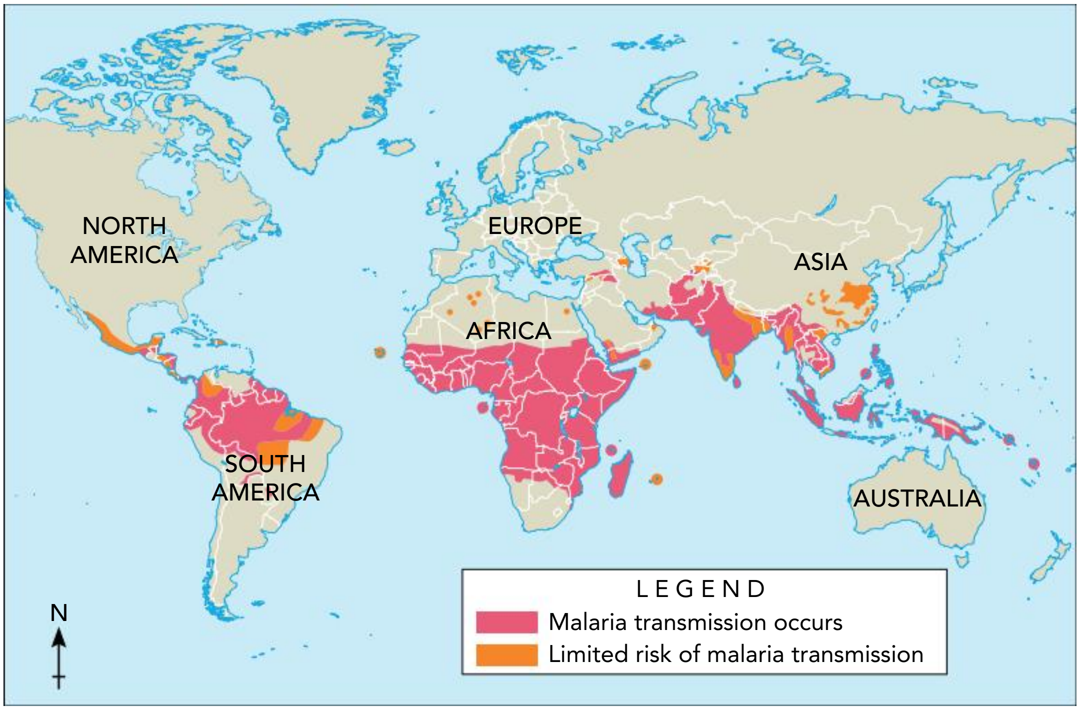


Figure 5 Countries and areas at risk of transmission of malaria, 2010

Species distribution

Rapid climate change over the past 50 years has resulted in many changes to the distribution and numbers of species and is thought to have caused extinctions. Many of the species at risk are Arctic and Antarctic animals, such as polar bears and emperor penguins, which live on the rapidly disappearing ice (Figures 6a and 6b). Other species, such as the white lemuroid possum, which is only found in high-altitude areas in north Queensland, can only live within certain temperature ranges (Figure 6c). These possums cannot survive extended temperatures over 30°C, which occurred in 2005. The species was thought to be extinct until recently when small numbers were seen.

Australian native plants and animals are well adapted to year-to-year climate fluctuations, such as floods and droughts.

They can often, however, only survive within a narrow range of temperatures. This means that many species and ecosystems could be highly vulnerable to the rapid and sustained increase in long-term average temperatures of 1–2°C that are expected as a result of global warming.

For example, climate change modelling suggests that the extent of highland rainforest ecosystems of tropical north Queensland may decrease by up to 50 per cent if the temperature increases by 1°C. These changes mean some species may become extinct.

As all organisms in the biosphere are interlinked, the loss of one species will affect the survival of other organisms. Even a small decrease in a population may cause a decrease in the number of alleles in the gene pool, making the species more vulnerable to disease in the future.

a

b

c

Figure 6 Many animals are at risk of extinction as a result of climate change, including **a** polar bears and **b** emperor penguins, which live in cold climates, and **c** lemuroid possums, which can only live within a certain temperature range.

4.2 Check your learning

Retrieve

1 **Define** the term 'extreme weather event'.

Comprehend

2 **Explain** how increasing levels of carbon dioxide have contributed to global climate change.

3 **Identify** and **explain** two sets of data that show how the climate has changed over the last 100 years.

4 **Describe** the ways that climate change can affect human health.

5 **Explain** how the loss of one species can affect other species.

Apply

6 **Evaluate** the statement 'An average increase in global temperature of 1°C is not going to have a large effect on me,' (by comparing weather and climate, defining 'average increase in global temperature', describing how climate change will affect your environment, and deciding if the statement is correct).

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

4.3 Deep ocean currents regulate global climate

Learning intentions

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

- explain how climate change models help make predictions about global climate trends
- describe how melting icecaps result from increased global temperatures and how this influences sea levels
- explain how deep ocean currents regulate global climate.

Key ideas

- Climate change is modelled through scientific principles and data gathered over long periods of time.
- Increased global temperatures are causing icecaps to melt and will increase sea levels.
- Deep ocean currents can regulate global climate and affect marine ecosystems.

Modelling the future

While there are many indicators of climate change, from increasing global temperatures and extreme weather events to reduction in biodiversity, scientists are constantly developing a series of models that predict how we may be able to reduce the impact of the change. Climate change models use scientific principles and data gathered over long periods of time to simulate the transfer of energy through the climate system. Each model uses mathematical equations to describe how the thermal energy will interact with different parts of the ocean, atmosphere, wildlife and land.

Climate change models break large areas into a series of smaller cell volumes ($100\,km^3$) so that the mathematical equations are more accurate.

These equations will estimate the temperature, wind speed and rainfall for each three-dimensional cell before moving on to the next cell and repeating the calculations. Using smaller cells means the calculations for a total area take longer than than if using larger cells, because more smaller than larger cells will cover the same area. Early climate models used very large cells, making them less accurate. The development of super computers has allowed scientists and mathematicians to use small cells ($50\,km^3$), making the climate change predictions more accurate. The use of current data from satellites and the improvement of mathematical models that predict how the climate will change every 30 minutes for the next 100 years means the current climate models are very accurate (Figure 1).

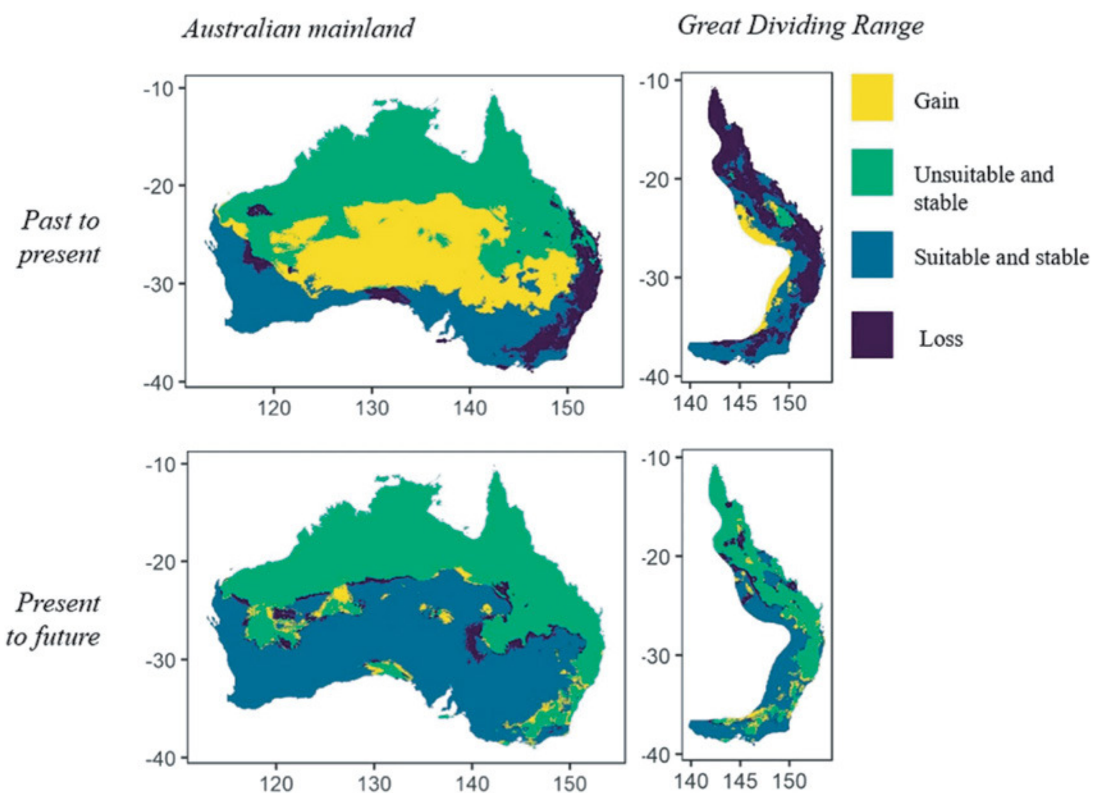


Figure 1 Super computers have used satellite data to predict how the changing climate in Australia will affect the distribution of emus.

EXPERIMENT
4.3A: Melting ice and its effect on sea levels
Go to page **246**.

CHALLENGE
4.3B: Salt water density
Go to page **247**.

Changing sea levels

The impact of global warming will vary. Some areas of the Earth will experience larger changes in average temperatures than other areas. At the Earth's poles, average temperatures have increased by up to 2°C over the past 40 years (compared to 1.1°C for the rest of the Earth). This is due to the increasingly warm ocean currents melting the glaciers and ice sheets (Figure 2). The extremely cold temperatures do not last long enough for the ice to fully re-form during the winter months. The thinner ice melts more quickly each year.

When this has been modelled by data scientists, it has shown that as the ice and snow melt at the poles, the rate of global warming will increase.

One of the main roles of the white ice and snow is to reflect solar radiation back into space. As the amount of snow and ice cover decreases, the amount of solar radiation that will be absorbed by the geosphere and hydrosphere will increase. This, in turn, will heat the atmosphere even more and increase the rate of global warming as more heat energy is retained by the Earth.

The water that is released from the land ice will contribute to increased sea levels. While floating sea ice replaces the water it displaces, melted land ice returns to the sea, increasing the overall sea level. This, combined with an increase in extreme storms, will have a large impact on the cities located in Australia's coastal regions (Figure 3).

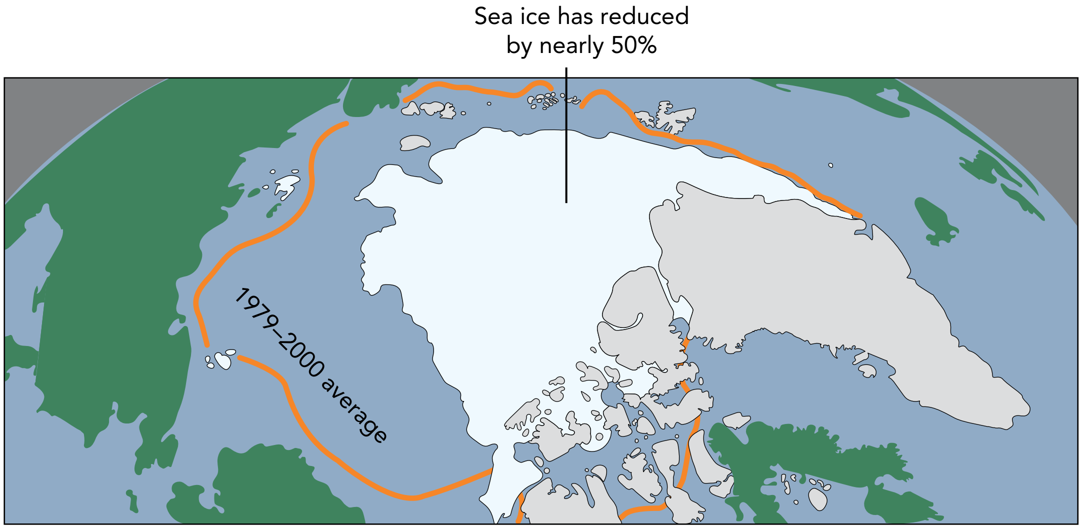


Figure 2 The amount of sea ice at the North Pole has been reduced by nearly 50 per cent in the past 20 years.

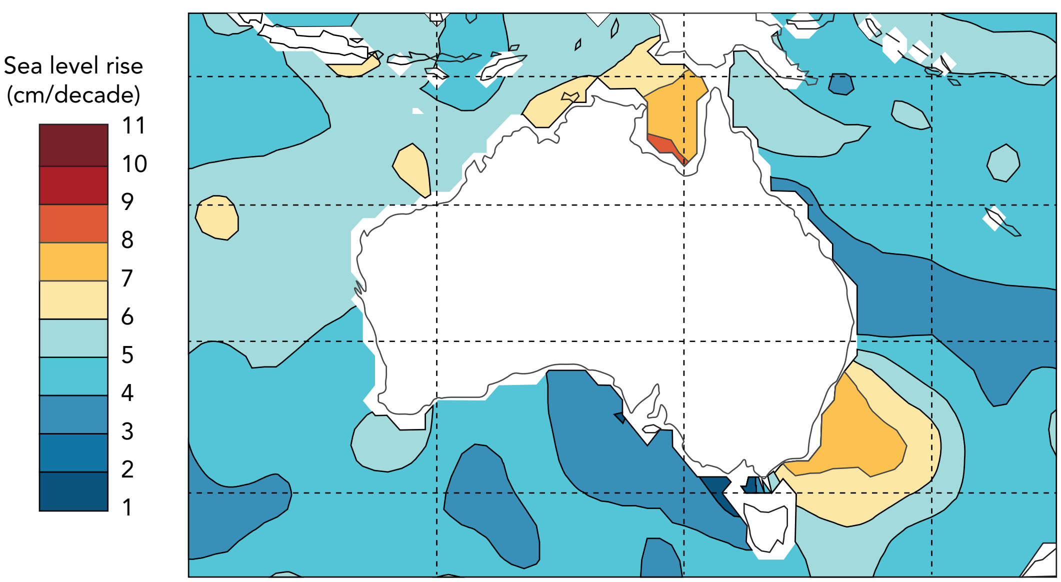


Figure 3 The modelled rise in sea levels in Australia every 10 years

Deep ocean currents and climate control

Within the oceans are large deep ocean currents that act like conveyor belts, distributing heat through parts of the world and regulating temperature (Figure 4).

Ocean currents have the important job of moving warm water from equatorial regions towards the poles; the water cools and travels from the poles back to the warmer areas of the Earth. These large conveyer belts of water are driven by the differences in temperature and salinity. Colder water is dense and heavy, and it moves towards the ocean floor picking up many nutrients along the way. Warmer water is less dense and moves up towards the surface, completing the up-and-down conveyer belt-like movement. Less salty water is also less dense and rises to the surface, whereas salty water is denser and sinks. Heat from the Sun evaporates the top layer of the ocean which causes the remaining water to become more concentrated in salt. The salty water will continue to sink once again. This cycle of warm water and cold water is disrupted by the melting of the fresh water in ice caps. This in turn can affect the ocean conveyor belt that controls climate.

Small changes in these large ocean currents can produce large changes in the marine life and the climate (Figure 5). El Niño events occur when the waters of the Pacific Ocean are warmer than normal. This in turn causes more rain to fall in the Pacific Basin instead of northern Australia. A La Niña event occurs when the Pacific Ocean is cooler than normal, causing increased rainfall and possible flooding in Australia. This means that small changes in the temperature of the Antarctic region will result in large changes in the climate of all parts of Australia.

Figure 5 Coral bleaching along the Great Barrier Reef may be the result of rising sea temperatures, which block the photosynthetic reactions corals need to stay alive.

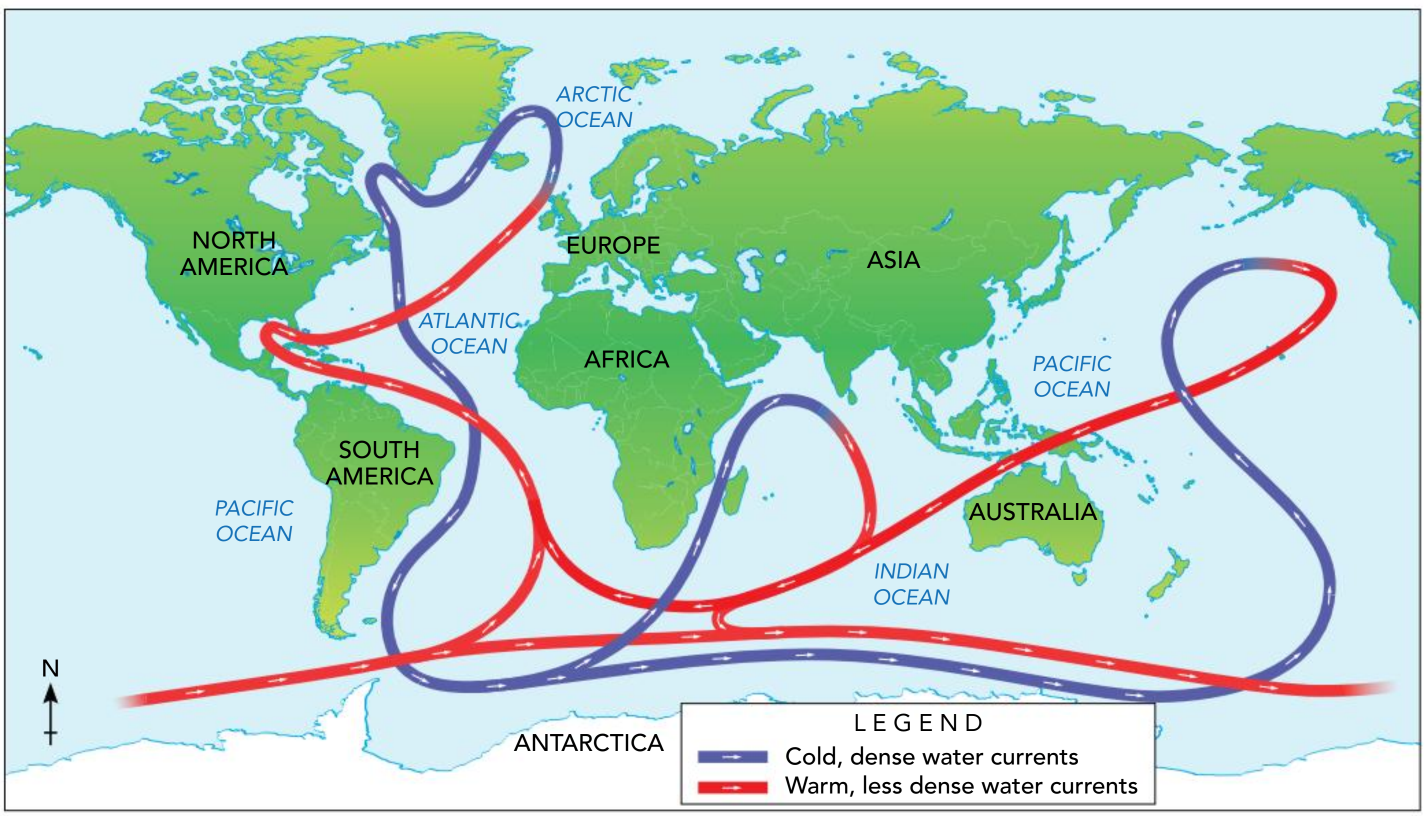


Figure 4 The path of the ocean 'conveyor belt', in which differences in temperature and salinity drive the movement of large currents of water

Deep ocean currents have a large impact on marine life. This can be seen in the Galapagos Islands in South America where cold ocean currents carrying nutrient-rich deep water travel up to the surface. This process is known as **upwelling** and helps transport nutrients to the surface of the islands. Nutrients then feed phytoplankton concentrations and support the food web of the marine ecosystem. The upwelling process also occurs along the coast of Queensland during monsoon season (Figure 6). Occasionally, the upwelled waters do not completely reach the surface. When this occurs it is called an **intrusion**.

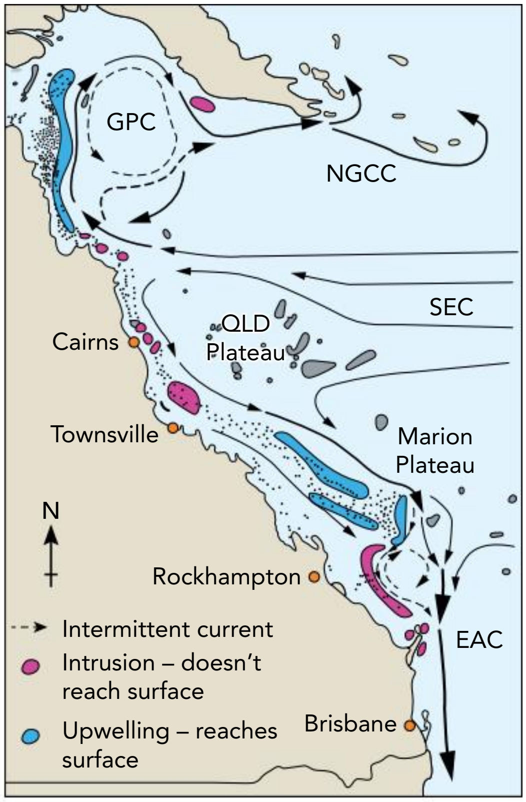


Figure 6 Ocean currents driving marine ecosystems through upwelling and intrusion during monsoon season in Queensland

upwelling
a process in which deep, nutrient-rich cold water moves up towards the surface

intrusion
when upwelled waters do not reach the surface

4.3 Check your learning

Comprehend

1 **Describe** how scientists and mathematicians model climate change.
2 **Describe** why the development of supercomputers has improved the accuracy of climate modelling.
3 **Explain** why ocean currents are responsible, in part, for global temperature.
4 **Explain** how the temperature of the Pacific Ocean can affect Australia's climate.

Analyse

5 **Compare** the impact of sea ice and land ice on sea levels.

Apply

6 Use Figure 3 to **determine** the expected rise in sea level at the coast closest to where you live.
7 It is expected that as the sea level rises, the inland water table will also rise. Many new housing developments are built just above the water table. **Create** a flyer that explains why the residents in a new housing development should care about global warming.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

//SCIENCE AS A HUMAN ENDEAVOUR//

4.4 Climate change can be mitigated

Learning intentions

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

- compare climate mitigation and climate adaptation strategies
- describe how First Nations peoples have used ecological knowledge to reduce carbon dioxide in the atmosphere.

climate change mitigation
efforts that aim to reduce or prevent greenhouse gas emission

Increasing awareness of the effects of climate change has resulted in increased urgency to implement change. There are two key approaches humanity is using to respond to climate change: mitigation and adaptation.

Mitigation

Climate change mitigation refers to actions that work to reduce the production of greenhouse gases, or that increase the rate of greenhouse gas removal from the atmosphere.

Reducing production of greenhouse gases

The greenhouse gas carbon dioxide (CO_2) is produced through the chemical reaction called combustion. In a combustion reaction, a fuel reacts with oxygen and produces carbon dioxide and water as follows:

fuel + oxygen → carbon dioxide + water

Combustion is used for powering cars, industrial production and even the heating of our homes. The demand for and consumption of oil, coal and gas has steadily increased in Australia over the past 50 years. However, as more people have become aware of the effects of global warming, they are changing their habits. Figure 1 shows that the consumption of electricity generated by coal has gradually reduced since 2009. Reducing the number of trips in cars and aeroplanes, and the insulation of houses and businesses to reduce heating and cooling costs can all contribute to the reduction in energy consumption and therefore reduce carbon dioxide production.

Another greenhouse gas that has a significant impact on climate change is methane (CH_4). This gas can store up to 25 per cent more heat than carbon dioxide. Approximately 32 per cent of human-caused methane comes from manure and gastroenteric releases from agricultural livestock such as cattle (Figure 2). Human-caused methane emissions can be reduced by cutting down on the amount of red meat consumed and by opting for plant-based substitutes for dairy and protein.

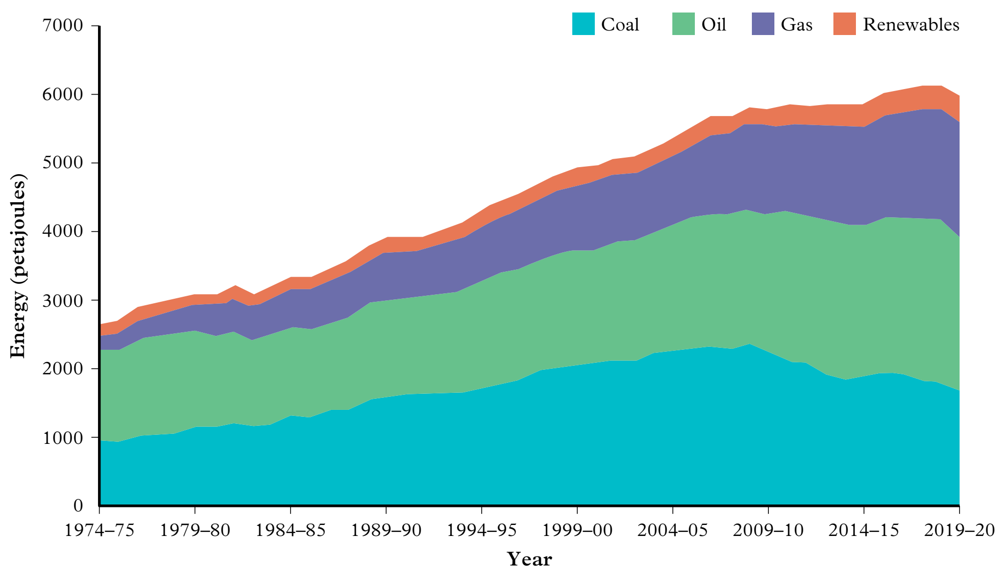


Figure 1 The amount of energy consumed in Australia over time

Figure 2 Reducing the amount of red meat and dairy consumed can reduce the demand for agricultural cattle.

Methane is also produced when food waste is broken down. The National Food Waste Strategy Feasibility Study calculated that food waste produces 3 per cent of Australia's greenhouse gas emissions. This is equivalent to 312 kg per person. This is the reason for the establishment of a National Food Waste Strategy and Action Plan that aims to reduce Australia's food waste by:

- redirecting more food to the food rescue sector
- delivering an education campaign, and
- making investments that aim to create value from food waste.

Removing greenhouse gases

Several different strategies to remove greenhouse gases (such as carbon dioxide) are currently being applied and having their effectiveness tested to determine best practice. The first of these strategies is **reforestation**. This process involves planting new trees and vegetation (Figure 3). Through the process of photosynthesis, the carbon dioxide is removed from the atmosphere and stored as other molecules in the plants. The risk of this process is that the carbon dioxide could be released during a bushfire.

reforestation
the process of replanting trees and vegetation to restore natural habitat

Figure 3 Reforestation restores vegetation which can remove CO_2 from the atmosphere.

climate change adaptation
coping adjustments made in response to the effects of climate change

biochar
a lightweight residue containing carbon and ash that is formed from the slow burning of biomass

Carbon dioxide is also being captured directly from the air using Direct Air Carbon Capture and Storage (DACCS). This process uses chemicals that directly bond to carbon dioxide. The gas is then extracted and stored in sedimentary rock that previously contained oil and gas. Rocks used to store the CO_2 are carefully chosen. They must have high porosity (contain small holes) and permeability (ability to let things in and out). After capturing and storing the carbon dioxide, the sedimentary rock is capped by a mud stone which prevents the carbon dioxide from escaping back into the atmosphere. The DACCS process is currently being trialled in several states of Australia.

A much older method of carbon dioxide removal used by First Nations peoples involves removing carbon dioxide from the atmosphere using **biochar**. Biochar is a fine-grained charcoal produced from the slow burning of organic material in a low oxygen environment (Figure 4). Plants emit carbon dioxide into the atmosphere when they decay. Slow burning biomass into biochar and then storing it in soil controls the release of CO_2. Instead of being released into the atmosphere, the CO_2 is stored in the ground for hundreds of years. This way, stored CO_2 can act as a fertiliser, improve the quality of water, and reduce soil acidity and the amount of irrigation needed.

Adaptation

Climate change adaptation refers to making changes to adjust to the current or predicted effects of climate change. A major struggle with global climate change is that some communities are currently being affected more than others. For example, low level islands in the Pacific (such as the Torres Strait Islands) are more susceptible to the effects of extreme weather and rising sea levels. In December 2016, the Torres Strait Regional Adaptation and Resilience Plan was released. This plan identified several actions that could be made to adapt to and limit some of the impacts of climate change. One action included the construction of a sea wall to protect Saibai Island from erosion and the impact of storm surges (Figure 5).

Torres Strait Islander peoples are also involved in monitoring the temperature and humidity levels in the community. This is used to reduce the heat stress risk for individuals. Plans have also been generated to organise outdoor activities during cooler times. Another action as a result of the plan includes the monitoring of five climate-sensitive infectious diseases, including tuberculosis and dengue fever. This is to ensure the local health systems of the Torres Strait Islands can adapt to the increasing risk of infections.

Figure 4 Biochar

Figure 5 The sea wall of Saibai Island

4.4 Test your skills and capabilities

Communication

A climate sceptic is someone who does not believe the increasing levels of carbon dioxide in the atmosphere are causing rapid climate change. It can be difficult to change someone's mind. A study published in the scientific journal *Nature* in 2015 identified that emphasising the shared understanding of climate change was an effective way to encourage people to take action.

People are more likely to listen if they know and trust the messenger. This means children are more likely to be persuaded by their parents than by a stranger. It is also important to use data and evidence in arguments.

Write a letter to someone you know **explaining** climate change. **Use** the data and evidence in this chapter to **explain** why it is important for them to make changes in their life that will reduce the impact of climate change.

CHAPTER 4 REVIEW

CLIMATE CHANGE

Retrieve

1 **Identify** which of the following is the result of sideways or horizontal movements of air due to pressure differences.
- A deep ocean currents
- B wind
- C the Coriolis effect
- D solar radiation

2 **Identify** the term that explains the impact of the Earth's rotation on the direction of air or water movement.
- A permafrost
- B carbon footprint
- C solar energy
- D the Coriolis effect

3 **Identify** which of the following best describes the 'ocean conveyer belt'.
- A the movement of water in the ocean
- B the migration of marine life
- C the heating and cooling of the ocean
- D the most effective path for sailing the ocean

4 **Define** the term 'solar radiation'.

5 **Recall** which of Earth's spheres describes all the water contents of Earth.

6 **Define** the term 'greenhouse gas'.

7 **Recall** the global temperature increase (in degrees Celsius) that NASA has predicted will cause annual heatwaves, water stress, increased heavy rainfall, floods, reduced biodiversity, increased wildfires and increased melting of the polar icecaps.

Comprehend

8 **Describe** one way that the greenhouse gas methane is released into the atmosphere.

9 **Describe** one way that the greenhouse gas carbon dioxide is released into the atmosphere.

10 **Explain** why cold water from melted sea ice will sink to the bottom of the ocean.

11 **Describe** two causes of climate change in the past 2000 years.

12 **Explain** why upwelling is important for some marine ecosystems.

13 **Explain** why animals that live in the polar regions of the Earth (the Arctic or Antarctic) are at great risk due to climate change.

Figure 1 Polar bears are at risk of extinction.

14 **Explain** how biochar is produced and how it can be used to reduce carbon dioxide emissions.

15 **Describe** how high-pressure and low-pressure weather systems are formed.

16 **Explain** why it is warmer near the equator than elsewhere on Earth.

17 **Explain** why increased melting of sea ice will trigger a more rapid rate of global temperature increase.

Analyse

18 **Contrast** weather and climate.

19 **Compare** climate change mitigation with climate change adaptation.

20 **Compare** ocean currents and air currents.

Apply

21 The Bramble Cay melomys was a rodent native to Bramble Cay, a small island on the surface of a coral reef in the Torres Strait (Figure 2). The species was declared extinct by the Queensland Government and University of Queensland in 2016. It was the first species reported to become extinct because of human-caused climate change.

Investigate the Bramble Cay melomys. **Identify** some of the effects of climate change that caused the species to become extinct.

Figure 2 The Bramble Cay melomys

22 **Discuss** how deep ocean currents can affect climate.

23 Consider the weather map of Australia shown in Figure 3.

a **Predict** whether the Queensland coast is more likely to experience storms and rain, or clear sunny skies. **Justify** your response.

b **Predict** whether the south coast of Western Australia is more likely to experience storms and rain, or clear sunny skies. **Justify** your response.

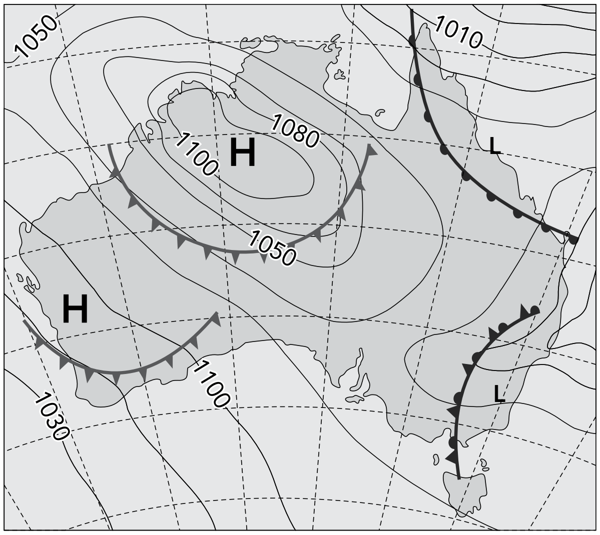


Figure 3 Weather map of Australia

Social and ethical thinking

24 Red meat and dairy from livestock are heavily consumed in Australia as they offer a range of nutritional benefits and tastes, and are easily accessible to purchase. However, the red meat industry in Australia contributes 11.8 per cent of Australia's total greenhouse gas emissions.

Discuss the ethical dilemma of red meat overconsumption by:

> **investigating** and **describing** the advantages of consuming/purchasing red meat

> **investigating** and **describing** the disadvantages of consuming/purchasing red meat

> **deciding** whether the advantages are more important than the disadvantages.

Figure 4 Red meat is a popular choice in many Australian households.

25 Not all countries have contributed to climate change equally. Countries that were industrialised earlier or industrialised to a large scale have had longer periods of time and greater capacity to emit greenhouse gases into the atmosphere. Climate debt is a concept that was proposed in the 1990s that suggests developing countries are owed a debt by developed countries for the disproportionate damage developed countries have contributed to climate change.

Investigate climate debt and **discuss** whether you believe it is fair for developed countries to owe a climate debt to developing countries severely affected by climate change.

Critical and creative thinking

26 One of your close personal friends tells you that they don't believe in climate change. **Use** evidence presented in this chapter to **write** a persuasive passage you could use to try and change your friend's mind about the climate crisis.

27 **Create** a concept map that links all the bolded glossary terms in this chapter together.

28 **Create** an infographic that explains three different climate change mitigation strategies and how they work.

29 Imagine you had to reduce your energy impact on the environment. Look at all the appliances and gadgets you use in your home. **Identify** one of these as one that you could not bear to give up. **Create** an A4 page outlining why this one item is 'essential' to you and then make a list of appliances and gadgets that you could live without.

Research

30 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

» Reducing methane production with FutureFeed

Approximately 1.3 billion people around the world rely on livestock for their livelihoods. Unfortunately, livestock also contributes 15 per cent of global greenhouse gas emissions. Scientists from CSIRO, Meat & Livestock Australia and James Cook University have developed livestock feed called FutureFeed which can reduce the emissions produced by the livestock that consume it. Research FutureFeed and describe:

- what FutureFeed is made of
- how it works to reduce methane emissions
- the impact FutureFeed can have if global ruminant producers adopt it as feed.

Figure 5 *Asparagopsis. spp.* are native to Australia and are used in FutureFeed.

» Rising sea level crisis

As the polar icecaps melt and sea levels rise, low level (low elevation) island countries are at serious risk of disappearing if sea levels continue to rise as they are now. One such island includes the island nation of Kiribati. Research Kiribati and describe:

- the factors that leave Kiribati so vulnerable to rising sea levels
- the climate adaptation strategies in place to deal with the impact of rising sea levels washing out Kiribati.

Figure 6 Tabuaeran Beach, Kiribati

» Responding to climate change

The Paris Agreement is an agreement between countries that aims to reduce greenhouse gas emissions in the atmosphere at a level that would prevent danger to the Earth's climate system.

- Investigate Australia's commitment and current goals that result from this agreement.
- Describe the strategy that Australia is using to meet its commitment.
- Evaluate the strategy to determine if Australia will be able to meet its commitment.
- Describe how you could contribute to this target.

Chapter checklist

Now that you have completed this chapter, reflect on your ability to do the following.

	I can do this.		I cannot do this yet.
• Explain the difference between weather and climate. • Explain how solar radiation influences the global climate system.	☐	☐	Go back to Topic 4.1 'Climate change is global'. Page 94
• Describe how increased greenhouse gases have resulted in increased global temperatures and extreme weather events. • Describe how climate change has led to changes in disease and species distribution.	☐	☐	Go back to Topic 4.2 'Climate change indicators include increased global temperatures, extreme weather, disease and species distribution'. Page 98
• Explain how climate change models help make predictions about global climate trends. • Describe how melting icecaps result from increased global temperatures and how this influences sea levels. • Explain how deep ocean currents regulate global climate.	☐	☐	Go back to Topic 4.3 'Deep ocean currents regulate global climate'. Page 102
• Compare climate mitigation and climate adaptation strategies. • Describe how First Nations peoples have used ecological knowledge to reduce carbon dioxide in the atmosphere.	☐	☐	Go back to Topic 4.4 'Science as a human endeavour: Climate change can be mitigated'. Page 106

Check your Student obook pro for these digital resources and more:

Quizlet
Play a Quizlet game to test your knowledge.

Chapter quiz
Test your understanding of this chapter with the chapter review quiz.

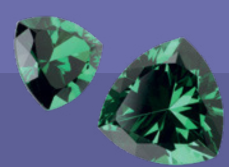
CHAPTER 5

THE PERIODIC TABLE

5.1 The structure of an atom determines its properties

- Describe the importance of atomic numbers in determining the number of electrons.
- Describe the relationship between valence electrons and element properties.

5.2 Groups in the periodic table have properties in common



- Identify the properties of group 1, group 2 and transitional metals.
- Relate the properties of group 1 and group 2 metals to their electron configurations.

5.3 Non-metals have properties in common

- Recognise and identify non-metals and metalloids on the periodic table.
- Identify and explain the properties of non-metallic elements, halogens and noble gases.

5.4

Ions have more or less electrons

- Define ion, anion and cation.
- Relate the number of electrons in the valence shell to whether the atom will become an anion or a cation.

5.5

Metal cations and non-metal anions combine to form ionic compounds

- Explain ionic compounds using the terminology anion and cation.
- Describe the properties of ionic compounds.
- Draw the electron transfer between atoms and the resultant ions.

5.6

Non-metals combine to form covalent compounds

- Define the term 'covalent compound' and describe how it is formed.
- Explain what a diatomic molecule is.
- Draw covalent molecules, showing the sharing of electrons to complete their valence shells.

5.7

Metals form unique bonds

- Describe the structure of metallic bonding as a grid of cations in a sea of delocalised electrons.
- Compare metallic compounds and alloys.

5.8

Science as a human endeavour: Nanotechnology involves the specific arrangement of atoms

- Describe what is meant by nanotechnology.
- Convert between length measurements of nanometres and more common units (e.g. cm).
- Provide examples of the uses of nanotechnology in society.

What if?

Charged water

What you need:

Glass of pure water (distilled or deionised), multimeter or speaker, 3 wires, 9 V battery, fine NaCl (salt) crystals

What to do:

1. Use the wires to connect an open circuit that includes the battery and the multimeter.
2. Place the open ends of the circuit in the glass of water so that they do not touch.
3. Observe whether the electricity passes through the pure water.

What if?

» What if two teaspoons of salt were mixed through the water?

» What if the electricity was passed through the salt crystals with no water?

5.1 The structure of an atom determines its properties

Learning intentions

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

- describe the importance of atomic numbers in determining the number of electrons
- describe the relationship between valence electrons and element properties.

Key ideas

- The atomic number and name of an atom is determined by the number of protons it contains in its nucleus.
- The relative atomic mass is the sum of the number of positive protons and number of neutral neutrons.
- Negatively charged electrons have negligible mass and move around the nucleus in electron shells.
- An atom's outermost electron shell is called the valence shell.
- The number of electrons in the valence shell determines many of the properties of an element and therefore its position in the periodic table.

Video 5.1
Atomic structure

period
in chemistry: a horizontal list of elements in the periodic table

group
a vertical list of elements in the periodic table that have characteristics in common

atomic number
the number of protons in an atom

electron shell
a defined area of space in which electrons move around an atom's nucleus

Bohr model
a model of the atom in which electrons orbit the nucleus in a series of defined orbits known as shells

The periodic table

The periodic table organises elements (or types of atoms) in rows and columns (Figure 1). The horizontal rows are called **periods**. The atomic number increases by one for each element as you go across a period (from left to right). The vertical (up–down) lists of elements are called **groups**. Elements in each group have similar properties.

The columns and rows in the periodic table have been given names and numbers. This makes communication easier, because these elements have similar properties and trends.

Atoms and their electrons

The protons and neutrons of an atom are located within the nucleus. These subatomic particles are responsible for most of the mass of the atom and therefore have a strong influence on the properties of the atom. The number of protons is called the **atomic number** and is used to order the elements in the periodic table.

In contrast, electrons have a 'negligible' mass, meaning the mass is so small it is ignored; it is almost too small to measure. However, because electrons orbit the nucleus, they affect the way the atoms bond with other atoms.

Electron configurations

You learnt about Ernest Rutherford's model of the atom in Year 9 Science. After Rutherford had refined his model, another scientist, Niels Bohr, concluded that the electrons in the atom do not behave exactly like the planets around the Sun.

Instead, electrons move about the nucleus in spaces that are at set distances from the nucleus. These spaces are known as **electron shells**. There is a limit to the number of electrons that can be in any of the shells. This special arrangement of electrons around an atom is called the **Bohr model**.

Table 1 shows that the further the electron shell is from the nucleus, the more electrons it can contain. The maximum number of electrons a shell can hold is related to its shell number by the simple formula $2n^2$, where n is the number of the shell from the nucleus. For example, the maximum number of electrons that the 3rd shell can hold is $2 \times 3^2 = 18$.

Table 1 The Bohr model of the atom

Shell number (from the nucleus outward) (n)	Maximum number of electrons in the shell ($2n^2$)
1	2
2	8
3	18*
4	32

*The formula $2n^2$ works for most atoms until we get to atomic number 19 (potassium). Once the third electron shell has eight electrons, the remaining electrons start moving into the fourth shell.

Bohr also stated that the electrons of an atom are normally located as close to the nucleus as possible, because this is a lower-energy state and is more stable. Therefore, electrons fill the shells closest to the nucleus first. Shells that are further from the nucleus need more energy to stay in the high energy shell.

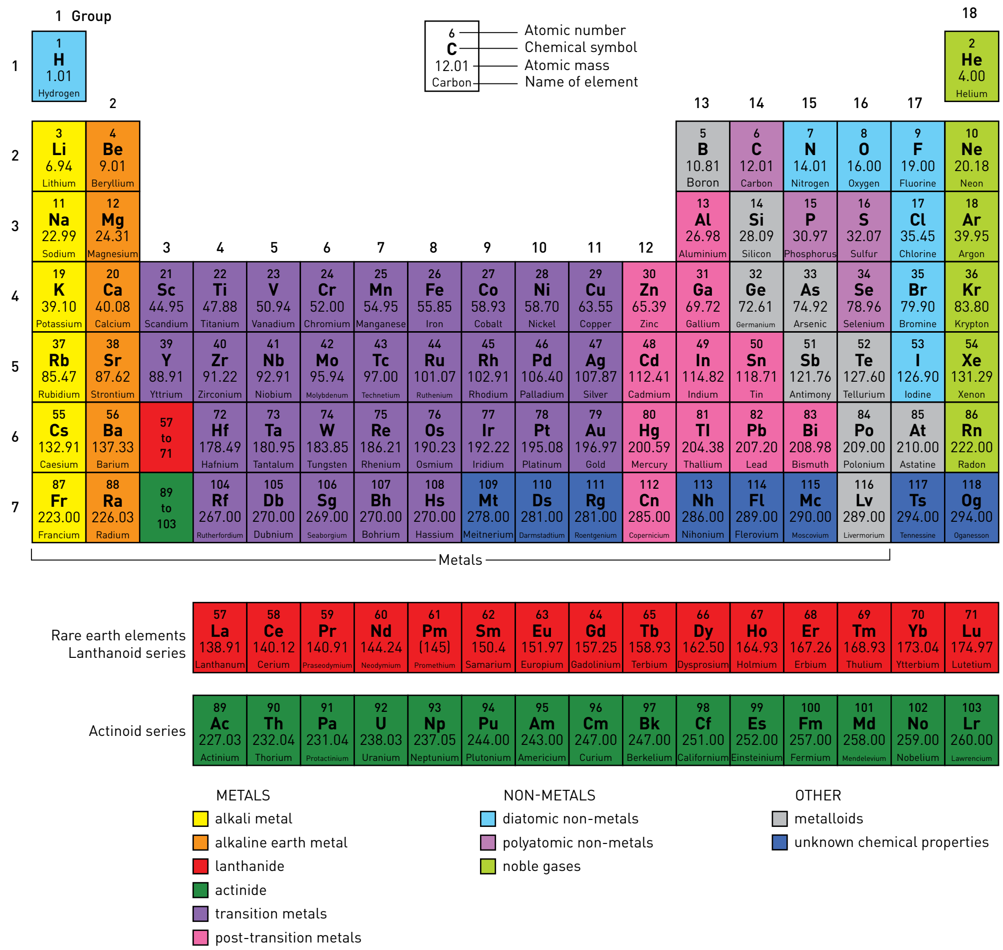


Figure 1 The periodic table of elements

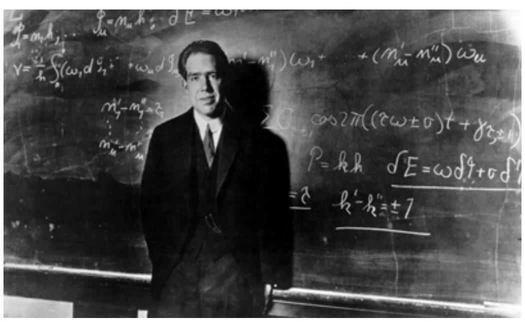


Figure 2 Niels Bohr proposed the idea of electron shells.

The arrangement of electrons in an atom is called its **electron configuration**. The electronic configurations of oxygen and calcium are compared in Figure 3.

Electron configurations are often represented by simple **shell diagrams** that show the electron shells as circles. The electrons are presented in pairs. The outermost occupied shell of uncharged atoms is known as the **valence shell**. The number of electrons in the valence shell of an atom determines the chemical properties of the element and affects how the atom will bond with other atoms.

Evidence for electron shells

Many substances give off coloured light when a small sample is introduced into a flame. This light can be seen through a spectroscope – an instrument that breaks the light up into its colours. A pattern of coloured lines is observed. This pattern is known as an **emission spectrum** and is unique for each element. Bohr explained this by saying that a particular atom is given energy in a flame. The electrons absorb the exact amount needed to jump from their normal shell to one further out from the nucleus. He described the electrons as being excited. Because this higher energy state is unstable, the electrons then jump back to their normal levels almost instantly. The extra energy that the electrons no longer need is released as light energy. The wavelength of the light (and therefore its colour) represents the energy difference between each electron shell. This unique combination of colours (or spectrum) is linked to a particular type of atom (element) with its unique number of electrons arranged in shells. This spectrum is therefore like the 'fingerprint' of that element. This is how flame tests work.

electron configuration
a numerical way of showing the number of electrons in each electron shell around a particular atomic nucleus

shell diagram
a diagram that shows the number of electrons in each electron shell around a particular atomic nucleus

valence shell
the outermost electron shell in an atom that contains electrons

emission spectrum
the pattern of wavelengths (or frequencies) that appear as coloured lines in a spectroscope; it is unique to each element

EXPERIMENT

5.1: Flame tests
Go to page 248.

Worked example 5.1: Determining electron configuration

Determine the electron configuration of:

a oxygen

b calcium.

Solution

a The atomic number of oxygen is 8, so an uncharged atom contains eight electrons.

> Oxygen is in period 2, so it has two electron shells.

> The first shell can only hold two electrons.

> The second shell holds the other six electrons.

> The electron configuration of oxygen is 2,6.

b The atomic number of calcium is 20, so an uncharged atom contains 20 electrons.

> Calcium is in period 4, so it has four electron shells.

> The first shell can only hold two electrons.

> There are 18 electrons left to place in shells. The second shell can only hold eight electrons. The third shell is stable with eight electrons (even though it holds a maximum of 18).

> The fourth shell holds the last two electrons.

> The electron configuration of calcium is 2,8,8,2.

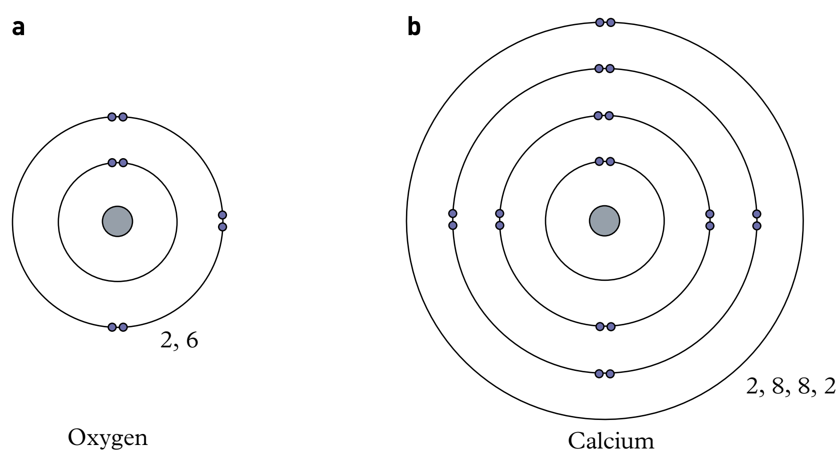


Figure 3 The electron configurations for oxygen and calcium are shown as simple shell diagrams.

Figure 4 The emission spectrum of hydrogen

Electrons and properties of elements

The electron configurations of the elements can explain the properties of the elements. Being able to confidently navigate the periodic table enables you to identify trends in electron shell arrangements, the properties of elements and the types of bonds that form in their compounds.

Groups and valence electrons

The vertical groups of the periodic table are numbered 1–18. Elements in the same group have similar chemical properties, which we now know are due to the arrangement of their electrons.

Elements in the same group have the same number of electrons in their valence (outermost) shell. For example, all the elements in group 13 have 3 electrons in their valence shells, which means they have very similar properties. Outer valance shells with 8 electrons are more stable than electron shells with less electrons. The valence-shell electrons often interact with other atoms.

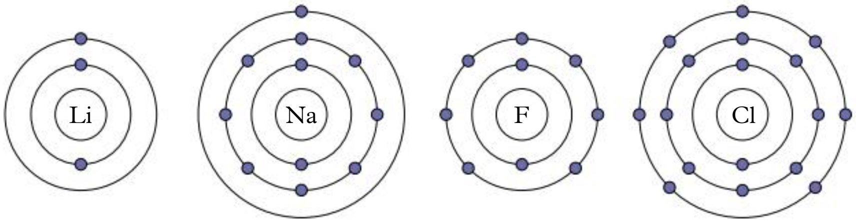


Figure 5 In group 1, the electron configuration of lithium is 2, 1, whereas that of sodium is 2, 8, 1. The atoms of all other group 1 elements also have one electron in their outer valence shell of electrons. Elements in group 17 (e.g. fluorine and chlorine) have seven valence electrons.

5.1 Check your learning

Retrieve

1 **Identify** the key feature of an atom that determines its atomic number. Use an example of two different elements to illustrate your answer.

2 For the Bohr model of the atom, **identify** the maximum number of electrons that the fourth electron shell can contain.

Comprehend

3 **Explain** why the second shell can contain more electrons than the first shell.

4 **Describe** the valence shell of an atom.

Analyse

5 Copy and complete Table 2.

6 **Identify** the element that is in period 3, group 1. Draw its electron configuration.

Apply

7 A potassium atom contains 19 protons.

a **Identify** the number of electrons that will be present in a potassium atom.

Table 2 Elements, atomic numbers and electron configurations

Element	Atomic number	Electron configuration
Beryllium		
	9	
Magnesium		
Neon		
		2,8,3
	11	
		2,8,7
Sulfur		

Justify your answer (by identifying how a potassium atom is given its atomic number, defining a neutral atom, and identifying the number of electrons in a neutral potassium atom).

b Use the Bohr model to **identify** the electron configuration of a potassium atom.

c From the electron configuration of potassium, it is clear that electrons do not normally occupy the fifth shell. **Propose** how the electrons in a potassium atom could be moved into this shell.

8 Robert Bunsen (1811–1899) was a German chemist who investigated the coloured flames given off by heated elements. From your results in the flame tests in Experiment 5.1, **determine** the atom that caused the yellow colour that Bunsen saw when he was heating glass.

Quiz me

Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

5.2 Groups in the periodic table have properties in common

Learning intentions

By the end of this topic, you will be able to:
- identify the properties of group 1, group 2 and transitional metals
- relate the properties of group 1 and group 2 metals to their electron configurations.

Key ideas
- Metals are defined by their lustrous appearance and their ability to conduct heat and electricity.
- The alkali metals in group 1 of the periodic table have a single electron in their outer shell and as a result are highly reactive when mixed with water.
- Transition metals have properties that are unique to groups 3–12.

Figure 1 Aluminium is a metal.

metals
elements on the left-hand side of the periodic table; they are malleable, lustrous, ductile and highly conductive

alkali metal
an element in group 1 of the periodic table

alkaline earth metals
elements with similar properties found in group 2 of the periodic table

Metals

Metals are one of the main types of elements in the periodic table. Almost all metal elements are solid at room temperature because they have high melting temperatures. The only exception is mercury, which is a liquid at 22°C. Metallic elements have many properties in common. Pure metals are usually:

> lustrous (shiny)
> able to conduct heat and electricity
> malleable (can be beaten into a new shape)
> ductile (can be drawn into a wire).

Group 1 metals

The **alkali metals**, such as sodium and potassium, are found in group 1 – the far-left column. Their position tells you that their uncharged atoms have just one electron in their valence shell. The alkali metals have quite low melting points and are soft and highly reactive.

Figure 2 Freshly cut sodium, a group 1 metal

Figure 3 Potassium reacts spectacularly with water.

In their pure state, they often resemble Plasticine and, when cut, are very briefly shiny silver before reacting with the air to become white again (Figure 2). Alkali metals react very strongly – some violently – with water, producing hydrogen gas and an alkaline solution. (An alkali is a soluble base.) As you go down the group, this reaction becomes more violent (Figure 3).

Group 2 metals

The **alkaline earth metals**, such as magnesium and calcium, are found in group 2. Their position tells you that their atoms have two electrons in their valence shell. The alkaline earth metals have quite low melting points and are relatively soft and very reactive; although in general they are not quite as reactive as group 1 alkali metals. Like the alkali metals, alkaline earth metals react with water, some strongly, producing hydrogen gas and an alkaline solution. As you go down the group, the metals become more reactive (Figure 4). Metals become less reactive as you go right across the periods and the group number increases.

EXPERIMENT

5.2: Reactivity of metals
Go to page **249**.

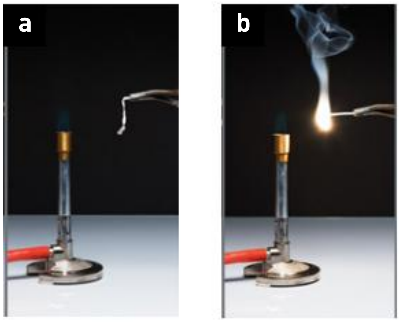


Figure 4 Magnesium, an alkaline earth metal, **a** before burning and **b** during burning.

Figure 5 Calcium is a soft grey metal; calcium carbonate is a white powder or stone.

Transition metals

The **transition metals** are found in a large block of the periodic table that consists of the 10 groups across the centre (groups 3–12). Many transition metals have special properties that are not shown by group 1 or group 2 metals.

> A small number are magnetic.
> Gold and copper are the only metals that are not silvery in colour.
> Many form coloured compounds (such as the gemstones in Figure 6).
> Many form more than one compound with a non-metal such as chlorine. For example, iron forms $FeCl_2$ and $FeCl_3$.

transition metals
the elements in groups 3–12 of the periodic table

Figure 6 Gemstones contain atoms of different metals, which gives them their different colours.

5.2 Check your learning

Retrieve

1 **Identify** three properties common to metals.

2 **Identify** two properties shown by some transition metals that are not shown by group 1 or group 2 metals.

Comprehend

3 **Describe** the properties that are shared by all metallic elements.

4 Use the properties of groups in the periodic table to **explain** why copper is found as a native element on Earth, but calcium metal is never found as a native element.

Analyse

5 **Calculate** the proportion of the periodic table that is composed of metals.

6 **Examine** the periodic table in Figure 1 on page 117.

a **Identify** the period and group for each of the following elements: fluorine, bromine, tin, radium, potassium, platinum, arsenic.

b **Identify** the elements listed in part **a** that are in the same group. **Explain** what this tells you about their properties.

c **Identify** the elements listed in part **a** that are in the same period.

Apply

7 Use your knowledge of the periodic table to **identify** the metal that will react the most strongly with cold water: copper, iron, magnesium, sodium or zinc. **Justify** your answer (by explaining what you know about how the reactivity of metals varies between the groups on the periodic table, comparing the properties of each element based on their group and identifying which element is the most reactive).

8 **Propose** a way to represent the different groups of metals clearly and informatively, identifying the distinguishing properties of each group.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

5.3 Non-metals have properties in common

Learning intentions

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

- recognise and identify non-metals and metalloids on the periodic table
- identify and explain the properties of non-metallic elements, halogens and noble gases.

Key ideas

- Non-metals (groups 14–18) do not conduct electricity or heat, are very brittle and have a dull appearance.
- Metalloids are found between metals and non-metals on the periodic table, and their properties are a combination of those of metals and non-metals.

metalloids
a small collection of elements that have characteristics of metals and non-metals

non-metals
elements on the right-hand side of the periodic table

halogens
the group of elements in group 17 of the periodic table

Metalloids

Metalloids are the small set of elements along the 'staircase' diagonal boundary between the metals and non-metals (Figure 1). They are in this location because the metalloids have a mixture of properties between those of metals and non-metals. Some of their properties are similar to those of non-metals; however, metalloids conduct electricity like the metals. Three of the metalloids are semiconductors, which means they only conduct electricity in a certain way under certain conditions.

Non-metals

Non-metals, as the name suggests, are elements that do not have the set of properties common to all metals. Non-metals are not lustrous (shiny) or ductile (easily manipulated); a small number of non-metals are coloured; and some are brittle (they break easily). In addition, non-metals have a much larger range of melting points and boiling points than the metals do.

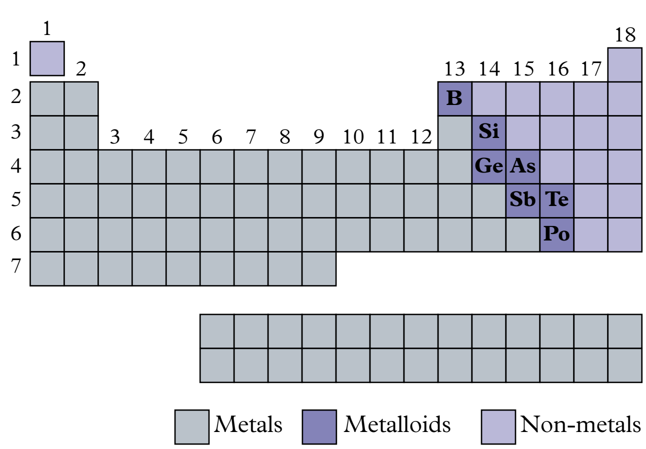


Figure 1 Regions of the periodic table

Figure 2 Boron and silicon are combined to form borosilicate glassware, such as the common Pyrex brand. This glassware is tough and has excellent heat-conduction properties that make it suitable for use in cooking.

At room temperature, several non-metals are gases and one (bromine) is a liquid, whereas all the metals except for one (mercury) are solids at room temperature. Only 18 elements in the periodic table are considered non-metals, compared with more than 80 metals. Despite this, non-metals make up most of the crust and atmosphere of the Earth, as well as the bulk of living organisms' tissues. Only two groups (vertical columns) in the periodic table are made up entirely of non-metals: groups 17 and 18.

Group 17: The halogens

The **halogens**, such as fluorine and chlorine, are found in group 17. The atoms of all the halogens have seven electrons in their outer shell. The halogens are mostly known for their capacity to react with metals to form salts. The word 'halogen' means 'salt-forming', and the term was coined for this group by Jacob Berzelius. Some halogens have bleaching properties as well (Figure 3).

As you go down the group, the melting points and boiling points of the halogens increase.

CHALLENGE
5.3: Identifying patterns in the periodic table
Go to page 250.

Figure 3 Bleaches often contain halogens.

At room temperature, fluorine and chlorine are gases, bromine is a liquid, and iodine and astatine are solids. This is the only group in which the elements range from gas to liquid to solid at room temperature. Astatine is radioactive and very unstable.

Unlike the metals in groups 1 and 2, the further down you go in this group of non-metals, the less reactive the element. Fluorine is the most reactive non-metal of all and is extremely dangerous to handle. Halogens are very effective cleaning and sterilising substances because of the lethal effects they can have on bacteria and fungi.

Group 18: The noble gases

The **noble gases**, such as neon and argon, are found in group 18. The uncharged atoms of the noble gases have eight electrons in their outer shell, except for helium, which has two.

Figure 4 Radon is responsible for most background radiation experienced in outdoor spaces. It occurs naturally as the decay product of uranium, and it can be found in natural springs.

The noble gases are so called because they are all gases at room temperature and are unchanged if mixed with other elements; that is, they are very unreactive or inert. The first three in the group (helium, neon and argon) do not react with any other element and form no compounds. It was first thought that the same was true of xenon and krypton, but recently chemists have discovered that these two elements will react with fluorine under certain conditions and form a very small number of compounds. The last member of the group, radon, is very dangerous – not because of any chemical reactivity, but because it is a radioactive gas (Figure 4).

noble gases
the stable gaseous elements in group 18 of the periodic table

5.3 Check your learning

Retrieve

1 **Identify** the dominant (most common) state of matter within the groups of non-metals.

2 **Identify** the properties that metalloids share with metals.

3 **Define** the term 'semiconductor'.

Comprehend

4 **Explain** why non-metals are named according to what they are 'not' rather than what they have in common.

5 The two main groupings of non-metals are in groups 17 and 18.

a **Describe** what the group number tells you about the elements it contains.

b **Describe** the properties that are shared by elements of group 17 and group 18.

6 **Explain** why many fluorescent lights contain an element from the top of group 18, instead of an element from the top of group 17.

Apply

7 **Explain** why the term 'metal-like' could be used to describe metalloid elements. **Propose** a better name for this group of elements. **Justify** your answer.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

5.4 Ions have more or less electrons

Learning intentions

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

- define ion, anion and cation
- relate the number of electrons in the valence shell to whether the atom will become an anion or cation.

Key ideas

- Electrons have a negative charge.
- When an atom loses electrons, it forms a cation (positve charge).
- When an atom gains electrons, it forms an anion (negative charge).

ion
an atom that is charged because it has an unequal number of electrons and protons

anion
a negatively charged ion formed when an atom gains electrons

cation
a positively charged ion that results from an atom losing electrons

Atoms and ions

Atoms are neutral. This means that the amount of negative charge within the atom is always the same as the amount of positive charge. This is because the number of protons (positive) is always the same as the number of electrons (negative). However, if electrons are lost or gained from the outside of the atom, there will no longer be the same number of protons and electrons, and the atom becomes an ion. The process of forming **ions** is called ionisation.

Ionisation can happen when atoms come together to form chemical bonds. It can also happen when atoms are exposed to radiation. When ions are formed, it is the electrons in the outer electron shell (the valence shell) that are affected. A valence shell that has all of its electrons, or that has 8 electrons, is stable. This means the electron shell is less likely to gain or lose electrons.

For example, the first three shells of a chloride ion are full, with 2, 8 and 8 electrons respectively.

An atom that originally had two electrons in its valence shell, such as magnesium, would lose both these electrons to achieve a full outer shell – it is easier to lose two electrons than to gain six.

An atom with seven electrons in its outer shell, such as chlorine, would gain one electron to complete this outer shell with eight electrons – it is easier to gain one electron than to lose seven to have a stable outer valence shell.

Figure 1 shows how magnesium and chloride ions are formed.

Calculating ion charge

When an ion is formed, the number of protons in the atom stays the same, because protons are located in the nucleus and are not affected by changes occurring on the outside of the atom. When electrons are gained or lost, an imbalance is formed between the number of positive charges and the number of negative charges.

Electrons are negatively charged, so when an atom gains an extra electron, the charge on the whole atom becomes negative. If two electrons are gained, then there is an overall charge of negative two. A negatively charged ion is called an **anion**.

If an electron is lost from an atom, the resulting ion will have a charge of positive one because there are more protons than electrons. One electron lost means there is effectively one extra proton. A positively charged ion is called a **cation**.

Table 1 contains some examples of anions and cations.

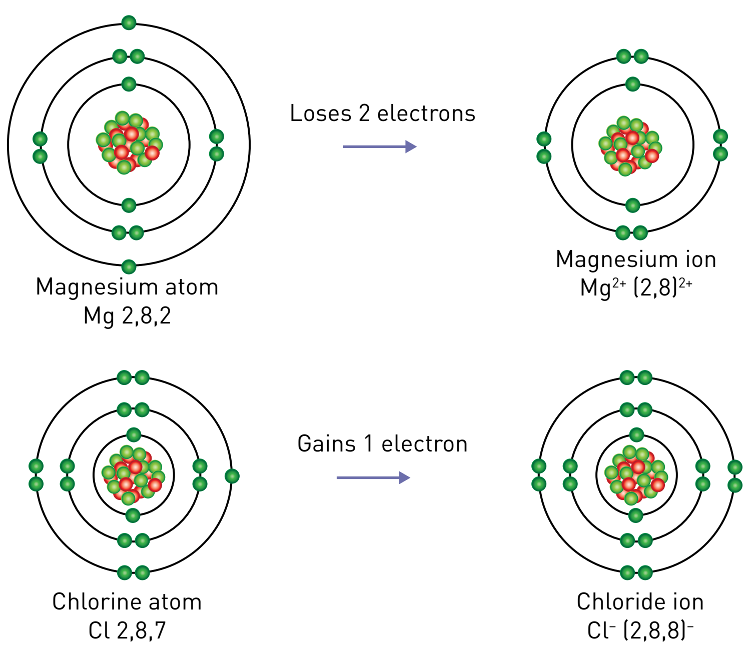


Figure 1 How magnesium and chloride ions are formed

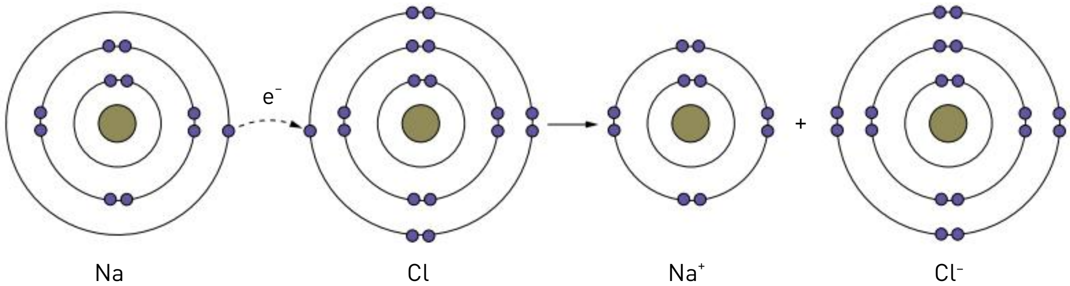


Figure 2 A sodium atom loses an electron to become a positively charged cation. Chlorine gains an electron to become a negatively charged anion. In this way, salt (sodium chloride, NaCl) is formed.

Worked example 5.4: Calculating the charge of atoms

Determine the likely charge of the following atoms:

a sodium ion **b** oxygen ion **c** neon atom.

Solution

a Sodium atoms are in group 1. This means they have one valence electron. It is easier to lose one electron than to gain seven electrons. This means the sodium ion will have one less negatively charged electron and have one more positive proton than electrons. Therefore, the sodium ion will have a charge of 1+.

b Oxygen atoms are in group 16 (with six valence electrons). It is easier to gain two electrons than to lose six electrons. This means the oxygen ion will have two extra electrons and have a charge of 2–.

c Neon is a noble gas (in group 18). This means neon atoms already have eight valence electrons (a stable outer shell) and will have no extra electrons or protons. The neon atom will be neutral.

Table 1 Examples of positive and negative ions

Name and symbol of atom	Electron configuration of atom	Electron configuration of ion	Metal or non-metal?	Change	Charge of ion	Name and formula of ion
Oxygen (O)	2,6	2,8	Non-metal	Gained 2 electrons	–2	Oxide (O^{2-})
Chlorine (Cl)	2,8,7	2,8,8	Non-metal	Gained 1 electron	–1	Chloride (Cl^{-})
Sodium (Na)	2,8,1	2,8	Metal	Lost 1 electron	+1	Sodium (Na^{+})
Calcium (Ca)	2,8,8,2	2,8,8	Metal	Lost 2 electrons	+2	Calcium (Ca^{2+})

Figure 3 To remember the difference between cations and anions, think of a positive CATion.

5.4 Check your learning

Retrieve

1 **Define** the term 'cation'.

Comprehend

2 **Use** an example from the periodic table to **explain** how an anion is formed.

3 **Describe** the patterns you observe in Table 1 for each of the following.

- **a** names of the negative ions
- **b** electron configurations of the ions
- **c** differences between the metals and non-metals

4 **Explain** why the elements neon (atomic number 10) and argon (atomic number 18) do not normally form ions.

5 **Explain** the relationship between the groups in the periodic table and the ions that are formed.

Analyse

6 **Calculate** the ionic charges of the following.

- **a** calcium cation
- **b** chloride anion
- **c** magnesium cation
- **d** argon atom

7 **Use** the groups in the periodic table to **identify** the charges on the following ions.

- **a** potassium (atomic number 19)
- **b** aluminium (atomic number 13)
- **c** nitride (produced from nitrogen atoms with atomic number 7)

Quiz me

Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

5.5 Metal cations and non-metal anions combine to form ionic compounds

Learning intentions

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

- explain ionic compounds using the terminology anion and cation
- describe the properties of ionic compounds
- draw the electron transfer between atoms and the resultant ions.

Key ideas

- Positive cations are attracted to negative anions and form ionic compounds.
- Polyatomic ions form when two or more atoms combine to form a charged ion.

Forming ionic compounds

Metallic elements are usually found on the left-hand side of the periodic table. This means they have fewer than four electrons in their valence shell. Therefore, metallic atoms tend to lose electrons and become positively charged cations.

In contrast, most non-metal atoms have almost-full valence shells. This means they need to gain only a few electrons to achieve a full valence shell. As a result, non-metal atoms will become negatively charged anions.

Positively charged cations are attracted to negatively charged anions. A cation with a 2+ charge is likely to combine (bond) with an anion of 2– charge or with two anions each with a charge of 1–. The positive charge is balanced by an equal negative charge. The bonds that are formed when ions interact are referred to as **ionic bonds** (Figure 1).

ionic bond
a bond between a negatively charged anion and a positively charged cation

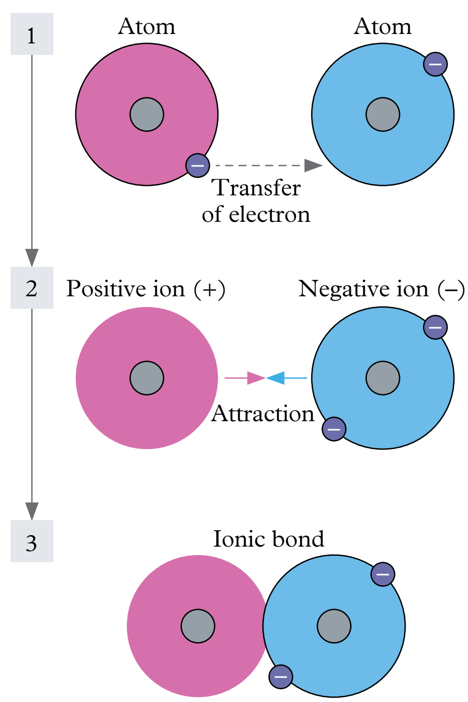


Figure 1 Ionic bonds form when a positive cation is attracted to a negative anion.

Properties of ionic compounds

Compounds that are held together by ionic bonds are called **ionic compounds**. As an ionic compound forms, the like-charged ions repel or push each other and the oppositely charged ions attract each other. After all the pushing and pulling, the ions settle into alternating positions, as shown in Figure 2, because this is the most stable arrangement. The particles are held together by strong electrostatic forces of attraction between the positively charged ions and the negatively charged ions. Because these forces bind the ions together, this is known as ionic bonding.

ionic compound
a substance made up of a negatively charged anion and a positively charged cation

A lot of energy is required to move the ions out of their positions. This means that ionic compounds are hard to melt. At room temperature, they are in the form of hard, brittle crystals. The most commonly known example of an ionic compound is sodium chloride (table salt). Its melting point is 801°C. If you use a salt grinder at home, you will be aware of how hard and brittle salt crystals are.

When naming ionic compounds, the cation is always written before the anion. For example, a sodium cation (Na^+) combined with chloride anion (Cl^-) is written as NaCl.

EXPERIMENT
5.5A: Conductivity of ionic compounds
Go to page **251**.

SKILLS LAB
5.5B: Ionic compounds
Go to page **252**.

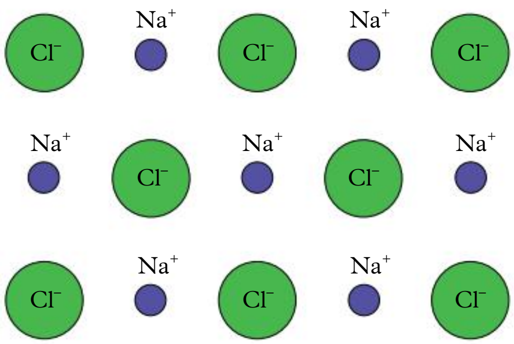


Figure 2 In an ionic compound, such as sodium chloride, the ions are arranged in alternating positions.

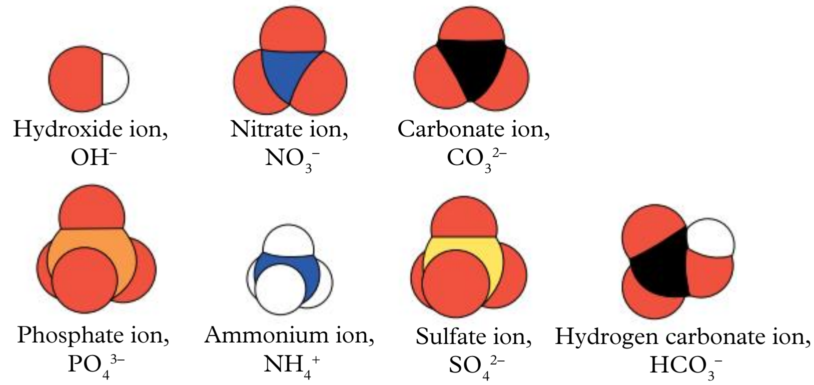


Figure 3 Some common polyatomic ions: the charge number indicates how many electrons have been lost. A negative charge number indicates how many electrons have been gained.

Polyatomic ions

A number of ions are made up of more than one atom. These are termed **polyatomic ions**. Figure 3 shows some examples of polyatomic ions.

These clusters of atoms have a charge because the total number of protons does not equal the total number of electrons present. For example, in the hydroxide ion, which is made up of two ions (one each of oxygen and hydrogen), there are nine protons and ten electrons. This means the two atoms that form the ion have an overall charge of 1–.

Calcium carbonate, the main constituent of chalk, is an example of an ionic compound that contains a polyatomic ion. Calcium carbonate contains calcium ions (Ca^{2+}) and carbonate ions (CO_3^{2-}). These ions must be present in the ratio 1 : 1 so that the total positive charge equals the total negative charge. The formula of calcium carbonate is $CaCO_3$.

Ammonium carbonate is used in smelling salts. It contains ammonium ions (NH_4^+) and carbonate ions (CO_3^{2-}). In this case, the ions need to be present in the ratio 2 : 1 (two NH_4^+ for every CO_3^{2-}). The formula of ammonium carbonate is $(NH_4)_2CO_3$.

polyatomic ion
a charged ion that consists of two or more atoms bonded together

5.5 Check your learning

Retrieve

1 **Define** the term 'ionic compound'.

Comprehend

2 **Describe** why the group of an element can be used to quickly identify one or more of its properties.

3 Use your knowledge of atomic structure and valence electrons to **explain** why many ionic compounds are made up of a metal and a non-metal.

Analyse

4 Carefully **examine** the periodic table in Figure 1 on page 117.
  a **Identify** the groups that are likely to form positively charged ions.
  b **Identify** the groups that are likely to form negatively charged ions.
  c **Explain** why elements from group 1 and group 17 are likely to form ionic compounds.

Apply

5 Use the information from Figure 3 to **determine** the formula of the ionic compound that contains a phosphate ion and a potassium cation.

6 **Calculate** the maximum number of electrons that can be gained or lost by any atom. **Justify** your answer (by contrasting how elements in group 13 and group 15 form ions, explaining why it can be difficult to determine the charge on elements in group 14, and explaining how this allowed you to calculate the maximum).

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

5.6 Non-metals combine to form covalent compounds

Learning intentions

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

- define the term 'covalent compound' and describe how it is formed
- explain what a diatomic molecule is
- draw covalent molecules, showing the sharing of electrons to complete their valence shells.

Key ideas

- Two non-metals merge their valence shells to share two electrons (one from each atom) so that each has a full valence shell.
- The sharing of pairs of electrons between atoms is called a covalent bond and can be used to explain the compound's properties.

You have seen that when electrons are transferred from one atom to another, positive and negative ions are produced and ionic compounds are formed. However, two non-metals that complete their outer shells of electrons by sharing electrons can also bond together.

We can see this with the smallest, lightest atom: hydrogen.

Hydrogen molecules

An uncharged (neutral) atom of hydrogen has just one electron in the first shell. If it could gain one more electron, this shell would contain its maximum number of electrons – two. If hydrogen was in contact with a reactive metal such as lithium, the hydrogen atom could gain that extra electron from a lithium atom. An ionic compound would form as a result. But what if only other uncharged hydrogen atoms are present? The only way each hydrogen atom can gain an extra electron is by sharing its electron with another.

As two uncharged hydrogen atoms come close together, the electrons are drawn into the region between the two nuclei. The atoms partially merge into one another, with the nuclei of both atoms now sharing the two electrons in a **covalent bond**. The electrons travel in the spaces surrounding the nuclei of each atom. In effect, each atom now has a stable electron configuration because its outer shell is full.

The particle produced has two hydrogen atoms bonded strongly together and is called a molecule. A **molecule** is a particle produced when two or more atoms combine so that the atoms share electrons.

Figure 1 The ball-and-stick model is often used to show atoms (balls) and the bonds (sticks) between them. This image shows a ball-and-stick model of a hydrogen (H_2) molecule.

covalent bond
a bond formed when two or more atoms share electrons

molecule
group of two or more atoms bonded together (e.g. a water molecule)

diatomic molecule
a molecule that consists of two atoms

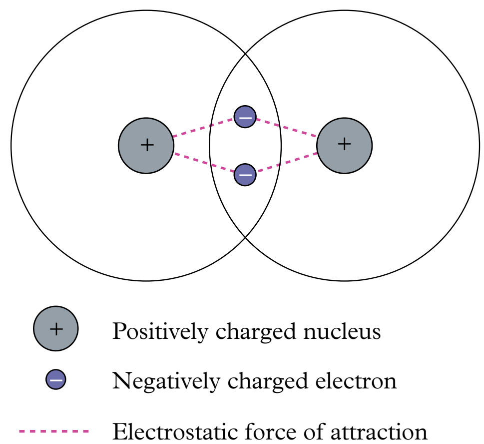


Figure 2 Some diagrams of molecules can show the electrons being shared between the atoms.

A molecule has no overall charge because the total number of electrons and the total number of protons is the same.

The hydrogen molecule is given the formula H_2 because there are two hydrogen atoms present in the molecule.

The hydrogen molecule is an example of a molecule of an element. It is called a **diatomic molecule** because it is made up of two atoms. Other examples of diatomic molecules of non-metals are fluorine (F_2), chlorine (Cl_2), oxygen (O_2) and nitrogen (N_2).

In a molecule such as the hydrogen molecule, there is strong electrostatic attraction between each positively charged nucleus and the negatively charged electrons that they share.

The electrons spend a considerable part of their time between the two nuclei. This electrostatic attraction is termed covalent bonding. The two shared electrons create a strong bond between the two atoms.

CHALLENGE
5.6: Modelling covalent molecules
Go to page 253.

Molecular compounds

Molecules can also be formed by combining different types of atoms into compounds. Water is an example of a **molecular compound**. Its formula is H_2O. To gain a more stable electron configuration, an:

> uncharged hydrogen atom, which has one valence electron, requires a share of one more electron
> uncharged oxygen atom, which has six valence electrons, requires two more electrons.

A single hydrogen atom cannot supply the two electrons the oxygen atom needs, but two hydrogen atoms can supply one electron each. This is why there are two hydrogen atoms and just one oxygen atom in a water molecule. An oxygen atom now effectively has eight electrons in its valence shell, and each hydrogen atom has two electrons. This is shown in Figure 3. Notice that each atom now has a full, stable outer shell of electrons.

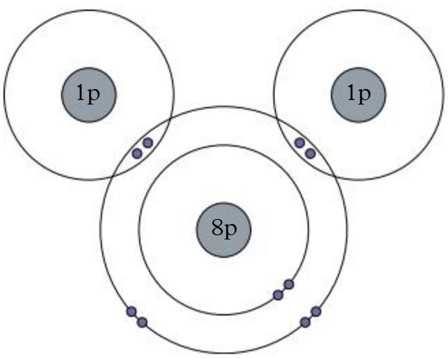


Figure 3 A shell diagram of a water molecule

There are other ways of representing the structure of molecules, including with three-dimensional models (see Figures 1 and 4 for examples). However, remember that in any representation, a single chemical bond holding the molecule together is actually a pair of negative electrons, shared between two atoms, attracted to the positive nuclei of both of these atoms.

molecular compound
a molecule that contains two or more different atoms bonded together

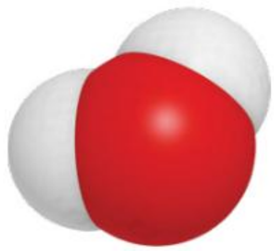


Figure 4 A 3D model is often used to show the arrangement of atoms in a molecule of water (H_2O).

Properties of molecular substances

Almost all molecular substances do not conduct electricity, even in the liquid state, because the molecules do not have free charged particles and so they cannot carry a current. There are only weak forces of attraction between molecules, so most molecular substances are liquids or gases at room temperature. It does not take much energy to separate the individual molecules and get them to move around.

5.6 Check your learning

Retrieve

1 **Define** the term 'diatomic molecule'.
2 **Identify** the types of atoms (metals, non-metals) that form covalent bonds.

Comprehend

3 **Describe** a covalent bond.
4 **Explain** why molecular substances cannot conduct electricity.
5 **Explain** why carbon dioxide has the formula CO_2. (HINT: It has covalent bonding.)

Analyse

6 a **Calculate** the number of electrons needed to be shared between two chlorine atoms when they combine to form a molecule.
b **Compare** the process of forming chlorine molecules to the process of forming an oxygen molecule.
7 **Compare** ionic bonding and covalent bonding.

Apply

8 In terms of the structure of the substance, **discuss** why it is easier to turn liquid water into a gas than to break the covalent bonds between the hydrogen and oxygen atoms.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

5.7 Metals form unique bonds

Key ideas

- All metals arrange their atoms into layers that can easily slide over each other.
- Metals are good conductors because some valence electrons are delocalised and are able to freely move from one atom to another.
- Metal alloys are mixtures of two or more metals that are stronger than pure metals.

Learning intentions

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

- describe the structure of metallic bonding as a grid of cations in a sea of delocalised electrons
- compare metallic compounds and alloys.

Metallic structure

Many metals are malleable (can be bent into any shape). This property of metals is a result of the arrangement of atoms. Metal atoms arrange themselves into layers. When the metal is bent or hammered into shape, the atoms slide over one another (Figure 1).

Metals and conductivity

Remember that metals are found on the left-hand side and centre of the periodic table. Metals do not have many electrons in their outer shells, and it does not take much energy for these outer electrons to move from one atom to another. This is the clue as to why metals are so good at conducting electricity.

A substance will conduct electricity if it contains charged particles that are free to move around the structure. In metals, these charged particles are electrons. Scientists refer to the outer-shell electrons as **delocalised electrons** because they are not 'stuck' in one locality (Figure 2). (Most electrons in metal atoms are not delocalised because they move around the nucleus of each metal atom in the inner electron shells.) Metals are good electrical conductors because the outer-shell electrons are free to move from nucleus to nucleus along the metal.

delocalised electron
an electron in a molecule that can easily move between atoms

Table 1 gives the electrical conductivity of a number of elements at 25°C.

All metals conduct electricity in the solid state – some better than others. They continue to conduct electricity when molten liquid, but poorly compared to the solids. The higher the temperature, the lower a metal's electrical conductivity.

Only some metals are used for their electrical conductivity. For example, power lines have a core of steel and an outside layer of aluminium. Household wiring is usually copper coated with a special kind of plastic. Metals like silver and gold are used in more specialised applications, such as in electronic devices.

Table 1 Electrical conductivities of some common elements at 25°C

Element	Electrical conductivity ($\times 10^6$ ohm^{-1} cm^{-1})
Aluminium	0.37
Carbon (graphite)	0.100
Copper	0.596
Gold	0.452
Iron	0.093
Lead	0.048
Magnesium	0.226
Silver	0.63
Sodium	0.210

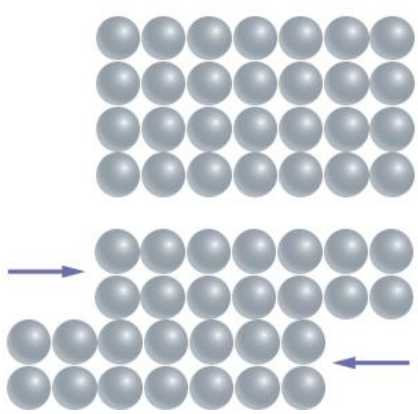


Figure 1 The arrangement of atoms in metals allows them to slide over each other when the metals are bent or hammered into shape.

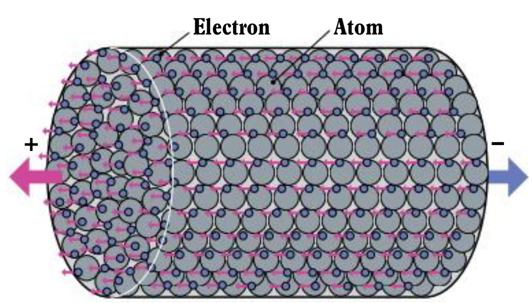


Figure 2 Delocalised electrons move about randomly in a metal, but they move towards the positive terminal of the power source when connected into a circuit.

CHALLENGE
5.7: Modelling alloys
Go to page **254**.

Delocalised electrons are responsible for a pure metal being lustrous (shiny). The delocalised electrons in its surface reflect light extremely well (Figure 3).

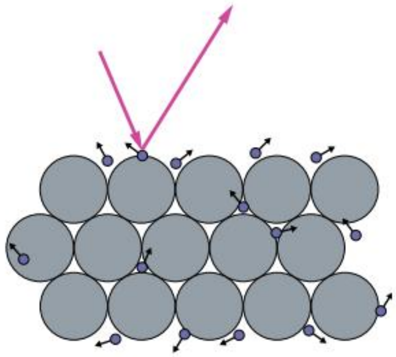


Figure 3 The delocalised electrons in the surface of a metal reflect light and cause it to be lustrous.

Metal alloys

A metal alloy is a mixture of two or more metals. Because the metal atoms are different sizes, the atoms are not arranged in the usual way. This means the atoms in an alloy cannot slide over one another as easily as in a pure metal. Alloys are usually stronger and harder than pure metals as a result.

Soft metals such as copper, gold and aluminium are often mixed with other metals to make alloys that are hard enough for everyday use.

Brass (70 per cent copper and 30 per cent zinc) is used in electrical fittings and hinges.

Jewellery is often made of 18-carat gold (75 per cent gold and 25 per cent copper and other metals).

Smart alloys

Some alloys have unique properties. When Nitinol (a mixture of nickel and titanium) is cast into a particular shape and heated to 500°C, the atoms arrange themselves into a compact and regular pattern. This allows the alloy to create a memory of this shape. If the alloy is bent out of shape, heat or electrical current can cause it to return to its original shape. These metals are often called memory alloys (Figure 5).

An example of memory wires are those used in orthodontic braces. The wires will constantly return to their original shape, reducing the need to retighten or adjust the wire.

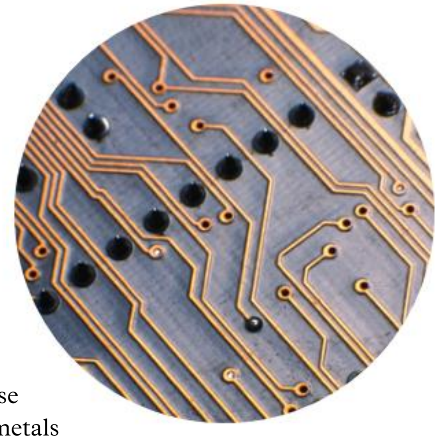


Figure 4 Gold bonding wire is used in integrated circuits.

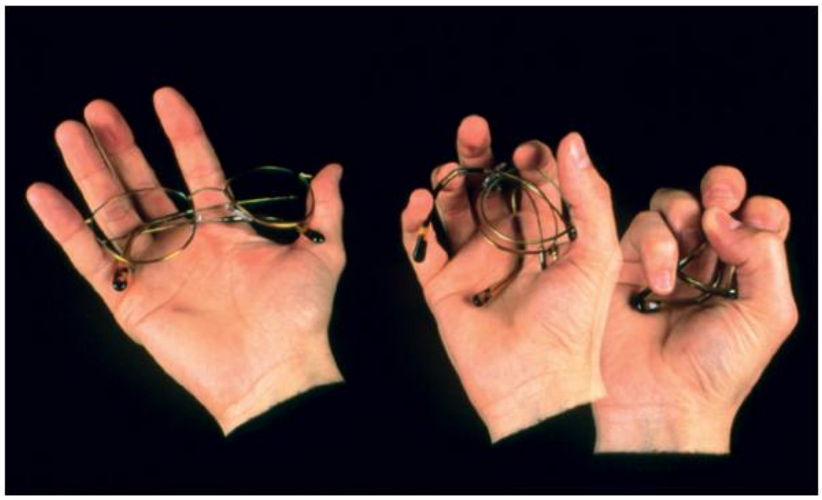


Figure 5 Memory wire is useful in eyeglass frames, allowing them to be bent out of shape without breaking.

5.7 Check your learning

Retrieve

1 **Identify** the arrangement of atoms in a metal that enables each of the following properties.
 a malleability
 b conductivity
 c shiny appearance

2 **Define** the term ‘alloy’.

Comprehend

3 **Describe** the structure of a metal.

4 **Describe** what is meant by the phrase ‘delocalised electrons’.

Analyse

5 **Compare** the properties of an alloy with those of pure metal.

6 Memory alloys have been used to repair broken bones. **Consider** why a memory alloy would be beneficial in this situation.

Apply

7 Nitinol (NiTi) is one of the most common memory alloys used in biomedical engineering. It is super-elastic and can resist corrosion in the body. **Evaluate** the effectiveness of using NiTi to replace part of the skull of a person who needed brain surgery (by comparing the properties of NiTi to the properties of the skull and deciding whether NiTi will be effective).

Quiz me
Complete the Quiz me to check how well you’ve mastered the learning intentions and to be assigned a worksheet at your level.

//SCIENCE AS A HUMAN ENDEAVOUR//

5.8 Nanotechnology involves the specific arrangement of atoms

Learning intentions

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

- describe what is meant by nanotechnology
- convert between length measurements of nanometres and more common units (e.g. cm)
- provide examples of the uses of nanotechnology in society.

nanotechnology
the manipulation of individual atoms to form structures

carbon nanotube
a very small tube of carbon atoms, made synthetically

The average atom is 0.3 nanometres (0.000 000 3 mm) in diameter. Understanding the structure and properties of individual atoms allows scientists to control how these atoms are arranged.

Nanotechnology operates at the scale of the nanometre, which is approximately one ten-thousandth of the width of a human hair. This is the level of atoms or molecules. Nanotechnology allows artificial manipulation of atoms or molecular processes or objects. For example, computers the size of blood cells with tiny wireless transmitters could report on the health of a person without that person requiring surgery. Nanomachines (or nanobots) are tiny structures that are being designed to rearrange the atoms in our bodies or to detect imbalances in chemical reactions. Scientists hope to develop nanobots as small as viruses or bacteria to perform tasks on a nanometre scale.

Nanobots in medicine

Many medical scientists are very excited about the use of nanobots in medicine. Imagine tiny structures monitoring a patient's body, constantly looking for viruses or bacteria that can cause disease. If a virus is detected, the nanobot could break it down molecule by molecule.

Nanotechnicians have designed a nanobot that is capable of carrying 9 billion oxygen and carbon dioxide molecules. This could potentially remove the need for blood transfusions in the future.

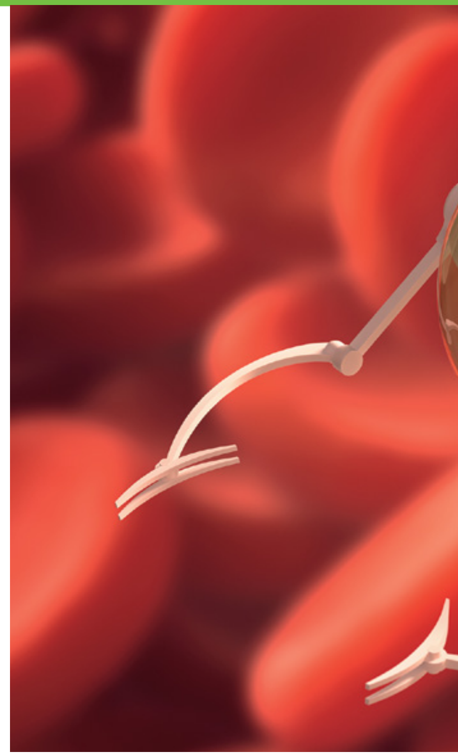


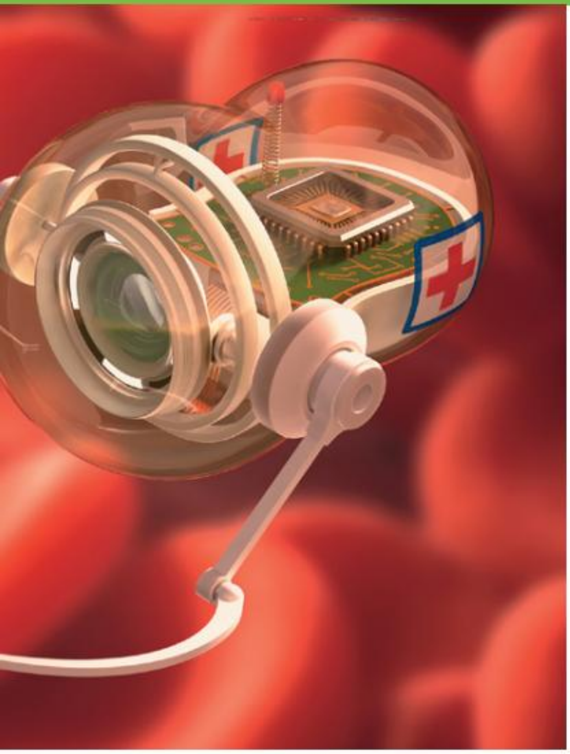
Figure 1 Nanobots could be used to treat viruses.

Carbon nanotubes

A **carbon nanotube** is an arrangement of carbon atoms that has very different properties from other arrangements of carbon atoms, such as graphite and diamond. Carbon nanotubes are the focus of intensive research for many applications in the future.

Carbon nanotubes are extremely hard, have high tensile strength and are efficient conductors of heat and electricity. That is, carbon nanotubes exhibit many properties usually found in metals. However, in contrast with most metals, carbon nanotubes are extremely light and flexible. Carbon nanotubes might be used:

- in medicine, where their high electrical conductivity may make them suitable to bypass faulty nerve cell wiring in damaged brains
- to create clothing with unique properties, such as protection against bullets
- in computing and television, where they are being used to develop flat, folding, futuristic television screens with greater image resolution than the human eye can detect
- for renewable energy devices, such as solar panels, due to their efficient absorption of heat, and in wind turbines for making blades lighter and stronger
- to break down pollution in waterways or in smog-ridden cities.



How carbon nanotubes are made

The emergence of nanotechnology as a key scientific force has resulted from relatively recent and rapid developments in the capacity of scientists to:

- put nano-sized quantities of matter where they are wanted
- use controlled amounts of nano-sized materials for a practical purpose
- detect and monitor the location and configuration of nanoscale materials.

There are two manufacturing approaches to making nano-sized materials.

1. The top-down method involves using mass materials and breaking them down by physical or other means into nanoscale components.
2. The bottom-up method, also known as molecular manufacturing, is a more complicated process because it relies on the construction of templates on which nanomolecules will form under the appropriate chemical and physical conditions.

A good example of the top-down method can be found in the sunscreen industry, where materials to block UV light, such as titanium oxide and zinc oxide, are transformed by a grinding process from their white, opaque mass forms into invisible, nano-sized particles. These are known as nanopowders.

A good example of the bottom-up method is the production of carbon nanotubes. A layer of metal catalyst particles is exposed to high heat and a carbon-containing gas. The nanotubes form at the interface between the gas and the metal catalyst.

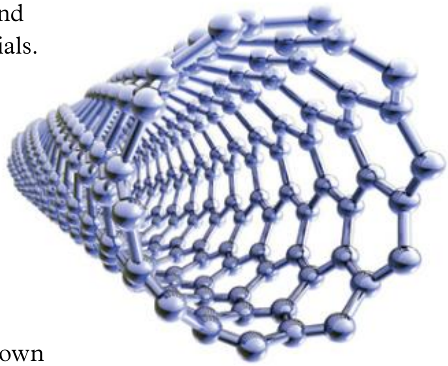


Figure 2 Nanotube technology is being investigated for a wide range of technological and medical uses.

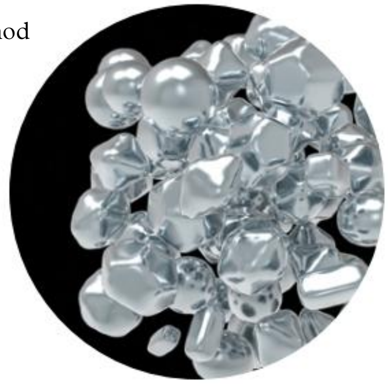


Figure 3 An illustration of zinc oxide nanoparticles

5.8 Test your skills and capabilities

Evaluating claims

There are many claims about the wonderful things that nanotechnology can achieve. As these things refer to objects that are so small, it is easy to accept what you are being told without questioning whether it is true.

1 **Examine** the following blog entry and answer the questions to critically assess the information.

Many sunscreens use zinc oxide and titanium dioxide particles to reflect the sunlight that can cause sunburn and skin cancer. Recently, these particles have been shrunk to nanoparticles, which are particles that are small enough to be taken into the body through the skin cells. This makes them dangerous!

a **Identify** the source of the blog. Describe the author's level of experience in nanotechnology. (HINT: Use your search engine to help you identify the source.)

b **Describe** the argument the author is presenting.

c **Identify** an assumption that the author is making.

d **Describe** an experiment that could be used to provide evidence that nanoparticles of zinc oxide can enter skin cells.

e **Describe** an alternative argument to that of the author. **Describe** the potential outcome of the experiment in part d that would support your alternative argument.

f Based on the previous questions, **evaluate** the validity of the claim made by the author of the blog.

CHAPTER 5 REVIEW

THE PERIODIC TABLE

Retrieve

1 **Identify** the transition metal.
- A caesium
- B palladium
- C fluorine
- D radon

2 **Recall** what rows of the periodic table are called.
- A groups
- B periods
- C valences
- D electron configurations

3 Use the periodic table on page 117 to **identify** the correct statement about calcium.
- A It is in period 2.
- B It has an atomic number of 20 and a mass of 40.08.
- C Its electron configuration is 2,8,6,2.
- D It has six electron shells.

4 **State** the name given to the following features of the periodic table.
- a horizontal row
- b vertical column
- c the set of 10 groups from group 3 to group 12

5 **Identify** the group number of:
- a alkaline earth elements
- b halogens
- c noble gases
- d alkali metals.

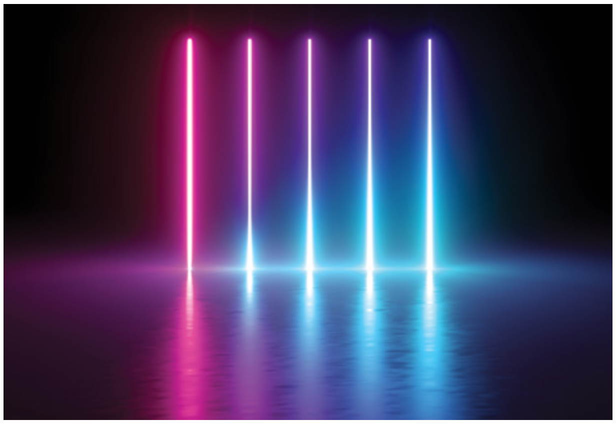


Figure 1 Neon lights use neon, a noble gas.

6 **Define** the term 'valence shell'.

7 **Identify** the characteristics that elements in group 1 have in common.

8 When naming an ionic compound, **recall** which ion (anion or cation) is written first.

Comprehend

9 **Describe** how electrons are arranged in the Bohr model of an atom.

10 **Describe** the characteristic that determines the overall order of elements in the periodic table.

11 An inert substance is one that will not react with any other substance. Originally, group 18 elements were known as the 'inert gases'. **Explain** why the name was changed to 'noble gases'.

12 **Describe** the key characteristic of metals that allows them to conduct electricity in the solid state.

13 **Explain** why elements in group 8 are more stable than elements in group 1.

14 **Explain** each of the following statements.
- a Argon will not react with any other element.
- b The reaction between sodium and chlorine gives out a lot of heat and light.
- c When you accidentally spill sodium chloride onto a stove while cooking, it does not melt.

15 Only two elements are liquids at room temperature – bromine and mercury. Bromine is a non-metal and mercury is a metal. **Describe** how these two liquids are likely to appear and behave differently from each other.

Figure 2 Mercury is a liquid at room temperature.

16 A substance will conduct electricity if it contains charged particles that are free to move across the sample. The charged particles can be electrons or ions. **Explain** why ionic compounds cannot conduct electricity when in the solid state, but they can conduct electricity when melted.

Analyse

17 **Consider** the following pairs of elements:
- i chlorine and oxygen
- ii nitrogen and lithium
- iii fluorine and argon
- iv aluminium and potassium.
- a **Draw** the electron configuration for each element.
- b **Identify** the pair(s) that will react to form an ionic compound.
- c **Identify** the pair(s) that will react to form a molecular compound.
- d **Identify** the pair(s) that will not react to form a compound.

  In each case, **explain** your answer by **contrasting** the properties of the elements.

18 **Compare** a cation and an anion.

19 When the uncharged atoms of potassium lose an electron, they then have an electron configuration of 2,8,8. This is the same as the electron configuration of argon. **Compare** the potassium ion and argon atom.

Apply

20 Scientists deduce what it is like inside an atom from indirect evidence, similar to how astronomers determine the temperature and composition of stars. **Discuss** two advantages and two disadvantages of using indirect evidence to develop scientific theories.

21 **Identify** two elements that you would expect to react together in the most violent way. **Justify** your answer (by identifying a group of metals and non-metals that are very reactive, identifying which element in those groups is the most reactive, and describing how you made your decision).

22 Before the 1980s, the groups of the periodic table were numbered with Roman numerals. Some scientists prefer this version because the atoms of the elements in group III (now 13) have three electrons in their valence shell, those in group IV (now 14) have four electrons in their valence shell, and so on. **Examine** how the groups of transition metals were numbered in the old way. **Propose** a reason why the numbering system was changed.

23 A particle was found to contain 16 protons and 18 electrons.
- a **Identify** the element that makes up the particle. **Justify** your answer (by describing the key characteristic that you used to make your decision).
- b **Identify** the charge of the particle. **Justify** your decision.
- c **Identify** the symbol (including the charge) of the particle. **Justify** your answer.

24 According to the Bohr model of the atom, the electron configuration of the uncharged atoms of a particular element is 2,8,8.
- a **Calculate** the atomic number of the element.
- b **Identify** the element.
- c **Describe** the electronic configuration of the next element on the periodic table. **Justify** your answer (by explaining how you made your decision).

Critical and creative thinking

25 A student claimed that sodium chloride is made of molecules. **Evaluate** this statement (by defining the term 'molecules', describing the bonded sodium chloride atoms, and comparing the definition to the description of bonded sodium chloride atoms).

26 **Create** a poster that shows the different models of the atom, from the original theory that it was a solid particle, as proposed by the English chemist John Dalton, to the Bohr model. Use the internet to find images of the scientists involved, and place copies onto your poster. **Investigate** the year in which each model was proposed and include a timeline.

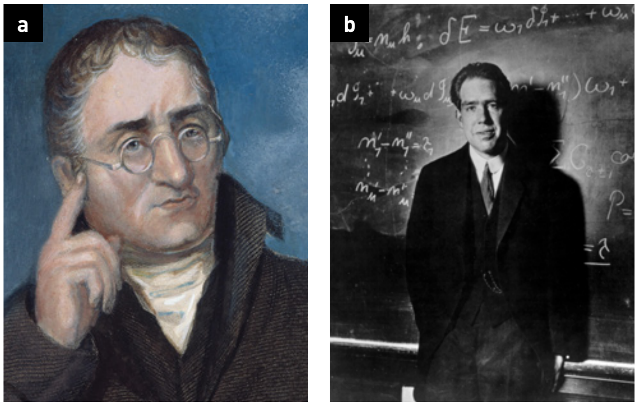


Figure 3 **a** John Dalton and **b** Niehls Bohr

Research

27 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

» The noble gases

The story behind the discovery of the noble gases is a fascinating one. The challenge was how to detect the existence of something that only exists as a gas, does not react with anything, and is only present in the air in extremely small concentrations (except for argon).

- » Describe how the first noble gas was found.
- » Describe the role the periodic table of that time played in helping chemists hunt for other noble gases.

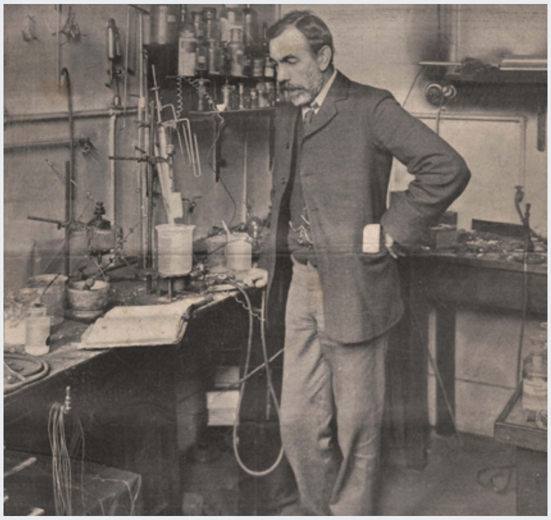


Figure 4 William Ramsay's discoveries added the noble gases to the periodic table.

» Hydrogen

Hydrogen is a most unusual non-metal because it can form H^+ ions and H^- ions depending on what it reacts with. Although alkali metals do not react with one another, hydrogen will react with alkali metals and form compounds, such as lithium hydride (LiH).

- » Explain why the hydride ion (H^-) is stable.
- » Describe the properties of metal hydrides such as lithium hydride.
- » Describe the way these compounds are used.

» Nanotechnology

Nanomaterials are now being used to assist in a range of products from sunscreen to clothing. Some nanomaterials are used to increase the rate of very specific reactions that produce valuable products.

- » Investigate a product that is produced by using nanoparticles.
- » Describe how the nano-produced product is an improvement on previous products.
- » Describe how the product is produced (top-down or bottom-up).

Figure 5 Nanoparticles have been used in sunscreens for many years.

Chapter checklist

Now that you have completed this chapter, reflect on your ability to do the following.

	I can do this.	I cannot do this yet.
• Describe the importance of atomic numbers in determining the number of electrons. • Describe the relationship between valence electrons and element properties.	☐	☐ Go back to Topic 5.1 'The structure of an atom determines its properties'. Page 116
• Identify the properties of group 1, group 2 and transitional metals. • Relate the properties of group 1 and group 2 metals to their electron configurations.	☐	☐ Go back to Topic 5.2 'Groups in the periodic table have properties in common'. Page 120
• Recognise and identify non-metals and metalloids on the periodic table. • Identify and explain the properties of non-metallic elements, halogens and noble gases.	☐	☐ Go back to Topic 5.3 'Non-metals have properties in common'. Page 122
• Define ion, anion and cation. • Relate the number of electrons in the valence shell to whether the atom will become an anion or a cation.	☐	☐ Go back to Topic 5.4 'Ions have more or less electrons'. Page 124
• Explain ionic compounds using the terminology anion and cation. • Describe the properties of ionic compounds. • Draw the electron transfer between atoms and the resultant ions.	☐	☐ Go back to Topic 5.5 'Metal cations and non-metal anions combine to form ionic compounds'. Page 126
• Define the term 'covalent compound' and describe how it is formed. • Explain what a diatomic molecule is. • Draw covalent molecules, showing the sharing of electrons to complete their valence shells.	☐	☐ Go back to Topic 5.6 'Non-metals combine to form covalent compounds'. Page 128
• Describe the structure of metallic bonding as a grid of cations in a sea of delocalised electrons. • Compare metallic compounds and alloys.	☐	☐ Go back to Topic 5.7 'Metals form unique bonds'. Page 130
• Describe what is meant by nanotechnology. • Convert between length measurements of nanometres and more common units (e.g. cm). • Provide examples of the uses of nanotechnology in society.	☐	☐ Go back to Topic 5.8 'Science as a human endeavour: Nanotechnology involves the specific arrangement of atoms'. Page 132

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Play a Quizlet game to test your knowledge.

Chapter quiz
Check your understanding of this chapter with the chapter review quiz.

CHAPTER

6

CHEMICAL REACTIONS

6.1

Synthesis, decomposition and displacement reactions can be represented by equations

> Identify the difference between synthesis, decomposition and displacement reactions.
> Write, balance and assign states to simple synthesis, decomposition and displacement reactions.

6.2

The solubility rules predict the formation of precipitates

> Identify precipitation reactions and explain why they are named this way.
> Determine whether a chemical is solid (s) or aqueous (aq) based on solubility rules.

6.3

Acids have a low pH, bases have a high pH

> Describe examples of acids and bases.
> Explain the structure of the pH scale.

6.4 Acid reactions depend on strength and concentration

> Distinguish between the key properties and features of acids and bases.

> Write, balance and assign states to neutralisation reactions.

6.5 Metals and non-metals react with oxygen

> Define the terms 'oxidation', 'combustion' and 'hydrocarbon'.

> Write, balance and assign states to oxidation reactions with metals and non-metals.

6.6 Polymers are long chains of monomers

> Define the terms 'monomer', 'polymer', 'cross-linked', 'thermosetting' and 'thermoplastic'.

> Determine if a polymer is thermosetting or thermoplastic based on its properties.

6.7 Surface area, concentration, temperature and stirring affect reaction rate

> Describe collision theory and explain how it relates to the rate of a chemical reaction.

> Explain how factors including surface area, concentration, temperature and stirring can be used to increase the rate of a reaction.

6.8 Catalysts increase the rate of a reaction

> Describe what a catalyst is.

> Explain the different ways catalysts can be used to increase the rate of a reaction.

6.9 Science as a human endeavour: Reactions are used to produce a range of useful products

> Describe how polymers are used in desalination plants and to produce bioplastics.

> Describe the properties of superalloys and their different uses in society.

What if?

Copper plated

What you need:

9 V battery, wires with crocodile clips, 250 mL beaker, strip of copper foil (1 cm wide), 0.5 M copper sulfate solution, brass key (to be plated)

What to do:

1 Pour 100 mL of copper sulfate solution into the beaker.

2 Fit the copper foil inside the beaker with the top 2 cm bent back over the edge of the beaker.

3 Use a wire to connect the positive terminal of the battery to the copper foil.

4 Use a wire to connect the negative terminal of the battery to the key.

5 Place the key into the copper sulfate solution, ensuring it does not touch the copper foil.

6 Observe any changes in the key.

What if?

» What if a smaller battery was used?

» What if water was used instead of copper sulfate?

» What if a carbon rod was used instead of the copper foil?

6.1 Synthesis, decomposition and displacement reactions can be represented by equations

Learning intentions

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

- identify the difference between synthesis, decomposition and displacement reactions
- write, balance and assign states to simple synthesis, decomposition and displacement reactions.

Key ideas

- Synthesis reactions combine multiple reactants to form a new compound.
- Decomposition reactions break down a reactant into multiple products.
- Displacement reactions involve an atom or group of atoms of a molecule being displaced by another atom or group of atoms.

Almost every substance that you will use today was made in a chemical reaction. One of the roles of chemists is to understand chemical reactions and the products they form. This is possible because of the law of conservation of mass, which states that the number and type of atoms at the start of a chemical reaction must be equal to the number and type of atoms produced.

Classifying reactions

Classifying compounds into groups makes them easier to name and identify. Because all the compounds in the same group have similar properties, you can predict most of the properties of an unknown substance if you know to which group it belongs.

Similarly, the chemical reactions that are used to make compounds can also be classified. Classifying reactions into different types helps us predict what products will be produced. Reactions can be classified as synthesis, decomposition, displacement, combustion or hydrolysis (reaction with water) reactions, among others.

Synthesis reactions

synthesis
a reaction that involves the building up of compounds by combining simpler substances, usually elements

Synthesis is the building up of compounds by combining simpler substances, normally elements:

$$A + B \rightarrow AB$$

This equation is a general equation and it helps you determine what will be produced in a synthesis reaction. In synthesis reactions, the two reactants combine to form a new product.

For example:

sodium + chlorine → sodium chloride

Writing chemical equations

Once you have predicted the product that will be formed and written the word equation, you can write the chemical equation.

1 Write the chemical formula for each of the molecules. Are they ionic compounds or covalent compounds? Use subscript numbers to indicate the number of each type of atom in the molecule:

$$Na + Cl_2 \rightarrow NaCl$$

2 Count the number of atoms on each side of the equation to ensure that no atoms are created or destroyed (law of conservation of mass). If more atoms are needed, add a large number (coefficient) before the molecule:

$$2Na + Cl_2 \rightarrow 2NaCl$$

3 Determine whether the reactants and products are solids (s), liquids (l), gases (g) or aqueous solutions (a soluble solution mixed with water) (aq):

$$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$$

Remember that all chemical equations should be written in balanced form. To view an example of how to balance equations, see Worked example 6.1 on page 142.

EXPERIMENT

6.1A: Direct synthesis with a 'pop'
Go to page **255**.

EXPERIMENT

6.1B: Decomposing a carbonate
Go to page **256**.

Ammonia

Ammonia (NH_3) is an important chemical that is required to make fertilisers, explosives and household cleaning products. Ammonia is produced in a synthesis reaction between nitrogen (from the air) and hydrogen (from water). The modern method used to produce ammonia is called the Haber process, which relies on the reaction:

$$3H_2(g) + N_2(g) \rightarrow 2NH_3(g)$$

Nitrogen is not a very reactive element so the reactants must be heated under very high pressure to make the reaction happen.

Decomposition reactions

Decomposition reactions are the breakdown of compounds into simpler substances, either elements or more simple compounds. These reactions often require energy in the form of electricity or heat.

Electrolytic decomposition is the breakdown of a compound as a result of an electric current passing through a solution. An example is the formation of hydrogen and oxygen from water:

$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$$

Electrolysis equipment has two diodes – an anode and a cathode. A different chemical reaction occurs at each diode (Figure 2). These reactions are endothermic because they need energy for the reaction to occur.

Electrolytic decomposition is used in the smelting of aluminium. Aluminium ore (bauxite) contains alumina (Al_2O_3). When an electrical current is passed through a solution of alumina, a decomposition reaction occurs:

$$2Al_2O_3 \rightarrow 4Al + 3O_2$$

Quicklime, or calcium oxide (CaO), is an important industrial product. It is used in agriculture as a fertiliser and to neutralise acidic soils. It is also a key component in building materials, such as mortar. Calcium oxide is produced by the thermal decomposition of calcium carbonate ($CaCO_3$):

copper(II) carbonate → copper(II) oxide + carbon dioxide

$$CuCO_3 \rightarrow CuO + CO_2$$

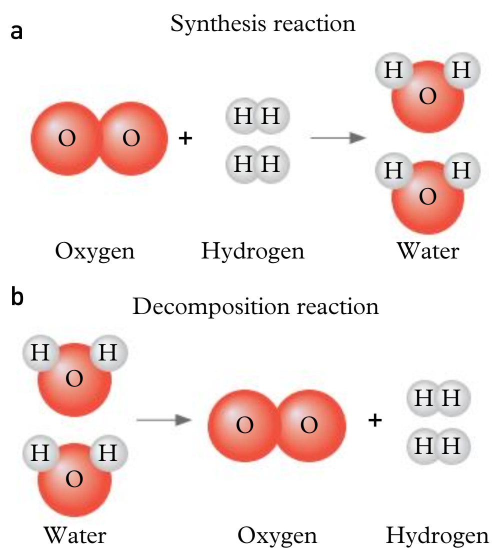
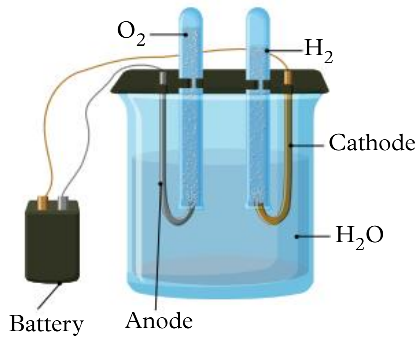


Figure 1 a Synthesis reactions combine the reactants to make a more complex product. **b** Decomposition reactions break the chemical bonds in the reactants to form simpler substances.

decomposition
a reaction that involves the breakdown of a compound into simpler substances

The most common and cheapest naturally occurring form of calcium carbonate is limestone. For many centuries, calcium oxide was produced from limestone in lime kilns. These stone structures were fuelled by coal, with blocks of limestone broken up, often by hand, and added to the kiln, where the temperatures could reach close to 1000°C.

Today, limestone is roasted in more modern furnaces, often fuelled by gas, where the temperature can be regulated by controlling the flow of gas and air into the furnace.



$$2H_2O \rightarrow 2H_2 + O_2$$

Figure 2 Electrolysis equipment. At the anode, water is being broken down into oxygen gas and hydrogen ions. At the cathode, hydrogen gas is being produced from hydrogen ions and electrons.

Displacement reactions

Displacement reactions are reactions that result in an atom or group of atoms of a molecule being displaced or shifted by another atom or group of atoms. For example, Figure 3 shows the reaction of potassium with sodium chloride. In this reaction, the potassium atom displaces the sodium atom of sodium chloride. The products of the reaction are potassium chloride and sodium. Since only one molecule had an atom or group of atoms displaced, this reaction is considered a single displacement reaction. **Single displacement reactions** occur due to a more reactive element replacing a less reactive element on a molecule.

displacement reaction
a reaction resulting in the displacement of an atom or group of atoms

single displacement reaction
a reaction in which a more reactive element displaces a less reactive element on a molecule

Figure 3 A single displacement reaction involves a molecule's atom or group of atoms being displaced by another atom or group of atoms.

Worked example 6.1: Writing balanced chemical equations

Write the chemical equation for the following reaction.

Hydrogen combines with oxygen to produce water.

Solution

The equation can be written using the following steps.

1 Write out the word equation for the reaction.

$$\text{hydrogen} + \text{oxygen} \rightarrow \text{water}$$

2 Write a simplified chemical equation using the formulas of each molecule involved. Identify the number of atoms in each molecule. For example, water is H_2O (two hydrogen atoms with a single oxygen atom), and hydrogen and oxygen exist as pairs of atoms. This is represented as subscripts (small numbers at the lower half of the symbol).

$$H_2 + O_2 \rightarrow H_2O$$

3 Work out the number of each type of atom in the reactants (left-hand side) and in the products (right-hand side), as shown in Table 1.

Table 1 Number of each type of atom in the reactants and products

	Reactants		→	Products	
Type of atom	H	O	→	H	O
Number of atoms	2	2		2	1

4 Compare the number of each type of atom in the reactants with the number in the product. In this case, there are three atoms in the product and four atoms in the reactants. This doesn't fit the law of conservation of mass. We can't have just 'lost' an oxygen atom. We cannot change the subscripts (from H_2O to H_2O_2) as this would change water into hydrogen peroxide. Instead, we need to add a whole water molecule by including numbers (called coefficients) before the formula of the substances. This balances the number of oxygen atoms but also doubles the number of hydrogen atoms (Table 2).

$$H_2 + O_2 \rightarrow 2H_2O$$

Table 2 The number of oxygen atoms is balanced

	Reactants		→	Products	
Type of atom	H	O	→	H	O
Number of atoms	2	2		4	2

The unbalanced hydrogen atoms can be balanced by doubling the number of hydrogen molecules (Table 3).

$$2H_2 + O_2 \rightarrow 2H_2O$$

Table 3 Check the equation is balanced

	Reactants		→	Products	
Type of atom	H	O	→	H	O
Number of atoms	4	2		4	2

This allows the number of reactant atoms to equal the number in the product – the equation is said to be balanced.

5 Add the state (solid, liquid, gas or aqueous) of each molecule.

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$$

The other type of displacement reaction is called a double displacement reaction. In a double displacement reaction, two reactants will exchange ions and form two new products. You will learn more about double displacement reactions in Topic 6.2. A summary of each different type of reaction covered in this topic is shown in Table 4.

Table 4 A summary of synthesis, decomposition, single displacement and double displacement reactions

Reaction type	Summary	Visual example
Synthesis	Two or more reactants react to form one product.	
Decomposition	A compound reacts and breaks down into two or more products.	
Single displacement	A more reactive element replaces another less reactive element on a molecule.	
Double displacement	Two reactants exchange ions to form two new products.	

6.1 Check your learning

Retrieve

1 **Define** the term 'synthesis reaction'.

Comprehend

2 **Describe** the law of conservation of mass.

3 **Explain** why decomposition reactions always produce more than one product.

4 **Explain** why synthesis reactions are sometimes called combination reactions.

5 **Explain** why energy is required in:

- **a** decomposition reactions
- **b** synthesis reactions.

Analyse

6 **Contrast** the reaction used to produce ammonia and the reaction used to produce calcium oxide, in terms of the types of chemical reactions.

7 **Compare** single and double displacement reactions.

Apply

8 **Predict** the products of the following synthesis reactions and write a balanced chemical equation for each one.

- **a** calcium and oxygen
- **b** hydrogen and chlorine

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

6.2 The solubility rules predict the formation of precipitates

Learning intentions

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

- identify precipitation reactions and explain why they are named this way
- determine whether a chemical is solid (s) or aqueous (aq) based on solubility rules.

Key ideas

- If a compound is soluble, it can dissolve in a liquid solvent.
- A precipitation reaction involves two soluble ionic solutions being mixed to form an insoluble solid product called a precipitate.
- Ions that do not take part in the reaction are called spectator ions.
- The solubility of a compound can be predicted from the solubility rules.

Precipitation reactions

A **precipitate** is an insoluble solid that can form as part of a reaction between two ionic solutions.

This can be written in a general form:

$$AB(aq) + CD(aq) \rightarrow AD(s) + CB(aq)$$

This means that in a water (aqueous) solution, the ions A and B separate, and the ions C and D separate. Ion A is positively charged so it forms a bond with negative ion D, and positive ion C forms a bond with negative ion B. It is important to note that the positive ions (A and C) are always written first. This is a **double displacement reaction** as both substrates change (or displace) their partners. It becomes a **precipitation reaction** if either AD or CB is insoluble and forms a solid.

The solubility rules

The formation of an insoluble solid precipitate can be predicted by using a set of solubility rules. The data shown in Table 1 can be used to decide whether a precipitate will form.

For example, a solution of lead(II) nitrate ($Pb(NO_3)_2$) consists of lead ions (Pb^{2+}) and nitrate ions (NO_3^-) together with many water molecules.

When a solution of lead(II) nitrate is added to potassium iodide – both colourless solutions – a bright yellow precipitate of lead iodide (PbI_2) is formed. The reaction can be written as:

lead(II) nitrate + potassium iodide → lead(II) iodide + potassium nitrate

$$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$$

The lead ions and the iodide ions have combined to form an insoluble precipitate of lead(II) iodide. This new compound forms as a solid in the solution. The potassium and nitrate ions are still dissolved in solution. They are not taking part in the reaction. They are called **spectator ions**. Because of this, it is possible to write the equation in a different way that shows only those ions that are changing in the reaction:

$$Pb^{2+}(aq) + 2I^-(aq) \rightarrow PbI_2(s)$$

Table 1 Solubility of some ionic compounds in water

Soluble	Insoluble	Slightly soluble
Group 1 elements		
All ammonium salts		
All nitrate salts		
Most chlorides, bromides and iodides	AgCl, AgI, AgBr, $PbCl_2$, PbI_2, $PbBr_2$	
	Most carbonate and phosphate compounds	
Group 1 hydroxides, $Ba(OH)_2$, $Sr(OH)_2$	Most hydroxides and sulfates	$Ca(OH)_2$, Ag_2SO_4, $CaSO_4$

precipitate
a solid, insoluble compound formed in a precipitation reaction

double displacement reaction
when two reactants exchange ions to form new products during a chemical reaction

precipitation reaction
a reaction used to produce solid products from solutions of ionic substances

spectator ion
an ion that does not take part in a chemical reaction

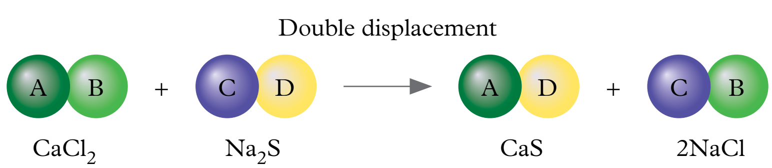


Figure 1 A double displacement reaction involves chemical compounds exchanging ions to form new compounds.

EXPERIMENT
6.2: Precipitation reactions
Go to page 257.

Because the lead ions and iodide ions are dissolved in the solution, they are described as aqueous (aq). This reaction is shown in Figure 2.

Using precipitation reactions

Precipitation reactions are important for chemical analysis. PbI_2 is insoluble, so, if any soluble lead(II) compound is mixed with any soluble iodide, a precipitate of PbI_2 will form (Figure 4). Similarly, Table 1 tells us that $Cu(OH)_2$ (a hydroxide) is insoluble. This means that if any soluble hydroxide, such as NaOH, is mixed with any soluble copper(II) compound, such as $CuSO_4$, a precipitate of $Cu(OH)_2$ will form.

Chemists sometimes use precipitation reactions to find out which chemicals are present in a substance or how much is present.

Common table salt (NaCl) is essential in our diet because the sodium is needed to maintain the correct concentration of body fluids, assist in the transmission of nerve impulses and help cells absorb nutrients. Chemical analysis can determine the amount of salt in foods by using a precipitation reaction with silver nitrate. The salt reacts with the silver nitrate to form a precipitate of silver chloride. The amount of sodium chloride present can be calculated by using the amount of silver chloride that has been precipitated:

$$NaCl(aq) + AgNO_3(aq) \rightarrow NaNO_3(aq) + AgCl(s)$$

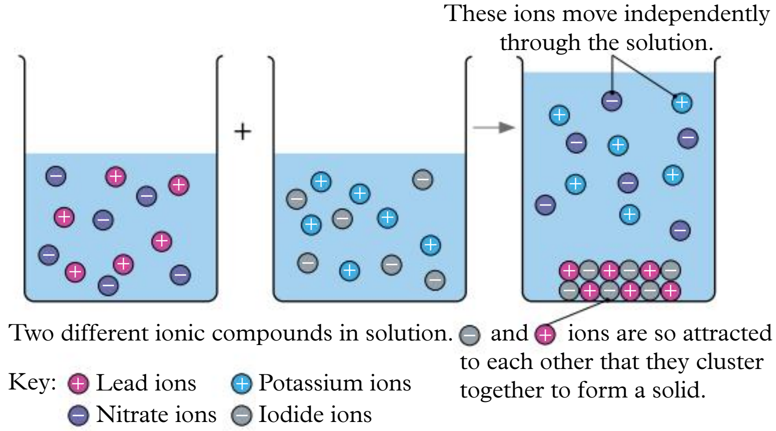


Figure 2 At the particle level, when a solution of lead(II) nitrate ($Pb(NO_3)_2$) is added to potassium iodide (KI), the ion partners are swapped.

Figure 3 Three test tubes containing (left to right) precipitate of copper hydroxide, precipitate of iron(III) hydroxide and precipitate of iron(II) hydroxide. All were made by adding sodium hydroxide.

6.2 Check your learning

Retrieve

1 **Identify** the symbol that is used to show the state of an insoluble compound.

Analyse

2 Use the solubility rules to **identify** which of the following substances would be insoluble:

Copper(II) chloride, calcium hydroxide, silver nitrate, magnesium bromide, silver bromide, magnesium nitrate, potassium chloride, lead(II) nitrate, potassium nitrate, lead(II) chloride

Apply

3 **Draw** a diagram to show which particles are present in a beaker containing a sodium chloride solution.

4 **Predict** what precipitate would form if solutions of lead(II) nitrate and sodium sulfate were mixed.

5 Complete the following word equations and then **construct** balanced chemical equations for each reaction.

a zinc nitrate + potassium hydroxide →

b calcium nitrate + sodium carbonate →

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

Figure 4 Yellow lead(II) iodide forming in a precipitation reaction

6.3 Acids have a low pH, bases have a high pH

Learning intentions

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

- describe examples of acids and bases
- explain the structure of the pH scale.

Key ideas

- Acids taste sour and contain at least one hydrogen ion, bases taste bitter and feel soapy to touch.
- A pH scale is used to describe the strength of an acid (less than 7) or a base (more than 7).
- Indicators are used to determine the pH of a solution.
- Acids have a pH less than 7, and bases have a pH greater than 7.

acid
a hydrogen-containing substance that has the ability to donate a proton

base
a substance that has the ability to accept a hydrogen proton

alkali
a base that dissolves in water

alkaline solution
a solution that consists of a base dissolved in water

indicator
a substance that changes colour in the presence of an acid or a base

Acids

Acids are commonly found around us. Unripe fruits taste sour because of the presence of acid. Weak acids in fruit include citric acid in oranges and lemons, tartaric acid in grapes, malic acid in green apples and oxalic acid in rhubarb. Vitamin C is ascorbic acid. Sour milk and yoghurt contain lactic acid. Vinegar is acetic acid. Lemonade contains carbonic acid.

Acids are a group of chemical compounds, all with similar properties. As well as tasting sour, acids produce a prickling or burning sensation if they touch your skin. All acids contain at least one hydrogen atom and they react with many metals.

Acids can be strong or weak. Strong acids are dangerous because they can burn through objects. Weak acids are safer, and we can eat and drink some of them. Acids also act as a preservative by preventing the growth of microorganisms.

Bases

Bases are the 'chemical opposite' of acids. They are bitter to taste and feel slippery or soapy to touch. Bases that dissolve in water are called **alkalis**, and solutions that are formed by these soluble bases are described as **alkaline solutions**.

Bases have many uses. They react with fats and oils to produce soaps. Some bases, such as ammonia solution, are used in cleaning agents. One very effective base is household cloudy ammonia.

Figure 1 Many cleaning products are alkaline solutions.

Sodium hydroxide is used in the manufacture of soap and paper. It is also used in drain cleaner. Calcium hydroxide is used to make plaster and mortar.

Table 1 Examples of common acids and bases

Acids	
Strong	**Weak**
Hydrochloric acid, HCl	Ethanoic acid, CH_3COOH
Nitric acid, HNO_3	Carbonic acid, H_2CO_3
Sulfuric acid, H_2SO_4	Phosphoric acid, H_3PO_4
Bases	
Strong	**Weak**
Sodium hydroxide, $NaOH$	Ammonia, NH_3
Potassium hydroxide, KOH	Sodium carbonate, Na_2CO_3
Barium hydroxide, $Ba(OH)_2$	Calcium carbonate, $CaCO_3$

How to tell if a substance is an acid or a base

It is possible to identify acids and bases by taste, touch and smell, but it is often not safe to do so. A safer alternative is to use an indicator.

An **indicator** is a substance that changes colour in the presence of an acid or a base. Some of these substances are found in plants.

In the laboratory, scientists use **litmus paper** and **universal indicator**. Litmus paper is the most common indicator for quickly testing whether a substance is an acid or a base. Litmus paper turns red in acidic solutions and blue in basic solutions. Universal indicator is a mixture of different indicators and is more accurate because it indicates the strength of the acidic or basic solution that it is testing.

CHALLENGE

6.3A: Testing with pH paper
Go to page **258**.

EXPERIMENT

6.3B: What if plants were used to create an indicator?
Go to page **259**.

Strong and weak acids (strength)

There are two types of acids. There are strong acids (such as hydrochloric acid) and weak acids (such as ascorbic acid). Strong acids donate their protons more easily, which makes them more acidic than weak acids.

Concentrated and dilute acids (concentration)

Concentrated acids have a large number of acid molecules per litre of solution. Dilute acids have a smaller number of acid molecules per litre of solution. Strength and concentration of an acid are not the same.

pH scale

The **pH scale** describes the relative acidity or alkalinity of a solution (Figure 3). All acids have a pH less than 7. The pH of an acid depends on the strength and concentration of the acid. A strong, concentrated acid may have a pH of less than 1. A weak, dilute acid may have a pH between 6 and 7. If a solution is **neutral** – that is, it is neither an acid nor a base – it has a pH of 7. Pure water has a pH of 7 because it is neutral.

Alkalis have pH values greater than 7. Strong bases, such as caustic soda (sodium hydroxide), can form solutions with a pH of up to 14.

Figure 2 Some vegetables, such as red cabbage, can be used to make pH indicators.

litmus paper
a paper containing an indicator that turns red when exposed to an acid and blue when exposed to a base

universal indicator
a solution that is used to determine the pH (amount of acid or base) of a solution

pH scale
a scale that represents the acidity or basicity of a solution; pH < 7 indicates an acid, pH > 7 indicates a base, pH 7 indicates a neutral solution

neutral
having a pH of 7, so neither an acid nor a base; an example is water

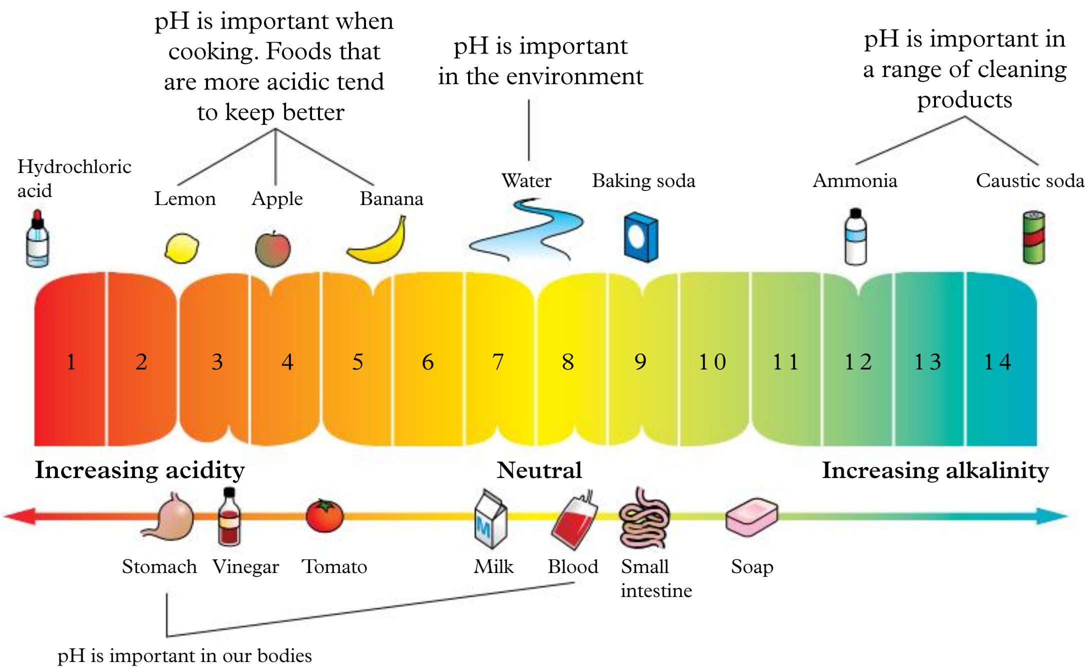


Figure 3 The pH scale

6.3 Check your learning

Retrieve

1 **Identify** three properties of acids.
2 **Identify** three properties of bases.
3 **Identify** one substance that has a pH of 7.
4 **Define** the term 'indicator' as it is used in chemistry.
5 **Recall** the colour of litmus paper in a solution of:
 a an acid
 b a base.

Analyse

6 **Contrast** the pH of an acid and a base.
7 **Contrast** a strong acid and a concentrated acid.

Apply

8 **Investigate** other types of indicators and their pH ranges. Based on your research, **decide** what kind of indicator would be suitable for testing each of the following items and **predict** their pH.
 a lemon juice
 b black coffee
 c vinegar
 d ammonia

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

6.4 Acid reactions depend on strength and concentration

Learning intentions

By the end of this topic, you will be able to:
- distinguish between the key properties and features of acids and bases
- write, balance and assign states to neutralisation reactions.

Key ideas
- A neutralisation reaction occurs when an acid reacts with a base to produce a neutral solution (pH 7).
- Acids react with metals to produce hydrogen and a metal salt.
- A concentrated acid has many acid molecules present with very little water.
- A strong acid readily donates a hydrogen ion to a base.

neutralisation
a reaction in which an acid and a base combine to produce a metal salt and water

Acids

All acids contain hydrogen. They taste sour, turn litmus paper red and have a pH of less than 7. Strong acids are dangerous because they are corrosive and can cause severe burns. Weak acids are much less reactive, and many are found in food and drinks, such as lemonade.

Although most acids are molecular compounds (with covalent bonding), when they dissolve in water they form ions. This is called an ionising reaction. This reaction is what gives acids their name. All acids donate a hydrogen ion (H^+) to a base. A hydrogen ion is a hydrogen atom that has lost its electron, so it is really just a proton.

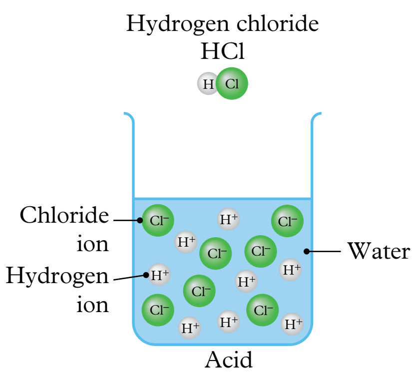


Figure 1 When acids dissolve in water, they form ions.

Bases

A base is defined as a substance that gains a hydrogen ion. It is this property that causes the litmus paper indicator to turn blue. Although all bases have a pH greater than 7, some are more reactive than others. Some, such as caustic soda (NaOH), can burn the skin.

Figure 2 Zinc metal reacting with acid

Neutralisation reactions

When an acid and a base are mixed together, hydrogen ions from the acid combine with hydroxide ions (OH^-) commonly found in bases to form water. The remaining ions form a metal salt. Water is considered neutral (pH 7).

This reaction is called a **neutralisation** reaction:

acid + base (metal hydroxide) → water + metal salt

For example:

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

Acid and metal reactions

The reaction between acids and metals is most obvious with acid rain. The carbon dioxide or sulfur dioxide gases in the air cause the formation of acid rain. This contributes to the corrosion of metalwork on buildings:

acid + metal → salt + hydrogen

For example:

sulfuric acid + zinc → zinc sulfate + hydrogen

$$H_2SO_4(aq) + Zn(s) \rightarrow ZnSO_4(aq) + H_2(g)$$

Note: Only the more reactive metals will form a metal salt and hydrogen when reacting with acids. Copper, silver and gold are less reactive metals.

EXPERIMENT

6.4: Acid titrations
Go to page **260**.

Acids and metal oxides

An acid and a metal oxide react to form a metal salt and water:

acid + metal oxide → metal salt + water

For example:

nitric acid + magnesium oxide →
magnesium nitrate + water
$2HNO_3(aq) + MgO(s) \rightarrow$
$Mg(NO_3)_2(aq) + H_2O(l)$

Acids and metal carbonates

An acid and a metal carbonate react to form a metal salt, water and carbon dioxide:

acid + metal carbonate →
metal salt + water + carbon dioxide

For example, acid rain can affect the calcium carbonate that makes up marble.

nitric acid + calcium carbonate →
calcium nitrate + water + carbon dioxide
$2HNO_3(aq) + CaCO_3(s) \rightarrow$
$Ca(NO_3)_2(aq) + H_2O(l) + CO_2(g)$

Concentrated or strong?

If you were to make a drink of cordial and not add enough water, you might describe it as 'too strong'. A chemist would describe it as 'too concentrated'. The strength and concentration of an acid or a base are two different things, so chemists need to be precise when using these terms.

The **concentration** of an acid or base is a measure of how many molecules of the acid or base are present in each litre of solution. A concentrated acid or base has very little water present – it is mostly molecules of acid or base. The labels of a container of concentrated hydrochloric acid might say, 'Conc. HCl' or '10 M HCl'. These solutions are very dangerous to handle.

The **strength** of an acid is a measure of how readily it will give away hydrogen ions to a base. Acid strength is compared at the same concentration – usually a very low concentration of 0.1 M, a very **dilute** (watered down) **solution**. Strong acids and strong bases are still dangerous at this concentration.

concentration
the number of active molecules in a set volume of solution

strength
how easily an acid releases a hydrogen ion in a chemical reaction; also describes the bond between different atoms

dilute
containing a small number of solute particles in the volume of solution

solution
a mixture of a solute dissolved in a solvent

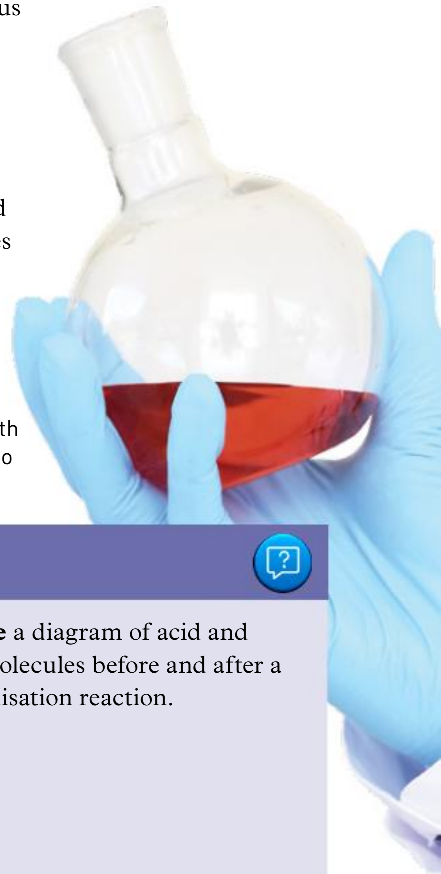


Figure 3 When working with chemicals, it is important to wear safety gloves.

6.4 Check your learning

Retrieve

1 **Identify** what must be reacted with an acid to produce:
  a hydrogen gas
  b carbon dioxide.

Comprehend

2 **Identify** the name of the reaction of an acid with a base. **Explain** why it is given this name.

3 **Explain** why metal containers are unsuitable for storing acids.

Analyse

4 **Contrast** the terms 'concentrated' and 'strong'. **Explain** whether a solution can be both concentrated and strong.

Apply

5 **Explain** whether it would require more, less or the same amount of base to neutralise 20 mL of 0.1 M strong acid than it would to neutralise 20 mL of 0.1 M weak acid. **Justify** your response.

6 Write chemical equations for:
  a dilute nitric acid (HNO_3) reacting with magnesium metal
  b dilute ethanoic acid (CH_3COOH) reacting with solid potassium carbonate (K_2CO_3)
  c dilute hydrochloric acid (HCl) reacting with calcium hydroxide ($Ca(OH)_2$) solution.

7 **Create** a diagram of acid and base molecules before and after a neutralisation reaction.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

6.5 Metals and non-metals react with oxygen

Learning intentions

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

- define the terms 'oxidation', 'combustion' and 'hydrocarbon'
- write, balance and assign states to oxidation reactions with metals and non-metals.

Key ideas

- Oxidation occurs when an element reacts with oxygen.
- Combustion reactions between non-metals and oxygen produce large amounts of energy in the form of heat and light.
- Combustion of hydrocarbons produces water and carbon dioxide.

Figure 1 The oxidation of magnesium is highly exothermic and produces a very bright flame.

hydrocarbon
a molecule that contains only carbon and hydrogen atoms

Figure 2 In oil refineries, distillation towers are used to isolate the different liquid fractions in crude oil as part of the process of making petroleum.

Oxidation reactions with metals

When molecules react with oxygen, it is called oxidation.

When metals react with oxygen, a basic metal oxide is formed:

$$\text{metal} + \text{oxygen} \rightarrow \text{metal oxide}$$

As the metal has formed a compound, this is also classified as a corrosion reaction. The metal oxide produced is an ionic compound.

In the case of very reactive metals, this oxidation is highly exothermic (it releases energy) and rapid (Figure 1). For example:

$$\text{magnesium} + \text{oxygen} \rightarrow \text{magnesium oxide}$$
$$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$$

In the case of moderately reactive metals, the oxidation reaction is still exothermic but slow.

Oxidation reactions with non-metals

Non-metals in group 18 of the periodic table do not react with oxygen, which is also a non-metal. Other non-metals do react with oxygen. Reaction results in the formation of a covalent bond. Consider the formation of water and carbon dioxide:

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$
$$C(s) + O_2(g) \rightarrow CO_2(g)$$

Both of these reactions are highly exothermic. The first reaction can cause explosions. (This is the reaction that causes the 'pop' in the pop test for hydrogen.)

Carbon is the principle constituent of coal. Both reactions produce a flame and so are classified as combustion reactions.

Combustion reactions require oxygen and a fuel. A fuel is a substance that will undergo a chemical reaction in which a large amount of useful energy is produced at a fast but controllable rate. According to this definition, fuels are the substances we use to produce heat and/or electricity, and to run engines and motors.

Combustion of hydrocarbons

The most common fuels we use for combustion are compounds of carbon and hydrogen (known as **hydrocarbons**) (Figure 3). When pure hydrocarbons burn in unlimited oxygen, carbon dioxide and water are produced:

$$\text{hydrocarbon} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}$$

When there is less oxygen available, carbon monoxide forms:

$$\text{hydrocarbon} + \text{limited oxygen} \rightarrow \text{carbon monoxide} + \text{water}$$

Carbon monoxide (CO) is a poisonous gas that binds tightly to haemoglobin in red blood cells, much tighter than oxygen binds. Carbon monoxide poisoning can be fatal because it starves the brain and other body tissues of oxygen.

With even less oxygen, unburnt carbon (soot) is formed, with water:

$$\text{hydrocarbon} + \text{limited oxygen} \rightarrow \text{carbon} + \text{water}$$

EXPERIMENT

6.5: Combustion of wire wool
Go to page **261**.

Small particles of soot cause breathing problems, especially in people with asthma. It is important that all users of hydrocarbon fuels burn them cleanly. In addition to releasing less pollution, burning these fuels cleanly provides more energy.

Our carbon economy

The chemical fuels that our society relies upon are based on carbon. Our ancestors burnt wood, which is mainly the carbon compound cellulose. Later generations burnt coal, which comes from buried plant remains that have been naturally dehydrated and compacted underground for tens of thousands of years. Coal is approximately 95 per cent pure carbon and 5 per cent other elements. Currently, we use coal to produce electricity and we use petroleum as a liquid fuel for transport.

All these fuels contain molecules made of carbon. Petrol is mostly octane (C_8H_{18}(l)), diesel is a mixture with the average formula $C_{12}H_{23}$(l), natural gas is mainly CH_4(g), and liquefied petroleum gas (LPG) is propane (C_3H_8(l)).

Petrol, diesel, natural gas and LPG are fossil fuels. The energy in them was captured by photosynthesis millions of years ago. This carbon in fossil fuels has been locked away underground for millions of years. Burning fossil fuels releases that carbon into the atmosphere as carbon dioxide. Renewable fuels, such as biodiesel and ethanol, contain carbon atoms. The carbon atoms in renewable fuels were captured by photosynthesis in the last growing season.

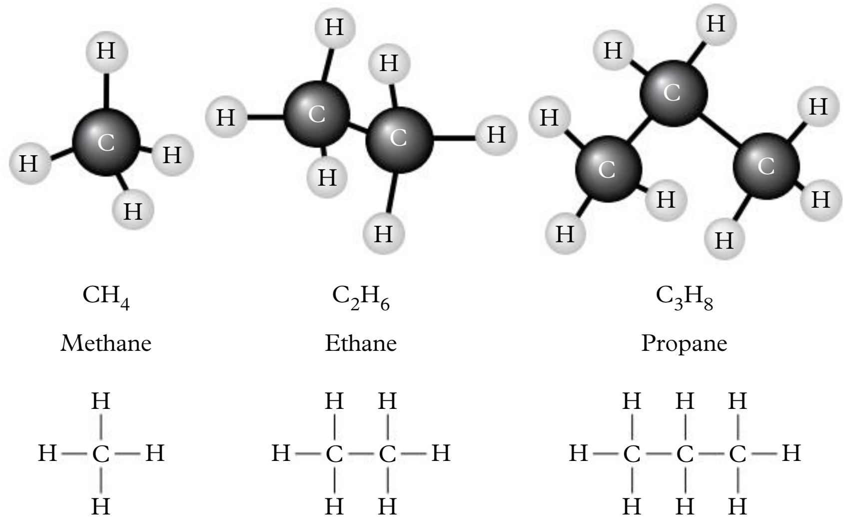


Figure 3 Hydrocarbons are compounds containing only carbon and hydrogen molecules.

You could say that our society runs on carbon. It is a very important fuel. Carbon is the mainstay of our economy, which is why it is sometimes called a carbon economy.

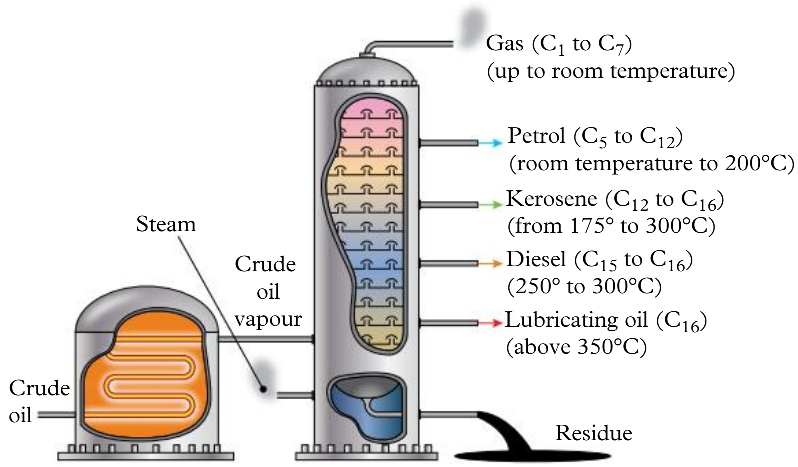


Figure 4 As the crude oil is slowly heated, vapour (gas) forms. As the vapour rises, it cools. When the vapour reaches the height where the temperature is equal to the fraction's boiling point, it condenses into a liquid.

6.5 Check your learning

Retrieve

1 **Define** the term 'oxidation reaction'.

2 **Identify** which group of elements does not react with oxygen.

3 **Identify** an example of a substance that might be considered a fuel by a:

a firefighter **b** chemist.

Comprehend

4 **Explain** why carbon fuels are so important to our society.

5 **Explain** why the amount of oxygen available can affect the products formed in the combustion process.

6 **Explain** why it is important to burn hydrocarbons in a well-ventilated area.

Apply

7 **Construct** a balanced equation for the combustion of each of the following hydrocarbons with unlimited oxygen. Add states to your equations.

a C_8H_{18} **b** C_3H_8

c CH_4 **d** $C_{12}H_{23}$

8 **Determine** which fuel in question 7 requires the most oxygen to burn cleanly.

Quiz me

Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

6.6 Polymers are long chains of monomers

Learning intentions

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

- define the terms 'monomer', 'polymer', 'cross-linked', 'thermosetting' and 'thermoplastic'
- determine if a polymer is thermosetting or thermoplastic based on its properties.

polymer
a long-chain molecule formed by the joining of many smaller repeating molecules (monomers)

monomer
a small molecule from which polymers are made

linear polymer
long single chains of polymers

elastomer
long chains of polymers occasionally linked together like a ladder

thermoplastic polymer
a polymer that softens and forms new shapes when heated

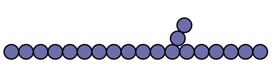


Figure 1 The basic structure of a linear polymer. The small circles represent small groups of atoms.

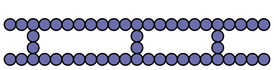


Figure 2 The basic structure of an elastomer

Key idea

- Polymerisation is the process of forming a long-chain polymer from smaller monomer molecules.

Different types of polymers

The plastics we use every day are a result of polymerisation. A polymer is a giant molecule that has been produced by joining many, many smaller molecules together – often thousands. **Polymer** means 'many parts'. The small molecules from which the polymers are made are called **monomers**.

If the polymer has been produced by chemists or chemical engineers, it is called a synthetic polymer. An example of a synthetic polymer is nylon. Before nylon was created, stockings were made from silk, which is a natural fibre produced by silkworms. Apart from being expensive, stockings made from silk easily developed holes and 'ladders'. Toothbrush bristles were made from another natural fibre – the fine hairs from boars! Nylon could replace both silk and boar bristles because nylon fibre is much tougher and more suitable for these applications.

There are three types of polymer structures: linear polymers, occasionally cross-linked polymers (also known as elastomers) and cross-linked polymers.

Linear polymers

Linear polymers are in the form of long chains (Figure 1). Generally, the chains consist of carbon atoms held together by covalent bonding, with other atoms or groups attached to the carbon atoms. In some linear polymers, the atoms of another non-metal are found at regular intervals along the chain of carbon atoms. For example, in nylon a nitrogen atom is found about every tenth atom along the chain. There may also be 'branches' hanging off the main chain.

The structure of **elastomers** is like a ladder (Figure 2). Elastomers are in the form of long chains that are connected every now and then with a small chain of atoms.

They are termed 'elastomers' because they are elastic. That is, they can be stretched and, when you let them go, they spring back into shape.

Cross-linked polymers

Cross-linked polymers are giant covalent lattices (Figure 3). Generally, they are largely made up of carbon atoms, although the atoms are much more haphazardly arranged than the carbon atoms in other covalent lattices, such as diamonds.

Apart from being classified according to their structure, polymers are classified according to how they respond to heat. This is a very important property.

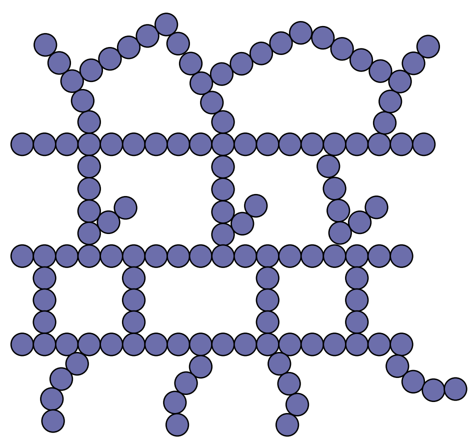


Figure 3 A cross-linked polymer

Thermoplastic polymers

Thermoplastic polymers soften when heated gently. This means they can be formed into new shapes by warming and pressing them, squeezing them through holes or even blowing them into the required shape. 'Plastic' means being able to have its shape changed. So, these are the only polymers that really should be described as 'plastic'. Thermoplastics include plastic film used to wrap foods and thermoplastic paint used to mark roads.

EXPERIMENT

6.6: Polymerisation of casein
Go to page **262**.

Thermosetting polymers

Thermosetting polymers do not melt or change shape when heated. If heated very strongly, they may char (turn black). These polymers must be produced in a mould because once they are formed they will not change shape again but stay hard and rigid (Figure 4).

Formation of polymers

There are many different types of **polymerisation** reactions, but they all follow the same process. Small molecules are reacted under specific temperature and/or pressure conditions that allow them to join together in a chain reaction to form giant molecules that can contain thousands of atoms. Polyethene is produced in this way, with molecules of ethene (C_2H_4) reacting together to form long-chain molecules of polyethene. This process can be represented using a diagram, as shown in Figure 5.

This polymerisation reaction requires high temperature and pressure, as well as a chemical catalyst.

How we use polymers today

Many different polymers are used today. More and more designer polymers are being developed and modified to suit particular applications. Many tents are made from nylon, which produces a lightweight, tear-resistant fabric. Bigger tents are made of cotton polyester. The bases of the tents are made of polyurethane, another useful, waterproof polymer.

Many people have at least one piece of clothing made of polar fleece, which is warm yet lightweight. Polar fleece is a synthetic wool made from PET or PETE (polyethylene terephthalate). PET is a thermoplastic polymer and, for polar fleece, is sourced from recycled plastic bottles that have been processed into a clothing fabric. PET gives polar fleece its soft, warm, durable and fast-drying properties, which make it perfect for camping and other outdoor activities.

Figure 4 The plastics that make up the covers of gaming consoles such as the Nintendo Switch are made of thermosetting polymers.

thermosetting polymers
polymers that do not melt or change shape when heated

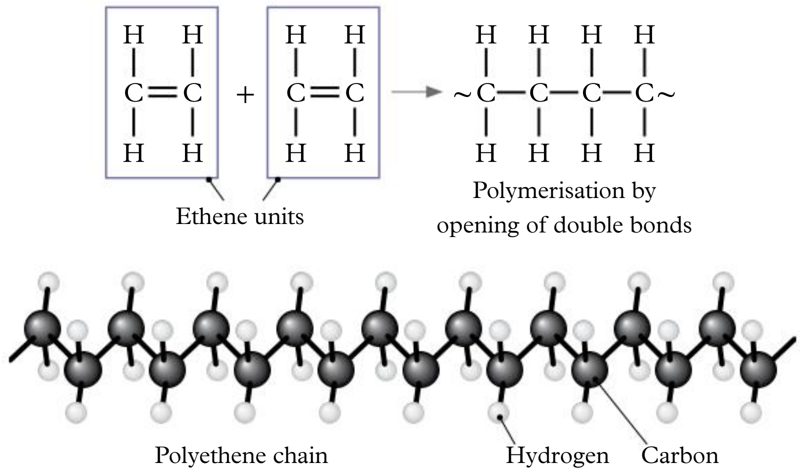


Figure 5 The formation of polyethene from ethene molecules

polymerisation
the process of joining smaller units (monomers) to form a long-chain molecule (polymer)

6.6 Check your learning

Retrieve

1 **Identify** the monomer unit of polyethene.

Comprehend

2 Use the structure of elastomers to **explain** their properties.

3 For each of the following applications, **explain** whether it would be better to make the object from a thermosetting polymer or a thermoplastic polymer.

- **a** food wrap
- **b** light switch
- **c** disposable cup for soft drinks
- **d** wash bottle for a science laboratory
- **e** handles of barbecue tongs

Analyse

4 **Contrast** a linear polymer and a cross-linked polymer.

Apply

5 **Identify** the plastic you would expect to be a thermosetting polymer: a linear polymer or a cross-linked polymer. **Justify** your response.

6 **Discuss** the decision to use thermoplastic paint for painting markings on roads, instead of other types of paint.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

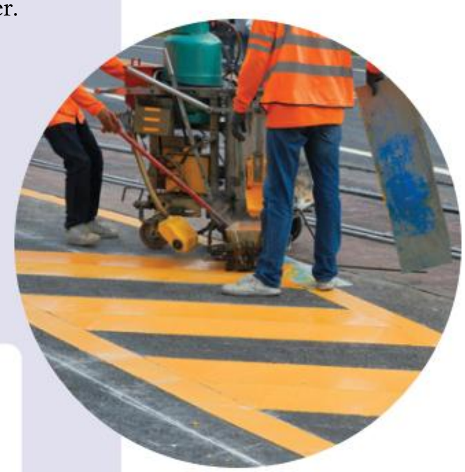


Figure 6 Thermoplastic paint is used to mark roads.

6.7 Surface area, concentration, temperature and stirring affect reaction rate

Learning intentions

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

- describe collision theory and explain how it relates to the rate of a chemical reaction
- explain how factors including surface area, concentration, temperature and stirring can be used to increase the rate of a reaction.

reaction rate
how fast or slowly a reaction proceeds

Key ideas

- The speed at which a reaction occurs is called the rate of a reaction.
- According to collision theory, reactants must collide in the correct orientation for a reaction to occur.
- The rate of a reaction can be increased by increasing the surface area, concentration or temperature, or by stirring the reactants.

Why reaction rates are important

A **reaction rate** is how fast a reaction proceeds. It is important to realise that this does not mean more products are formed in the reaction. This can be illustrated by a 100 m race. A runner can run fast or slowly; the only difference is how quickly the runner finishes the 100 m. A fast reaction has a high reaction rate; a slow reaction has a low reaction rate.

In the chemical industry, controlling the rate of a reaction is vital. Reactions that are too slow are not economical, because equipment is tied up for a long time. Reactions that are too fast need to be controlled. Chemists and chemical engineers have the role of making chemical reactions as cheap as possible. A large part of this is achieved by controlling the rate of the reaction.

Collision theory

For a chemical reaction to occur, the atoms, ions or molecules must collide with enough energy for that reaction to occur. This model is known as collision theory.

One reaction that has been studied is the decomposition reaction of hydrogen iodide. The reaction, in symbols, is:

$$2HI(g) \rightarrow H_2(g) + I_2(g)$$

Hydrogen iodide is a gas and its molecules move around quickly. Each hydrogen iodide molecule must collide with another hydrogen iodide molecule in order to react.

Some collisions do not result in a reaction. If a collision is unsuccessful, the hydrogen iodide molecules bounce apart with no reaction, as shown in Figure 1.

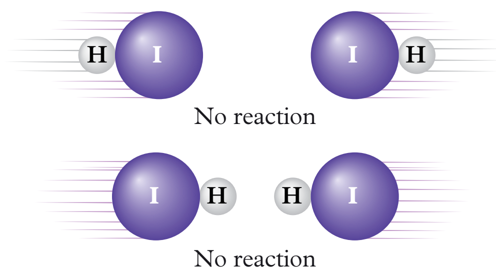


Figure 1 If collisions between HI molecules are unsuccessful, the HI molecules do not react with each other.

Only some collisions result in a reaction. The molecules must collide in the correct orientation for a reaction to occur. If the collision is successful, there will be a reaction (Figures 2–4). A weak chemical bond forms between the iodide ions and between the hydrogen ions. This intermediate substance is unstable and only exists for a short time before it breaks apart.

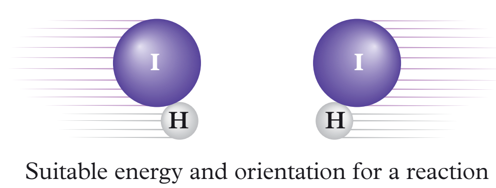


Figure 2 When the collisions between particles have enough energy, and the particles are aligned correctly, a reaction may occur.

EXPERIMENT
6.7: Factors affecting reaction rate
Go to page **263**.

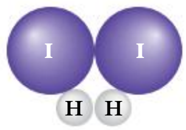


Figure 3 During the intermediate stage, H_2I_2 is formed. This molecule is unstable and short-lived.

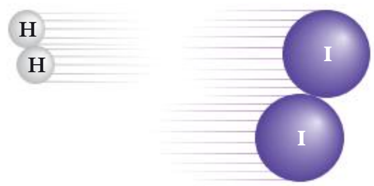


Figure 4 The final products are formed and move apart (partly due to electrostatic repulsion).

Increasing the rate of collisions

To increase the rate of a reaction, you need to increase the number of collisions occurring. This can be done by increasing the:

- surface area of the particles reacting
- concentration of the reactants
- temperature of the reaction.

Increase the surface area

A metal such as magnesium reacts with dilute hydrochloric acid. For a reaction to occur, hydrogen ions in the acid must collide with magnesium atoms. There are more metal atoms exposed to the hydrogen ions if the metal is in small pieces. Because the reaction occurs on the surface of the magnesium, breaking it up into smaller pieces provides a larger surface area on which the reaction can occur.

Powders have a much larger surface area than larger bits of material. The surface area is not the size of the pieces but the total area exposed to possible collisions (Figure 5).

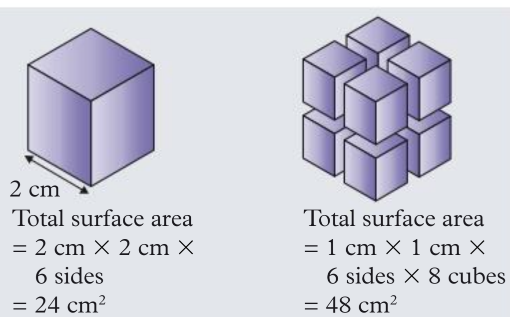


Figure 5 The total surface area of many small particles is larger than that of a single large particle of the same volume.

Increase the concentration

In a dilute solution, the particles (molecules or ions) of the reactant are spread out in a solvent, such as water. There is a lot of space between the reactant particles. In a concentrated solution, there are many more reactant particles in the same volume, so they are much closer together (Figure 6).

In the reaction between magnesium and hydrogen ions, the reaction will occur faster if there are more hydrogen ions in a given volume. So, using a hydrochloric acid solution with a higher concentration (i.e. more hydrogen ions in a given volume) will speed up the reaction. When there are more particles, there are more collisions and therefore a higher reaction rate.

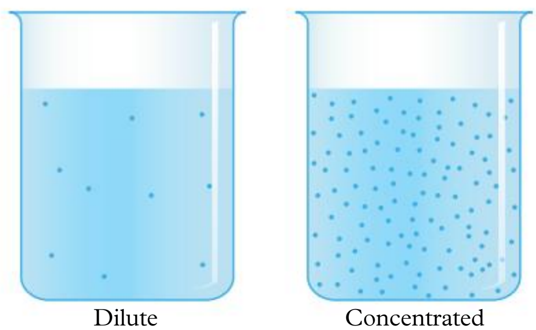


Figure 6 A concentrated solution contains more dissolved particles than a dilute solution.

Increase the temperature

Particles in a hot substance have more **kinetic energy** than particles in a cold substance. This means that the particles in a hot substance vibrate faster than the particles in a cold substance (Figure 7).

Particles at a high temperature will collide more frequently and with more speed than particles at a low temperature. More frequent collisions between particles, plus an increased likelihood of each collision being successful, means that reactions happen faster at higher temperatures.

Slow-moving gas molecules will be pushed apart by the repulsion of the electrons that orbit the atoms – they never come close enough to form new chemical bonds. Fast-moving molecules can 'push through' the repulsion, so their electrons can move to a different atom. Reactions involving enzymes are an exception.

kinetic energy
the energy an object or particle has due to its motion

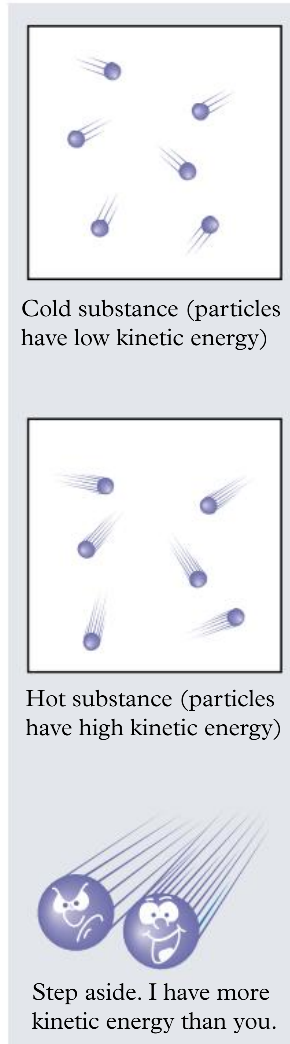


Figure 7 At higher temperatures, the average energy of the particles is increased and the particles vibrate faster.

Stir and mix

As a chemical reaction proceeds, the particles of the reactants get used up – when there are fewer particles of reactants, there are fewer collisions and so the reaction rate slows. To maintain the reaction rate, the products of the reaction should be removed and replaced with more particles of reactants. A basic way of doing this is by stirring or mixing the reactants.

In the reaction between magnesium and acid, one of the products is hydrogen gas. The gas forms bubbles that gather on the surface of the magnesium, covering the unreacted magnesium (Figure 8). This prevents the reaction from continuing. Stirring sweeps the hydrogen gas away so that more hydrogen ions can react with the fresh magnesium surface.

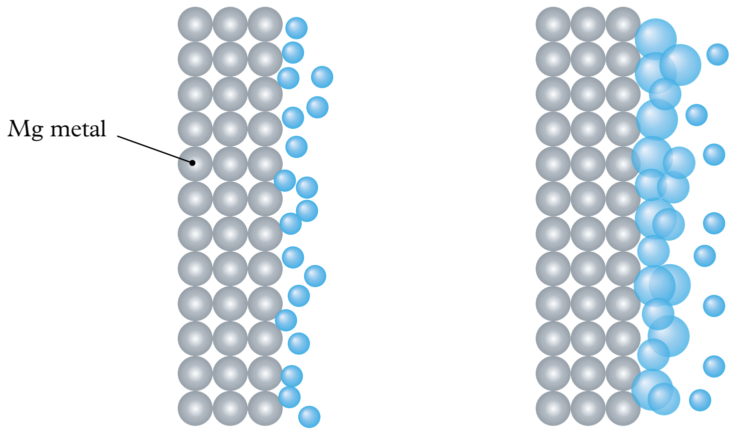


Figure 8 Sometimes the presence of the product can slow down a chemical reaction.

Detoxifying cycad seeds

First Nations peoples belonging to the Djabugay language group around northern Queensland detoxify cycad seeds or kernels for eating by using processes that speed up chemical reactions. The cycad seeds are a rich source of energy, but they also contain a toxin called cycasin. The toxin can cause vomiting and nausea as well as long-term damage to the nervous system and liver. It is also a carcinogen, so removing this toxin is important before using cycad seeds as food.

Figure 9 Cycad seeds must be detoxified before they can be safely consumed.

The cycasin toxin will break down very slowly if it is soaked in running water for many weeks. To increase the rate of this breakdown, the First Nations peoples in northern Queensland developed a technique that involves grinding the cycad seeds into smaller pieces and heating the water slightly. Regular mixing allows the reactants (the plant material and water) to come into contact with each other and increases the rate of the detoxifying process.

If the First Nations peoples had not developed this knowledge of the detoxification process, food resources such as cycad seeds would have made many people sick and a potential food resource would have been overlooked.

6.7 Check your learning

Comprehend

1 **Describe** how products are formed when molecules of reactants collide.
2 **Explain** why increasing the surface area increases the rate of reaction.
3 **Explain** why diluting a solution decreases the rate of reaction.
4 **Explain** why a reaction occurs faster when the reactants are stirred together.
5 **Describe** how collision theory explains the dramatic increase in the rate of a reaction as reactants are heated.

Analyse

6 **Consider** the text under the subheading 'Detoxifying cycad seeds'.
   a **Identify** the techniques used that would increase the rate of the detoxification process.
   b Use what you have learnt in this chapter to **explain** how these techniques increase the reaction rate.

Apply

7 A scientist investigated the rate of a reaction between a magnesium ribbon and 1 mol/L of hydrochloric acid. They added both substances to a conical flask, which was connected to an inverted measuring cylinder in a trough of water (Figure 10). Then they measured the amount of hydrogen gas that was produced every 30 seconds. Their results are shown in Table 1.

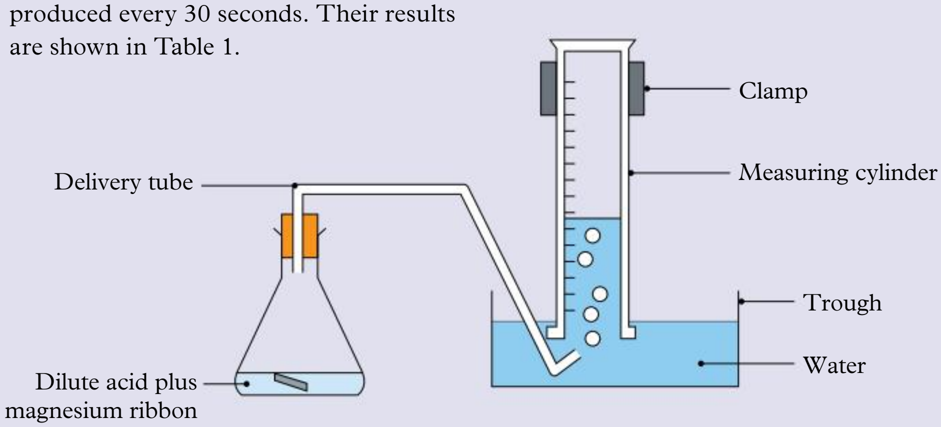


Figure 10 The scientist's experimental set-up

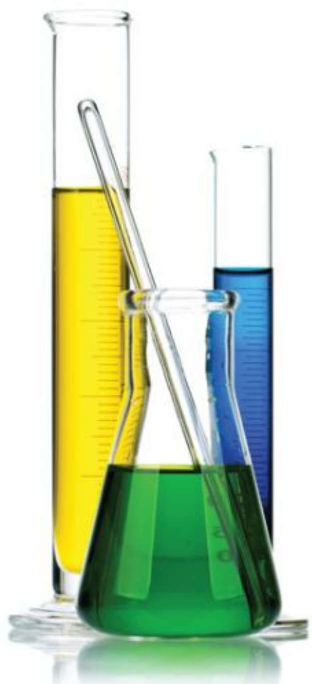
Table 1 Results from the scientist's experiment

Time (s)	Volume of gas (mL)
0	0
30	51
60	70
90	82
120	91
150	91
180	91

a **Construct** a graph of the scientist's results.
b **Analyse** the data and **describe** any trends in terms of the independent and dependent variables in this experiment.
c **Identify** the time point on your graph at which the reaction appears complete. **Justify** your decision.
d **Propose** how the scientist might collect more precise data for their results table.
e The scientist only conducted their test once to collect the data in Table 1. **Propose** one way they could make their results more reliable.
f **Describe** two ways that the scientist could increase the speed of the reaction.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

Figure 11 Stirring the reactants increases the rate of a chemical reaction.



6.8 Catalysts increase the rate of a reaction

Learning intentions

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

- describe what a catalyst is
- explain the different ways catalysts can be used to increase the rate of a reaction.

catalyst
a substance that increases the rate of a chemical reaction without undergoing any permanent chemical change

Key idea

- Catalysts increase the rate of a chemical reaction without being permanently changed.

A **catalyst** is a substance that speeds up a chemical reaction but is not used up in the reaction. Catalysts work in many different ways.

Solid catalysts provide a surface on which the reaction can occur. The particles of reactants get adsorbed (stuck onto) the surface, where they react to form the products. The products are then released from the surface of the catalyst. This frees up the catalyst to be used again by other reactant molecules.

Pollution control in cars

Solid catalysts are used in the catalytic converters of car exhaust pipes. A honeycomb-like grid of metals provides a large surface area to increase the rate of reaction (Figure 2). As the exhaust gases pass through the converter, they react on the surface of the metals to form harmless gases. The metals absorb (hold onto) pollutant gases such as $CO(g)$ and $NO(g)$ and help to convert them into gases that are safer to release into the atmosphere, such as $CO_2(g)$ and $N_2(g)$. Catalysts are usually metals such as platinum, palladium and rhodium.

Figure 1 Catalytic converters are used to reduce harmful pollution from exhaust gases.

The overall reaction that occurs in the catalytic converter in a car's exhaust pipe is:

$$2CO(g) + 2NO(g) \rightarrow 2CO_2(g) + N_2(g)$$

While catalysts can be reused many times, they can sometimes become contaminated after excessive use. Impurities in petrol can poison a car catalyst and prevent the catalyst from functioning properly.

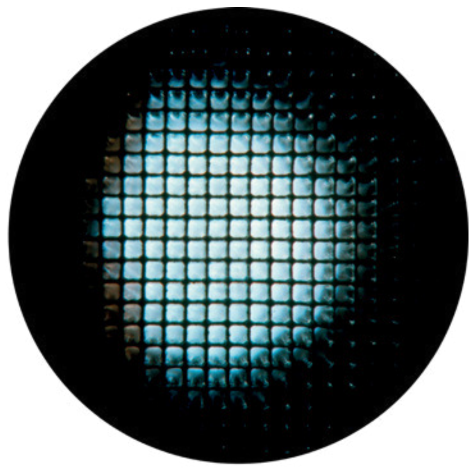


Figure 2 Catalysts are often in the form of a grid to maximise the surface area.

Reactions in the ozone layer

Another way in which catalysts work is to take part in the reaction and be regenerated later. This occurs in the destruction of ozone, $O_3(g)$, by chlorofluorocarbons (CFCs).

The ozone layer is a region in the stratosphere between 10 km and 50 km high, with the greatest concentration at an altitude of 30 km. Ozone in this region absorbs ultraviolet (UV) light, which would otherwise reach the Earth's surface and cause increased levels of skin cancers and eye problems.

EXPERIMENT

6.8: Using a catalyst
Go to page **264**.

Figure 3 Chlorofluorocarbons (CFCs) were used to pressurise the gas in aerosol cans before it was proved that CFCs damage the ozone layer.

The main destroyers of ozone are CFCs. CFCs are non-flammable, non-toxic, cheap to manufacture, easy to store and chemically stable. They were used in aerosol cans (Figure 3), fire extinguishers and asthma inhalers, as well as in foam insulation for furniture, bedding, coffee cups and hamburger containers and as a refrigerant gas in refrigerators and air conditioners. Today, manufacturers use alternative gases where possible to avoid damaging the ozone layer.

CFCs such as CCl_3F (trichlorofluoromethane or freon-11) are broken apart by the UV rays from the Sun, releasing a free chlorine atom. This chlorine atom catalyses the destruction of ozone and is regenerated.

In this way, one chlorine atom from the original CFC can destroy up to 10 000 ozone molecules.

In 1987, the Montreal Protocol (an agreement made in Montreal, Canada) phased out the use of CFCs. Chemicals that were 'ozone friendly' were developed and used as replacements for the ozone-depleting substances. Figure 4 shows ozone levels over the Southern Hemisphere before and after the phasing out of CFCs.

Enzymes as catalysts

An **enzyme** is a catalyst made and used in living cells. Enzymes play an important part in all cellular processes. All the reactions that occur inside a cell are catalysed by enzymes. There are numerous enzymes in our bodies to help speed up reaction rates. For example, enzymes in the digestive system help break down food. Enzymes only work with specific reactants called **substrates** and so will only catalyse certain reactions. The region in which reactants can bind to an enzyme is called the **active site**. This is shown in Figure 5.

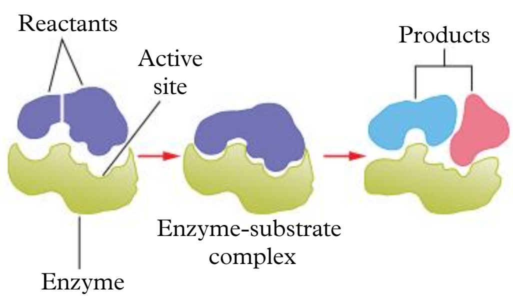


Figure 5 Enzymes only work with specific reactants that can bind to their active site.

enzyme
a rotein-based catalyst

substrate
a molecule that reacts with an enzyme

active site
the region of an enzyme that substrates can bind to

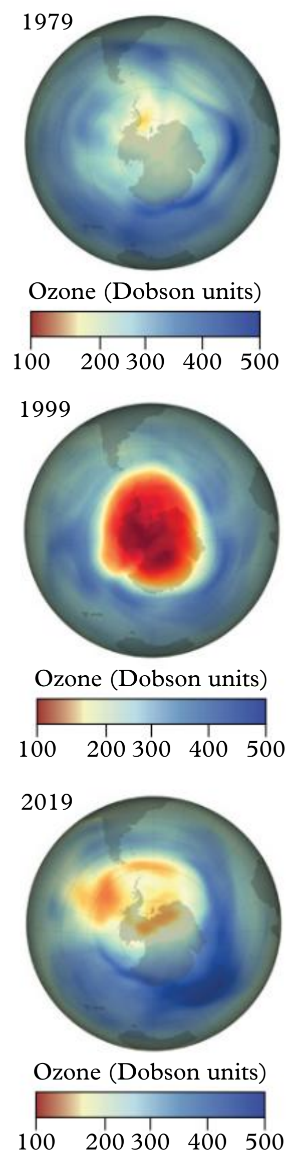


Figure 4 The darker colours show the growth of the 'hole' in the ozone layer between 1979 and 1999, and its decrease after CFCs were banned.

6.8 Check your learning

Retrieve

1 **Define** the term 'catalyst'.

Comprehend

2 **Describe** two ways in which catalysts can work.

3 **Describe** a catalytic converter. **Explain** why they are used.

4 **Explain** why it is important that the amount of ozone in the atmosphere remains stable.

5 **Describe** what has caused the change in the amount of ozone in the atmosphere over time.

Apply

6 **Determine** which part of the CFC molecule destroys ozone. **Describe** how this atom becomes detached.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

//SCIENCE AS A HUMAN ENDEAVOUR//

6.9 Reactions are used to produce a range of useful products

Learning intentions

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

- describe how polymers are used in desalination plants and to produce bioplastics
- describe the properties of superalloys and their different uses in society.

Scientific research is an important endeavour as it moulds how we live our lives. It shapes what we eat, how we live, how we use transport and the technology that we use. In our world of food shortages, climate change, pollution, conflict and poor water quality, scientific research and the use of reactions to create innovative products has become even more important. Innovation in chemistry can be seen in reactions used to produce polymers and superalloys.

Innovations in polymer chemistry

Polymer chemists are scientists who look at the synthesis, structure and properties of polymers. Polymers are large molecules that are made from the joining together of many smaller molecules (monomers). Synthetic polymers are used to manufacture many household and industrial products such as furniture, packaging, transportation and communication. Polymer chemists develop these chemicals to make products with specific properties related to degradability, durability and conductivity.

Water quality

In Australia most of our drinkable water comes from water catchments like the Wivenhoe Dam. However, due to drought and climate change, water levels have declined over the years. To help supplement the water requirements in South East Queensland, the Gold Coast Desalination Plant was built. Using scientific technologies such as reverse osmosis filtration an additional 125 ML of water per day can be added to the water supply of South East Queensland.

Figure 1 Times of drought decrease the level of available water in the Wivenhoe Dam.

Seawater is drawn 1 km from the Queensland coast to the Gold Coast plant and filtered of particles. Reverse osmosis removes remaining impurities, including salt. Very high-pressure pumps then push pure water molecules through thousands of semi-permeable membranes, leaving the salt (and other impurities) behind on the other side of the membranes. The water passes through this system twice.

The membranes used in this process are made from polymers called polyamides. Polyamides are formed by a polymerisation reaction that links together many small organic molecules called amides. Once formed the polyamides are then rolled into thin membranes able to filter water.

Figure 2 Reverse osmosis filtration for desalination plants

Bioplastics

Bioplastics are plastics that are made from living things, usually biomass. Examples of biomass come from plants such as vegetable based oils, corn and wood chips. Polylactic acid (PLA) is a common polymer bioplastic made from corn. Its properties are similar to fossil fuel derived plastics such as polyethylene (PE).

Bioplastics are said to use less energy to manufacture compared to fossil fuel derived plastics and the manufacture of bioplastics also produces significantly less greenhouse gas. However, it is a major misconception that all bioplastics are biodegradable. A lot of research is currently being done in this area to minimise the environmental impact of bioplastics after their use.

Figure 3 Disposable cutlery made from a bioplastic that uses avocado seeds

Superalloys

Superalloys are created by reactions that combine specific metals (often iron, nickel and cobalt) and metal alloys to produce an alloy with a highly complex structure. The complex structure and combined properties of metals provide superalloys with extremely high tolerance to heat, stress and corrosion. Being able to endure extreme temperatures (greater than 1000°C) over long-term application has made the use of superalloys common in the aerospace engine industry. However, superalloys are now also being used across power industries, construction, to improve defence armour and even to create prosthetic limbs.

Figure 4 The metal cobalt is commonly used to produce superalloys.

Some disadvantages of superalloy use include that most of these materials are costly and many also have poor **machinability**. This has limited the capacity for superalloys to be used in manufacturing. However, research today – including that by the CSIRO – is currently investigating how to improve the efficiency of superalloys and minimise costs involved with producing these materials.

bioplastic
plastic produced from renewable biomass sources

superalloy
high-strength complex metal alloy resistant to extreme temperature and stress

machinability
ability of a metal to be cut and shaped

6.9 Test your skills and capabilities

Personal and environmental safety

One achievement of the Commonwealth Scientific and Industrial Organisation (CSIRO) was the development of a polymer called Elast-Eon™.

Research the polymer Elast-Eon and create an infographic that presents information on the following:

> What is the polymer?
> Who are the scientists/scientist credited to its discovery?
> What are the different applications and industries it is used in?
> When did the polymer become commercially available?
> What would be the impact if this polymer had not been discovered?
> What awards/accolades have been awarded to this research?

CHAPTER 6 REVIEW

CHEMICAL REACTIONS

Retrieve

1 **Identify** the correct way to describe a decomposition reaction.
  A substances that are present at the start of a chemical reaction
  B the building up of compounds by combining simpler substances
  C the breakdown of compounds into simpler substances
  D bases that dissolve in water

2 **Identify** which of the following describes a catalyst.
  A an exothermic reaction
  B an ignition for a reaction
  C a substance that speeds up a chemical reaction
  D a substance that slows down a chemical reaction

3 **Identify** the types of products that are formed when acids react with metals, carbonates or bases.

4 **Recall** four factors that will affect the rate of a chemical reaction.

Comprehend

5 **Describe** the differences between decomposition reactions and synthesis reactions.

6 A student mixed the following solutions together in a beaker: ammonium nitrate, sodium chloride, lead(II) nitrate, sodium sulfate. **Describe** what would be seen in the beaker. **Explain** your answer using a chemical equation.

7 **Describe** two different types of reactions that produce carbon dioxide.

8 **Describe** the link between CFCs and the ozone layer.

9 In terms of particles, **explain** what is required for a chemical reaction to take place.

10 **Describe** two ways that the rate of chemical reactions can be measured.

11 **Describe** one situation where it could be dangerous if a reaction occurs too quickly.

12 Polypropylene is a plastic that can be easily melted and formed into a range of products. **Describe** the likely structure of polypropylene and **explain** how its structure allows the plastic to be moulded into a range of shapes.

13 **Describe** two examples of catalysts used in the production of chemical products.

14 **Explain** how the particle model of matter helps us understand the rate of reactions.

15 **Describe** two applications of polymers in society.

Analyse

16 **Identify** the correct product for this synthesis reaction:
$2Mg + O_2 \rightarrow$
  A $2MgO$
  B MgO_2
  C MgO
  D $2Mg_2O_4$

17 **Classify** each of the following reactions as either synthesis, decomposition, single displacement or double displacement.
  a $CaCO_3 \rightarrow CaO + CaO_2$
  b $Mg + Cu(NO_3)_2 \rightarrow Mg(NO_3)_2 + Cu$
  c $2CO + O_2 \rightarrow 2CO_2$
  d $HCl + NaOH \rightarrow NaCl + H_2O$
  e $Zn + 2HCl \rightarrow ZnCl_{2\,+}\,H_2$
  f $NH_3 + HCl \rightarrow NH_4Cl$

18 **Compare** thermosetting and thermoplastic polymers.

Apply

19 In many industrial environments, the presence of a fine dust is regarded as an explosion hazard. **Suggest** why coal dust is more likely to explode than chunks of coal.

Figure 1 Coal dust is a greater explosion risk than chunks of coal.

20 A reaction is carried out in a well-ventilated environment with outside air regularly circulating. A chemical engineer noticed that a reaction that gave a high yield of a product in summer gave a low yield of that same product in winter, despite the reagents and concentrations being identical. **Propose** a possible explanation for the different yields.

21 Sodium metal was reacted with purified bauxite (Al_2O_3) to produce aluminium and sodium oxide (Na_2O).
  a **Identify** the type of reaction that occurred.
  b **Construct** a chemical equation for the process, ensuring that the law of conservation of mass is applied to the equation.

22 During an experiment, solid calcium carbonate ($CaCO_3$) was added to an aqueous solution of hydrochloric acid (HCl). The two substances reacted to produce calcium chloride ($CaCl_2$), water (H_2O) and carbon dioxide gas (CO_2).

The reaction was performed at two temperatures: 20°C and 30°C. The results of each trial were graphed together as shown in Figure 2.

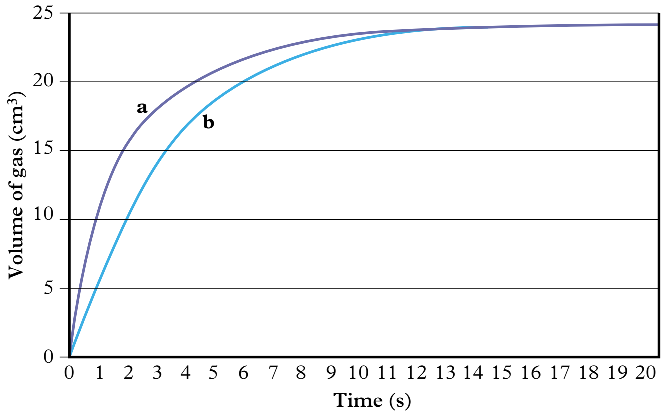


Figure 2 The results of each trial

- **a** Use the information provided to **construct** a title for the graph.
- **b** **Identify** which line (a or b) represents the trial at 20°C and which represents the trial at 30°C.
- **c** Use the information provided in the graph to **describe** the relationship between temperature and the rate of reaction.
- **d** Use the collision model to **provide** an explanation for the relationship identified in part c.
- **e** If a third trial was conducted at 35°C, **predict** how it might be graphed with the other trials (by sketching another line on the graph).
- **f** Write a balanced equation to **summarise** the chemical reaction taking place. (HINT: The information you need to start is in the question.)

23 The reaction $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$ is very slow at room temperature. The reaction occurs in two steps, which are shown as follows. The reaction occurs more quickly in the presence of nitrogen dioxide gas.

Step 1

$2SO_2(g) + 2NO_2(g) \rightarrow 2SO_3(g) + 2NO(g)$

Step 2

$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$

Propose two reasons why the nitrogen dioxide is regarded as a catalyst.

Social and ethical thinking

24 In the 1920s, the compound tetraethyl lead was developed to prevent 'knocking' in car engines. ('Knocking' is where the spark plugs fire too early, resulting in loss of power and possible engine damage.) Adding tetraethyl lead saved the cost of additional refining of petrol, which reduced costs for consumers and motorists. However, some people were concerned about the use of a lead compound that was being released from the exhaust of cars. Imagine you had been part of the debate in the 1920s and **propose** two arguments you would make against the use of tetraethyl lead.

Critical and creative thinking

25 Some catalysts work by providing a surface on which reactions can occur. These surface catalysts work by allowing the reacting particles to interact together on the surface of the catalyst.

- **a** **Explain** why binding particles onto a surface of another chemical would encourage a chemical change to occur.
- **b** **Explain** why a substance that actually bonded chemically to the reacting particles would not make a good catalyst.
- **c** **Identify** an example of the use of a surface catalyst, describing in detail the chemical reaction.
- **d** Use your knowledge of collision theory to **discuss** why most catalysts are used in the form of a powder or fine mesh.

26 Haemoglobin is responsible for the transport of oxygen in the bloodstream from your lungs to the cells in your body, where respiration takes place. The oxygen molecules interact with the haemoglobin and combine to form oxyhaemoglobin. When the blood reaches the cells (having been pumped through the heart), the oxyhaemoglobin releases the oxygen. If carbon monoxide molecules are breathed into the lungs, they can attach themselves permanently to haemoglobin molecules, thus preventing the essential transfer of oxygen. Carbon monoxide poisoning is a very real danger, and many Australians are killed by it each year.

- **a** **Create** a diagram to represent the transfer of oxygen from the lungs to body cells.
- **b** **Explain** why the chemical changes occurring between haemoglobin and oxygen need to be reversible.
- **c** **Identify** if the reaction between carbon monoxide and haemoglobin can be reversed. **Justify** your answer.
- **d** **Describe** two ways that carbon monoxide poisoning can be prevented.

Research

27 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

» Rare metals

A range of rare metals is used in microelectronic devices. Many of these metals, such as tantalum and niobium, are sourced from Australia.

- » Investigate where these metals are found in Australia.
- » Identify in what form they occur naturally.
- » Identify what chemical processes are used to extract the pure metals.

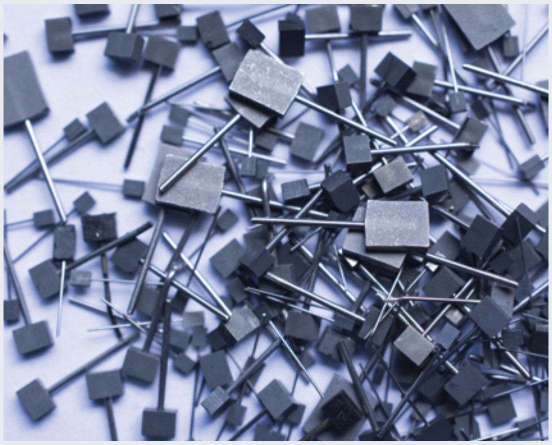


Figure 3 Tantalum wire scrap

» Minamata disease

Minamata disease is caused by people eating seafood contaminated with a compound containing mercury. The condition was called a 'disease' because when it was first described no one knew its cause. Investigate this disease and present your findings using the following headings.

- » Symptoms
- » Cause
- » Action taken
- » Lasting consequences (for the people affected, the chemical industry and the world)

» Protective alloys

An understanding of metallic alloys has allowed the development of new materials with unique properties. Aluminium alloys have been used in the development of protective body armour. Steel alloys are used for added strength in building and construction.

- » Select one alloy and investigate the elements used in the material.
- » Describe the properties that are unique to the alloy.
- » Explain how these properties determine how the alloy is used.

Figure 4 Rebars (reinforcement bars) are made of steel alloy and used in construction to reinforce concrete.

Chapter checklist

Now that you have completed this chapter, reflect on your ability to do the following.

	I can do this.	I cannot do this yet.	
• Identify the difference between synthesis, decomposition and displacement reactions. • Write, balance and assign states to simple synthesis, decomposition and displacement reactions.	☐	☐	Go back to Topic 6.1 'Synthesis, decomposition and displacement reactions can be represented by equations'. Page 140
• Identify precipitation reactions and explain why they are named this way. • Determine whether a chemical is solid (s) or aqueous (aq) based on solubility rules.	☐	☐	Go back to Topic 6.2 'The solubility rules predict the formation of precipitates'. Page 144
• Describe examples of acids and bases. • Explain the structure of the pH scale.	☐	☐	Go back to Topic 6.3 'Acids have a low pH, bases have a high pH'. Page 146
• Distinguish between the key properties and features of acids and bases. • Write, balance and assign states to neutralisation reactions.	☐	☐	Go back to Topic 6.4 'Acid reactions depend on strength and concentration'. Page 148
• Define the terms 'oxidation', 'combustion' and 'hydrocarbon'. • Write, balance and assign states to oxidation reactions with metals and non-metals.	☐	☐	Go back to Topic 6.5 'Metals and non-metals react with oxygen'. Page 150
• Define the terms 'monomer', 'polymer', 'cross-linked', 'thermosetting' and 'thermoplastic'. • Determine if a polymer is thermosetting or thermoplastic based on its properties.	☐	☐	Go back to Topic 6.6 'Polymers are long chains of monomers'. Page 152
• Describe collision theory and explain how it relates to the rate of a chemical reaction. • Explain how factors including surface area, concentration, temperature and stirring can be used to increase the rate of a reaction.	☐	☐	Go back to Topic 6.7 'Surface area, concentration, temperature and stirring affect reaction rate'. Page 154
• Describe what a catalyst is. • Explain the different ways catalysts can be used to increase the rate of a reaction.	☐	☐	Go back to Topic 6.8 'Catalysts increase the rate of a reaction'. Page 158
• Describe how polymers are used in desalination plants and to produce bioplastics. • Describe the properties of superalloys and their different uses in society.	☐	☐	Go back to Topic 6.9 'Science as a human endeavour: Reactions are used to produce a range of useful products'. Page 160

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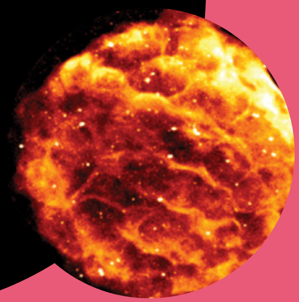
Quizlet
Play a Quizlet game to test your knowledge.

Chapter quiz
Check your understanding of this chapter with the chapter review quiz.

CHAPTER

7



THE UNIVERSE

7.1

Science as a human endeavour: The universe was studied by First Nations peoples

> Describe the significance of astronomy to the culture, spirituality and calendars of First Nations peoples, which date back thousands of years.

> Identify some stars and constellations in the night sky.

7.2

The Earth is in the Milky Way

> Explain the process of nuclear fusion in stars.

> Describe the difference between relative magnitude, absolute magnitude and luminosity.

> Convert distances in light-years to kilometres.

> Describe the structure of the universe in terms of stars and galaxies.

7.3

Stars have a life cycle

> Describe how gravity contributes to the formation of stars and galaxies.

> Explain how hydrostatic equilibrium is attained in stars.

> Describe what happens to a star when hydrostatic equilibrium cannot be maintained.

7.4

The galaxies are moving apart

- Explain how absorption and emission spectra are produced by stars and nebulae.
- Describe how the Doppler effect changes the apparent frequency and wavelength of sound waves.
- Describe how red and blue shift of galaxies provide evidence of speed and direction of movement.

7.5

Evidence supports the Big Bang theory

- Explain how the Big Bang theory provides an explanation for the expansion of the universe from a single point.
- Describe how cosmic microwave background radiation provides evidence to support the Big Bang theory.
- Understand that evidence for the Big Bang theory has also been used to estimate the age of the universe.

7.6

Science as a human endeavour: Technology aids cosmological research

- Explain what the ASKAP radio telescope is and what research it can be used for.
- Explain what the Event Horizon Telescope is and describe what it captures.

What if?

Measuring distances

What you need:

Stopwatch, large open space (basketball court), long tape measures

What to do:

1. Mark a starting point on the basketball court.
2. Walk heel to toe in a straight line, carefully touching the heel of one foot to the toe of the previous foot for exactly 1 minute.
3. Measure the distance you walked in 1 minute.

What if?

» What if you walked heel to toe for 1 hour? (How far would you walk?)

» What if you walked heel to toe for 1 day (24 hours)?

» What if you walked heel to toe for 1 year (365.25 days)?

» What if you travelled at the speed of light? (How far would you travel?)

//SCIENCE AS A HUMAN ENDEAVOUR//

7.1 The universe was studied by First Nations peoples

Learning intentions

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

- describe the significance of astronomy to the culture, spirituality and calendars of First Nations peoples, which date back thousands of years
- identify some stars and constellations in the night sky.

While many people consider the ancient Greeks (400 BCE) to be the first astronomers, there is increasing recognition of early astronomers among First Nations peoples, who have been observing the movement of the stars for navigation, animal and plant behaviour, hunting, Dreaming stories and reflections of Earth for over 60 000 years. First Nations peoples continue to have many practical uses for what they observe in the night sky. The night sky is a calendar and an integral part of First Nations cultures and spiritualities.

First Nations peoples' calendars

constellation
a group of stars that form a pattern or picture

Constellations are groups of stars that form a picture in the night sky. To many groups of First Nations peoples, the appearance of certain constellations at sunrise or sunset and how they track across the sky provide information on animal activity. This provides information about what to hunt and when.

Many people in Australia are familiar with the whitish hazy band that appears across the sky. This is the Milky Way, which is our galaxy (a group of stars held together by their own gravity). Deep within the Milky Way is a dark patch that looks like an emu (Figure 1). Across Australia, there are many First Nations stories about the emu in the sky. To the Wiradjuri people living on Country in central New South Wales, when the emu, known as Gugurmin, appears on the eastern horizon at sunset, the emus are nesting and there are no eggs to collect. Later in the year, Gugurmin appears directly overhead at sunset and it is time to collect the emu eggs. Stories are often told that warn not to collect too many eggs or Gugurmin will disappear. This is sustainable practice and part of the seasonal hunting calendar.

To the Boorong people living on Country at Lake Tyrrell in Victoria, the appearance of the ancestral mallee fowl constellation, called Neilloan, during March and September, signals that the bird is building its nest mounds. When the constellation disappears in late September or early October, it is time to gather the eggs.

To the First Nations peoples living on Country in the Gulf of Carpentaria, in northern Australia, a group of stars (called Scorpius by Europeans) appearing in the night sky in April means the wet season is over and soon the dry southeasterly wind will start. This forms part of the seasonal calendar.

Figure 1 The emu-shaped dark patch in the Milky Way tells First Nations peoples when it is time to hunt.

SKILLS LAB
7.1A: Using a star chart
Go to page **265**.

CHALLENGE
7.1B: Modern-day Australian astronomers
Go to page **266**.

Farming by the stars

First Nations peoples also plan farming by the stars. Torres Strait Islander peoples identify a constellation in the southern sky as Tagai, the great fisherman standing in a canoe. His left hand is holding a spear in the Southern Cross and points to the south. Tagai is used both for navigation and to identify the best time to start planting gardens at the start of the wet season (when Tagai's left hand dips into the sea in November). This also forms a part of the seasonal calendar.

Stories in the stars

First Nations peoples are diverse and live in all parts of Australia. Each Nation has its own language and Dreaming stories of the stars. Many of the stories are used to pass on information or explain lore and traditions.

The constellation of stars called Orion by Europeans has different stories told about it by different Nations. The Yolngu people of the Northern Territory call this constellation Djulpan. To the Yolngu people, Djulpan tells of three brothers of the King-fish (Nulkal) clan sitting side-by-side in a canoe. The cloud of stars in the nearby nebula are the fish, and the stars marking Orion's sword are the fishing line. The three brothers are forbidden to eat any king-fish. The brothers catch king-fish after king-fish but have to throw them all back. Eventually one of the brothers becomes so hungry he eats the king-fish. The Sun-woman (Walu) sees him kill the king-fish and in anger, creates a water spout that lifts the brothers up into the sky.

To the Napaljarri-warnu Jukurrpa people of Central Australia, this same group of three stars are a Jakamarra man chasing seven young Napaljarri sisters across the sky. The fleeing women found in a cluster of stars always ahead of the man in the sky act as a warning for the two groups to respect their differences.

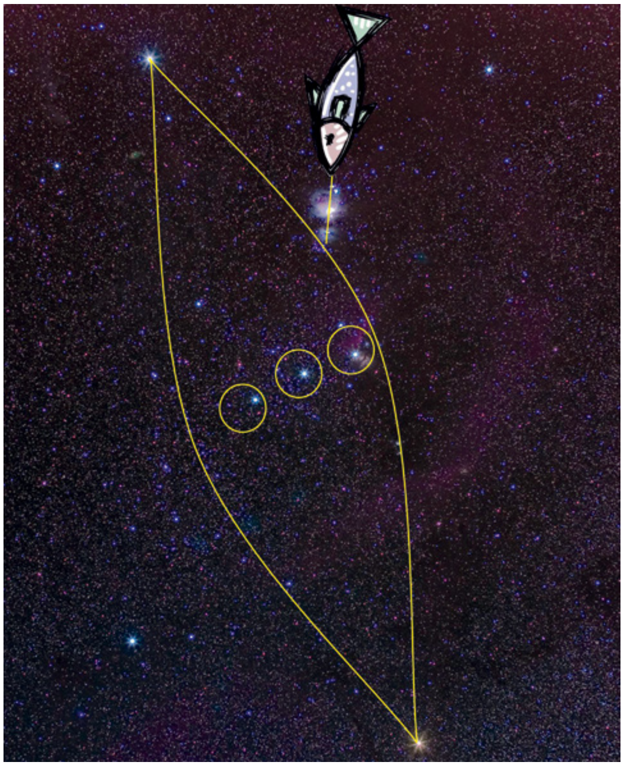


Figure 2 Different Dreaming stories are used by First Nations peoples to explain the same constellation. The Yolngu people call the Orion constellation Djulpan.

7.1 Test your skills and capabilities

Early scientists

For thousands of years, First Nations peoples have observed and recorded the recurring patterns of star movement in the sky. Developing these Dreaming stories requires the use of many scientific skills, such as asking questions about the surrounding environment, making detailed observations, recording data (through oral traditions or painting landscapes), data analysis to recognise patterns, making conclusions, and communicating through paintings or oral traditions.

1 **Identify** the name of the First Nations language group in your local area.

2 **Describe** a Creation story that is told through secondary sources (books or a trustworthy internet website) or primary sources (a local Elder). Remember to ask the permission of the Elder to write the story down.

3 **Identify** which science inquiry skills from the list below were used to develop the story, and **describe** how each skill was used.
> questioning and predicting
> planning and conducting
> processing, modelling and analysing
> evaluating
> communicating

7.2 The Earth is in the Milky Way

Learning intentions

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

- explain the process of nuclear fusion in stars
- describe the difference between relative magnitude, absolute magnitude and luminosity
- convert distances in light-years to kilometres
- describe the structure of the universe in terms of stars and galaxies.

Key ideas

- Stars are large balls of gas that undergo nuclear fusion.
- Stars that appear brighter are described as having a high apparent magnitude.
- Larger, hotter stars that are further away have a higher absolute magnitude.
- As the Earth rotates, stars appear to move in the sky due to stellar parallax.
- One light-year is the distance light travels in a vacuum in 1 year.

The universe (all existing matter and space) consists of many different galaxies, stars (suns), planets with and without moons, comets, and clouds of dust and gas. Understanding how all these objects evolve and affect each other allows us to understand how our nearest star (the Sun) will continue to change over time.

Galaxies

Our Sun is one of millions of stars that make up the spiral Milky Way galaxy. Our Sun is found on one of the tail ends of the flattened spiral. When you look up at a darkened sky (away from city lights), you should see a white ribbon of stars across one part of the sky. This is because you are looking across the flattened disc of the Milky Way galaxy (Figure 1).

Galaxies come in all shapes and sizes including spiral, elliptical or irregular. The galaxies are constantly moving away from each other. It is thought that the centre of our Milky Way spiral galaxy contains a massive black hole that uses gravity to hold all the other solar systems in orbit. It can take approximately 250 million years for our Sun to orbit the centre of the Milky Way.

light-year
the distance that light travels in one year

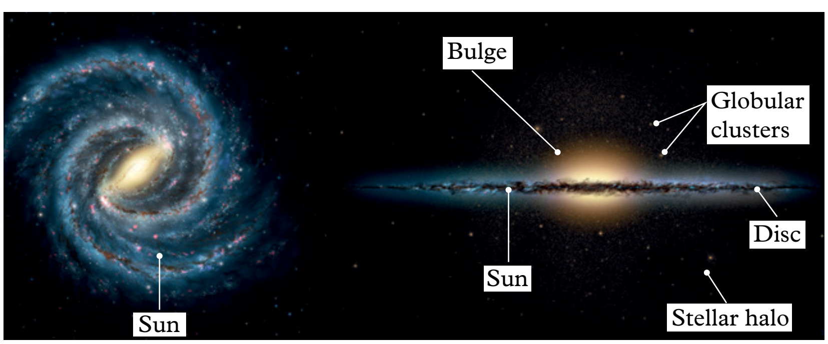


Figure 1 Left: The Earth is located in the spiral galaxy called the Milky Way. Right: When viewed from the side, the galaxy is a disc shape that can be viewed across the night sky on Earth.

The solar system

The Earth is a very small part of a group of planets that orbit the Sun. Our solar system consists of a single star (the Sun) with eight orbiting planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune), five dwarf planets (Eris, Pluto, Ceres, Makemake and Haumea), and many moons, asteroids and comets, all bound together by gravity.

The Earth is a relatively small planet that takes 1 year (365.25 days) to travel approximately 940 million kilometres around the Sun. This path travelled by the Earth is called an orbit. Every 4 years we have a leap year. This adds an extra day in our calendar (February 29) to allow for the accumulation of the extra distance travelled by the Earth each year.

Light-year

The universe that we can observe consists of all the stars, galaxies and other objects that we can see from the Earth – it is enormous. We can only see these objects because light, or another type of signal, from these objects has had time to reach the Earth and we can detect the signal.

Light travels very fast, at 300 000 km/s. The distance that light travels in one year is called a **light-year** (9 500 000 000 000 km). Light-years are used to measure the distance of stars from the Earth.

CHALLENGE

7.2A: Understanding parallax
Go to page **267**.

EXPERIMENT

7.2B: Calculating the distance to the Sun
Go to page **268**.

The nearest star to the Earth is our Sun, which is only 500 light-seconds from the Earth. This means it takes 500 seconds (approximately 8 minutes) for the light from the Sun to reach the Earth. The nearest star in the Southern Cross is Gacrux (88 light-years away from the Earth). The closest star to the Earth is Proxima Centauri, which is 4.2 light-years away. This means if Proxima Centauri was to explode, it would take 4.2 years for the light to reach the Earth and for you to see the explosion!

Worked example 7.2 shows how to use light-years to calculate distance in kilometres.

Stars

A star (including our Sun) is a giant ball of hot glowing gases. Most stars are made almost entirely of hydrogen and helium. These gases are constantly colliding and reacting at the core (centre) of the star. When the atomic nuclei collide and fuse, they release energy to the star through **nuclear fusion**. This energy is emitted as light (and other forms of electromagnetic radiation) and is what we see when we look at the stars at night. Stars can be different sizes, masses, temperature and brightness.

What does a star's brightness mean?

The brightness of a star viewed from the Earth is measured on a scale called the **apparent magnitude scale** – a measure of how bright it appears to be. The Sun is the brightest object in the sky and has an apparent magnitude of –27. In comparison, a full Moon has an apparent magnitude of –13. So, the closer to zero (and the less negative) the number, the dimmer the star.

A star may appear to be quite bright because it is close to the Earth, but it may not actually be very bright (Figure 2). For example, the Sun is not a very bright star compared with other stars, but it is the closest star to the Earth.

The **absolute magnitude scale** measures a star's brightness as if all stars are the same distance from the Earth – its actual brightness or **luminosity**. Therefore, a star may have a higher absolute magnitude but appear less bright because it is a long way from the Earth.

apparent magnitude scale
a scale for measuring the brightness of an object when viewed from Earth

absolute magnitude scale
a scale for measuring the brightness (luminosity) of objects from the same distance

luminosity
the actual brightness of a star (amount of energy it radiates); measured using the absolute magnitude scale

nuclear fusion
a reaction in which two lighter atomic nuclei fuse to form a heavier nucleus, releasing energy

Worked example 7.2: Converting light-years to kilometres

Calculate the distance from Earth, in kilometres, of the Large Magellanic Cloud, which is 180 000 light-years away.

Solution

1 light-year is 9 500 000 000 000 = 9.5×10^{12} km/light-year

$$\begin{aligned}\text{Distance to Large Magellanic Cloud} &= (9.5 \times 10^{12}) \times \text{light-years of Large Magellanic Cloud}\\ &= (9.5 \times 10^{12}) \times (1.8 \times 10^{5})\ \text{km}\\ &= 9.5 \times 1.8 \times 10^{(12+5)}\ \text{km}\\ &= 17.1 \times 10^{17}\ \text{km}\end{aligned}$$

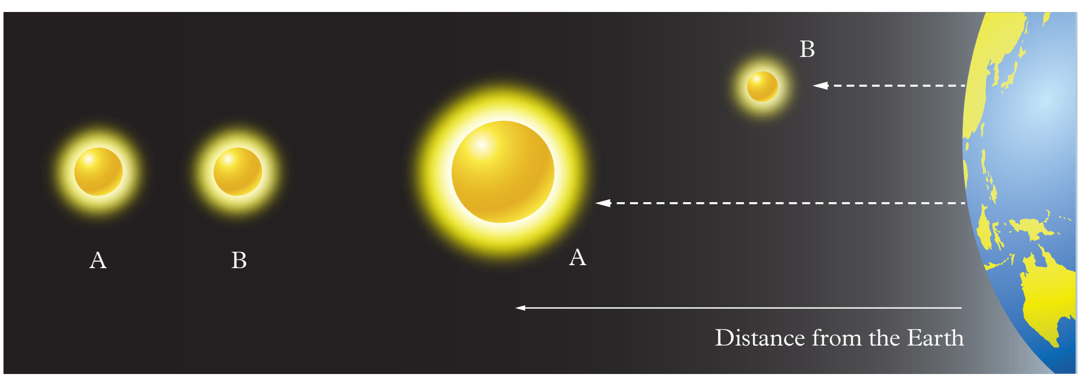


Figure 2 Although both stars A and B have the same apparent magnitude, A is more luminous and has a higher absolute magnitude than B.

In the Southern Cross (Figure 3), Alpha Crucis (Acrux) and Beta Crucis (Mimosa) have the greatest apparent magnitude. Acrux appears brighter because it is two stars that sit close together and are closer to Earth than Mimosa.

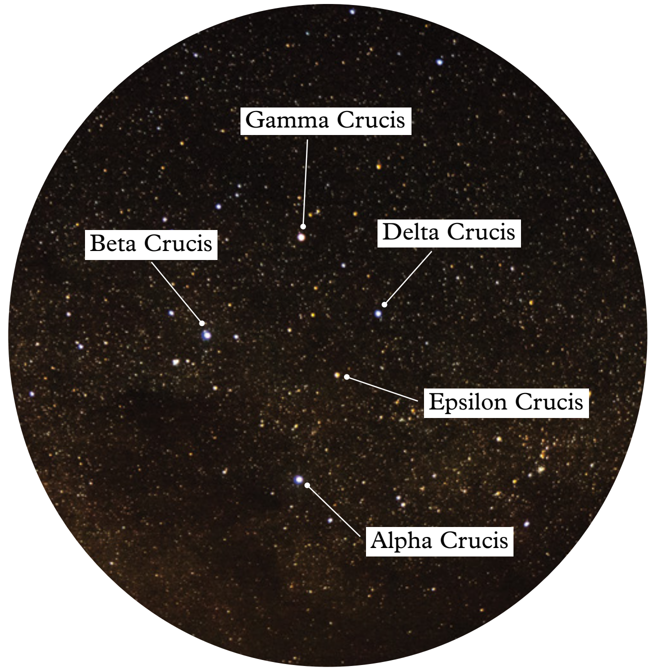


Figure 3 The Southern Cross constellation

What does a star's colour mean?

Another way of comparing stars is to analyse their colour. The colour of a star depends on its surface temperature. Blue stars are the hottest and red stars are the coolest.

A method of displaying star data is a **Hertzsprung–Russell diagram** (Figure 4). This shows a plot of the star's temperature on the *x*-axis and the star's absolute magnitude on the *y*-axis. When plotted this way, most stars, including our Sun, fall into a narrow diagonal band called the main sequence.

Hertzsprung–Russell diagram
a graph displaying star data, with the star's spectral class (temperature) on the *x*-axis and its absolute magnitude (luminosity) on the *y*-axis

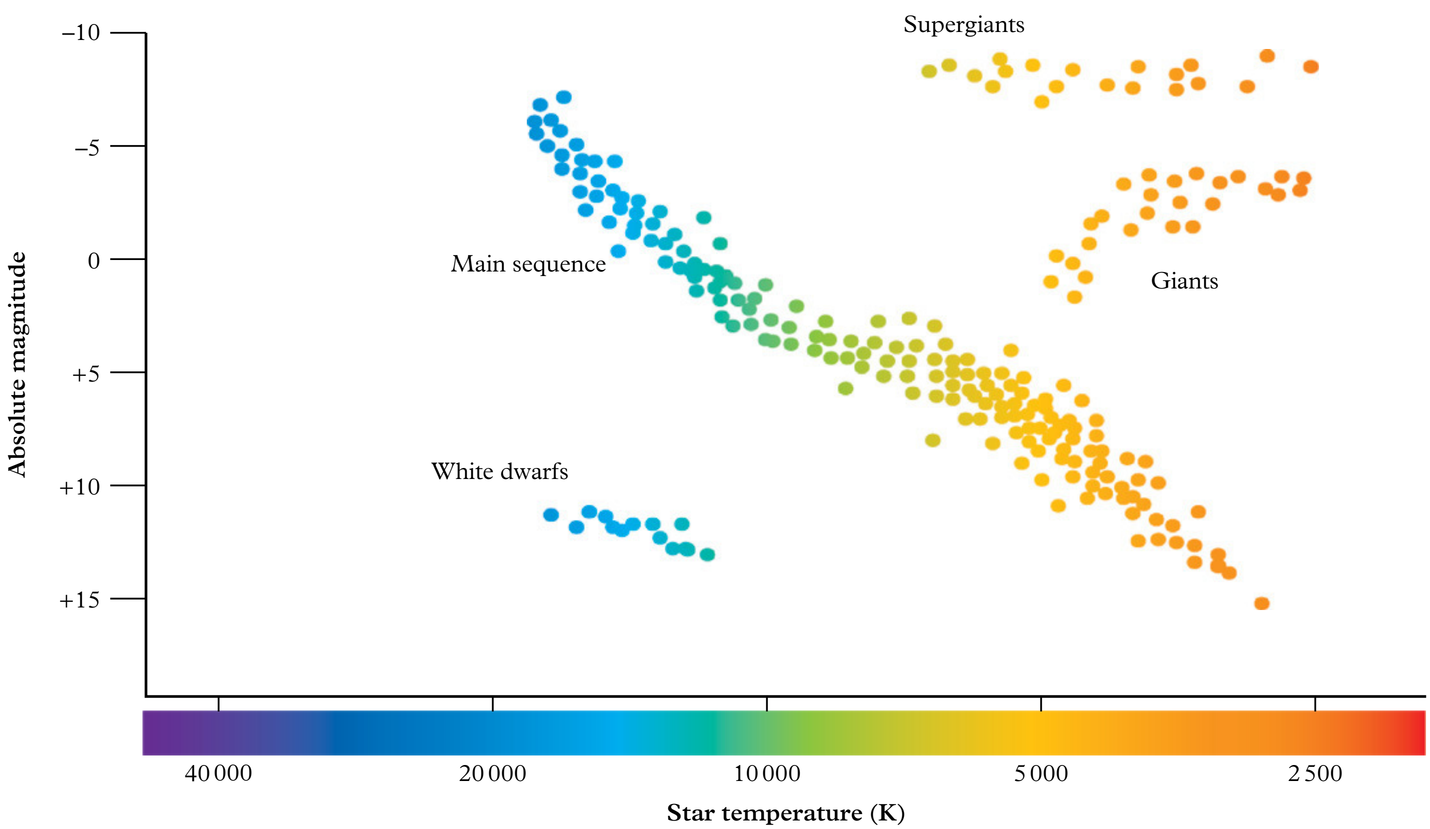


Figure 4 A Hertzsprung–Russell diagram

Stellar parallax

Every night, the stars and planets appear to move across the night sky. During the night we can observe the 'movement' of our Moon through the sky as it rises and, much later, as it sets. All stars 'move' in the sky, although, because they are so far away, their movement is much less noticeable than that of the Moon.

This effect, known as **stellar parallax**, is used by astronomers to calculate the distance to nearby stars (those stars closer than 100 light-years). Beyond this distance, spacecraft are needed to calculate the distance accurately. When a star is observed from two different positions (for example, in January and then six months later in July), its position relative to other stars may appear to be different (Figure 5).

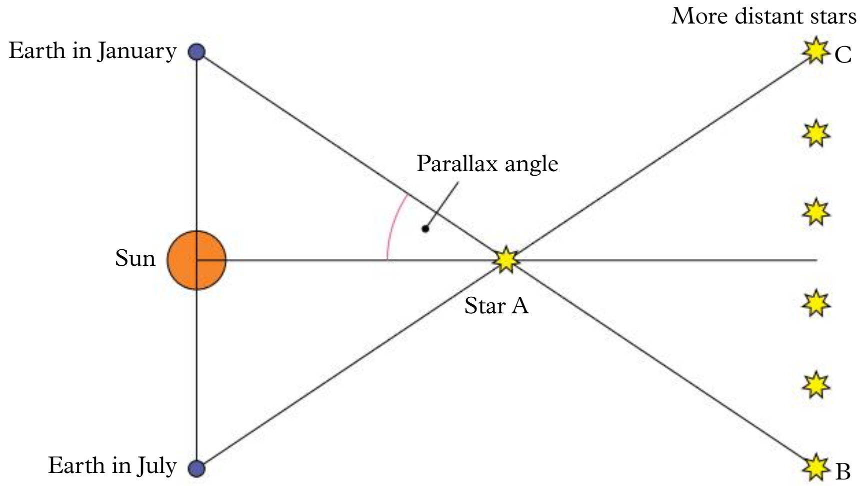


Figure 5 Measuring the distance to stars using stellar parallax. In January, star A, a close star, is in line with a more distant star, star B, but in July it is in line with star C. By measuring the parallax angle and knowing the radius of the Earth's orbit, the distance to star A can be calculated.

Figure 6 An elliptical galaxy

stellar parallax
a change in the apparent position of a star against its background when viewed from two different positions

7.2 Check your learning

Retrieve

1 **Define** the following terms.
   a star
   b galaxy
   c light-year
   d stellar parallax

2 **Recall** the name of the galaxy that contains our solar system.

Comprehend

3 **Explain** the process of nuclear fusion in stars.

4 **Describe** a main sequence star.

5 Draw the Southern Cross constellation and **describe** what you know about the different stars in the constellation.

6 **Explain** why the Milky Way galaxy appears so large in the night sky compared with other galaxies.

Analyse

7 **Compare** absolute magnitude scale and apparent magnitude scale.

8 **Calculate** the distance (in km) to Beta Centauri at 525 light-years away from the Earth.

9 If a star that was 20 light-years away exploded right now, **calculate** when we would see it exploding.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

7.3 Stars have a life cycle

Learning intentions

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

- describe how gravity contributes to the formation of stars and galaxies
- explain how hydrostatic equilibrium is attained in stars
- describe what happens to a star when hydrostatic equilibrium cannot be maintained.

Interactive 7.3
Life cycle of a star

nebula
a cloud of gas and dust in space

hydrostatic equilibrium
in relation to Earth's atmosphere: a state of stability, with upward forces balanced by downward forces

red giant
a star that has become large and bright with a cool surface, because it has run out of hydrogen fuel

Key ideas

- Nebulae are large clouds of gas where stars are born.
- Each star exists in a hydrostatic equilibrium between the gravitational pull to the centre and the release push of energy from nuclear fusion.
- Small stars will cool and die, forming white dwarfs and black dwarfs.
- Large stars explode in novas and supernovas, releasing large amounts of light and energy.

In the constellation of Orion lies a group of stars informally known as the Saucepan. Just above it is a misty patch, just visible to the naked eye. This is M42, or the Orion Nebula, a region of gas and dust in which new stars are just beginning to emit light. It is a stellar nursery, with stars being born all the time. Our own Sun would have been born in a similar region. Throughout the universe, stars are at various stages of their lives. Young, medium, old and dying stars can be found, as well as exploded stars.

Birth of a star

Across the universe are large clouds of hydrogen gas called **nebulae**. Even though these hydrogen atoms are very small, they are attracted to each other by gravity. The more the hydrogen atoms gather together, the greater the attractive force.

Figure 1 This image of Kn 61, a confirmed planetary nebula, was taken by Professor Travis Rector, University of Alaska, Anchorage, using the 8.1 m Gemini Telescope. The nebula appears as a blue bubble, and a bright star and spiral galaxy can also be seen.

The hydrogen atoms in the centre of the cloud are under a great deal of pressure, causing the centre of the gas cloud to heat up. Eventually there is enough heat and pressure to fuse two hydrogen atoms together, forming helium. This nuclear fusion releases large amounts of energy in the form of heat and light. A star is born. You can see a nebula in Figure 1.

Adult stars

The release of energy from the nuclear fusion of hydrogen atoms forces the gas particles out, while the force from gravity pulls the atoms in. These two forces become balanced so that the star stabilises to a consistent size. This balance of forces is called **hydrostatic equilibrium**. A main sequence star can maintain this balance between the forces for millions of years.

Older stars

Eventually the hydrogen available for nuclear fusion starts to decrease. When this occurs, the force from gravity becomes stronger than the force pushing the hydrogen atoms out. The gas particles are pulled closer to the centre of the star, producing even greater pressure (and higher temperatures). Eventually the helium atoms start to fuse, forming carbon atoms. This form of nuclear fusion releases even more energy than hydrogen fusion. The star grows larger as the forces reach a new hydrostatic equilibrium. This cooling and expansion results in the formation of a **red giant** star (Figure 2). Our Sun will do this in about 5 billion years from now. Because of its size, the Sun will swallow up the inner planets of the solar system – Mercury, Venus, Mars and Earth.

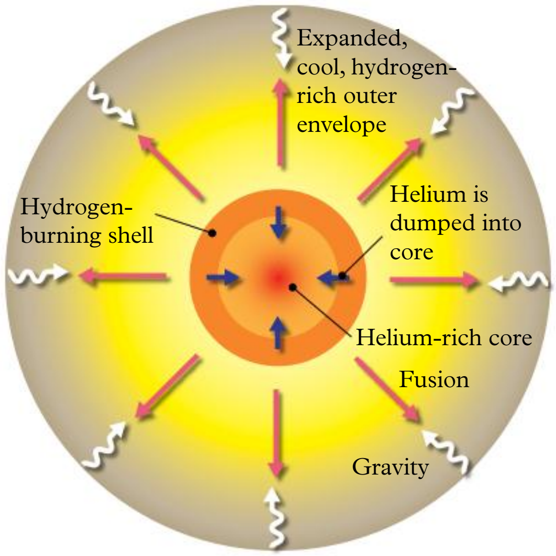


Figure 2 How a red giant star forms

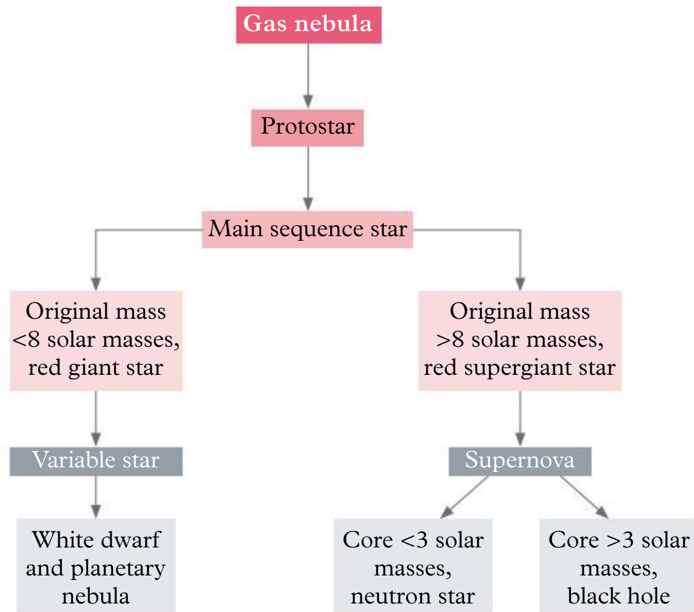


Figure 3 The life cycle of a star

Death of a star

Eventually the amount of helium available decreases as well. As the outer regions of lighter red giants fade away, the shell is called a **planetary nebula**, although it has nothing to do with planets (Figure 3). Only the core remains at the centre. Further nuclear reactions occur, increasing the rate of energy release and therefore the temperature. The core becomes white hot and the star is called a **white dwarf**. As this mass cools, the star gradually fades away to become a **black dwarf**.

Heavier red giants seem to have a different fate. The nuclear fusion process continues through various elements until iron is formed. Eventually, the star runs out of energy for fusion reactions and collapses. This increases the pressure and temperature to extreme levels. The resulting explosion is the largest explosion in the universe – a **supernova**.

After the supernova, the remaining core is amazingly dense and electrons and protons collide to form neutrons, creating a **neutron star**. Neutron stars are only tens of kilometres in diameter and are remarkably dense. A teaspoonful of neutron star material would have the same mass as 100 000 cars!

If a neutron star collapses further, its gravitational pull and density become so huge that not even light can escape. These are **black holes**. As matter falls towards a black hole, X-rays are emitted. This is how possible black holes are detected in space, although their existence is still to be determined absolutely.

planetary nebula
a glowing shell of gas formed when a star dies

white dwarf
a small, hot star that forms when a star (e.g. our Sun) runs out of fuel and slowly fades and cools

black dwarf
a remnant formed when a white dwarf star cools and gradually fades away

supernova
the explosive death of a star

neutron star
a small, highly dense star made mostly of neutrons

black hole
a region in space of infinite density where gravity is so strong that nothing, not even light, can escape from it

7.3 Check your learning

Retrieve

1 **Identify** the event that occurs between gas atoms that marks the birth of a star.

2 **Define** the term 'nebula'.

3 **Identify** what is left after a supernova.

Comprehend

4 **Explain** the forces involved in hydrostatic equilibrium.

5 **Describe** a red giant star.

Analyse

6 **Compare** a white dwarf and a black dwarf.

Apply

7 **Create** a flow chart to show the life cycle of a star the size of our Sun.

8 Our Sun is 1 solar mass. **Predict** what will happen when hydrogen becomes limited in our Sun.

9 Blue stars are much larger than our Sun. However, they do not have enough energy to explode. **Create** a flow chart to show the life cycle of a blue star.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

7.4 The galaxies are moving apart

Learning intentions

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

- explain how absorption and emission spectra are produced by stars and nebulae
- describe how the Doppler effect changes the apparent frequency and wavelength of sound waves
- describe how red and blue shift of galaxies provide evidence of speed and direction of movement.

Key ideas

- Elements absorb light energy in specific wavelengths, creating an absorption spectrum.
- When the same elements return to a stable state, they release the wavelengths of energy as an emission spectrum.
- The Doppler effect describes the change in frequency of a wave as an object moves towards or away from an observer.
- A red shift in the emission or absorption spectrum of a galaxy indicates that the galaxy is moving away from the observer.

Measuring the movement of galaxies

As a star undergoes nuclear fusion, it releases energy in the form of light. This is usually a full spectrum of light containing all the wavelengths and colours possible. The outer layers of gas surrounding the star contain elemental atoms that will absorb specific wavelengths of light energy that correspond to the movement of electrons in shells. When the particular amount of energy is absorbed, it appears as dark lines in the spectrum of light that leaves the star. This is called the **absorption spectrum** of a star because the missing wavelengths of light are absorbed from the spectrum. The set of dark bands in the light spectrum is unique to the element contained in the star (Figure 1a).

Alternatively, if there is a nebula or gas cloud near a star, the elements in the gas will also absorb some of the energy from the star and become excited.

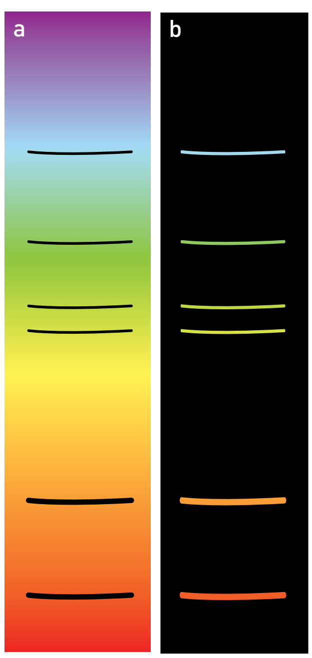


Figure 1 **a** Absorption spectrum and **b** emission spectrum of helium

absorption spectrum
a spectrum with dark bands missing from the pattern, where the element has absorbed characteristic light wavelengths; the opposite of an emission spectrum

emission spectrum
the pattern of wavelengths (or frequencies) that appear as coloured lines in a spectroscope; it is unique to each element

Doppler effect
the apparent change in wavelength (or frequency) when the source of the waves or the observer is moving; responsible for the red shift of distant stars

Eventually the elements will return to their stable state and emit (release) the unique bands of light energy they absorbed. This is called the **emission spectrum** (Figure 1b).

Compare the emission spectrum and the absorption spectrum of helium in Figure 1. The absorption spectrum contains lines in exactly the same positions as in the emission spectrum.

In the 1920s, using the most powerful telescope in the world at the time, Edwin Hubble examined the spectra of light absorbed and emitted by the galaxies.

Absorption spectra can also reveal the velocity of a distant star – which is what Hubble discovered.

Doppler effect

When a racing car zooms past you, the pitch of its sound appears to change. This can be modelled by making a 'yeee … owww' sound with your voice. The 'yeee' is the high pitch from the car's engine as it approaches you – its sound waves are being bunched up as the car speeds in your direction. This causes the lengths between the waves to be shorter, increasing the pitch, or frequency, of the sound. As the racing car passes you, the pitch you hear drops – that's the 'owww' part. The car is now speeding away from you and sending the sound waves back to you, lengthening their wavelength and lowering the pitch. The faster the car goes, the more pronounced the effect.

This is known as the **Doppler effect**, after its discoverer, Christian Doppler. The Doppler effect happens with ambulance and police car sirens, trains, fast noisy objects and light (Figure 2).

CHALLENGE 7.4A: Exploring the Doppler effect
Go to page 269.

EXPERIMENT 7.4B: Investigating emission spectra
Go to page 270.

Red shift, blue shift

When Hubble looked at the absorption spectra of distant galaxies, he saw that the lines were shifted in the red direction of the spectrum. Red light has a long wavelength; blue light, at the other end of the visible spectrum, has a shorter wavelength. A shift in the red direction, known as a **red shift**, indicates that the galaxy is moving away from the Earth (Figure 3). The greater the shift of the emission light bands towards the red spectrum, the faster the galaxy is moving. A shift in the blue direction, a **blue shift**, indicates that the star is moving towards the Earth. The greater the shift towards the blue spectrum, the faster the galaxy is moving.

Edwin Hubble's big discovery was that the more distant galaxies tended to have more red-shifted spectra and, hence, were travelling faster away from the Earth. This discovery became known as Hubble's law and provides compelling evidence for the **Big Bang theory**.

Hubble's law was followed up by a group of scientists including United States–born Australian Brian Schmidt. Their research determined that the expansion of the universe is accelerating. As a result, Brian Schmidt was one of three scientists awarded a Nobel Prize in 2011.

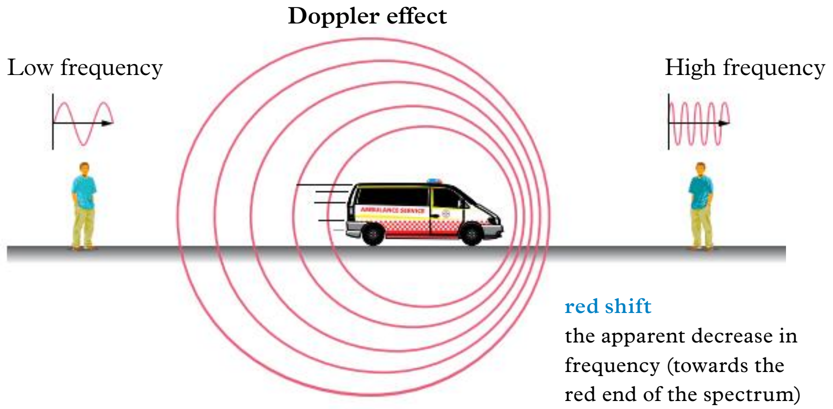


Figure 2 The Doppler effect

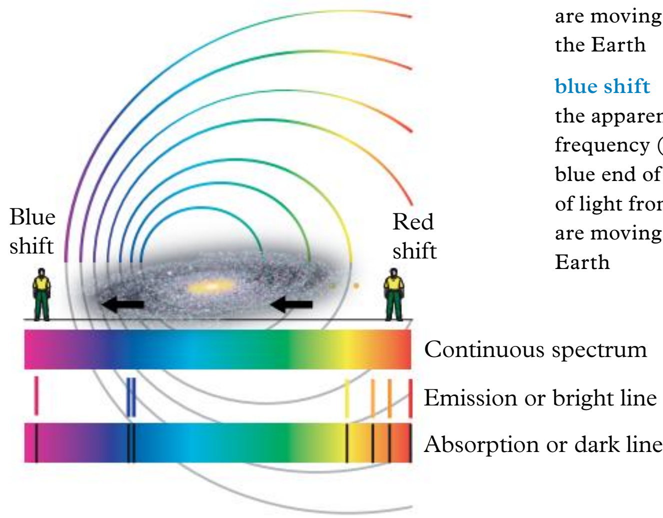


Figure 3 Red shift and blue shift

red shift
the apparent decrease in frequency (towards the red end of the spectrum) of light from galaxies that are moving away from the Earth

blue shift
the apparent increase in frequency (towards the blue end of the spectrum) of light from galaxies that are moving towards the Earth

Big Bang theory
the theory that the universe began as a hot, dense, single point at some time in the past, and since then has expanded and will continue to expand into the future

7.4 Check your learning

Retrieve

1 **Identify** whether a racing car that has a higher pitch than normal (higher frequency) is travelling towards or away from you.

Comprehend

2 **Explain** the Doppler effect.

3 **Describe** how you would identify an absorption spectrum.

4 **Explain** why red-shifted light shows that a galaxy is moving away from the Earth.

Analyse

5 **Compare** the emission spectra and absorption spectra for helium, shown in Figure 1.

6 Figure 4 shows the spectra observed from three stars. Star A is at a fixed distance from the Earth, whereas stars B and C are moving.

a **Explain** what the dark lines on each spectrum represent.

b **Identify** which star, B or C, is moving towards the Earth.

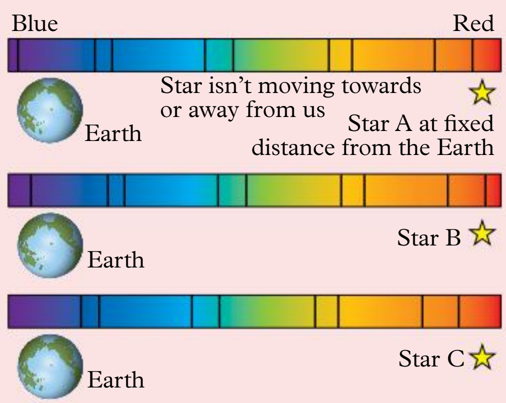


Figure 4 The spectra observed from three stars: A, B and C

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

7.5 Evidence supports the Big Bang theory

Learning intentions

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

- explain how the Big Bang theory provides an explanation for the expansion of the universe from a single point
- describe how cosmic microwave background radiation provides evidence to support the Big Bang theory
- understand that evidence for the Big Bang theory has also been used to estimate the age of the universe.

Key ideas

- The Big Bang is a theory supported by evidence that describes how the universe began.
- The expansion of the universe is continuing to accelerate.

How the universe began has been debated and studied by many scientists. In ancient civilisations, people believed that the Earth was at the centre of the universe. Astronomers today theorise that the universe came into existence from a single, dense hot point called a singularity. From this point, space expanded rapidly and silently – it wasn't really a bang at all. Over time, the universe cooled, and matter (atoms) was formed.

Big Bang theory

The concept of the Big Bang was originally proposed in the 1920s, although it wasn't called this then. In 1929, the US astronomer Edwin Hubble discovered that the spectra of light from galaxies implied that they were moving away from the Earth. Hubble also found one of the most significant results in the history of the origin of the universe: that the further away galaxies were from the Earth, the faster they were moving.

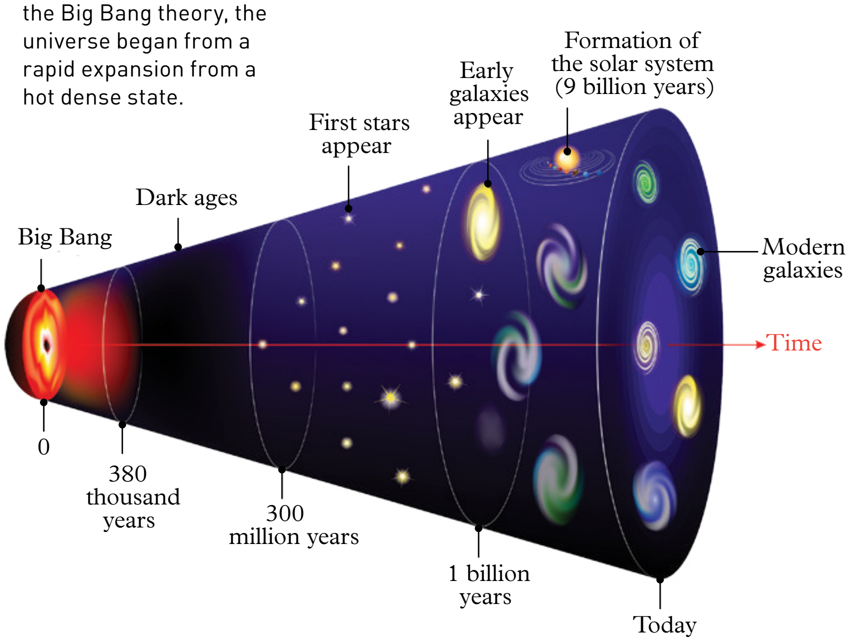


Figure 1 According to the Big Bang theory, the universe began from a rapid expansion from a hot dense state.

The speeds were enormous. In fact, it is not the galaxies themselves that are moving away; rather, space is expanding and taking the galaxies with it (Figure 1).

But what is the universe expanding into? Based on Hubble's observations that the galaxies are racing away from each other, the obvious conclusion is that if you run things in reverse, rewinding the path of all the galaxies, everything must have come from the same spot. This idea led to the development of the Big Bang theory.

This theory starts with an enormous amount of energy that eventually formed the subatomic particles called quarks. These quarks eventually formed protons and neutrons that (3 minutes later) cooled to 1 billion degrees Celsius. This allowed the protons and neutrons to fuse to form the nucleus of hydrogen (and some helium) atoms. Twenty minutes later, the fusion slowed and for approximately 380 000 years the mainly hydrogen nuclei were surrounded by a cloud of electrons. Further cooling allowed the electrons to form shells around the hydrogen nuclei, producing the hydrogen atoms we now know. It is thought to have then taken millions of years for the first hydrogen atoms to start nuclear fusion to form the first star.

As with all science, this theory is supported by many forms of evidence.

Microwave background

The concept of the Big Bang relied on the idea of the existence of some sort of thermal radiation. It was hypothesised that the enormous amounts of heat released as part of the Big Bang would still exist in a much cooler form. In 1965, two US scientists, Arno Penzias and Robert Wilson (Figure 2), found evidence that the leftover energy existed as background radiation.

CHALLENGE

7.5: The expanding universe
Go to page **271**.

Figure 2 Arno Penzias (left) and Robert Wilson (right) in front of their horn antenna, with which they discovered cosmic microwave background radiation.

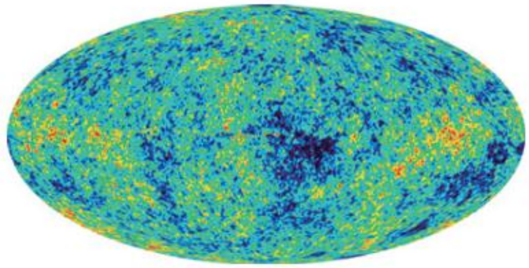


Figure 3 Fluctuations in the cosmic microwave background radiation are shown as temperature fluctuations over the sky. These fluctuations correlate with the formation of nearby matter.

cosmic microwave background radiation remnant electromagnetic radiation left from early stages of the universe

While testing a new, sensitive horn-shaped radio telescope antenna, Penzias and Wilson found a strong background noise that was interfering with transmission. They weren't trying to find it, they just happened to notice it. Being good scientists, they investigated where it came from and why it occurred. They found that this background noise was a form of electromagnetic radiation known as **cosmic microwave background radiation** (Figure 3).

The existence of cosmic microwave background radiation was one of the greatest discoveries of all time. It was so important that Penzias and Wilson were awarded a Nobel Prize in 1978 for their discovery.

Mixtures of elements

As shown by cosmic microwave background radiation, the universe has cooled since the Big Bang. As energy cannot be created or destroyed, the energy must have been converted into elementary matter. The simplest element that could have been made is hydrogen.

The amount of hydrogen (and subsequent heavier elements) formed should be proportional to the amount of energy available. If the energy caused the formation of matter, it would leave cool spots in the universe that are directly related to the mass of elements present. In 1992, the Cosmic Background Explorer (COBE) satellite detected these predicted ripples in temperature fluctuations, which are consistent with the formation of distant galaxies and old stars.

The universe is changing

When we examine distant galaxies, we are also looking back in time. The light from these galaxies takes many years to reach the Earth. As a result, scientists can see old galaxies that developed millions of years before our own Milky Way. Observations of how stars form are consistent with the energy changes predicted by the Big Bang theory.

All these observations have allowed astrophysicists to estimate that the universe is 13.7 billion years old.

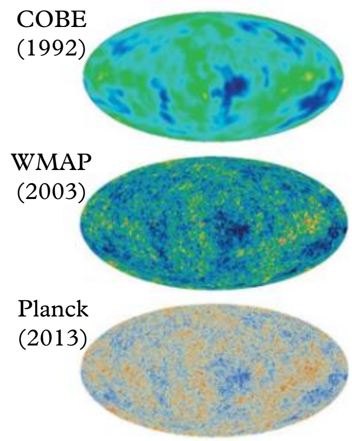


Figure 4 Images from the COBE (Cosmic Background Explorer), WMAP (Wilkinson Microwave Anisotropy Probe) and Planck satellites

7.5 Check your learning

Comprehend

1 **Explain** why the Big Bang was not a bang at all.
2 **Describe** the events that occurred during the Big Bang.
3 **Define** the term 'cosmic microwave background radiation', and **explain** why its existence is important.

Analyse

4 A theory is never final. Evidence is always needed to reinforce a theory. The Planck satellite was designed to examine cosmic microwave background radiation. **Compare** the information provided by the images from the different satellites in Figure 4.

Apply

5 Cosmic microwave background radiation has been called 'ancient whispers'. **Discuss** why this name is appropriate.
6 **Discuss** one other example of evidence that supports the Big Bang theory.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

//SCIENCE AS A HUMAN ENDEAVOUR//

7.6 Technology aids cosmological research

Learning intentions

By the end of this topic, you will be able to:
- explain what the ASKAP radio telescope is and what research it can be used for
- explain what the Event Horizon Telescope is and describe what it captures.

As technology continues to advance, our ability to map and view the universe continues to improve. The improvement and development of supercomputers, radio telescopes and observatory facilities have led to the identification and imaging of new black holes and galaxies.

ASKAP

The ASKAP radio telescope is situated at the Inyarrimanha Ilgari Bundara, CSIRO Murchison Radio-astronomy Observatory in Western Australia. ASKAP consists of 36 large (12-metre wide) antenna dishes that work together as a single telescope. The apex of each ASKAP antenna is attached with a phased array feed (PAF). The PAF acts as a 'radio camera' and can detect radio waves millions of light years away from Earth. Each PAF provides the ASKAP telescope with a large field of view to survey and detect millions of new distant galaxies and black holes.

Data from ASKAP is generated at a rate of 100 trillion bits per second. This data is processed by supercomputing facilities in Perth's Pawsey Supercomputing Research Centre. Once processed the data can be used to create optical images we can view. In 2020, ASKAP's surveying capabilities were tested and resulted in ASKAP mapping 3 million galaxies in 300 hours.

Figure 1 Three ASKAP telescopes are trained towards the sky east of Geraldton.

One million of the galaxies mapped by ASKAP during this test had never been seen before. Australia's new supercomputer 'Setonix' has incredible imaging capacity and is able to produce the likes of highly detailed supernova remnants as shown in Figure 3.

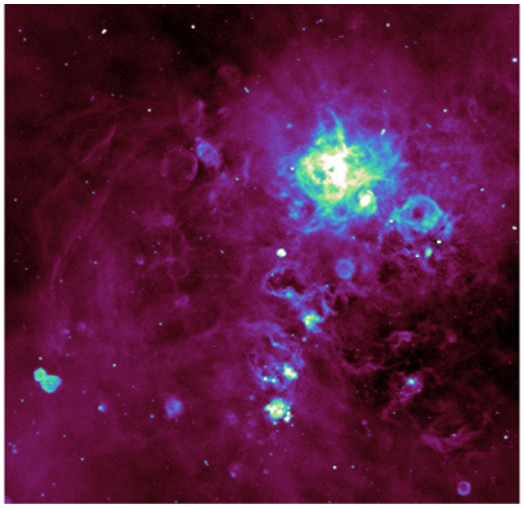


Figure 2 Image of the Large Magellanic Cloud, a galaxy neighbouring the Milky Way, created from ASKAP data

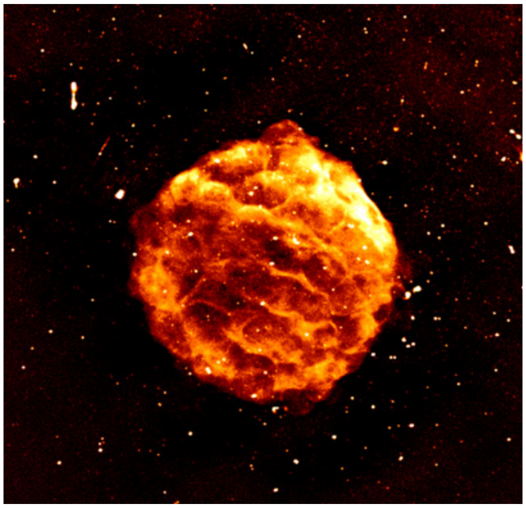


Figure 3 Image of a remnant supernova produced by Setonix processing of ASKAP data

Event Horizon Telescope

Black holes are regions in space where gravitational pull and density are so great that nothing, including light, can escape from them. The surface or 'edge' of a black hole is called its **event horizon**. The event horizon is the boundary where velocity needed to escape the gravitational pull of the black hole is greater than the speed of light. Einstein's theory of special relativity states that nothing can travel faster than the speed of light. This essentially means that the event horizon is a 'point of no return'.

The Event Horizon Telescope (EHT) is a collection of radio telescopes from around the world that work together to image the emissions produced by supermassive black holes. The EHT is a collaborative project that uses radio telescopes from observatories in Europe, North America, South America, Hawaii, and Antarctica. These telescopes all work to detect a specific target, and data from each telescope is transferred onto hard drives and sent to the MIT Haystack Observatory in the USA and the Max Planck Institute for Radioastronomy in Germany. Once the data is processed it can be transferred into an image.

In 2019, the EHT produced the first confirmed image of the supermassive black hole M87. The mass of the M87 black hole is approximately 6.5 billion times that of the Earth's Sun. In 2022, the EHT released the first image of the black hole Sagittarius A (Sgr A), a supermassive black hole located at the centre of our own galaxy the Milky Way.

event horizon
the boundary around a black hole at which no light or matter can escape

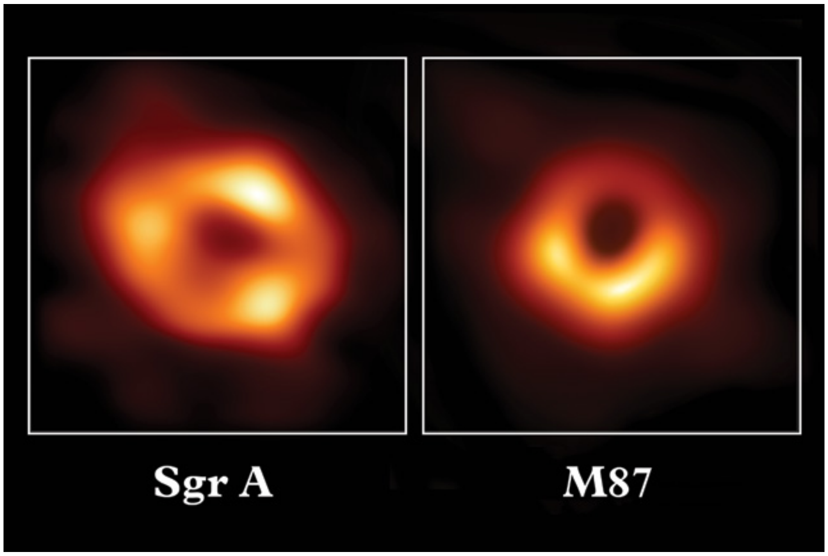


Figure 4 Images of the black holes Sgr A and M87 produced from EHT data

7.6 Test your skills and capabilities

Communicating science ideas

1 **Investigate** the Square Kilometre Array, a project that ASKAP is part of. Use the following questions to guide your investigation.
   > Why was ASKAP built in Murchison, Western Australia?
   > What benefits are there in having so many countries involved with the ASKAP?
   > Other than astronomers, what other researchers work on the ASKAP program?
   > Why are super computers needed to interpret the data from ASKAP?
   > What are the researchers using ASKAP hoping to find?

2 Use your research to write a media release for the public. **Decide** who is the intended audience and what media you will use to reach them. **Consider** their level of scientific knowledge when determining the style of language and illustrations you will use to **describe** the Square Kilometre Array.

CHAPTER 7 REVIEW

THE UNIVERSE

Retrieve

1 **Identify** the shape of the galaxy in Figure 1.
- **A** oblong
- **B** elliptical
- **C** regular
- **D** cubic

Figure 1 The Andromeda galaxy

2 **Recall** which of the following makes up nebulae clouds.
- **A** helium
- **B** oxygen
- **C** lithium
- **D** hydrogen

3 A light-year is:
- **A** the same as stellar parallax
- **B** the range of colours we see
- **C** the distance light travels in 1 year
- **D** the apparent change in wavelength when the source of the wave or the observer is moving.

4 **Define** the term 'event horizon'.

5 **Identify** the correct definition for each of the terms in Table 1.

Table 1 Terms and definitions

Term	Definition
Sun	Groups of stars that are close together in the sky
Galaxy	Theory of the creation of the universe in a huge explosion-like event
Star chart	Everything that exists in space
Constellation	Huge collection of stars held together by gravity
Universe	Map used to locate and identify objects in the night sky
Big Bang	Our closest star

6 **List** the following in order of size from largest to smallest: neutron star, the Sun, white dwarf, red giant.

Comprehend

7 **Describe** the Doppler effect

8 **Describe** why scientists Penzias and Wilson won the Nobel Prize.

9 **Explain** why the ASKAP is an important tool for astronomers.

10 **Describe** the evidence that supports the Big Bang theory.

11 **Explain** why light-years are used instead of kilometres as a unit of distance in space.

12 **Explain** why it is difficult to judge the distance of a star by measuring only its brightness.

13 **Explain** how the night sky enables us to look back in time.

14 **Explain** the link between Hubble's observations and the Doppler effect.

15 **Explain** why you cannot see stars (apart from the Sun) during the day.

16 **Explain** why we do not use light-years for measuring distances within our solar system.

Analyse

17 **Compare** a white dwarf and a red giant.

18 **Contrast** the emission spectra and absorption spectra of an element.

19 **Compare** red shift and blue shift.

20 If the Sun is 149 600 000 km from the Earth and light travels at 300 000 km/s, **calculate** how long it takes for light to reach us from the Sun. Express your answer in minutes.

Figure 2 The Sun

21 **Calculate** the distance (in kilometres) between the Earth and each of these celestial objects.
a Altair star at 16.7 light-years
b Coalsack Nebula at 600 light-years
c Jewel Box star cluster at 7600 light-years

22 If the speed of light is 300 000 km/s, **calculate** the distance light travels in:
a 1 second
b 1 minute
c 1 hour
d 1 day.

Apply

23 **Create** a diagram to **explain** why different stars are visible from different places on the Earth's surface.

24 a **Describe** how the pitch of an ambulance siren changes as it races past you.
b **Explain** why this change occurs.
c **Identify** if the driver of the ambulance could hear this change. **Justify** your answer (by describing the Doppler effect, explaining how it would affect people in front of and behind the ambulance, and deciding if this will affect the sounds the driver hears).

25 **Identify** whether the following statements are true or false. **Justify** each answer.
a All stars are yellow and very hot.
b All galaxies are the same shape and size.
c The brightness of a star when viewed from the Earth is its absolute magnitude.
d Bigger stars are usually hotter, brighter and burn for longer than smaller stars.

26 Many cultures, including those of First Nations peoples, have beliefs about the origin of constellations based on observations. These observations are used for cultural and farming practices. **Investigate** First Nations peoples' beliefs about constellations and how these were and are used. **Discuss** how these observations still influence how we view and understand the constellations today.

Social and ethical thinking

27 On 27 September 2007, the space probe Dawn was launched from Cape Canaveral at a cost of US$357 million, excluding the cost of the rocket (Figure 3). Dawn's journey includes exploration of the asteroid Vesta (in 2011) and the dwarf planet Ceres, between Mars and Jupiter (in 2015). **Investigate** and **describe** the information gathered by Dawn. **Describe** how this information improved our understanding of celestial bodies. Use ethical reasoning to **compare** the cost of this mission and how the money could be spent on Earth.

Figure 3 The Dawn space probe is on an interplanetary cruise.

28 Watch the movie *Interstellar* and **investigate** how the discovery of gravitational waves would help us understand the nature of the dark energy that is causing the universe's expansion to accelerate. Have a class discussion about this.

Critical and creative thinking

29 **Create** an animation or comic strip explaining the Big Bang for Year 10 students who have not yet studied this unit. Include a simple explanation of all the evidence that supports this theory.

30 View a space movie or television series. **Describe** its plot. **Create** a poster identifying the things in the movie that are scientifically correct and the things that are not.

Research

31 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

» Dark matter

Vera Rubin studied the way galaxies rotated in the 1970s and discovered that there was extra matter in the universe that is invisible. This is now called dark matter.

» Compare ordinary matter and dark matter.

» Describe the evidence that supports Vera Rubin's hypothesis of the existence of dark matter.

» Describe the composition of dark matter.

» Scientists believe that the universe started from the Big Bang and that it will expand before gravitational forces pull it back in to start the entire process all over again. Describe the effect dark matter has on the future of our universe.

Figure 4 Vera Rubin operating a telescope at Kitt Peak Observatory

» Ion propulsion

The engines on some spacecraft use a unique, hyper-efficient system called ion propulsion.

» Define the term 'ion'.

» Evaluate if such an engine could lift a spaceship from the Earth's surface.

» Identify the fuel used in these engines. Explain how this fuel produces thrust.

» Explain why large solar collectors are necessary.

» Describe the thrust produced by the engines.

Figure 5 Ion propulsion system in development by NASA

» Gravitational waves

Einstein's theory of general relativity predicted that gravitational waves would occur in space-time when massive objects such as black holes and neutron stars collided.

» Explain what gravitational waves are.

» Describe the evidence that supports the existence of gravitational waves.

» Explain why this evidence was not discovered until 100 years after Einstein's prediction.

Figure 6 Laser Interferometer Gravitational-Wave Observatory (LIGO) gravitational wave detector in Louisiana, USA. LIGO first detected gravitational waves from the collision of two black holes in 2015.

» Exoplanets

Australian scientist Penny Sackett has led teams of scientists in searching for exoplanets similar to Earth.

» Define the term 'exoplanet'.

» Describe how astronomers search for them.

» Explain why the existence of these planets may be important.

» Describe the conditions that would be needed on an exoplanet for humans to survive.

Figure 7 Astrophysicist Penny Sackett

Chapter checklist

Now that you have completed this chapter, reflect on your ability to do the following.

	I can do this.	I cannot do this yet.
• Describe the significance of astronomy to the culture, spirituality and calendars of First Nations peoples, which date back thousands of years. • Identify some stars and constellations in the night sky.	☐	☐ Go back to Topic 7.1 'Science as a human endeavour: The universe was studied by First Nations peoples'. Page 168
• Explain the process of nuclear fusion in stars. • Describe the difference between relative magnitude, absolute magnitude and luminosity. • Convert distances in light-years to kilometres. • Describe the structure of the universe in terms of stars and galaxies.	☐	☐ Go back to Topic 7.2 'The Earth is in the Milky Way'. Page 170
• Describe how gravity contributes to the formation of stars and galaxies. • Explain how hydrostatic equilibrium is attained in stars. • Describe what happens to a star when hydrostatic equilibrium cannot be maintained.	☐	☐ Go back to Topic 7.3 'Stars have a life cycle'. Page 174
• Explain how absorption and emission spectra are produced by stars and nebulae. • Describe how the Doppler effect changes the apparent frequency and wavelength of sound waves. • Describe how red and blue shift of galaxies provide evidence of speed and direction of movement.	☐	☐ Go back to Topic 7.4 'The galaxies are moving apart'. Page 176
• Explain how the Big Bang theory provides an explanation for the expansion of the universe from a single point. • Describe how cosmic microwave background radiation provides evidence to support the Big Bang theory. • Understand that evidence for the Big Bang theory has also been used to estimate the age of the universe.	☐	☐ Go back to Topic 7.5 'Evidence supports the Big Bang theory'. Page 178
• Explain what the ASKAP radio telescope is and what research it can be used for. • Explain what the Event Horizon Telescope is and describe what it captures.	☐	☐ Go back to Topic 7.6 'Science as a human endeavour: Technology aids cosmological research'. Page 180

Check your Student obook pro for these digital resources and more:

Quizlet
Play a Quizlet game to test your knowledge.

Chapter quiz
Check your understanding of this chapter with the chapter review quiz.

CHAPTER

8

MOTION

8.1 Displacement is change in position with direction

> Explain the difference between distance and displacement using appropriate examples.

> Plot and interpret displacement–time graphs for linear motion.

8.2 Velocity is speed with direction

> Explain the difference between speed and velocity using appropriate examples.

> Determine the speed/velocity of an object from the gradient of a displacement–time graph.

8.3 Acceleration is change in velocity over time

> Calculate acceleration from the velocity at two points in time.

> Manipulate the formula $a = \frac{(v - u)}{\Delta t}$ to determine the unknown variable: initial velocity, final velocity, acceleration or time.

> Determine the velocity of an object from the gradient of velocity–time graphs.

8.4

An object in motion remains in motion until a net unbalanced force acts on it

- Describe how unbalanced forces cause a change in the velocity of an object.
- State Newton's first law of motion (inertia) and explain this law using appropriate examples.

8.5

Net force equals mass × acceleration

- Describe how unbalanced forces acting on an object can cause it to accelerate or decelerate using appropriate examples.
- State Newton's second law of motion and explain this law using appropriate examples.
- Manipulate the formula $F_{net} = ma$ appropriately to determine the unknown variable: net force, mass or acceleration.

8.6

Each action has an equal and opposite reaction

- State Newton's third law of motion and explain this law using appropriate examples of action–reaction pairs.
- Understand that action and reaction pairs always act on different objects.

8.7

Momentum is conserved in a collision

- Manipulate the formula $p = mv$ appropriately to determine the unknown variable: momentum, mass or velocity.
- State the law of conservation of momentum and explain this law using appropriate examples.

8.8

Science as a human endeavour: Understanding motion improves vehicle safety

- Explain how safety features of modern vehicles limit the force experienced by drivers and passengers when accidents occur.

What if?

Speeding cars

What you need:

Stopwatches, trundle wheel

What to do:

CAUTION! Do not distract drivers in any way during this activity because this could have serious consequences. Always remain on the footpath at a safe distance from the road.

1. Working in a group of three or four, find a straight stretch of road near your school and set up a 'speed trap'. Measure a distance along the side of the road and, using a stopwatch, time the motion of vehicles over that distance.
2. You will need one person to stand at the start of the distance and wave to the others as each car passes them to indicate to the people in your group to start their stopwatches.
3. From your times and distance, work out the average speed of the vehicles in metres per second and then in kilometres per hour. Decide if any of the vehicles were speeding.

What if?

» What if you compared your results to that of a police speed gun? (Would they be the same?)

8.1 Displacement is change in position with direction

Learning intentions

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

- explain the difference between distance and displacement using appropriate examples
- plot and interpret displacement–time graphs for linear motion.

Key ideas

- Distance describes how far an object has travelled.
- Displacement describes the final distance and direction of an object from its starting point.
- Displacement is a vector quantity because it has position and direction.

distance
the length of the path travelled by an object

displacement
the change of position of a moving object in a particular direction

scalar
having only magnitude (a numeric quantity)

magnitude
the size or extent of something

vector
having magnitude and direction

Distance and displacement

During a normal day, you may cover a considerable distance – on the way to school, on the way home and around school from classroom to classroom. However, at the end of the day you will most likely end up in exactly the same place as where you started – your bed! So, you could say that you haven't really gone anywhere at all.

Distance is how far an object travels. The distance you moved during the day could be large or small. **Displacement** describes the difference between the starting position and the finishing position, including direction. It does not include all the in-between movements. If you end up back in bed after a whole day of moving, then your daily displacement is zero. For distance we use the symbol *d*, and for displacement we use the symbol *s*. The standard unit (or SI unit) for both is the metre (m).

Distance is known as a **scalar** quantity because it only has size (or **magnitude**) and no direction. Displacement is known as a **vector** quantity because it has size and direction. The direction can be a compass direction (north, south, east or west) or a bearing, or it may be as simple as left, right, up, down, forwards or backwards.

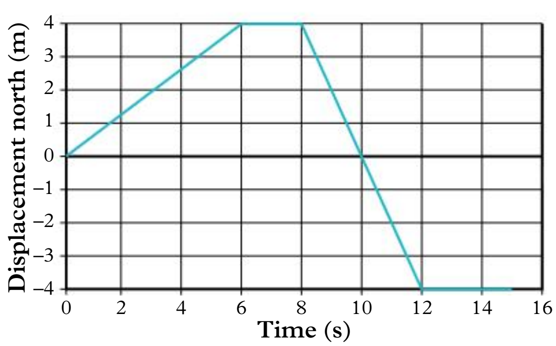


Figure 1 This displacement–time graph shows the position of a person walking north from the starting point for 6 seconds, stopping for 2 seconds and then walking south for 4 seconds. Their final position is 4 m south of the starting point.

Displacement–time graphs

Have you ever seen a movie or read a book where a cryptic code is used to find the buried treasure or precious artefact? These codes often contain instructions such as 'walk 15 paces south and then 20 paces west', which could lead to a very different outcome depending on how big, or small, your steps are.

Motion graphs are a model or visual representation of a movement and can take many forms. The simplest is a displacement–time graph. A displacement–time graph is a picture of the motion of an object. Displacement–time graphs are really only useful when the motion is linear; that is, in the same line, such as north–south or east–west or up–down. Time is always on the *x*-axis and displacement is always on the *y*-axis (Figure 1). Always remember to mark the units (e.g. seconds, metres) on the graph. Worked example 8.1A shows how to calculate distance and displacement over time.

Distance and displacement diagrams

The distance an object travels can also be represented by diagrams. Distance and displacement diagrams (as opposed to graphs) are most useful when the movement changes from linear to two dimensions. We can use arrows to show the directions and a scale to show the distances. North commonly points towards the top of the page. For example, Figure 2 shows a diagram of a person walking 5 m north, then 4 m west and then 2 m south. This gives a total distance covered of 11 m. However, this is not their displacement. Their displacement only compares where they finish to where they started. Worked example 8.1B shows how to calculate distance and displacement using direction.

CHALLENGE
8.1: Bringing graphs to life
Go to page 272.

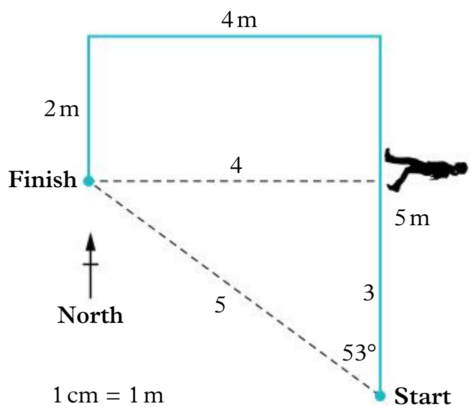


Figure 2 This person walks a total of 11 m. The displacement can be calculated by drawing a right-angle triangle and using Pythagoras' theorem. The final position of the person is 5 m north, 53° west or 5 m on a bearing of 307°.

Worked example 8.1A: Calculating distance and displacement over time

The displacement–time graph shown in Figure 1 shows the movements of a person over 15 seconds.

a Calculate the distance they travelled.

b Calculate the displacement of the person.

Solution

a The person walked away from the starting point (north) for 4 m, stopped for 2 seconds and then walked faster back and past the starting point (south) for 8 m (4 m back and then 4 m further south).

Their total distance travelled (sum of all values) = 4 + 8 = 12 m.

b The total displacement is the distance and direction from their starting point.

Their displacement = 4 m south of the starting point.

Worked example 8.1B: Calculating distance and displacement using direction

A person walks 5 m north, 4 m west and then 2 m south.

a Calculate the distance travelled by the person.

b Calculate the displacement of the person from their starting point.

Solution

a The total distance travelled by the person can be calculated by adding all the distances together.

5 + 4 + 2 = 11 m

b The displacement of the person must include the distance from their starting point and the direction (Figure 2).

The distance can be determined using Pythagoras' theorem: $c^2 = a^2 + b^2$ where c is the (long) hypotenuse, and a and b are the sides on each side of the right angle.

$a = 3\text{ m}, b = 4\text{ m}, c = ?$

$c^2 = 3^2 + 4^2$

$= 9 + 16$

$= 25\text{ m}$

$c = \sqrt{25}$

$= 5\text{ m}$

The angle can be determined by using sine, cosine or tangent.

$$\cos\theta = \frac{\text{adjacent length}}{\text{hypotenuse length}}$$

$$\cos\theta = \frac{3}{5}$$

$\theta = 53°$

The displacement of the person is 5 m north, 53° west (an angle of 53 degrees in the west direction of the north/upwards line).

8.1 Check your learning

Comprehend

1 **Describe** a motion that has zero displacement.

2 A car starts from rest (stationary) and moves north at a constant rate for 400 m, then stops for 10 seconds before moving north another 150 m. On a piece of paper, **represent** this movement as a displacement–time graph.

Analyse

3 **Compare** displacement and distance.

4 **Compare** a vector quantity and a scalar quantity.

5 An object moves 14 m north and then 14 m south. **Calculate** the distance that it has covered. **Calculate** its displacement.

6 A person runs 50 m north, then 20 m south and then 30 m west. **Calculate** the total distance covered. **Calculate** the person's displacement.

7 **Consider** the graph in Figure 3.

a **Describe** the motion shown.

b **Calculate** the distance covered in the graph.

c **Calculate** the displacement shown.

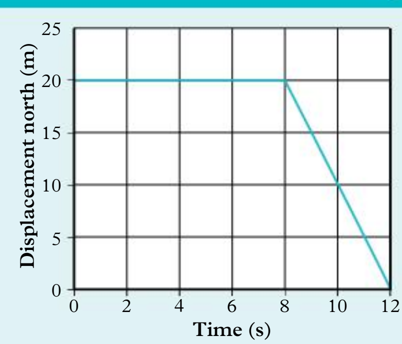


Figure 3 A displacement–time graph

Quiz me

Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

8.2 Velocity is speed with direction

Learning intentions

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

- explain the difference between speed and velocity using appropriate examples
- determine the speed/velocity of an object from the gradient of a displacement–time graph.

Key ideas

- Speed is a scalar quantity that measures the distance travelled in a set time.
- The average speed can be determined by dividing the distance travelled by the total time taken.
- Velocity is a vector quantity and it measures the change in displacement over time.

Video 8.2 How to work out velocity

Figure 1 The cheetah is the fastest land animal. It can reach speeds of up to 112 km/h.

speed
the distance travelled per unit of time

velocity
the vector quantity that measures speed in a particular direction

Speed

Speed is a measure of how fast a car, person or moving object is travelling. It is measured in SI units of metres per second (m/s or m s^{-1}), although kilometres per hour (km/h or km h^{-1}) is often used instead, especially for cars and planes.

Speed is defined as the distance travelled per unit of time. A speed of 5 m/s, for instance, means the object travels 5 m in every second of its motion. Speed is a scalar quantity because it only has size and no direction.

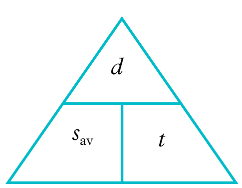
Average speed

Often it is more convenient to work out (or calculate) an object's average speed. To calculate average speed (s_{av}), divide the total distance travelled (d) by the total time taken (t). The units for speed depend on the units of distance and time. The formula for calculating the average speed is:

$$\text{Average speed} = \frac{\text{total distance travelled}}{\text{total time taken}}$$

This rule, or formula, can also be expressed in a triangle, as shown in Figure 2. The triangle is a good memory tool to help you work out three formulas from the one diagram. Worked example 8.2A shows an example calculation.

Average speed can also be determined by the gradient (or slope) of a displacement–time graph (Figure 3).



$$s_{av} = \frac{d}{t}$$

$$t = \frac{d}{s_{av}}$$

$$d = s_{av} \times t$$

Figure 2 The average speed triangle is used to work out the formula for average speed. Cover the quantity you want to calculate with your finger and the other two quantities will form the formula.

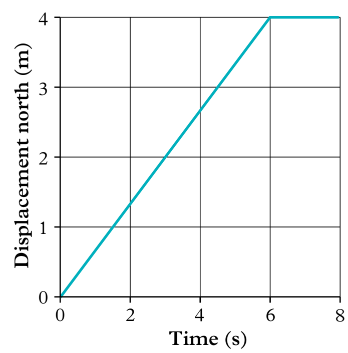


Figure 3 The speed of the object in this displacement–time graph can be calculated by determining the gradient of the graph.

Worked example 8.2A: Calculating distance using speed

Calculate the distance travelled by an object moving at an average speed of 5 m/s for 1.5 seconds.

Solution

Use the triangle in Figure 2 to determine the formula for distance travelled.

$$\begin{aligned} \text{Distance travelled } (d) &= s_{av} \times t \\ &= 5\,\text{m/s} \times 1.5\,\text{s} \\ &= 7.5\,\text{m} \end{aligned}$$

Instantaneous speed

Over the course of a bus or car trip, your speed changes. When you start moving, your speed increases as you accelerate. Over time, you may reach a constant speed where there is no change. As you become close to your final destination, your speed will decrease. The speedometer in the vehicle gives the instantaneous speed in km/h. This is the speed at each moment of the trip.

EXPERIMENT

8.2A: The ticker timer
Go to page **273**.

EXPERIMENT

8.2B: Using a motion sensor
Go to page **274**.

Velocity

Pilots and sailors need to know both the speed of the wind and its direction. **Velocity** (v) is speed in a particular direction and is therefore a vector quantity (a measurement of both size and direction). It has the same unit as speed (m/s). The average velocity of an object (v_{av}) is calculated in a similar way to average speed, but displacement is used instead of distance (Figure 4).

$$\text{Average velocity } (v_{av}) = \frac{\text{displacement}}{\text{time}}$$

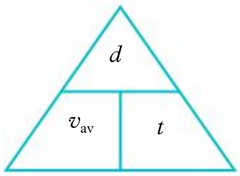


Figure 4 The average velocity triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

The direction of the average velocity is the same as the direction of the displacement. Like speed, average velocity can be determined from the gradient of a displacement–time graph, but the nature of the gradient indicates the direction. For example, if the gradient is a straight line and positive on a displacement–time graph, the velocity is constant or unchanging in the positive direction. If the gradient on a displacement–time graph is zero or flat, then the object is not moving and the velocity is zero. If the gradient is sloping downwards, then the velocity is constant and moving in the negative direction. Worked example 8.2B shows how to calculate the displacement of the object.

Graphing speed and velocity

It is useful to graph either speed or velocity on a graph. As velocity is a vector quantity (with direction) the graph can show a negative velocity when an object moves in the opposite direction. Speed–time graphs do not show negative numbers. In speed–time graphs speed is plotted on the y-axis and time on the x-axis. If the graph slopes upwards, then the object is speeding up (accelerating). If the gradient is negative (sloping downwards) towards the x-axis, then the velocity is decreasing (slowing down) until it reaches 0 m/s. In velocity–time graphs, if the graph slopes below the x-axis, then the object is speeding up in the southerly direction. The area under the graph determines the distance travelled in that time.

Worked example 8.2B: Calculating displacement

Calculate the total displacement of the object in Figure 5.

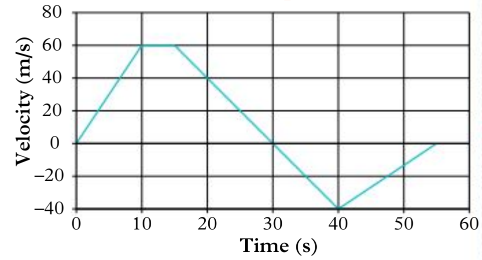


Figure 5 This velocity–time graph shows an object with changing velocity.

Solution

The area under the graph describes the displacement of the object.

The graph needs to be broken into different sections so that the area under the graph can be calculated.

- 0–10 seconds (triangle): The object increased speed or accelerated.

  Area (0–10 s) $= \frac{1}{2} \times$ base $\times$ height $= 0.5 \times 10 \times 60 = 300$ m
- 10–15 seconds (rectangle): The object kept the same speed.

  Area (10–15 s) = base $\times$ height $= 5 \times 60 = 300$ m
- 15–30 seconds (triangle): The object slowed to a stop.

  Area (15–30 s) $= \frac{1}{2} \times$ base $\times$ height $= 0.5 \times 15 \times 60 = 450$ m

  Total displacement in the positive (north) direction = 300 + 300 + 450 = 1050 m
- 30–40 seconds (triangle): The object increased speed in the negative (south) direction.

  Area (30–40 s) $= \frac{1}{2} \times$ base $\times$ height $= 0.5 \times 10 \times -40 = -200$ m
- 40–55 seconds (triangle): The object decreased speed in the negative (south) direction.

  Area (40–55 s) $= \frac{1}{2} \times$ base $\times$ height $= 0.5 \times 15 \times -40 = -300$ m

  Total displacement in the negative (south) direction = 200 + 300 = 500 m

Therefore, total displacement = 1050 m north – 500 m south = 550 m north.

8.2 Check your learning

Comprehend

1 **Describe** what the area under a velocity–time graph indicates.

Analyse

2 Use the average velocity triangle to **represent** the three different formulas.

3 **Calculate** the value of 80 km/h in metres per second.

Apply

4 **Identify** 4 m/s as a speed or a velocity. **Justify** your answer (by defining both speed and velocity, and comparing the definition to your decision).

5 a **Create** a story that describes the motion of a person moving according to the graph in Figure 6.

b **Calculate** their displacement from the point of origin.

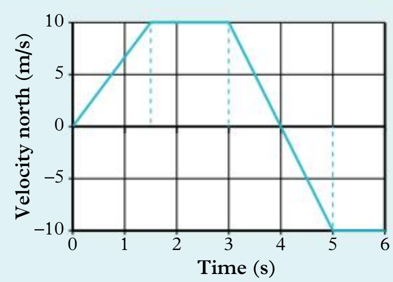


Figure 6 A velocity–time graph

Quiz me

Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

8.3 Acceleration is change in velocity over time

Learning intentions

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

- calculate acceleration from the velocity at two points in time
- manipulate the formula, $a = \frac{(v - u)}{\Delta t}$ to determine the unknown variable: initial velocity, final velocity, acceleration or time
- determine the velocity of an object from the gradient of velocity–time graphs.

Video 8.3
How to work out acceleration

acceleration due to gravity
acceleration of an object due to a planet's gravitational field; on Earth, $g = 9.8\,\text{m/s}^2$

Key ideas

- Acceleration is the rate at which the velocity of an object changes.
- Acceleration can be due to changing speed or changing direction.
- An object travelling at a constant, unchanging velocity has an acceleration of zero.

Acceleration

Pressing the accelerator pedal in a car makes the car move and increase in speed. This is the same as saying the car accelerates. In physics, acceleration is a vector quantity, which means it also has a direction. This means acceleration is how fast an object changes its velocity. As velocity can change when the direction changes, acceleration can also change when the direction changes. This means acceleration is the rate of change of velocity. The term 'rate' in this case refers to time, so acceleration is the change of velocity over time.

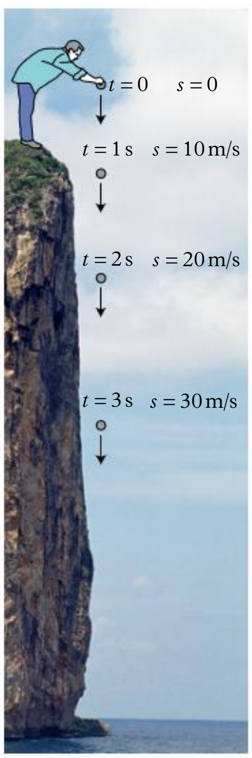


Figure 1 Each second, the speed of the falling rock increases by almost 10 m/s, ignoring air resistance. This means the acceleration is $10\,\text{m/s}^2$ downwards.

Just as the accelerator pedal causes a car to speed up, the brake pedal causes a car to slow down. This is called deceleration.

Acceleration is measured in units of metres per second per second (m/s/s) or metres per second squared (m/s^2 or m s^{-2}) because velocity is usually measured in metres per second and time is usually measured in seconds. However, other units for acceleration are possible depending on the units of velocity and time.

To understand acceleration, we will only consider objects travelling in one direction in a straight line and under constant acceleration. Consider a falling object, such as the rock shown in Figure 1.

When dropped vertically (not thrown), the rock starts at rest and increases in speed as it falls. If it were dropped from high enough, the rock may accelerate to a high speed.

After 1 second, it should reach a velocity of 9.8 m/s due to gravity. We say it has accelerated at a rate of 9.8 m per second in 1 second or at 9.8 m per second per second (written as 9.8 m/s/s or $9.8\,\text{m/s}^2$ or $9.8\,\text{m s}^{-2}$).

After another second at the same rate, the rock would reach a velocity of 19.6 m/s.

After 3 seconds, it would reach a velocity of 29.4 m/s. Of course, this analysis ignores the effects of air resistance, which would prevent the rock from reaching a velocity of 29.4 m/s after 3 seconds.

The acceleration value of $9.8\,\text{m/s}^2$ is called **acceleration due to gravity** and is given the special symbol of g. When people skydive, their movement follows the pattern of the rock. They speed up as they fall until they open their parachute and slow down to land.

Calculating acceleration

The formula for calculating acceleration (a) is:

$$\text{Acceleration } (a) = \frac{\text{change in velocity } (\Delta v)}{\text{change in time } (\Delta t)}$$

where Δ is the Greek letter 'delta' and means 'change in'. This can also be seen in the acceleration triangle (Figure 2).

This can also be written as:

$$a = \frac{(v - u)}{\Delta t}$$

where v is the final velocity and u is the initial (or starting) velocity.

CHALLENGE

8.3: Measuring acceleration by timing or using a motion sensor
Go to page **275**.

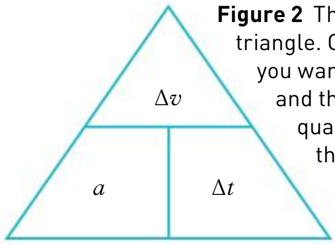


Figure 2 The acceleration triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

Acceleration is indicated by the gradient of a speed–time graph. The steepness of the gradient indicates the magnitude of the acceleration. This is shown in Figures 3 and 4.

Worked example 8.3A describes the velocity and acceleration of an object, and Worked example 8.3B shows how to calculate the acceleration of the object.

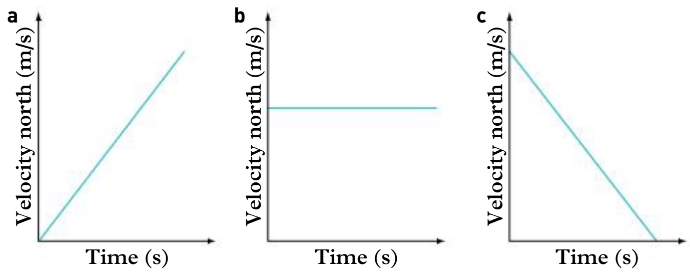


Figure 3 Velocity–time graphs (for an object moving in the positive direction) showing **a** constant positive acceleration (i.e. speeding up), **b** zero acceleration (i.e. constant speed) and **c** negative acceleration (i.e. slowing down or decelerating)

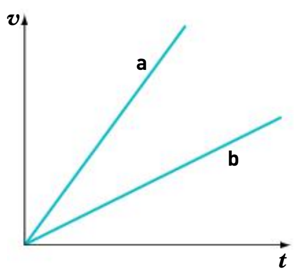


Figure 4 Velocity–time graphs showing a **a** steep gradient, indicating high acceleration, and **b** gentle gradient, indicating lower acceleration

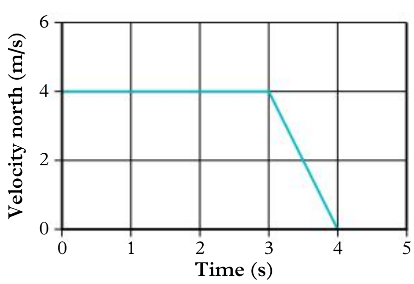


Figure 5 Acceleration can be determined by the gradient of a velocity–time graph.

Worked example 8.3A: Describing velocity and acceleration

Describe the velocity and acceleration of the object in the first 3 seconds of Figure 5.

Solution

The object in the graph is travelling at a constant velocity of 4 m/s for the first 3 seconds. Its gradient (and therefore its acceleration) is zero.

Worked example 8.3B: Calculating acceleration

Calculate the acceleration of the object in the last second of Figure 5.

Solution

Acceleration is the gradient of the velocity–time graph. The object slows from 4 m/s to 0 m/s in the last 1 second.

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{change in time}}$$

$$= \frac{\text{final velocity} - \text{starting velocity}}{\text{final time} - \text{starting time}}$$

$$= \frac{0 - 4\,\text{m/s}}{4 - 3\,\text{s}}$$

$$= \frac{-4\,\text{m/s}}{1\,\text{s}}$$

$$= -4\,\text{m/s}^2$$

Since the velocity is positive, the negative number indicates the object has decelerated.

8.3 Check your learning

Retrieve

1 **Recall** the acceleration of an object if its velocity is constant.

Comprehend

2 **Describe** the motion of an object with the speed–time graph shown in Figure 6.

3 **Explain** what is meant by the term 'deceleration'.

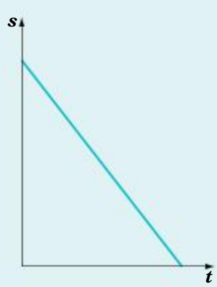


Figure 6 A speed–time graph

4 Use the acceleration triangle to **represent** the three different acceleration formulas.

Analyse

5 An object starts from rest and accelerates at a rate of $4\,\text{m/s}^2$. **Calculate** its velocity after each second for 5 seconds.

6 **Compare** accelerating and decelerating objects.

Quiz me

Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

8.4 An object in motion remains in motion until a net unbalanced force acts on it

Learning intentions

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

- describe how unbalanced forces cause a change in the velocity of an object
- state Newton's first law of motion (inertia) and explain this law using appropriate examples.

Key ideas

- A force occurs between two objects.
- Newton's first law states: 'An object remains at rest or in constant motion in a straight line unless acted on by a net unbalanced force.'

Imagine driving along a road with your schoolbooks sitting next to you on your seat. If the car brakes suddenly, your seatbelt will stop you moving forwards. Your schoolbooks will not have a seatbelt to stop them, and so they will fly forwards to the front of the car. This can be explained by Newton's first law of motion.

Newton's laws

English scientist Isaac Newton (1642–1727) is often pictured as sitting under a tree until an apple falls on his head. We are not sure if this story is true (Newton liked to embellish his stories); however, he was the first person to explain why an apple would fall down instead of up or sideways. He even wrote mathematical formulas to explain how and why the apple would move. In his book the *Philosophiae Naturalis Principia Mathematica*, Newton outlined his laws of motion and his law of universal gravitation.

Figure 1 Newton is famous for the story of the apple falling from a tree as he sat in his family orchard. Although the story is fictional, Newton himself is responsible for its creation.

A force always occurs between two objects. One object will provide a push or a pull force on another object. Force has the symbol F and is measured in newtons (N). The push or pull can change how an object moves (its motion). The force can start or stop a movement, or it can change the object's speed or direction. A force is not necessarily needed to keep an object moving, but most objects slow down because of the force of friction. Force is a vector quantity with a magnitude and direction.

Inertia and stationary objects

Newton's first law, also known as the law of inertia, has two applications. A stationary object, such as someone sitting on a chair (Figure 2), is being pulled down due to gravity (its weight force). It doesn't move because there is another force, equal in magnitude (strength) to the weight force but acting in the opposite direction, pushing up on the object from the surface.

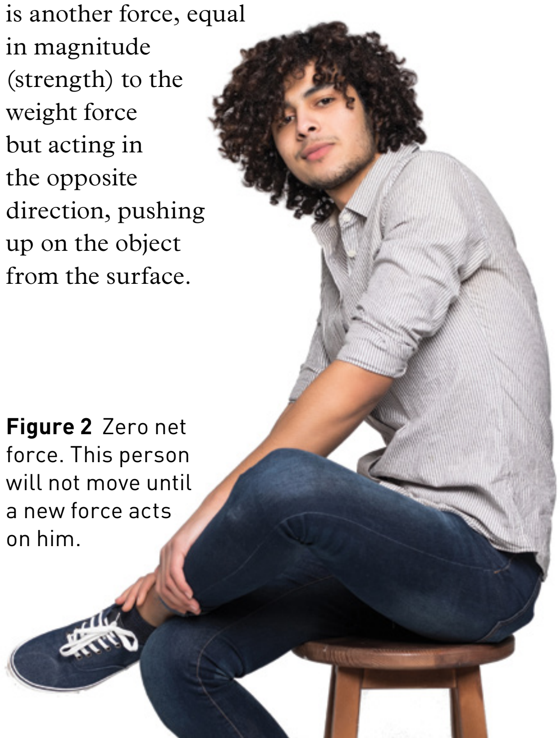


Figure 2 Zero net force. This person will not move until a new force acts on him.

CHALLENGE

8.4A: Make an accelerometer
Go to page **276**.

CHALLENGE

8.4B: How do you like your eggs?
Go to page **277**.

Figure 3 Inertia is responsible for vehicles tilting as they turn. Without friction from tyres gripping the road, turning would be nearly impossible.

Because these two forces are equal in magnitude and opposite in direction, and because they both act on the same object, we say that the object has zero **net force** (or zero resultant force) acting on it. The two forces are balanced. The movement (or lack of movement) will only change if another force is added (such as someone pushing the object). This will cause the forces to become unbalanced and the object will change its motion. It will start moving.

> Newton's first law states: 'An object remains at rest or in constant motion in a straight line unless acted on by a net unbalanced force.'

Inertia and moving objects

Think of any motion you have experienced today, maybe in a car, bus, train or tram, or even on a bike. In constant motion, you sometimes hardly notice you are moving, but if the vehicle stops or starts suddenly or turns a sharp corner, your body may move unexpectedly.

If you are a passenger in a car and not wearing a seatbelt and the car comes to a very sudden stop, your body will continue moving forwards. This is due to **inertia**. Inertia is the property of matter that keeps it in its existing state of motion (Figure 4). The friction of the brakes stops the car; however, it does not stop you. Your seatbelt is the only thing stopping you moving at 60–100 km/h. If you are not wearing your seatbelt, Newton's first law says that you will keep moving at the same speed (60–100 km/h), through the windscreen and onto the road. The same thing also happens in a bus, train or tram, especially if you are standing up and not holding on to something. The brakes will stop the bus, but you will keep moving forwards until the friction of your shoes or your hand grabbing for a handrail stops you. Your motion will remain constant unless a new (unbalanced) force stops you. Heavier objects with more mass are more difficult to start or stop moving. For this reason, objects with larger mass are described as having more inertia.

inertia
the tendency of an object to resist changes in its motion while either at rest or in constant motion

net force
the vector sum of all the forces acting on an object; also known as resultant force

Figure 4 Seatbelts are an inertia device. They are often called 'inertia reel seatbelts'. The aim of a seatbelt is to transfer the force on the car to the passenger wearing the seatbelt so that the person moves with the car. You start moving when the car starts moving and, when wearing your seatbelt, you stop moving when the car stops moving.

8.4 Check your learning

Retrieve

1 **Define** the term 'net force'.
2 **Define** the term 'inertia'.

Comprehend

3 **Describe** what happens to a moving object with zero net force acting on it.
4 **Describe** what happens to a stationary object with zero net force acting on it.
5 **Describe** how inertia affects your motion inside a car, bus, tram or train.
6 **Explain** why people lurch backwards in a tram when it starts moving suddenly.
7 **Explain** why you should wear a seatbelt in a moving car.

Apply

8 **Create** a poster for Year 7 students that explains why you should wear a seatbelt in a car.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

8.5 Net force equals mass × acceleration

Learning intentions

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

- describe how unbalanced forces acting on an object can cause it to accelerate or decelerate using appropriate examples
- state Newton's second law of motion and explain this law using appropriate examples
- manipulate the formula $F_{net} = ma$ appropriately to determine the unknown variable: net force, mass or acceleration.

Key idea

- Newton's second law states: 'The acceleration of an object is directly related to the magnitude and direction of the net force acting on the object, and inversely related to the mass of the object: $F_{net} = ma$.'

Newton's laws are used in many unexpected ways. The coding of automated trains (with no drivers) must plan for the number of passengers in the carriages. During peak hour, there are many more passengers, and the carriages have greater mass. This means the trains will need a greater force to slow down than the lighter, empty carriages. The weight is a measure of the forces from gravity acting on the carriages. It is measured in newtons (N).

Force affects acceleration

If an object experiences an unbalanced net force, it will push or pull the object. This means the object will change its speed, direction or both. A moving object will speed up (accelerate) if the net force acts on it in the same direction as it is already moving. This is like a bike rider pedalling harder to increase the driving force (known as thrust) (Figure 1). The thrust is in the same forward direction, so the bike will increase its speed.

When the net force acts in the opposite direction, the moving object will slow down (decelerate) and eventually stop. This is like the brake adding a friction force to the moving bike. The net force is in the opposite direction to the bike's movement. This net force causes the bike to change its speed. It decelerates or slows down (Figure 2).

Figure 1 Pedalling provides the thrust force when riding a bike.

Figure 2 Braking provides a drag force.

Interactive 8.5
Force definitions

Force, mass and acceleration

Would you need more push force to start moving a car or start moving a bike? A car has greater mass than a bike; therefore, it needs a greater force to change its motion. A bike, with less mass, needs less force to change its motion.

We can express this relationship in a simple equation:

$$\text{Net force} = \text{mass} \times \text{acceleration}$$

$$F_{net} = m \times a$$

This relationship can also be expressed in a force triangle (Figure 3). You need a larger force to accelerate a heavy object from rest, and a smaller force to accelerate a lighter object from rest.

When mass is in kilograms (kg) and the acceleration is in metres per second squared (m/s^2), the net force will be in newtons (N). Acceleration and net force are both vectors and always act in the same direction.

Often, you need to consider all the individual forces acting on an object in order to work out the net force.

Worked example 8.5 shows how to calculate acceleration using net force and mass.

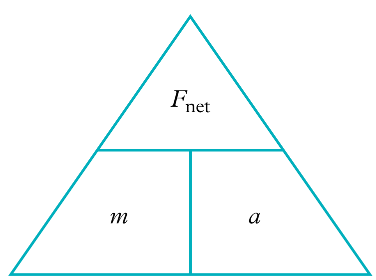


Figure 3 The net force equation can be written as a triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

EXPERIMENT
8.5A: Resultant forces
Go to page **278**.

EXPERIMENT
8.5B: Accelerating masses
Go to page **279**.

Figure 4 Various forces act on a cyclist.

Worked example 8.5: Calculating acceleration using net force and mass

Consider the cyclist and bike with a mass of 90 kg shown in Figure 4. The forwards-acting thrust force is 400 N, and the total drag force from air resistance and friction is 300 N backwards. Calculate the acceleration of the cyclist.

Solution

The net force is the sum of the vector forces.

Forward forces (thrust) = +400 N

Reverse forces (drag + friction) = –300 N

Net force = 400 – 300 = 100 N forwards

$$\text{Acceleration} = \frac{\text{net force}}{\text{mass}}$$

$$= \frac{100\text{ N forwards}}{90\text{ kg}}$$

$$= 1.11\text{ m/s}^2$$

The cyclist would increase his speed by 1.11 m/s every second.

Mass or weight

We often use the term ‘weight’ to indicate how much mass something has in kilograms but, strictly speaking, in physics weight is a force not a mass. Weight is the force from gravity acting on an object. Because it is a force, weight is measured in newtons. For example, gravity on the Moon is approximately 1.6 m/s^2 and on the Earth is 10 m/s^2. This means an object with a mass of 100 kg would have a weight of 160 N (100 kg × 1.6 m/s^2) on the Moon and 1000 N (100 kg × 10 m/s^2) on the Earth.

An object on the Moon will have less weight (N) but the same mass (kg).

Weight can be calculated by using the following formula, or the triangle shown in Figure 5.

Weight = mass × gravitational acceleration

$W = m \times g$

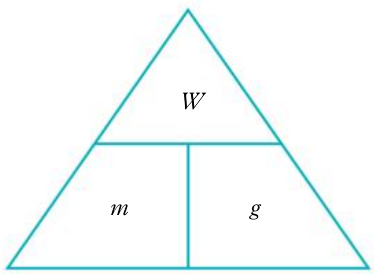


Figure 5 Weight is the force of gravity acting on an object's mass. Weight (force) = mass × acceleration due to gravity.

Figure 6 Cars can accelerate faster than trucks mainly because of their smaller mass. Cars will also decelerate faster. This means a truck will take longer to stop than a car.

8.5 Check your learning

Retrieve

1 **Define** the term ‘weight force’.

Comprehend

2 **Describe** what happens to a moving object if it is acted on by a net force in the same direction as its motion.

3 **Describe** what happens to a moving object if it is acted on by a net force in the opposite direction to its motion.

4 **Explain** why a bike slows down on a level road when the rider stops pedalling.

Analyse

5 **Compare** the acceleration of a bus full of passengers to that of an empty bus, if the same net force was used.

6 A net force causes a mass of 10 kg to accelerate at 2 m/s^2. **Calculate** the magnitude of the net force.

Apply

7 **Create** a poster that explains why trucks need a greater stopping distance than cars.

Quiz me

Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

8.6 Each action has an equal and opposite reaction

Learning intentions

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

- state Newton's third law of motion and explain this law using appropriate examples of action–reaction pairs
- understand that action and reaction pairs always act on different objects.

Key ideas

- Newton's third law states: 'For every action, there is an equal and opposite reaction'.
- Action–reaction pairs always act on different objects and therefore cannot cancel each other out.

reaction force
the force acting in the opposite direction to an initial force

Newton's third law

If you blow up a balloon and let it go, it flies around the room like a crazy rocket. As the air is forced backwards out of the opening, the balloon is propelled forwards by another force. These two forces are equal in magnitude and opposite in direction. They form an action–reaction pair and obey Newton's third law. The action force in this example is the rubber of the balloon contracting and pushing the air backwards. The **reaction force** is the force of the air rushing out, pushing forwards on the balloon.

Action and reaction pairs always act on different objects. When you lean against a wall, you exert a force on the wall.

The wall exerts a force on you (you can feel it pushing against your hands). Because these two forces act on different objects (you and the wall), they cannot be described as being balanced or cancelling each other out. A net force is balanced or zero when all the forces acting on a single object are equal and opposite.

Action–reaction pairs can never cancel under any circumstances because the two forces act on different objects.

When an insect hits a car windscreen, the action on the windscreen is equal and opposite to the reaction on the insect. The insect is much smaller, so its mass is less able to withstand the deceleration.

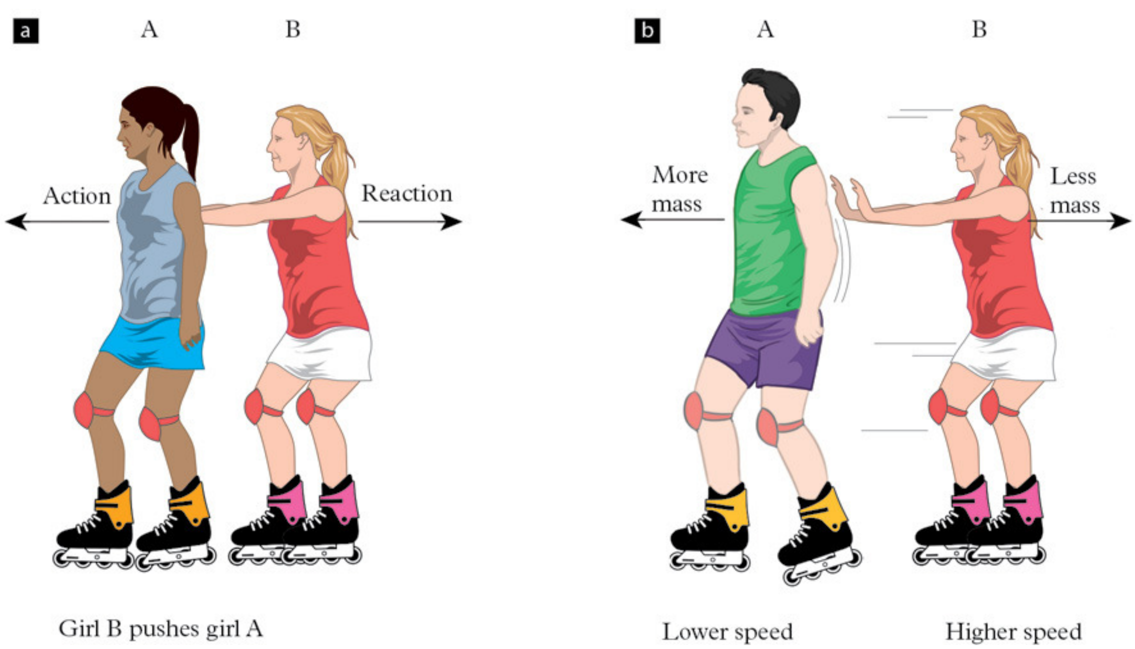


Figure 1 **a** Girls A and B have equal mass. Girl B pushes girl A (action), and girl A pushes girl B backwards (reaction). Girl A moves forwards and girl B moves backwards. **b** Boy A has more mass than girl B. Both the action and reaction forces are identical and opposite in direction. As boy A has more mass, his speed will be less than that of girl B.

EXPERIMENT

8.6: What if forces were changed on Newton's rocket?
Go to page **280**.

The motion of a girl on roller blades pushing off from another girl (Figure 1) works in a similar manner. The two girls experience an identical but opposite force. Newton's second law ($F_{net} = ma$) tells us that smaller masses have higher accelerations for the same force. So, if the two girls have different masses, the lighter girl will have a higher acceleration and will reach a higher speed while the force is acting.

Rockets, missiles and jet engines work on the action–reaction principle. For many years, it was thought that rocket ships would not be able to accelerate in space because there was very little air for the rocket to push against. However, rocket fuel undergoes a combustion reaction, producing exhaust gases. These gases are forced out of the back of the rocket, producing an opposite and equal reaction on the rocket. This moves the rocket forwards (Figure 2).

Figure 2 The rocket pushes exhaust gases back. As a result, the rocket is propelled forwards.

8.6 Check your learning

Retrieve

1 **Recall** the action and reaction forces of leaning against a wall.

Comprehend

2 **Describe** Newton's third law in your own words.

3 A boy of weight 500 N sits on a chair. **Describe** the direction and magnitude of the reaction force that acts on the boy.

4 In space, an astronaut pushes on another astronaut with a force of 80 N. **Describe** the magnitude and direction of the reaction force in this case. **Explain** why the second astronaut might have a higher acceleration than the first astronaut.

Analyse

5 **Identify** the action–reaction pair when a sprinter uses a set of starting blocks for the start of a sprint race.

6 **Identify** the action–reaction pair when a softball player hits a home run.

7 A person pushes forwards on an object with a force of 30 N. **Calculate** the reaction force that acts on the person.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

Figure 3 Sprinters use starting blocks to help them start a race with more power.

8.7 Momentum is conserved in a collision

Learning intentions

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

- manipulate the formula $p = mv$ appropriately to determine the unknown variable: momentum, mass or velocity
- state the law of conservation of momentum and explain this law using appropriate examples.

Key ideas

- Momentum is the product of the mass and velocity of an object.
- The law of conservation of momentum states that in an isolated system, the total momentum does not change during a collision.

momentum
the product of an object's mass and velocity

law of conservation of momentum
a scientific rule that states that the total momentum in an isolated system does not change during a collision

Modern cars are fitted with many safety devices, but arguably the most important are the airbags that deploy in the event of a crash. Sensors inside the car act like mini accelerometers and when they detect rapid deceleration, the airbag system is triggered. These innovations are the result of the scientific understanding of movement and, more importantly, collisions. All collisions involve force, mass and momentum, and these quantities link together according to the laws of motion as we know them.

Momentum

All moving objects possess 'mass in motion' or **momentum**. Momentum is not a form of energy, although the faster an object travels, the more momentum it has. A cricket ball is harder to stop than a tennis ball travelling at the same speed. This is because the cricket ball has more mass in motion than the tennis ball. So, objects with more mass have more momentum, if they are travelling at the same velocity.

The velocity of a travelling object will also affect its momentum. A tennis ball travelling at 60 km/h will have more momentum (and hurt more) than a tennis ball travelling at 30 km/h. The formula for calculating momentum is:

$$\text{Momentum} = \text{mass} \times \text{velocity}$$
$$p = m \times v$$

where mass is in kilograms (kg), velocity is in metres per second (m/s), and momentum is in kilogram metres per second (kg m/s).

This relationship can also be expressed in a momentum triangle (Figure 1).

In an isolated system, momentum is passed from one object to another in a collision, but the total momentum of the system is conserved or remains constant. This means the initial momentum before the crash is equal to the final momentum of all objects after the crash.

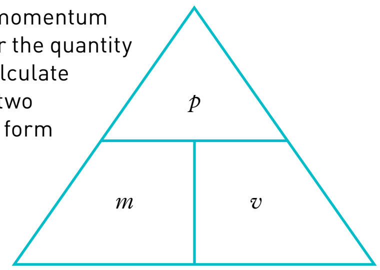


Figure 1 The momentum triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

This is known as the **law of conservation of momentum** and is similar to the law of conservation of energy.

The isolated system referred to in the law of conservation of momentum is the set of objects that interact in the collision. In the case of Newton's cradle (Figure 2), this would be the two spheres that collide. Because velocity is a vector, momentum is also a vector quantity. We can indicate opposite directions in a collision as positive and negative.

To stop a moving object, a force is used to reduce its momentum. If the brakes are applied slowly, a force is used over a long time to bring the car to a slow stop. In a car crash, a force on the front of the car causes it to stop quickly. In both examples, the force exerted on the car is related to the initial momentum of the car. The average force involved in a collision equals the change in momentum divided by the time it takes for the collision to occur.

Worked example 8.7A shows how to calculate initial momentum, and Worked example 8.7B shows how to calculate momentum.

Figure 2 Newton's cradle clearly demonstrates how momentum can be passed from one object to another.

EXPERIMENT

8.7: Colliding trolleys
Go to page 281.

Worked example 8.7A: Calculating initial momentum

Figure 3 represents a relatively safe head-on collision between two dodgem cars.

a Calculate the initial momentum of each car.

b Calculate the total initial momentum of the two cars.

Solution

a Velocity (green car) = 0.8 m/s; mass (green car) = 701 kg

Initial momentum (green car):

$p \text{ (green car)} = m \times v$

$= 701 \times 0.8$

$= 561 \text{ kg m/s}$

The purple car is moving in the opposite direction and therefore the velocity is negative.

Velocity (purple car) = –0.7 m/s; mass (purple car) = 660 kg

Initial momentum (purple car):

$p \text{ (purple car)} = m \times v$

$= 660 \times -0.7$

$= -462 \text{ kg m/s}$

b The total initial momentum of the two cars = 561 – 462 = 99 kg m/s. The positive number tells us that the total momentum is to the right, 99 kg m/s.

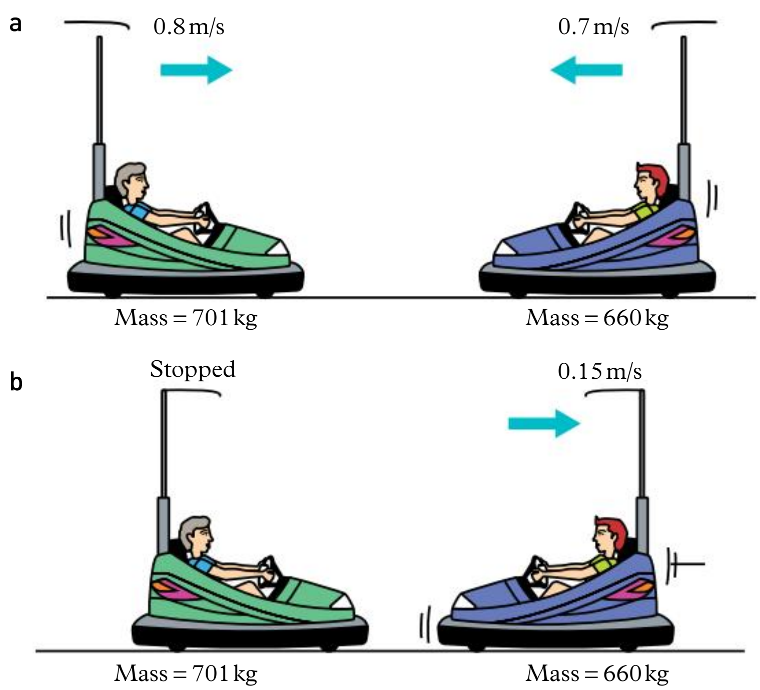


Figure 3 **a** Before the collision **b** After the collision

Worked example 8.7B: Calculating momentum

Calculate the momentum of the purple car in Figure 3 after the collision.

Solution

The total momentum before the crash was 99 kg m/s to the right.

As total momentum is conserved, the total momentum after the crash should also be 99 kg m/s to the right. As the green car is not moving, it will not have momentum (mass in motion).

Therefore, the momentum of the purple car = 99 kg m/s to the right.

8.7 Check your learning

Retrieve

1 **Identify** the units of momentum.

Comprehend

2 **Describe** the law of conservation of momentum.

3 Use the momentum triangle to **represent** the three different momentum formulas.

4 **Explain** why it is harder to stop a cricket ball than a tennis ball travelling at the same velocity.

5 **Explain** why it is harder to stop a fast-moving tennis ball than a slow-moving tennis ball.

Analyse

6 **Calculate** the momentum of a 600 kg golf cart that is travelling at 0.8 m/s.

Apply

7 Use your understanding of momentum to **evaluate** which would cause the greatest damage: colliding with a truck or colliding with a car.

Quiz me

Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

//SCIENCE AS A HUMAN ENDEAVOUR//

8.8 Understanding motion improves vehicle safety

Learning intentions

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

- explain how safety features of modern vehicles limit the force experienced by drivers and passengers when accidents occur.

When buying a car, one of the key messages from the dealer is the list of safety features offered. This was not always a priority in a car. Prior to 1970, the wearing of seatbelts was not compulsory in Australia. When the seatbelt laws were first introduced, there were media reports suggesting that seatbelts increased the number of injuries experienced in an accident. This can be explained using Newton's laws.

Car safety

When a car is in an accident, it stops quickly. Newton's first law (a body in motion remains in motion until a force stops it) suggests that if a person in the car is not wearing a seatbelt, they will keep moving through the windscreen until the road, tree or something else stops them. If they are wearing a seatbelt, then the belt will stop the passengers and driver when the car stops. Although this may increase the number of belt related injuries, it also decreases the number of deaths. Modern cars also feature several other safety mechanisms to protect passengers from injury (Figure 1).

Bike and e-scooter safety

The recent increase in the number of electric scooters has caused much debate. Although e-scooters and push bikes have similar weights, the speeds they travel can vary considerably.

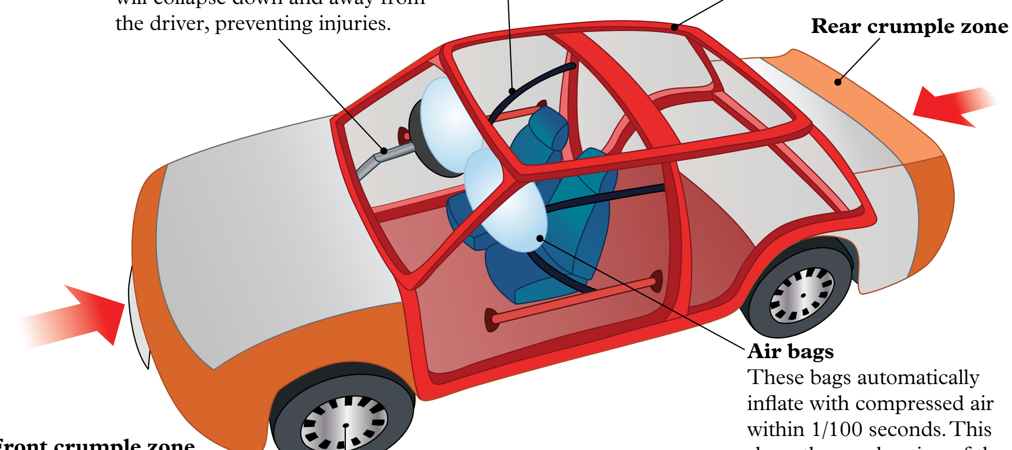


Figure 1 Safety mechanisms built into modern cars

The momentum generated by a moving object is related to the combined mass of the rider, their bike or scooter, and the speed they are travelling. A larger person or a faster traveller will have more momentum in an accident than a smaller person or a person travelling slowly. If the scooter or bike was to crash into a standing pedestrian, the momentum would be conserved. This means the pedestrian would be thrown backwards with the shared momentum. Because they weigh less than the scooter and rider combined, the pedestrian would be thrown further.

Both bike and scooter riders are expected to wear a helmet to protect themselves from an accident. The helmet acts like the airbag in a car, slowing the deceleration of the head and reducing the force experienced by the brain on impact.

Figure 2 Helmets are required when riding a bike or e-scooter.

Driverless cars

Most car accidents are due to drivers overestimating their skills or not understanding the conditions of the road or car. Driverless cars can help to address these issues. These autonomous vehicles use sensors and cameras to identify potential crash risks. Lidar (light detection and ranging) sensors use a 3D laser to scan their environment. Pulses of light are regularly sent into the local environment. Any objects that are nearby will reflect the light back to the car. The time taken between the pulse and reflection can be used to determine the distance between the car and object. The system can send a warning to the driver or take corrective action to prevent a potential accident. When combined with virtual maps and route planning, this has the potential to remove the need for the driver to pay attention to other drivers on the road.

Driverless sensor systems are not perfect as low light conditions and rain can confuse the lidar systems. In 2016, a large 18-wheeler truck crossed a highway in the United States. The sensors on a partially automated Tesla car did not recognise that the white side of the truck was different to the white sky and attempted to continue driving, causing a crash. The court ruled that the occupant/driver of the car was at fault as they would have had time to stop if they had been paying attention.

8.8 Test your skills and capabilities

Ethical conundrums

While automated cars can be programmed to follow all the road rules to prevent injuries, there are many ethical decisions that must be programmed into the pre-written lines of code. This can be best illustrated through a variation of the ‘trolley problem’. Use your understanding of consequential ethics and deontological ethics (see Topic 1.6 to refresh your memory about these ideas) to **justify** which decision should be programmed into an automated car to act in the following scenario.

A driverless car carrying you is crossing a bridge when it detects a presence in the middle of the road on the bridge. If the car swerves off the bridge, you will fall to your death. The car cannot stop in time to prevent hitting the presence detected on the bridge.

Which decision should be programmed into the car if:

- the person on the bridge is six years old
- the person on the bridge is elderly with a walking stick
- there is a group of three people on the bridge
- there is one person on the bridge and three of your friends in the car with you?

MOTION

Retrieve

1 **Identify** which term relates to the following sentence.
'An object's acceleration directly relates to the magnitude and direction of the net force acting on the object.'
A Newton's first law
B Newton's second law
C Newton's third law
D law of inertia

2 **Identify** the correct definition for each of the terms in Table 1.

Table 1 Terms and definitions

Term	Definition
Vector	Speed of an object at a moment in time
Average velocity	Rate at which an object's velocity changes
Average speed	Slope of a graph
Acceleration	Graph where speed is plotted against time
Distance	Quantity that has magnitude and direction
Instantaneous speed	Calculated by dividing distance by time
Gradient	How far an object has travelled
Speed–time graph	Calculated by dividing displacement by time

3 **Recall** the formula that is used to calculate average speed.
A Average speed = $\frac{\text{total time taken}}{\text{total distance travelled}}$
B Average speed = $\frac{\text{total displacement}}{\text{total time taken}}$
C Average speed = $\frac{\text{total acceleration}}{\text{total displacement}}$
D Average speed = $\frac{\text{total distance travelled}}{\text{total time taken}}$

4 **Identify** each of the following quantities as scalar or vector.
a force
b speed
c distance
d displacement
e velocity
f acceleration
g momentum

5 **Identify** the quantity that can be determined by the gradient of a displacement–time graph.

6 **Identify** the quantity that can be determined by the area under a velocity–time graph.

Comprehend

7 **Describe** an object's speed if it travels with zero acceleration.

8 **Describe** an object's speed if it travels with constant deceleration.

9 Renee catches a softball.
a **Describe** the action.
b **Describe** the reaction.

10 **Describe** the motion for each of the following time periods in Figure 1.
a 0–5 seconds
b 5–10 seconds
c 10–15 seconds

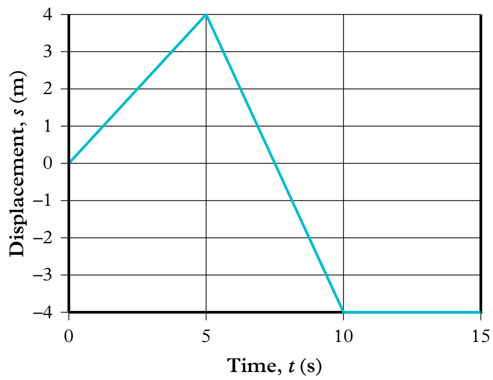


Figure 1 A displacement–time graph

11 Motion is the result of forces acting in different directions. **Describe** the forces you believe to be acting when an object is stationary.

12 Some objects or devices require high accelerations that are many times greater than 9.8 m/s^2, the acceleration due to gravity. Think of an object or device in this category. **Describe** the force that is used to propel the object. **Identify** the fuel it uses. **Explain** how this fuel enables it to achieve such a high acceleration.

Analyse

13 **Identify** whether the following statements are true or false. Rewrite any false statements so that they are true.
a A force will only change an object's speed.
b A force is always needed to keep an object in motion.
c The quantity of weight is measured in kilograms.
d A force has magnitude and direction, making it a vector.
e Acceleration increases if the net force increases and the mass is kept constant.
f A stationary object can have several forces acting on it.

14 Object A has more mass than object B. **Compare** the acceleration of the two objects if they are pushed with the same force.

15 **Compare** velocity and speed.

16 A bike travels 100 m in 5 seconds before stopping for 2 seconds. It then travels back to the starting point in 10 seconds.
a **Calculate** the total distance travelled by the bike.
b **Calculate** the final displacement of the bike.
c **Calculate** the average speed of the bike.

17 A parachutist jumps out of a plane and falls at 10 m/s².

a **Calculate** their speed at $t = 0$ seconds.

b **Calculate** their speed at $t = 1$ second.

c **Calculate** their speed at $t = 3$ seconds.

18 A person walked 3 km east, then 4 km north and then 9 km east again (Figure 2).

a **Calculate** the total distance travelled.

b **Calculate** the final displacement (by calculating the total distance east and total distance north, drawing a right-angle triangle with these values and using Pythagoras' theorem).

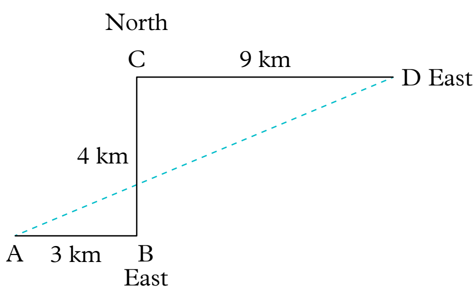


Figure 2 The displacement of a person

19 A professional bike rider measured their velocity over time (Figure 3).

a **Describe** their motion over the 50 seconds.

b **Calculate** the acceleration in the first 10 seconds.

c **Calculate** their acceleration in section B.

d **Calculate** the distance travelled in section D.

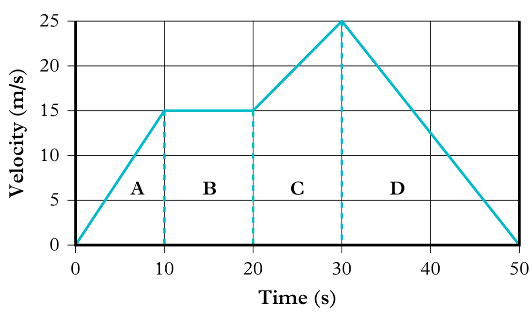


Figure 3 The velocity–time graph of a bike rider

20 A car is driven along a straight road. Starting from rest, it takes 10 seconds of steady acceleration for the car to reach a speed of 20 m/s. The car then cruises for 60 seconds at 20 m/s, before slowing to a halt over a period of 30 seconds.

a **Calculate** the maximum speed of the car in m/s.

b **Calculate** the maximum speed in km/h.

c Plot a speed–time graph for the car using SI units.

d Use the graph to **calculate** the distance moved in metres and then in kilometres.

21 Charlie walked 1 km to the supermarket from her house, then 3 km to the florist and then 3 km back home again. **Calculate** Charlie's total displacement and **identify** the correct answer from the list below.

A 7 km

B 0 km

C 21 km

D 14 km

22 Figure 4 shows a rear-end car crash between two dodgem cars. Before the collision, the green car had a velocity of 2.2 m/s and a mass of 140 kg. The purple car had a velocity of 1.7 m/s and a mass of 160 kg.

a **Calculate** the momentum of each of the two dodgem cars before the collision.

b **Calculate** the total momentum of the two dodgem cars before the collision.

c **Calculate** the velocity of the two dodgem cars after the collision.

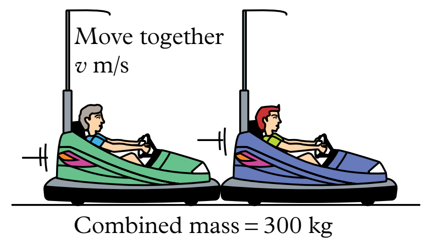


Figure 4 A collision between two dodgem cars

23 On a wet Monday morning, a school bus that has to travel 24 km leaves its starting place at 7:35 am and only manages an average speed of 36 km/h on its trip to school. There is a clear section on the highway when the bus has a speed of 74 km/h. The bus then does various runs during the day and arrives back at the school in time to depart at 3:45 pm. It arrived back exactly at its starting place at 4:25 pm.

a **Calculate** the displacement of the bus between 7:35 am and 4:25 pm.

b **Calculate** the time the bus will arrive at school in the morning.

c **Calculate** the average speed of the bus.

d The bus's average speed on the way to school is 36 km/h, but on one stretch the bus moves at 74 km/h. Use this data to **explain** the difference between 'average speed' and 'instantaneous speed'.

24 **Calculate** the mass of an object that would accelerate at 3.5 m/s² under the influence of a net force of 70 N.

25 **Calculate** the acceleration of a 500 g object under the influence of a net force of 500 N

Apply

Social and ethical thinking

26 **Identify** the safety features of the car shown in Figure 5. **Identify** the safety features that could be added to this car. Adding extra safety features adds to the cost of the car. **Discuss** how the socioeconomic status of a person can determine the safety of the car they drive.

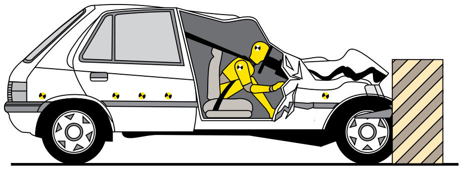


Figure 5 A crash-test car

Critical and creative thinking

27 **Create** a poster on motion that explains each of Newton's three laws. Use a detailed example that illustrates each law and is not already mentioned in the text.

Research

28 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

» Female crash test dummies

Crash test dummies are used to test the safety features of a car. The average test dummy was developed in 1970 and is male, 175 cm tall and weighs 77 kg.

- » Compare these dimensions to the average Australian male.
- » Describe how differences in height and weight would affect the way the dummy would be affected in a crash.
- » Research the development of female test dummies.
- » Describe the differences in the size, mass and shape between the male and female dummies.

Figure 6 A female crash test dummy

» First Nations forces

For thousands of years, First Nations peoples from the Australian mainland and the Torres Strait Islands have experimented with forces when designing weaponry such as spear throwers and bows and arrows for hunting. Research and describe how variables including force, mass and acceleration have been used to increase the speed and impact force of spear throwers and bows.

Figure 7 Stone spear points used by First Nations peoples in Australia

» School speed limits

The speed limit on a road can vary according to the conditions of the road, the amount of traffic and the likelihood of pedestrians crossing the road.

- » Identify the speed limit around your school.
- » Describe why the speed limit might be different to similar roads 1 km away from the school.
- » Use Newton's laws to explain why the speed limit will vary between the two roads.

» Movement of aircraft

Aircraft are the second fastest mode of transport, after rockets.

- » Investigate different types of aircraft and how they move.
- » Explain the interactions between lift, weight, thrust and drag in aircraft movement.
- » Identify the maximum speeds aircraft can attain.

Figure 8 Aircraft use a combination of the forces of lift, weight, thrust and drag in different balances for different movements.

Chapter checklist

Now that you have completed this chapter, reflect on your ability to do the following.

	I can do this.	I cannot do this yet.
• Explain the difference between distance and displacement using appropriate examples. • Plot and interpret displacement–time graphs for linear motion.	☐	☐ Go back to Topic 8.1 'Displacement is change in position with direction'. Page 188
• Explain the difference between speed and velocity using appropriate examples. • Determine the speed/velocity of an object from the gradient of a displacement–time graph.	☐	☐ Go back to Topic 8.2 'Velocity is speed with direction'. Page 190
• Calculate acceleration from the velocity at two points in time. • Manipulate the formula $a = \frac{(v - u)}{\Delta t}$ appropriately to determine the unknown variable: initial velocity, final velocity, acceleration or time. • Determine the velocity of an object from the gradient of velocity–time graphs.	☐	☐ Go back to Topic 8.3 'Acceleration is change in velocity over time'. Page 192
• Describe how unbalanced forces cause a change in the velocity of an object. • State Newton's first law of motion (inertia) and explain this law using appropriate examples.	☐	☐ Go back to Topic 8.4 'An object in motion remains in motion until a net unbalanced force acts on it'. Page 194
• Describe how unbalanced forces acting on an object can cause it to accelerate or decelerate using appropriate examples. • State Newton's second law of motion and explain this law using appropriate examples. • Manipulate the formula $F_{net} = ma$ appropriately to determine the unknown variable: net force, mass or acceleration.	☐	☐ Go back to Topic 8.5 'Net force equals mass × acceleration'. Page 196
• State Newton's third law of motion and explain this law using appropriate examples of action–reaction pairs. • Understand that action and reaction pairs always act on different objects.	☐	☐ Go back to Topic 8.6 'Each action has an equal and opposite reaction'. Page 198
• Manipulate the formula $p = mv$ appropriately to determine the unknown variable: momentum, mass or velocity. • State the law of conservation of momentum and explain this law using appropriate examples.	☐	☐ Go back to Topic 8.7 'Momentum is conserved in a collision'. Page 200
• Explain how safety features of modern vehicles limit the force experienced by drivers and passengers when accidents occur.	☐	☐ Go back to Topic 8.8 'Science is a human endeavour: Understanding motion improves vehicle safety'. Page 202

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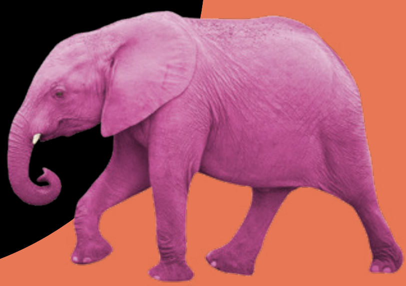
Play a Quizlet game to test your knowledge.

Chapter quiz
Test your understanding of this chapter with the chapter review quiz.

CHAPTER

9



LEARNING AND MEMORY

9.1

The brain is responsible for learning and memory

> Identify the structure of a neuron.

> Explain how neurons relay information from our senses to our brain.

> Identify and explain the role of each of the four lobes of the cerebral cortex.

> Recall that memories are stored in specific areas of the cerebral cortex.

9.2

Animals have innate behaviours to survive

> Explain that animal behaviours can be innate or learned.

> Describe imprinting, species-specific behaviours and maturation as examples of innate behaviours.

9.3 Animals can learn behaviour from their environment

> Explain that learning is a demonstrated change in behaviour as a result of experience.

> Describe the processes of operant conditioning and classical conditioning.

9.4 Information must be effectively encoded and stored for it to be recalled

> Explain the processes of encoding, storage and retrieval.

> Describe the differences between sensory memory, short-term memory and long-term memory.

9.5 Memory and learning can be improved

> Explain how mnemonics can improve short-term memory capacity and long-term memory stores.

9.6 Science as a human endeavour: Neuroimaging makes memory and learning visible

> Explain the difference between MRI, fMRI and PET imaging.

> Describe how neuroimaging assists scientists with understanding how memory and learning works.

What if?

How can we improve our memory?

What you need:

List of 10 words (of objects)

What to do:

1. Take 2 minutes to create a story that incorporates the 10 objects from your list of words in the order they appear on the list. Make it a creative, crazy and novel story to make it memorable!
2. Use the next 1 minute to rehearse your story with all 10 words in the correct order. Visualise the objects in your mind as you rehearse your story.
3. Put the list of words away. Get a fresh piece of paper or turn to a new page in your book.
4. Re-tell your story to yourself, and as you come to each word to be remembered, write it down on your recall list. It is important to recall the words in the order they were originally presented!
5. Test yourself the next day or lesson. See how many of the 10 words you can recall in the same order as originally presented.

What if?

» What if you tried to remember another set of words without a story?

» What if you had to remember a list of 15 words?

CHALLENGE
9.1A: Neuroscientist interview
Go to page **282**.

9.1 The brain is responsible for learning and memory

Learning intentions

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

- identify the structure of a neuron
- explain how neurons relay information from our senses to our brain
- identify and explain the role of each of the four lobes of the cerebral cortex
- recall that memories are stored in specific areas of the cerebral cortex.

stimulus
any information that the body receives that causes the body to respond

cerebral cortex
the outer layer of the brain that is responsible for conscious thought

Key ideas

- Neurons relay information from our senses to our brain to create our experience of the world.
- The cerebral cortex is made up of four lobes; each has a specific function.
- Memories are stored in specific parts of the cerebral cortex.

When watching a brilliant sunset, our senses are alive. We may be aware of the vivid colours in the sky, the bird sounds around us as the day ends, the smells in the air and the feel of the breeze on our skin. To understand each of these experiences, we rely on our brain. Since childhood, we have all been collecting memories of our experiences and storing information about them that helps us to understand different things, such as what different colours look like. Without the ability to store this information, our brains would not be able to produce an image when we hear the name of a colour.

Our senses, including what we see, hear, taste, touch and smell, help our brains to understand our surroundings. Information that can be detected by our senses is called a **stimulus**.

Lobes of the brain

You may recall from Year 9 that the brain's outer layer is called the **cerebral cortex**. This part of the brain is responsible for all our conscious thoughts and is where our memories are stored.

The cerebral cortex is divided into two hemispheres (or sides) – left and right. Each hemisphere is divided into four lobes (Figure 1), each with different functions. Table 1 describes the functions of each lobe.

Table 1 The functions of the lobes of the brain

Lobe	Function
Frontal lobe	Responsible for higher mental functioning including language, learning, memory, decision-making and problem solving. It also coordinates movement of the left and right sides of the body.
Parietal lobe	Allows us to understand spatial tasks, such as reading maps, and processes sensations from the body about touch, pressure, pain and temperature.
Occipital lobe	Processes visual information.
Temporal lobe	Processes smells and sounds, as well as understanding of language.

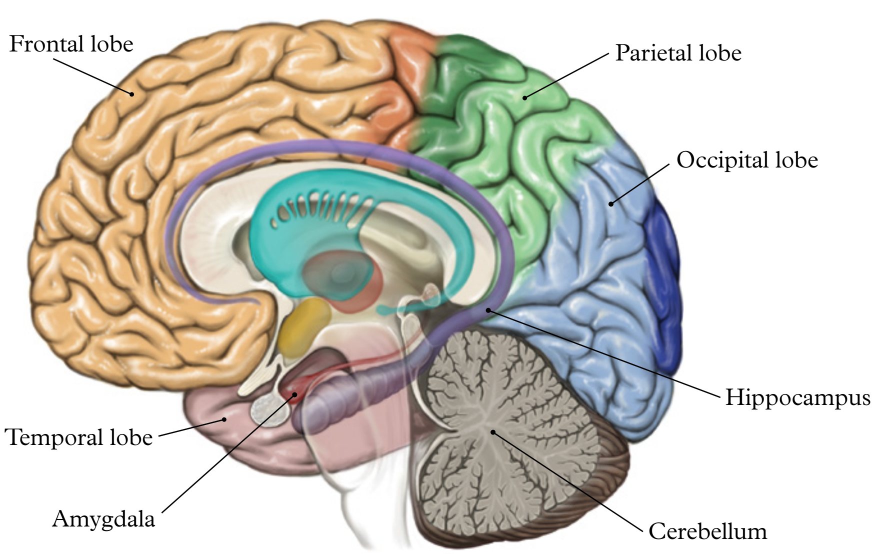


Figure 1 Parts of the brain involved in memory

CHALLENGE
9.1B: Modelling neural pathways
Go to page 283.

SKILLS LAB
9.1C: Modelling brain structure and function
Go to page 284.

Hippocampus, amygdala and cerebellum

To store information from our external environment and internal thoughts as memories, it must be encoded. We use the word 'encoding' to describe the transformation of stimulus into a form that can be stored as memories in the brain.

Memories are stored in our cerebral cortex, but other parts hidden below this outer layer also play an essential role in learning and memory.

> The cerebral cortex is where specific long-term memories of experiences and facts are stored.
> The **hippocampus** is located in the middle of our brain and encodes memories by changing them into a form that the cerebral cortex can store.
> The **amygdala** is involved in encoding emotional memories (e.g. fear).
> The **cerebellum** is located at the rear of our brain, below the cerebral cortex. The cerebellum assists with encoding and storing memories involving movement, balance and coordination, like how to ride a bike or play the guitar.

Neurons carry messages

As you may recall from Year 9, **neurons** are cells designed to send and receive messages. A network of neurons connects the tips of your toes and fingers all the way back to your brain. This allows the body to detect sensory information, such as a bad smell or cold weather, and send this information to a specific part of the brain for processing and to be stored as memory. Our bodies can act on the information straight away or the information can be accessed later when we recall a memory.

Neuron structure

Neurons are made up of three key structures:

> soma (the cell body)
> axon, covered in a protective layer called the myelin sheath
> dendrites.

Neurons communicate rapidly via an electrochemical process. A neuron's dendrites receive a message and send a signal down the axon (Figure 2). At the end of the axon, the electrochemical message is released as neurotransmitters into the synapse.

Neurotransmitters are picked up by the next neuron, and the message continues. Learning and memory use specific neurotransmitters including glutamate, GABA (gamma-aminobutyric acid) and acetylcholine.

Learning and neural pathways

As we re-learn or recall memories, messages are sent between neurons along a specific neural pathway. The more we practise a task, the stronger the neural pathway becomes, allowing faster transmission of messages. Neurons in learning pathways also grow more dendrites. Faster transmission and increased dendrites improve communication between neurons in the neural network. Once these specific pathways are created, the brain can access these to recall information as needed.

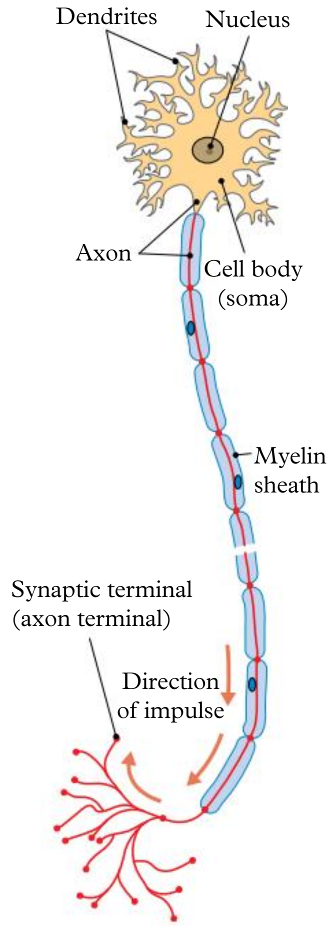


Figure 2 A neuron receives messages via the dendrites, and sends messages via the axon terminal.

hippocampus
a central part of the brain responsible for encoding memories

amygdala
a part of the brain responsible for encoding the emotional part of a memory

cerebellum
a small lobe at the lower rear of the brain responsible for fine motor movement, balance and coordination

neuron
a nerve cell

9.1 Check your learning

Comprehend

1 **Explain** how our brain is central to our understanding of the world.

2 **Describe** two roles of the cerebral cortex.

3 **Describe** why the hippocampus is important in enabling memories to be stored in the cerebral cortex.

4 **Describe** the pathway that electrical signals take through a neuron.

Apply

5 Use an example of a memory you have to **discuss** the role of the hippocampus and amygdala in creating memories.

6 Use a variety of materials to **create** a model of two neurons. Connect the two neurons and **describe** how messages are passed from one to the next.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

9.2 Animals have innate behaviours to survive

Learning intentions

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

- explain that animal behaviours can be innate or learned
- describe imprinting, species-specific behaviours and maturation as examples of innate behaviours.

Key ideas

- Behaviours are innate (due to biological factors) or learned (through experiences in the environment).
- Imprinting, species-specific behaviours and maturation are all examples of pre-programmed behaviours that increase the chance of survival.

innate behaviour
a common behaviour that all members of a species are born with

imprinting
a form of learning where a baby rapidly encodes a memory that identifies a parent or object

species-specific behaviour
a behaviour that is unique to a single species

In psychology, behaviours are often discussed in terms of natural influences (such as our genetics) and the influence of our experiences and environment. Debate around how much these factors affect our behaviour is referred to as nature versus nurture.

A baby bird is born with the potential to fly – this is determined by its genetics (nature). However, it is only through practice and training by its parents that it learns to fly (nurture). Nature and nurture therefore play an important role in animals learning to survive and thrive in their environment.

Figure 1 Ducklings are programmed to imprint on their mother when they hatch. If its mother is not the first thing a duckling sees, it can imprint on another animal.

Pre-programmed behaviour

Innate behaviours are those we are born with; they are determined by our genetics. There are many animal behaviours that are innate. This means that they are born with the potential to behave in ways that do not require experience. Examples of pre-programmed behaviours are imprinting, species-specific behaviours and maturation.

Imprinting

Some baby animals instinctively follow the first moving object they see. For example, a baby duck is programmed to follow its mother as soon as it hatches (Figure 1). It is common to see a group of ducklings pull into line behind the mother duck as they are walking along a riverbank, or when swimming in the water. This behaviour is an adaptation to make sure the ducklings stay with their mother for food and protection. If a baby duckling is exposed to a different object when it is born, such as a human, a dog or even a balloon, this will become the object that the duckling will follow!

This process is known as **imprinting**. The duckling's chances of survival will be greatly increased if it has imprinted on its mother. Imprinting is common in birds such as ducks, geese and turkeys.

Species-specific behaviour

A male bowerbird creates a mound of twigs and sticks as a nest to attract a female. The nest also usually includes blue objects to give him an edge over other males in the competition to attract a mate (Figure 2a). This is a **species-specific behaviour** that is carried out by all male bowerbirds, which increases a male's chance of finding a mate and producing offspring.

Figure 2 a A bowerbird nest decorated with blue **b** A lyrebird dances to attract a mate.

Most animals carry out species-specific behaviours. Spiders spin characteristic webs to trap prey and increase their chances of obtaining food. A male lyrebird will dance and show off with its colourful tail to create a display intended to attract a female for mating (Figure 2b). Short-tailed shearwaters are pre-programmed to fly from Australia to Alaska and back at the same time each year.

Maturation

Some animal behaviours require an animal to reach physical and mental **maturation** to achieve their full potential. For example, a baby magpie is born with the potential to fly, but its body does not have the physical ability to support flight. As the magpie grows, it will learn from its parents how to fly. This is the influence of nature and nurture on learning behaviours. Similarly, a foal will learn to gallop with encouragement from its mother (Figure 3).

maturation
the process of becoming an adult

Figure 3 A foal is born with the potential to walk, and with help from its mother it learns how to run.

9.2 Check your learning

Comprehend

1 **Explain** whether pre-programmed behaviour is a result of nature or the environment.

2 **Describe** how imprinting can increase the chances of survival for a newly hatched family of ducklings.

3 **Describe** the influences of nature and nurture when a baby bird learns to fly.

4 **Explain** why a male bowerbird's nest-building behaviour is a species-specific behaviour.

5 A male lyrebird's mating dance is a species-specific behaviour. **Explain** why it is important for the survival of the species that this is a pre-programmed behaviour.

Analyse

6 **Compare** imprinting and species-specific behaviours.

7 **Classify** the following animal behaviours as examples of imprinting, species-specific behaviours or maturation.

- **a** Herring gull chicks are genetically hard-wired to peck at a red dot on the parents' beak. This action stimulates the parent to regurgitate food to feed the chicks.
- **b** A young penguin relies upon its parents to feed it fresh fish when young, but it eventually has the ability to swim and catch its own fish.
- **c** Farmer Joe has a group of geese follow him around on the farm after he reared them from hatchlings.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

9.3 Animals can learn behaviour from their environment

Learning intentions

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

- explain that learning is a demonstrated change in behaviour as a result of experience
- describe the processes of operant conditioning and classical conditioning.

Key ideas

- Learning is demonstrated by a change in behaviour as a result of experience.
- Operant conditioning is the result of learning through reward or punishment.
- Classical conditioning is the result of learning through association and pairing a reflex response with an environmental stimulus.
- Young animals learn survival and social skills through observation and play.

Figure 1 This chimpanzee has learnt that using the stick can help it find food.

operant conditioning a way of learning that some behaviours result in a reward and other behaviours result in a punishment

Figure 2 Cats may avoid an area if they have been startled by a loud noise.

Although some animal behaviours are pre-programmed, many are learned through experience. Psychologists define learning as a lasting change in the way a living organism behaves as a result of previous experience.

In their natural habitats, animals learn through observing or through training from their parents. Animals can also be trained by humans through rewards. Some ways in which animals can change their behaviour through their environment are operant conditioning, classical conditioning and observational learning.

Operant conditioning

Animals survive in their environment by learning from the consequences of their actions; this type of learning is **operant conditioning**. If an echidna finds a feast of ants in a specific ant nest, it will repeatedly visit the nest to keep getting the positive consequence of a desirable food source. When a behaviour is followed by a desirable outcome it is more likely to be repeated. This is known as **positive reinforcement**. Consider the following examples of animals learning because of positive reinforcement:

> Dogs quickly learn that a ball is fun. They will also realise that the faster they return the ball to their owner, the more often it will be thrown for them to chase and collect. In a similar way, dogs can be taught to sit, roll over and shake hands, as they expect it will lead to a reward.

> A chimpanzee can learn that poking a stick into a termite mound will enable it to more easily reach the food source that lives within (Figure 1).

Animals can also learn through operant conditioning to avoid repeating behaviours that in the past have resulted in a negative consequence. This is known as **punishment**.

> A cat that has been frightened by a loud noise in the garage may avoid that area to reduce the chances of another negative consequence (Figure 2).

Classical conditioning

One of the simplest forms of learning is **classical conditioning**. This type of learning was first observed in the early 1900s by Russian physiologist Ivan Pavlov. He was measuring the salivation effect in dogs when he observed that they not only salivated when given food, but also when they heard a bell or a whistle that was used just before the food was about to arrive. Pavlov was amazed to learn that he could teach the dogs in his laboratory to salivate when a bell was sounded through repeated trials of sounding a bell just before presenting food.

In Pavlov's experiment, the way the dogs salivated was an innate **reflex response**. They did not have to learn how to salivate.

The bell is referred to as an **environmental stimulus**; it was the external sensory information that triggered the reflex.

It is now a well-observed phenomenon that animals can be taught to associate an innate reflex response with an environmental stimulus that it has been repeatedly exposed to.

Common reflex responses that can be conditioned in this way are excitement, salivation and fear.

Figure 3 demonstrates how Pavlov observed classical conditioning. Pavlov observed that a dog salivates (a reflex response) in anticipation of receiving food. He then discovered that you could condition a dog, by pairing a bell with food, so that the dog would salivate when hearing a bell, as the dog has now repeatedly associated the bell (an environmental stimulus) with food.

Observational learning

Animals, including humans, can also learn behaviours by observing and imitating the adults (and other people) in their life. Young monkeys will intently watch their elders to learn how to perform a range of tasks including grooming, making and using tools, and locating food sources. Primates commonly live in social groups, and learn about communication and social skills by watching their elders. Young primates learn how to behave by watching whether their elders are positively reinforced or punished for their actions. This helps them learn what social behaviours are appropriate. This type of learning is called **observational learning**.

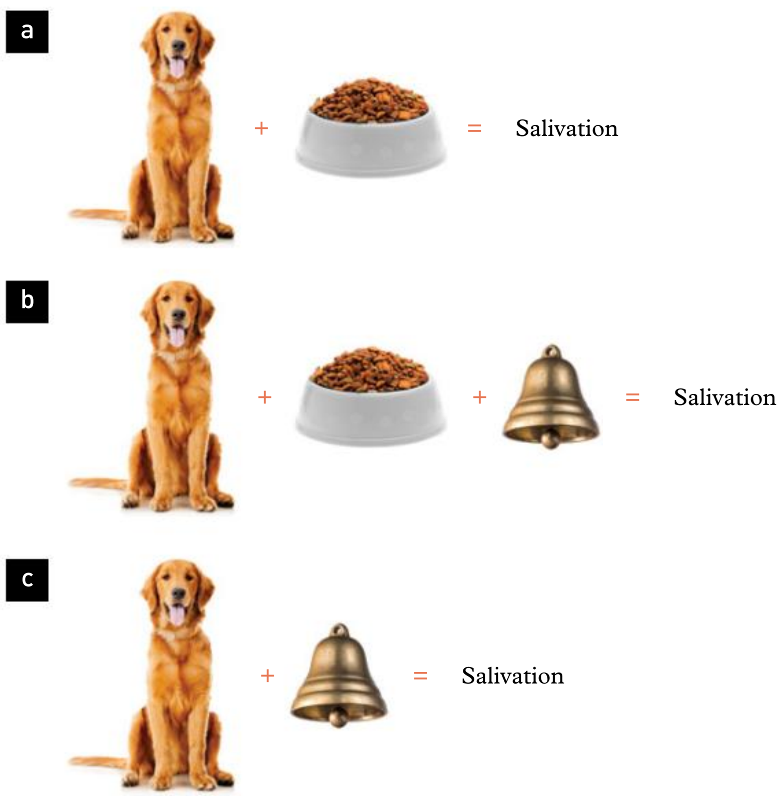


Figure 3 **a** Before classical conditioning, the dog salivates when it sees its food. **b** During conditioning, the dog pairs the sound of a bell with food and salivates. **c** The dog salivates when it hears the bell because it has associated the bell with food.

9.3 Check your learning

Retrieve

1 **Define** the term 'learning'.

Comprehend

2 **Describe** how learning occurs through operant conditioning.

3 Use an example to **describe** observational learning.

Apply

4 **Identify** which type of learning (operant conditioning, classical conditioning or observational learning) matches the following scenarios. **Justify** your answer for each response (by comparing the definition of the term to the scenario).

a Birds will readily learn where a feeder is placed in a garden, as it provides them with a desirable food source.

b A girl may avoid dogs because she was once bitten by a dog and now feels frightened every time she sees one.

c A girl plays with a dress-up box, dressing in high-heel shoes and pretending to put on make-up, just as she has seen her mother do.

5 **Identify** which type of learning (positive reinforcement or punishment) matches the following scenarios. **Justify** your answer for each response.

a Buzz the cocker spaniel loves visiting the vet because every time he does, he is given a treat.

b Sammy is sent out of the classroom by the teacher because the teacher wants him to learn not to misbehave in class.

Quiz me

Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

positive reinforcement
a positive result or consequence of a behaviour

punishment
a negative result or consequence of a behaviour

classical conditioning
a learned behaviour that is linked to a previously neutral stimulus

reflex response
a behaviour that does not have to be learnt

environmental stimulus
sensory information from the environment (sound, smell, feel) that can start a behaviour

observational learning
when an animal learns from watching others

9.4 Information must be effectively encoded and stored for it to be recalled

Learning intentions

By the end of this topic, you will be able to:
- explain the processes of encoding, storage and retrieval
- describe the differences between sensory memory, short-term memory and long-term memory.

Key ideas
- Memory relies on three processes: encoding, storage and retrieval.
- Sensory memory enables information from the environment to be encoded for processing in the brain.
- Short-term memory is where information is held while we are using it.
- Long-term memory is where we store information that we can access later.

encoding
the act of information moving into our memory

storage
the ability to keep information in the brain

retrieval
the act of taking a memory out of storage

sensory memory
the ability of our senses to store a specific memory

echoic memory
auditory memory that decays after a few seconds

iconic memory
visual memories that decay in less than 1 second

Processes of memory

When we remember our favourite song, we have stored it in our memory and then retrieved it into our conscious awareness. This process involves three stages: encoding, storage and retrieval.

Encoding

Encoding is required to convert information detected by our senses into a form that our brain can understand. When the receptors in our inner ear detect the vibrations in the air created by a guitar, they convert the physical energy of the sound wave into an electrochemical message that can be transmitted throughout our nervous system.

Storage

Once information is encoded, it can be stored in our short-term memory and then long-term memory. **Storage** is essential for us to have access to it later.

Retrieval

When we recall information from our memory stores into our conscious awareness, we use the process of **retrieval**.

Types of memory

There are three types of memory, and each plays an important role in encoding, storage and retrieval. These types of memory were described by psychologists Atkinson and Shiffrin (1968) as 'a multi-store model of memory'.

The store includes sensory memory, short-term memory and long-term memory. Table 1 compares the three types of memory.

Sensory memory

Our senses have the ability to briefly store memories. But not all **sensory memory** is transferred to short-term memory. It is only the stimuli that we pay attention to that are encoded and transferred to short-term memory.

For example, when we focus our attention on the sounds of a guitar, those sounds are held briefly before being encoded and transferred to short-term memory. Other sounds detected by our auditory sensory memory at that time but of which we were not aware will fade or decay – anything not paid attention to will not be sent for storage.

Our auditory or **echoic memory** has a duration of only 3–4 seconds before it decays (Figure 1) – unless we have paid attention to it for encoding to occur. Have you ever asked someone to repeat what they have said, but then remembered what they said before they could repeat themselves? Echoic memory allows you to access this sensory information (sound) a few seconds after you heard it.

Similarly, visual or **iconic memory** has a duration of 0.3 seconds. Information that we pay attention to will be transferred to short-term memory.

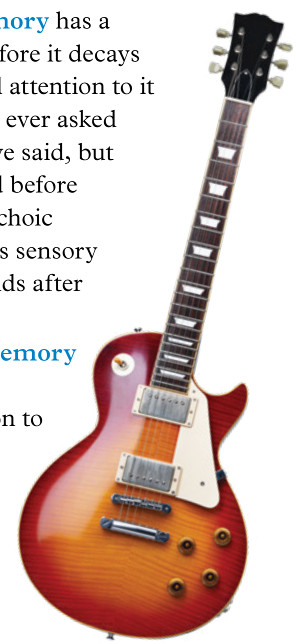


Figure 1 Our sensory memory can only hold the sounds of a guitar for 3–4 seconds.

Short-term memory

Short-term memory (STM) is where we hold information while we process or manipulate it. This may be while we're doing a maths equation, or using words as we read or write in a sentence. Once we have held or used this information, we can hold it in our short-term memory for up to 30 seconds before we either discard it or transfer it to our long-term memory. Our short-term memory can hold between five to nine items at any one time for a duration of 12–30 seconds.

When we consciously retrieve information from our long-term memory, we bring it into our STM, making this memory store the one in which we actually use new or previously stored information.

Long-term memory

Long-term memory (LTM) is our memory store. It holds information for a virtually unlimited period of time and at a virtually unlimited capacity! Certain memories can be strengthened if they are retrieved more often. Similarly, memories not accessed frequently may become weaker. Memories are stored throughout the cerebral cortex, including the cerebellum.

Long-term memory also stores ideas, facts, images and skills in connected areas of the brain, enabling the awareness of a stimulus such as the word 'kookaburra', which can trigger the image of a kookaburra in the brain and the memory of a kookaburra's laugh.

This is because information is stored in long-term memory in **semantic networks**. Semantic networks are frameworks that link information by meaning in our brain. Information in our long-term memory is therefore organised according to meaning. Everyone's individual brain allocates different meaning to information; therefore, long-term memory is organised uniquely for everyone (Figure 2). For example, when you see a horse, you might also think of cows and chickens, because your brain links horses to farms. However, when your friend sees a horse, they might think of a zebra and a donkey, because their semantic network links horses with similar-looking animals.

short-term memory (STM)
a type of memory where we can hold information while we use it or before we transfer it to long-term memory

long-term memory (LTM)
memory that stores information for an unlimited period of time

semantic networks
a framework that links information in our brain

Table 1 Comparison of duration and capacity for different memory types

Memory type	Duration	Capacity
Sensory memory	3–4 seconds (echoic memory) 0.3 seconds (iconic memory)	Unlimited
Short-term memory	12–30 seconds	5–9 items
Long-term memory	Unlimited	Unlimited

9.4 Check your learning

Comprehend

1 **Describe** the roles of encoding, storage and retrieval as processes involved in memory.

2 **Describe** the role of sensory memory.

3 **Describe** the role of short-term memory.

4 Use the terms 'semantic networks' and 'meaning' to **explain** how memories are stored in long-term memory.

Analyse

5 **Compare** the different types of memory (sensory, STM and LTM) in terms of their capacity and duration.

6 **Contrast** echoic and iconic sensory memories.

7 **Identify** the type of memory we would be using if we were focusing on the words as we read a sentence. **Identify** the type of memory we would be using if we were trying to recall the meaning of a word.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

Figure 2 We may associate a kookaburra with birds, Australia, morning or a sports team based on the organisation of semantic networks.

9.5 Memory and learning can be improved

Learning intentions

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

- explain how mnemonics can improve short-term memory capacity and long-term memory stores.

Key ideas

- Mnemonics can be used to improve the capacity of short-term memory.
- Mnemonics can increase long-term memory by strengthening neural networks in the brain.
- Mnemonics can improve retrieval of information from long-term memory by adding meaning.

neuroscience
the study of how the brain works to improve learning and memory

mnemonic
a learning strategy of using a song, rhyme or visual image to help in the encoding, storage and recall of a memory

To understand ways of improving memory and making our learning more effective, we need to apply our knowledge of how the brain works to enable learning and memory. This is also known as the **neuroscience** of learning and memory.

A **mnemonic** is a learning strategy that can improve our ability to store and retrieve information. Mnemonics can come in the form of a song, a rhyme, a story, a visual image or words. The following examples illustrate ways in which our memory can be improved.

Increasing short-term memory

Short-term memory (STM) has a limited capacity of five to nine items and only lasts for 12–30 seconds. However, there are strategies that can increase the capacity and duration of short-term memory.

Chunking

We can group individual items together into a 'chunk' to increase the number of items we can hold in STM.

For example, when given a string of 16 numbers to recall, the features of STM suggest we will not be able to hold all the numbers at one time, as the total exceeds nine items. This is like trying to squeeze 16 shoes into a small box – they are not going to fit! However, if we group those numbers into smaller 'chunks' that are easier to recall, we reduce the number of items to be remembered and increase our ability to keep this information in STM. For example, the number 196220212984 can be chunked into four smaller items, 196 220 212 984, that can be much easier to recall (Figure 1).

Maintenance rehearsal

We can increase the amount of time we hold information in STM by rehearsing it (repeating it over and over). For example, to hold a mobile phone number or someone's name in our STM, we can repeat it over and over.

Figure 1 By 'chunking' information we can make it easier to remember long numbers, such as mobile phone numbers.

EXPERIMENT

9.5: Improving memory recall
Go to page **285**.

Increasing long-term memory

Memories with meaning are more likely to be recalled and stored in long-term memory. Meaning can be added by **elaborative rehearsal**. This improves encoding from STM to LTM, and it connects information that is being learned with information already learned.

Elaborative rehearsal enables us to make more connections between memories stored in our cerebral cortex – the more connections we have, the easier it is to access stored information. Elaborative rehearsal strengthens our neural pathways within our semantic networks and therefore strengthens our capacity for recall. The elaborative rehearsal strategies shown in Table 1 can increase the effectiveness of our long-term memory.

elaborative rehearsal
a memory technique that involves thinking about the meaning of the term to be remembered

Table 1 Strategies to increase the effectiveness of long-term memory

Strategy	How it works
Acronyms	An acronym is an abbreviation formed from the first initial of words. For example, FPOT is a useful acronym to recall the lobes of the brain from front to back: F = frontal lobe, P = parietal lobe, O = occipital lobe, and T = temporal lobe.
Acrostics	The initials of words are used to create a novel phrase or poem. For example, 'Every Good Boy Deserves Fruit' is a useful phrase when learning to read music for the notes that fall on lines. The initials of these words (EGBDF) are the notes represented by the lines on the treble.
Rhymes	Repeating a rhyme assists recall. For example, 'i before e, except after c' helps with spelling.
Chaining	We create a story that connects words to be recalled in order; the more entertaining or strange the story is, the more likely we are to recall it. For example, to recall the words, taco, cat, tomato, bucket and cheese, we could create the following story: Taco the cat jumped on a giant tomato, which squirted the bucket, as he said 'cheese'. In this way, the words can be recalled in their correct order.
Visualisation	This strategy links meaningful images with items to be remembered. A 'mental walk' strategy requires a learner to visualise a room they are familiar with, and to imagine walking around that room in a specific order, observing different items along the way. The learner then mentally walks through this room, attaching items to be recalled along the way using a visual image of the item. For example, to recall the word 'elephant', the learner could visualise a pink elephant sitting on their bedside table. Again, the more humorous an image is, the more likely it is that it will be stored (Figure 2).

9.5 Check your learning

Comprehend

1 Use an example to **describe** mnemonics.

2 **Explain** how the use of mnemonic strategies can improve short-term memory.

3 **Describe** why elaborative rehearsal can improve our ability to recall from long-term memory.

Analyse

4 **Compare** chunking and maintenance rehearsal.

5 **Compare** an acronym and an acrostic.

Apply

6 Use ideas from this topic to **justify** the following statement: 'Mind maps are a useful tool for improving your ability to recall the key ideas in this chapter on learning and memory.'

7 **Create** your own acrostic for recalling the five different mnemonic strategies for improving long-term memory as listed in Table 1.

Quiz me
Complete the Quiz me to check how well you've mastered the learning intentions and to be assigned a worksheet at your level.

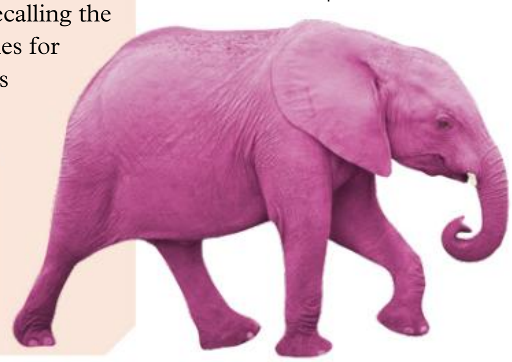


Figure 2 When trying to remember something, the more unusual the image you conjure up is, the more it can help!

//SCIENCE AS A HUMAN ENDEAVOUR//

9.6 Neuroimaging makes memory and learning visible

Learning intentions

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

- explain the difference between MRI, fMRI and PET imaging
- describe how neuroimaging assists scientists with understanding how memory and learning works.

Neuroimaging technology has provided greater understanding of memory and learning processes in the brain. The use of functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) scans allows scientists to see how areas of the brain function as a subject (human or animal) undertakes a task. Ideas about the brain continue to evolve as neuroimaging provides greater understanding of how areas of the brain are interconnected.

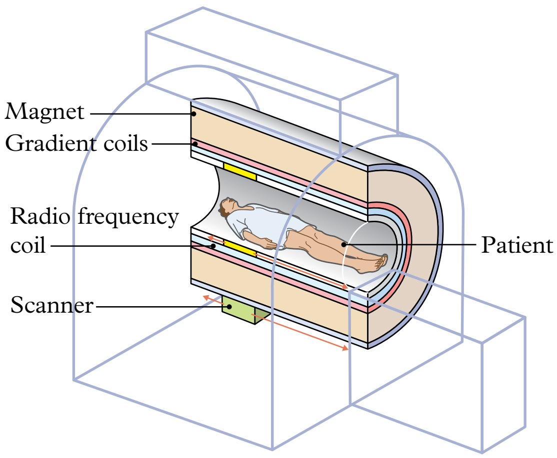


Figure 1 An MRI scanner

The more sophisticated neuroimaging technology becomes, the more neuroscientists have realised that original assumptions about how the brain functions were very simplistic. **Neuroimaging** is the process of creating images of brain structures or brain activity.

The first neuroimaging equipment was available in the 1970s and was called computerised tomography (CT). This invention enabled doctors and scientists to see beyond the skull, to the inner structures of the brain. Prior to CT scans, researchers had to rely upon observing the brains of patients who had died. This provided information about the physical structure of the brain but did not provide much insight into how it worked.

Today there are different types of neuroimaging techniques.

Magnetic resonance imaging

Magnetic resonance imaging (MRI) uses a very strong magnetic field and radio waves to produce highly detailed images of both surface and deep brain structures. It produces three-dimensional (3D) images that scientists use to distinguish between normal and abnormal brain structures (Figure 2a). It also allows scientists to identify memory-related structures, such as the hippocampus, amygdala, cerebellum and cerebral cortex.

neuroimaging
the creation of an image of brain structures or brain activity

magnetic resonance imaging (MRI)
the use of magnetic fields and radio waves to produce detailed images of organs and tissues of the body

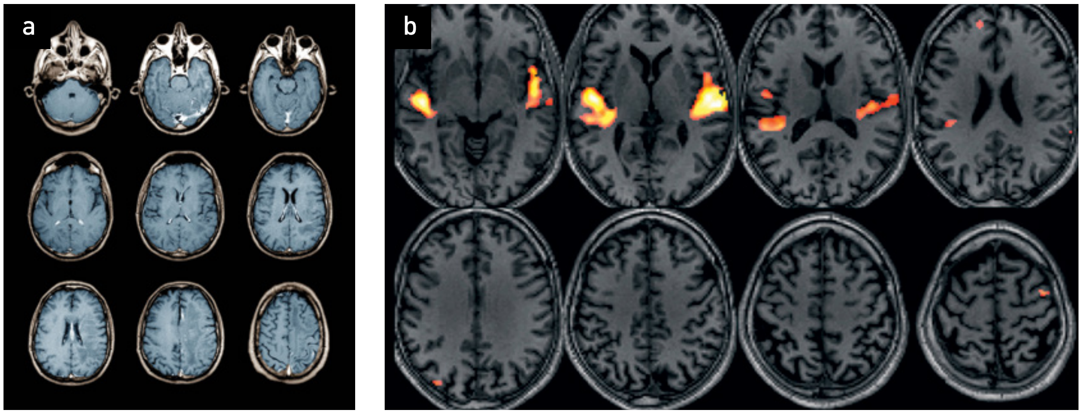


Figure 2 **a** MRI scans show 3D images of the brain. **b** fMRI scans show the activity patterns of the brain.

MRI scanners don't provide a moving image, so they do not provide information about a working brain. Therefore, MRI is limited in explaining how memory and learning occur.

Functional magnetic resonance imaging

Functional magnetic resonance imaging (fMRI) also uses a strong magnetic field to take images of the brain, but this technique has the added advantage of showing areas of the brain that are working or functioning in real time (Figure 2b). Researchers can detect changes in oxygen levels and blood flow when neurons are processing or working to carry out a task. This has been important in revealing the areas of the brain that are working while a patient is thinking, learning a task or recalling information from memory.

Positron emission tomography

Positron emission tomography (PET) detects neurons that are using radioactive glucose as they function to carry out a process. As the neurons in an area of the brain work to think, learn or recall, they require energy in the form of glucose – this is tracked to identify the areas involved in these processes. A coloured 'map' is produced in real-time – the most active areas show up as red, while the less active areas show up as blue (Figure 3).

Recent evidence from PET and fMRI scans demonstrates the interconnectedness of different areas of the brain in undertaking specific functions such as memory and learning.

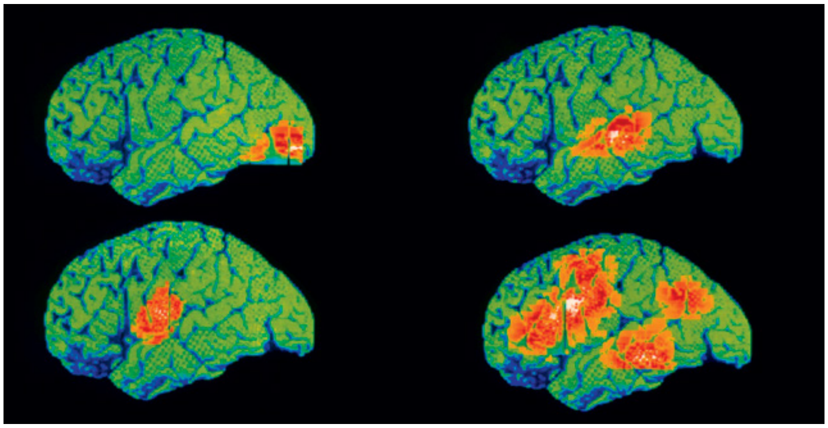


Figure 3 PET scans show brain activity in particular areas.

As the technology becomes more sensitive and informative, it is helping researchers to better understand the more specific subregions of the brain where specific tasks occur.

There is a rapidly expanding body of research on human memory because of improved neuroimaging techniques. PET and fMRI scanning of both typical and atypical brains (in patients with injured or diseased brains) has increased our knowledge of what memory is and how it works. These techniques provide a greater understanding of how memories are organised, how we store information as a memory, and how we access memories that have been stored so we can retrieve them and use them later.

We continue to revise our understanding of human learning and memory processes, as older theories are shown to be much too simplistic for what current neuroimaging methods are revealing. These methods have also revealed that thinking, learning and memory processes have a neurobiological basis, involving changes in the function of neurons and neural networks.

functional magnetic resonance imaging (fMRI)
the use of magnetic fields to show high blood flow in areas of the brain

positron emission tomography (PET)
the use of radioactive glucose to produce an image of the highly active areas of the brain

9.6 Test your skills and capabilities

Describing validity

The use of fMRI and PET scans to identify potential areas of the brain that are not functioning normally has increased rapidly in recent years. While these tests are useful in identifying possible damage to parts of the brain, they are unable to identify what people are thinking. Each person stores their memories in slightly different ways. Some people remember the smell of a particular food, whereas other people remember where they were or who they were with when they ate the food. This means different parts of their brain will be active when asked to think about that food. Instead, the researchers scan the brain of the participant when they are deliberately thinking about the food. This pattern of brain activation can then be used to identify when the participant is thinking about the food next time.

1 Use critical thinking to **describe** the validity of the following tests.
   a Comparing the fMRI image of a person before and after concussion.
   b Comparing the PET images of two sisters to determine whether one sister has a better memory than the other.
   c Using an fMRI image to identify whether a person has Alzheimer's disease.

CHAPTER 9 REVIEW

LEARNING AND MEMORY

Retrieve

1 **Identify** the word missing from the following statement. The ___________ is responsible for encoding memories into the cerebral cortex so that they can be recalled at a later time.
   A amygdala
   B cerebellum
   C hippocampus
   D frontal lobe

2 **Identify** the correct statement about short-term memory.
   A has unlimited capacity
   B has a duration of 12–30 seconds
   C converts raw sensory energy into electrochemical signals
   D is a relatively permanent memory store

3 **Recall** which type of learning features the use of consequences such as rewards and punishment.
   A species-specific behaviours
   B classical conditioning
   C operant conditioning
   D innate learning

4 **Identify** each of the following statements as true or false.
   a Operant conditioning is a type of learning influenced more by nature than by nurture.
   b Classical conditioning is a type of learning shaped by consequences.
   c Punishment and positive reinforcement are examples of learning through consequences.
   d Observational learning allows young monkeys to learn about socially appropriate behaviour.

5 **Name** the three types of memory.

Comprehend

6 **Define** the term 'neural pathway'. **Explain** why it is important in learning.

7 Copy and complete Table 1 to **summarise** the key roles of the four lobes of the brain.

Table 1 Lobes of the brain and their key roles

Lobe	Key role
Frontal lobe	
Occipital lobe	
Temporal lobe	
Parietal lobe	

8 **Describe** the role of genetics in pre-programmed behaviours.

9 **Describe** how encoding, storage and retrieval each contribute to the processing of memories.

10 **Describe** the role of short-term memory.

11 **Describe** the role of long-term memory.

12 **Describe** an example of a mnemonic strategy. **Identify** the type of memory it can enhance.

13 **Explain** how mnemonic strategies can improve:
   a short-term memory
   b long-term memory.

14 **Describe** the strategy known as 'maintenance rehearsal', and **explain** how it can improve our recall of key words stored in short-term memory.

15 **Explain** how the hippocampus and cerebral cortex work together when creating memories.

16 **Describe** two roles of the cerebral cortex.

17 **Explain** why a light stimulus must be encoded in order for our brain to understand what we have seen.

18 **Explain** how imprinting can enhance the survival of newborns.

19 Drawing on your own observations, **illustrate** a species-specific behaviour.

20 **Summarise** classical conditioning, with reference to Ivan Pavlov's experiments.

21 **Summarise** the three types of memory.

22 **Explain** why short-tailed shearwaters flying between south-west Victoria and Alaska is a species-specific behaviour. **Describe** why it is important for the species for this behaviour to be genetically pre-programmed.

Analyse

23 **Contrast** imprinting and species-specific behaviour.

24 Katia is learning gymnastics. **Identify** the area of her brain that will store the memory of the actions for her gymnastic routines.

25 Trung is using the map on his GPS (global positioning system) to identify the direction he is to travel. **Identify** the lobe of the brain that will play a key role in this task.

26 Tex recalls an occasion when he was frightened by a large dark shape at the window when home alone.
   a **Identify** which structure in his brain has encoded the fear associated with this memory.
   b **Identify** which structure has encoded the details of the event not associated with the emotion.

c **Explain** why Tex experiences the emotion of fear when he recalls the memory of this event.

27 **Identify** the following animal behaviours as examples of imprinting, species-specific behaviours or maturation.

a All golden orb spiders make sticky wheel-shaped webs out of golden threads.

b Human babies will crawl before they stand and then walk as their bodies become physically able to carry out the actions.

28 **Identify** your own example of an animal behaviour that would be described as:

a species-specific behaviour

b maturation.

29 **Contrast** positive reinforcement and punishment.

30 **Identify** one similarity and one difference between:

a positive reinforcement and punishment

b operant conditioning and classical conditioning

c operant conditioning and observational learning.

31 **Compare** the capacity and the duration of echoic and iconic sensory memories.

32 **Compare** maintenance rehearsal and elaborative rehearsal.

33 **Compare** chunking and chaining.

Apply

34 Copy and complete Table 2 by **developing** examples from your own experiences. An example has been provided for you.

Table 2 Examples of different types of learning

Type of learning	Initial behaviour	Specific consequence	Influence on behaviour
Positive reinforcement	Keeping bedroom tidy	Praise from parents	Always keeps room tidy
Positive reinforcement			
Punishment			
Observational learning			

35 **Determine** which type of learning (positive reinforcement or punishment) matches the following scenarios. **Justify** your answer for each response.

a Ducks in the park will readily swim to the edge of the lake when children visit because the ducks know they are likely to be fed.

b A child fell out of a tree and broke her arm, so now she chooses not to climb trees.

36 **Determine** the reflex response and the environmental stimulus in the following classical conditioning scenario.

A dingo that eats a sheep carcass laced with poison will feel nauseated. This means it will learn to avoid sheep in the future.

37 **Determine** which type of memory we would be using if we were adding up the prices of three items at the supermarket.

38 **Discuss** the roles of both nature and nurture in enabling animals to survive and thrive in their environment.

39 **Determine** whether classical conditioning or operant conditioning would be the best method for training a seal to balance a ball on its nose. **Justify** your choice.

40 **Discuss** how learning is different from a pre-programmed behaviour. **Elaborate** on how both influences on behaviour might be an advantage to the survival of an animal species.

41 **Create** a poster with a mind map or diagram explaining how sensory memory, short-term memory and long-term memory interact.

42 **Create** a story using the strategy of chaining to recall the following 10 terms in order: dog, beach, fire truck, koala, beach towel, fire, window, balloon, bucket, sun. Rehearse your story, then mentally revisit your list and write the key terms in order.

Figure 1 Can you remember the words, like koala, in order?

Social and ethical thinking

43 Imagine you were offered the opportunity to take a smart pill that would improve your memory. **Consider** whether you would take the pill. **Describe** the reasons for making your decision. **Identify** three questions that you would want answered before making your choice. **Discuss** the ethical issues that could possibly arise as a result of taking such a pill.

Critical and creative thinking

44 'Neurotypical' is a word that describes a person who does not display any unexpected thought patterns or behaviour. People who are neurotypical often assume that the way they experience the world is identical to other people's experiences. **Discuss** why this assumption could not be true.

45 In 2009, scientists performed an fMRI scan on a dead salmon's brain. They found that the activity in the salmon's brain appeared to change during this single test. **Discuss** why it is important to repeat fMRI scans several times before drawing a conclusion about the activity of the brain.

Research

46 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

» Neurotransmitters in memory

Investigate the actions of the neurotransmitters glutamate and GABA at the synapse in a neural pathway.

» How are they similar?
» How are they different?
» How do they contribute to the process of learning?

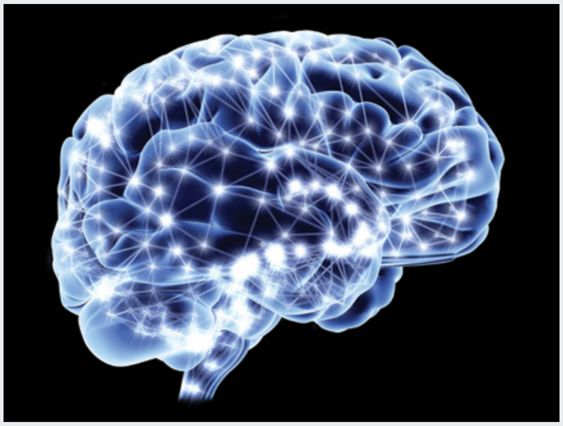


Figure 2 Neurotransmitters carry messages across the neural pathway of the brain.

» How does shaping help learning?

Define the term 'shaping'. Describe how shaping is used and why it is a successful method for teaching animals more complex behaviours.

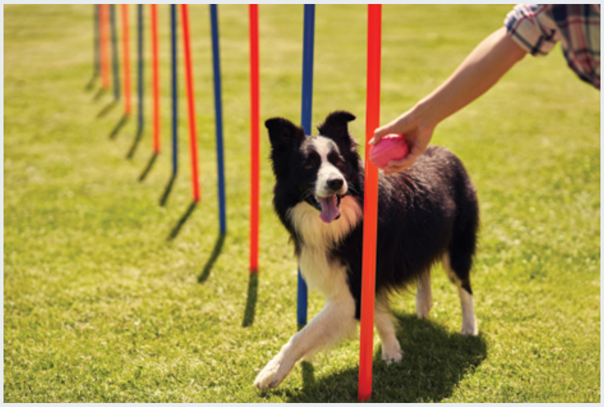


Figure 3 Shaping is likely to have contributed to this dog's agility training.

» Increasing learning

Maintaining a good diet and healthy sleep habits are important for effective learning.

» Investigate tips for advising a teenager on how to help their brain to function effectively.
» Include reasons why diet and sleep are important for a healthy brain.
» Suggest strategies for including healthy eating and sleep habits as part of a regular routine.

Figure 4 Healthy sleep habits are important for effective learning.

Chapter checklist

Now that you have completed this chapter, reflect on your ability to do the following.

	I can do this.	I cannot do this yet.
• Identify the structure of a neuron. • Explain how neurons relay information from our senses to our brain. • Identify and explain the role of each of the four lobes of the cerebral cortex. • Recall that memories are stored in specific areas of the cerebral cortex.	☐	☐ Go back to Topic 9.1 'The brain is responsible for learning and memory'. Page 210
• Explain that animal behaviours can be innate or learned. • Describe imprinting, species-specific behaviours and maturation as examples of innate behaviours.	☐	☐ Go back to Topic 9.2 'Animals have innate behaviours to survive'. Page 212
• Explain that learning is a demonstrated change in behaviour as a result of experience. • Describe the processes of operant conditioning and classical conditioning.	☐	☐ Go back to Topic 9.3 'Animals can learn behaviour from their environment'. Page 214
• Explain the processes of encoding, storage and retrieval. • Describe the differences between sensory memory, short-term memory and long-term memory.	☐	☐ Go back to Topic 9.4 'Information must be effectively encoded and stored for it to be recalled'. Page 216
• Explain how mnemonics can improve short-term memory capacity and long-term memory stores.	☐	☐ Go back to Topic 9.5 'Memory and learning can be improved'. Page 218
• Explain the difference between MRI, fMRI and PET imaging. • Describe how neuroimaging assists scientists with understanding how memory and learning works.	☐	☐ Go back to Topic 9.6 'Science as a human endeavour: Neuroimaging makes memory and learning visible'. Page 220

Check your Student obook pro for these digital resources and more:

pro

Quizlet
Play a Quizlet game to test your knowledge.

Chapter quiz
Check your understanding of this chapter with the chapter review quiz.

CHAPTER

10

EXPERIMENTS

SCIENCE LAB RULES

Being safe in the lab is essential to prevent you and others from getting hurt. Whenever you are in the lab, you must always follow the rules below.

DO:

- wear a lab coat for practical work
- keep your workbooks and paper away from heating equipment, chemicals and flames
- tie long hair back whenever you do an experiment
- wear safety glasses while mixing or heating substances
- tell your teacher immediately if you cut or burn yourself
- tell your teacher immediately if you break any glassware or spill chemicals
- wash your hands after any experiments
- listen to and follow the teacher's instructions
- wear gloves when your teacher instructs you to.

DON'T:

- run in a laboratory
- push others or behave roughly in a laboratory
- eat in a laboratory
- drink from glassware or laboratory taps
- look down into a container or point it at a neighbour when heating or mixing chemicals
- smell gases or mixtures of chemicals directly; instead, waft them near your nose and only when instructed
- mix chemicals at random
- put matches, paper or other substances down the sink
- carry large bottles by the neck
- enter a preparation room without your teacher's permission.

2.1 Extracting DNA

EXPERIMENT

CAUTION! Ethanol is flammable – do not use near ignition sources. Minimise vapours. Wear safety glasses, lab coat and gloves. Keep hands, clothing and hair away from the sharp blades of the blender.

Aim

To extract a sample of DNA from peas.

Materials

Part A

- 100 g dried peas soaked overnight in 2 cups of water, or frozen peas (thaw first)
- 200 mL water
- 6 g table salt
- 20 mL dishwashing liquid
- 1 g meat tenderiser
- Measuring cylinder
- Blender
- 1 L beaker
- Sieve
- Stirring rod or spoon
- Timer

Part B

- Ice-cold ethanol (stand a sealed bottle containing 200 mL ethanol in a metal bowl of ice water for an hour prior to using)
- Methylene blue stain (liquid)
- Test tubes and test-tube rack or 50 mL beakers
- Skewer or glass stirring rod (toothpick for vials)
- Microscope
- Clean microscope slides and cover slips

Method

Part A

1 Dissolve the salt in the water.
2 Combine the peas and salty water in a blender. Mix for 15 seconds to form a lumpy liquid in which the peas are only just broken up. Do not overblend the mixture.
3 Pour the contents through a sieve into the 1 L beaker. Discard the pulp in the sieve.
4 Add the dishwashing liquid and stir the mixture gently to avoid making bubbles. Stir for 8 minutes.
5 Add the meat tenderiser and continue to stir gently for another 2 minutes.
6 This is your prepared DNA source.

Part B

1 Pour 15 mL of the DNA source into a test tube or a 50 mL beaker. There should be enough of this mix for eight test tubes or beakers, which can be shared in the class.
2 Dribble 15 mL of ice-cold ethanol down the side of the test tube or beaker – there should be equal amounts of filtrate and ethanol in the test tube or beaker.
3 Leave the test tube or beaker to allow the mixture to separate into layers. This will take at least 10 minutes. The alcohol will eventually settle on top of the watery pea mixture. DNA is less dense than water and should float up into the alcohol layer, leaving the other cellular components behind.
4 When the mixture has separated completely, use a stirring rod to gently twirl and twist the DNA to collect it from the alcohol layer (Figure 1). DNA is white in colour.

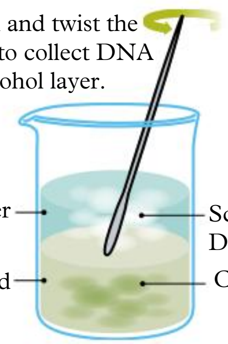


Figure 1 Procedure for collecting DNA from the alcohol layer

5 Put a small amount of the DNA sample onto a glass slide. Gently spread the DNA mixture. Add 1 drop of methylene blue stain to the DNA mixture. Place the cover slip on the edge of the methylene blue and allow it to fall into place. This should eliminate any air bubbles.
6 Look at your sample under ×10 magnification. Once you have focused the microscope, you can then try the higher magnifications using the fine focus knob to focus. You will not see the double helix strands, but you should see clumps of DNA material that may look like a tangled mass of strands.

Results

Construct a flow chart of the method by drawing a labelled diagram of each step.

Draw a labelled diagram of the microscope's view, with several short statements explaining your observations.

Discussion

1 Briefly describe the appearance of the DNA under the microscope. Explain why you cannot see the double helix.
2 Compare the DNA of the peas with human DNA.
3 Describe the role of each of the additives (dishwashing detergent, meat tenderiser and alcohol) in isolating the DNA from the cells.
4 Identify and describe the materials that would remain in the watery layer of the pea mixture.

Conclusion

Describe the function of DNA in peas.

2.2 Modelling the structure of DNA

CHALLENGE

Aim

To construct a model of DNA that shows the complementary bases arranged in a double helix.

What you need:

4 long pipe cleaners (2 different colours), 24 beads (6 different colours: colour 1 = phosphate; colour 2 = sugar; colour 3 = adenine; colour 4 = thymine; colour 5 = cytosine; colour 6 = guanine)

What to do:

1 Choose two pipe cleaners of the same colour.
2 On each pipe cleaner, thread beads with alternating phosphate beads and sugar beads (i.e. colour 1, colour 2, colour 1, colour 2, etc.). Leave about 2 cm of space between each bead. This represents the sugar–phosphate backbone of DNA molecules (Figure 1).

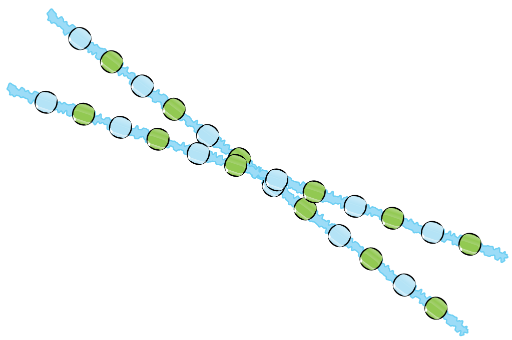


Figure 1 Representation of the sugar–phosphate backbone of DNA molecules

3 Cut the remaining two pipe cleaners into 5 cm segments. These will be used to create the paired nitrogen bases A-T and G-C.
4 Choose the two bead colours that represent the adenine and thymine nitrogen bases. Thread one of each bead onto half of the cut pipe cleaner strands.
5 The remaining bead colours represent guanine and cytosine. Thread these two beads onto each of the remaining cut pipe-cleaner strands (Figure 2).

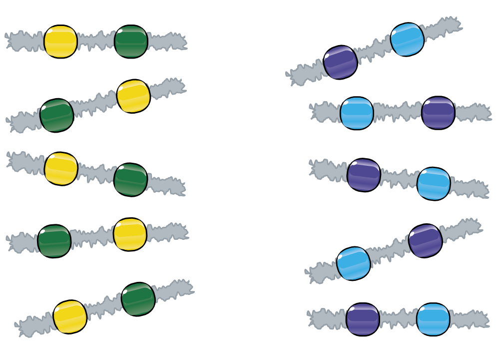


Figure 2 Representation of paired nitrogen bases A-T and G-C

6 Lie the two sugar–phosphate backbones down so that they are parallel. The colour 1 beads (phosphate) should be opposite the colour 2 beads (sugar) on the other strand.
7 Attach the short pipe cleaner segments with the nitrogen bases onto the backbone of the DNA molecule. Make sure each nitrogen base strand is attached next to a sugar (colour 2) bead. You should have formed a ladder-like structure with the A-T and G-C nitrogen bases as the rungs of the ladder.
8 Twist your ladder so that it forms a double helix structure (Figure 3).

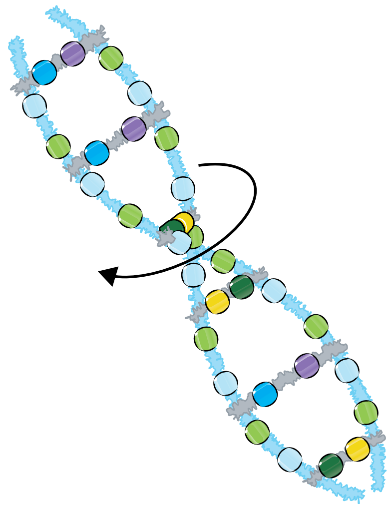


Figure 3 Representation of the DNA double helix structure

Discussion

1 Identify the bead colour that represents the nitrogen bases:
   a adenine
   b thymine
   c guanine
   d cytosine.
2 Explain what is meant by the term 'sugar–phosphate backbone'.
3 Identify what the letters DNA represent.
4 Describe a 'double helix'.
5 Identify the base that is complementary to:
   a adenine
   b guanine.
6 Identify the type of bond that holds the nitrogen bases A-T or G-C together.

2.4 Making protein

SKILLS LAB

Aim

To model the production of protein from DNA.

A section of a DNA sequence made from a particular gene is shown here:

T A C T T A G A G A T G C T G A C T

1 Write the complementary sequence of DNA for this part of the gene.
2 Transcription: If the strand shown is the template strand of the gene, write the mRNA sequence that would be made. (Remember to use uracil instead of thymine.)
3 Translation: Break the mRNA strand into groups of three. Each group is called a codon. Using the genetic code in Figure 1, write down the amino acids that the sequence codes.
4 Describe how the protein strand would change if the twelfth nucleotide in the DNA template strand (guanine) was changed to a thymine.

Discussion

1 Compare the genetic code of DNA (ATGC) with a chromosome.
2 Contrast (the differences between) DNA and RNA.
3 Evaluate the effect of a nucleotide changing from guanine to thymine (by describing how the DNA sequence will change, describing how the mRNA strand will change, and describing how the protein strand will change).

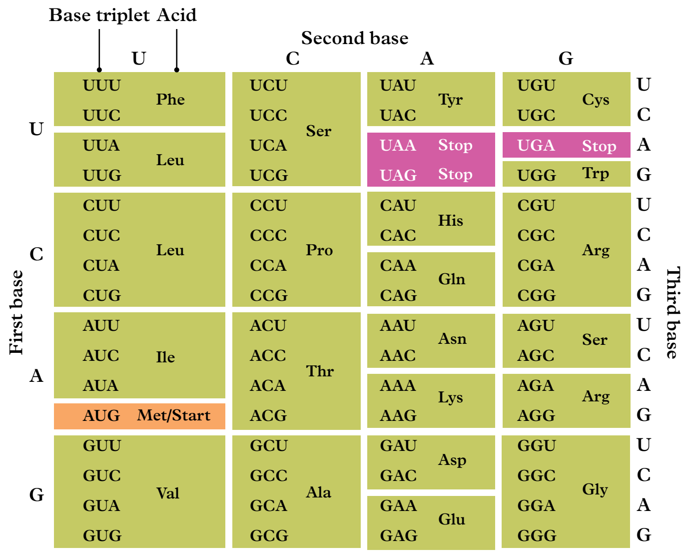


Figure 1 The entire genetic code was deciphered by 1966, and scientists now understand which amino acid is coded for by each codon. There are three stop codons and one start codon.

2.5 Cell division in action

SKILLS LAB

Aim

To identify cells undergoing different stages of mitosis.

What you need:

Prepared microscope slide (or slides) showing tissue that is in the process of growth and development, light microscope

Alternatively, you could prepare your own slides from the growing root tips of a plant, such as garlic or spring onion.

What to do:

1. View a slide under the microscope at the greatest magnification possible.
2. In your field of view, identify the cells that are in interphase and those that are undergoing the phases of mitosis (prophase, metaphase, anaphase and telophase).
3. Sketch at least four cells undergoing different stages of cell division. Remember the conventions for drawing biological images under the microscope. Clearly label all the components within the cell that you can identify correctly.

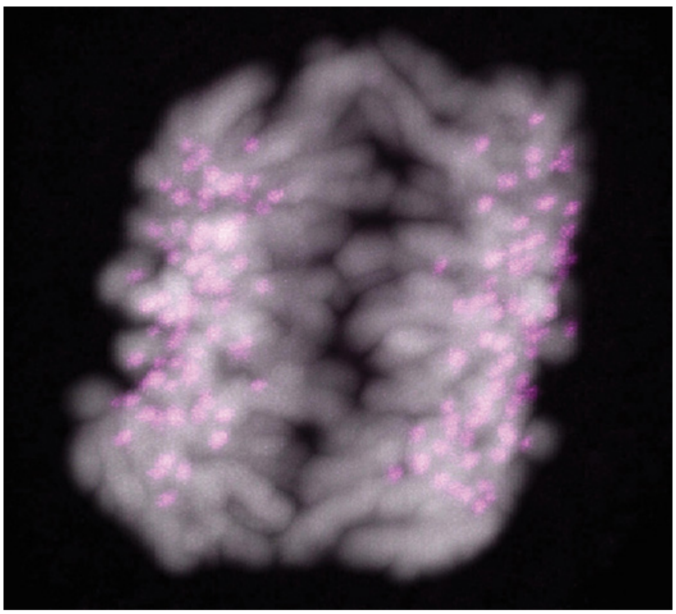


Figure 1 These human chromosomes are in one of the phases of mitosis.

Discussion

1. Explain why DNA can be difficult to see under the microscope during interphase.
2. Describe an advantage of DNA being tightly wound around a protein during mitosis.
3. Describe the possible consequences for a cell if errors occur during the process of DNA replication that occurs during interphase.
4. Describe an advantage of cellular mitosis for an organism.

2.6 Modelling meiosis

CHALLENGE

Aim

To model the stages of meiosis.

What you need:

Pipe cleaners, sticky tape, felt-tipped pens, A4 sheet of paper

What to do:

1. Draw the outer membrane of a cell on the sheet of paper.
2. Cut a pipe cleaner in half and place both halves in the centre of the cell. These represent two single chromosomes in a cell starting meiosis.
3. Cut a second pipe cleaner in half and twist each half around the centre (centromere) of the first duplicated chromosomes.
4. Place the two chromosomes in the centre of your cell. Identify the phase of meiosis that this represents.
5. Move each chromosome to opposite ends of your cell, keeping the twisted centromeres intact. Identify the phase of meiosis that this represents.
6. Turn the paper over and draw two cells half the size of the original cell.
7. Place one chromosome in the centre of each cell. Identify the phase of meiosis that this represents.
8. Untwist the two pipe cleaners and move them to the opposite ends of each cell. Identify the phase of meiosis that this represents.
9. Draw a line down the centre of each cell. Identify the phase of meiosis that this represents.
10. Draw a labelled picture of each stage that you demonstrated with the pipe cleaners. Include:
    - the phase name
    - labels for the nuclear membrane, centromeres and single/duplicated chromosomes
    - a description of what is happening at each stage.

Discussion

1. Contrast the number of chromosomes in a cell before and after it undergoes meiosis.
2. Define the following terms.
    a. haploid
    b. diploid
    c. gamete
3. Explain why gametes need to be haploid.
4. Explain the process of meiosis.

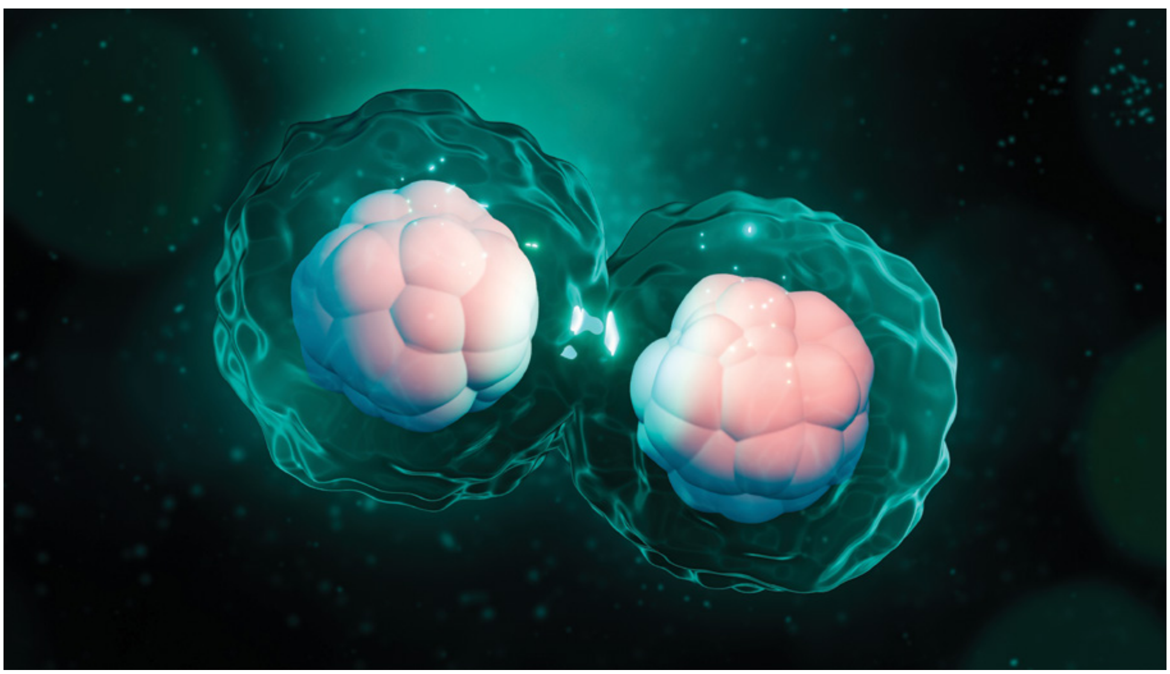


Figure 1 Can you identify this stage of meiosis?

2.7 Zazzle genetics

EXPERIMENT

CAUTION! Do not eat or drink in the laboratory.

Aim

To demonstrate the role of alleles in determining the phenotype of an individual.

Materials

- A bag containing 6 different coloured counters
- Permanent marker
- Toothpicks
- Pipe cleaners
- Large pink and white marshmallows
- Small marshmallows
- Blue and black felt-tipped pens

Figure 1 Zazzles

Method

1 Choose a counter from the bag. Use the permanent marker to draw an 'A' on one side and an 'a' on the other side. This represents the inheritance of a long antenna (A) or a short antenna (a) from the parent.

2 Flip the counter once. The letter that is showing on the upper side represents the allele that is passed on to your baby Zazzle from the father. Write your results in Table 1.

3 Use a second counter to represent two body segments (L) or one body segment (l). Flip the counter to determine which allele is passed on from the father. Write your result in the table.

4 Use three of the remaining counters to represent the following characteristics of the father, and write your results in the table.
   - four eyes (E) or two eyes (e)
   - straight tail (T) or curly tail (t)
   - one hump (H) or two humps (h)

5 Repeat steps 1–4 to determine the alleles passed from the mother to your baby Zazzle.

6 The final counter is used to determine the sex of your Zazzle. The mother has two X chromosomes. This means she can only pass on an X chromosome to your Zazzle baby. To determine which sex chromosome is passed from the father to your baby Zazzle, draw an 'X' on one side of the counter and a 'Y' on the other. Flip the counter. You have now determined the sex of your Zazzle. A girl (XX) will have a pink marshmallow body. A boy (XY) will have a white marshmallow body.

7 Determine the phenotype of your Zazzle.

8 Use the materials to construct your Zazzle.

Results

Copy and complete Table 1.

Table 1 Alleles inherited from the parent

Chromosome	Trait and letter representing it	Allele donated by father	Allele donated by the mother	Phenotype of baby Zazzle
1	Antenna (A or a)			
2	Body length (L or l)			
3	Eyes (E or e)			
4	Tail (T or t)			
5	Hump (H or h)			
6	Sex (X or Y)		X	

Discussion

1 Identify whether this activity is a case study, modelling/simulation, quantitative analysis or a controlled experiment. Justify your reasoning (by identifying the key characteristics of the activity and comparing these with the definition of the term you chose).

2 Identify the number of chromosomes present in each of the:
   a mother's somatic (non-gamete) cells
   b father's gametes
   c baby Zazzle cells.

3 Identify your baby Zazzle's genotype for each trait.

4 Identify the dominant trait for each of the Zazzle genes.

5 Explain why the baby Zazzle has two alleles for each trait.

6 Compare the definitions of phenotype and genotype.

7 Draw a diagram or take a photo of your baby Zazzle.

Conclusion

Describe how dominant traits and recessive traits are inherited.

2.8 Blood typing experiment

EXPERIMENT

CAUTION! Wear safety glasses, lab coat and gloves when working with chemicals.

Aim

To determine the inheritance of blood groups.

Materials

- Anti-A solution (2 M hydrochloric acid solution)
- Anti-B solution (2 M sulfuric acid solution)
- Sample blood O (deionised/distilled water)
- Sample blood A (0.1 M silver nitrate solution)
- Sample blood B (0.1 M barium nitrate solution)
- Sample blood AB (a 50 : 50 mix of 0.1 M silver nitrate and 0.1 M barium nitrate solution)
- Spotting tiles
- 6 pipettes, one for each solution
- 6 toothpicks

Method

1. Place two drops of sample blood O in the first wells of two rows of your spotting tile (Figure 1).
2. Using a fresh pipette, place two drops of sample blood A in the second wells of your spotting tile.
3. Repeat for the remaining blood samples.
4. Add a drop of anti-A solution to each of the wells in the first row of your tile.
5. Add a drop of anti-B solution to each of the wells in the second row of your tile.
6. Use a different toothpick to carefully mix each well.
7. If the red blood cells react with the anti-A or anti-B, it will form small clumps in the well. Record your observations ('+' for clumps; '–' for no clumps) in Table 1.

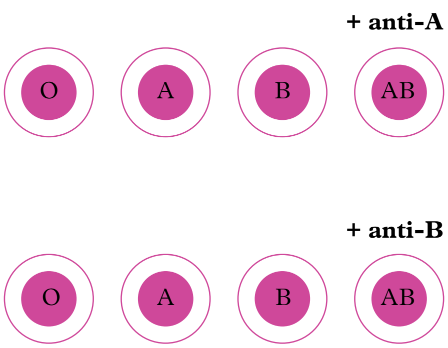


Figure 1 Where to place blood samples on the spotting tile

Results

Copy and complete Table 1.

Table 1 Results from the blood typing experiment

	Sample blood O	Sample blood A	Sample blood B	Sample blood AB
Anti-A				
Anti-B				

Discussion

1. Define the term 'co-dominance'.
2. Identify the possible genotype, or genotypes, of the following phenotypes.
   a. person with blood group A
   b. person with blood group B
   c. person with blood group AB
   d. person with blood group O
3. Identify the alleles that a person with type AB blood could pass on to their children.
4. Identify whether a person with blood group AB could have a child with blood group O. Justify your answer (by identifying the genotype of a person with blood type AB, identifying the genotype of a person with blood type O, describing how a parent passes on an allele to a child, and deciding whether an AB parent could have an O child).
5. A girl with blood group O claimed that she must have been adopted, because her mother's blood group is A and her father's blood group is B. Outline how you would explain to her that it is possible to be blood type O with type A and type B parents.

Conclusion

Describe how blood group is inherited.

2.9 Colour-blindness inheritance

EXPERIMENT

Aim

To examine the inheritance of X-linked traits.

Materials

- 2 counters
- Permanent marker

Li is colour blind (X^bY) and would like to start a family with Maria. Maria is not colour blind but knows that she is heterozygous (X^BX^b) for the trait as her father is colour blind.

Method

1 On one counter, write X^b on one side and Y on the other.
2 On the second counter, write X^b on one side and X^B on the other.
3 Toss the counters eight times and record the possible genotypes of Li and Maria's children in Table 1.

Results

Copy and complete Table 1.

Table 1 Possible genotypes of Li and Maria's children

Coin toss	Genotype of child
1	
2	
3	
4	
5	
6	
7	
8	

Discussion

1 Identify the number of girls and boys that Li and Maria had in your experiment.
2 Identify the number of children who were colour blind. Identify the number of children who had normal vision.
3 Contrast the number of girls and boys who had colour blindness.
4 Evaluate whether non-colour-blind parents can have a colour-blind son (by using a Punnett square to support your answer).
5 Evaluate whether a non-colour-blind daughter can have a colour-blind father.
6 Evaluate whether two colour-blind parents can have a non-colour-blind son.
7 Many parents think that if they have three daughters first, they are more likely to then give birth to a boy. Evaluate this idea (by describing how the sex of offspring is determined, describing the law of segregation, and describing the probability of inheriting an X or Y chromosome in each generation).

Conclusion

Explain how colour blindness is inherited.

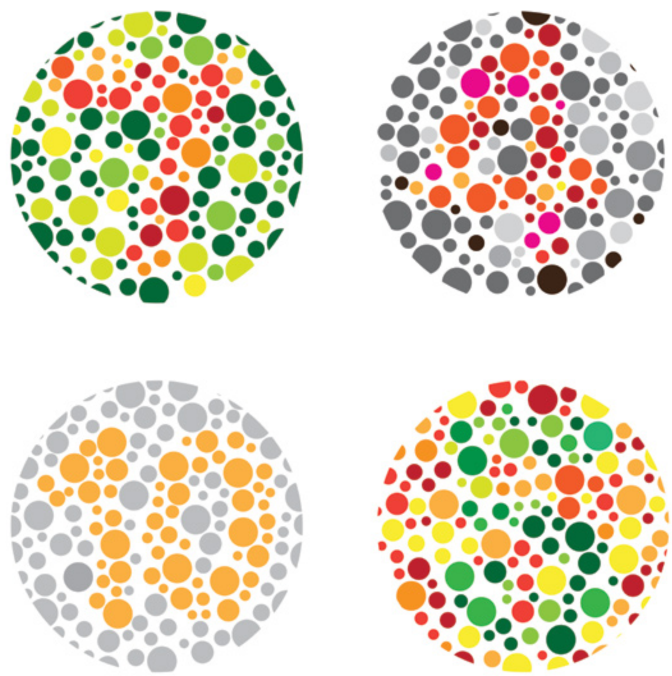


Figure 1 The Ishihara colour test uses coloured dots to identify whether a person is colour blind. The dots in each of these pictures are arranged to represent a number.

2.11 Identifying mutations

SKILLS LAB

Aim

To identify how a mutation in a DNA sequence can cause a disease.

1 A normal RNA sequence is shown as follows, together with two different genetic mutations.

> Normal
AUG ACG CAG AAU UGG GAU CCU ACG

> Mutation 1
AUG ACA CAG AAU UGG GAU CCU ACG

> Mutation 2
AUG AGC AGA AUU GGG AUC CUA CG

a Identify the type of mutation represented in each case. Justify your answer (by describing the mutation and comparing the type of mutation with its definition).

b Describe the outcome of mutation 1 on protein synthesis. You may wish to consult the codon table in Figure 1.

c Describe the outcome of mutation 2 on protein synthesis.

2 Genetic Creutzfeldt–Jacob disease (CJD) is caused by an abnormal protein called PrPc. This protein is formed because of a mutation in the *PrPc* gene on chromosome 20 and occurs in DNA base triplet 200 in the gene's sequence (Table 1).

Table 1 Genetic Creutzfeldt–Jacob disease is caused by a single nucleotide mutation.

DNA base triplet number	199	200	201
Normal gene	TGG	CTC	CAA
Mutated gene	TGG	TTC	CAA

a Identify the type of mutation.

b Describe the amino acid change that would occur in the PrPc protein.

c Distinguish between natural and induced mutation.

Discussion

1 Compare the definitions for mutation and mutagen.

2 Identify three types of mutagens.

3 Evaluate which type of mutation (substitution or deletion) has the greatest impact on the protein produced by a gene (by describing what happens in a substitution mutation, describing what happens in a deletion mutation, comparing how each change affects the reading frame, comparing how each change affects the final protein, and deciding which change most affects the protein).

First base	Second base: U	C	A	G	Third base
U	UUU Phe	UCU Ser	UAU Tyr	UGU Cys	U
U	UUC Phe	UCC Ser	UAC Tyr	UGC Cys	C
U	UUA Leu	UCA Ser	UAA Stop	UGA Stop	A
U	UUG Leu	UCG Ser	UAG Stop	UGG Trp	G
C	CUU Leu	CCU Pro	CAU His	CGU Arg	U
C	CUC Leu	CCC Pro	CAC His	CGC Arg	C
C	CUA Leu	CCA Pro	CAA Gln	CGA Arg	A
C	CUG Leu	CCG Pro	CAG Gln	CGG Arg	G
A	AUU Ile	ACU Thr	AAU Asn	AGU Ser	U
A	AUC Ile	ACC Thr	AAC Asn	AGC Ser	C
A	AUA Ile	ACA Thr	AAA Lys	AGA Arg	A
A	AUG Met/Start	ACG Thr	AAG Lys	AGG Arg	G
G	GUU Val	GCU Ala	GAU Asp	GGU Gly	U
G	GUC Val	GCC Ala	GAC Asp	GGC Gly	C
G	GUA Val	GCA Ala	GAA Glu	GGA Gly	A
G	GUG Val	GCG Ala	GAG Glu	GGG Gly	G

Figure 1 The codon table

2.14 Edible genetic engineering

CHALLENGE

CAUTION! Do not eat or drink in the laboratory.

Aim

To model how insulin is genetically engineered.

What you need:

1 packet of lolly snakes, 1 packet of sour worm lollies

What to do:

1 Carefully remove a small amount from the end of one lolly snake and stick the ends together so they form a loop. You have formed a plasmid of DNA.

2 Obtain one sour worm. This is your insulin gene. Carefully remove a small amount off the ends of your insulin gene and insert it into your plasmid to form a larger circle. You have created a recombinant plasmid with DNA from a different organism.

3 Draw a picture of your plasmid. Label the plasmid and the introduced gene.

4 Describe how you could clone your insulin plasmid in a bacterial cell.

Discussion

1 Define the term 'plasmid'.

2 Explain why insulin is needed by some members of the community.

3 Before genetic engineering was possible, pig insulin was often used. Explain why genetically engineered human insulin is preferable (by considering the way the immune system would respond to pig insulin and comparing this with the way the immune system would react to insulin produced by a human gene).

Figure 1 In this challenge, sour worm lollies are used to form a plasmid.

3.2 What if the habitat of bean prey was changed?

EXPERIMENT

Aim

To examine the selection pressures involved in hunting prey.

Materials

- Paper cups
- Tools: knives, forks, spoons, sticky tape, plastic gloves
- Bean prey: dried red butted beans (kidney beans), long-toothed yellow beans, panther-toothed black beans, wicked white beans
- Timer

Method

1. Divide the class into five groups. Each group represents a separate tribe.
   - The Knife tribe can only use knives to hunt beans.
   - The Spoon tribe can only use spoons to hunt beans.
   - The Hand tribe are allowed to use their hands to hunt beans.
   - The Sticky-tape tribe can only use sticky tape to hunt beans.
   - The Glove tribe should wear plastic gloves to hunt beans but they must turn the thumb of their glove inside out so they cannot use their opposable thumb.
2. On a section of grass, randomly spread out 20 of each bean type.
3. Each tribe has 10 seconds to collect as many beans as they can. Record the data in an appropriate table, as shown in the Results section.
4. The two tribes with the least beans collected become extinct and must sit out the next round.
5. Each bean left on the grass will breed. This means the number of beans remaining on the grass will double. For example, if 6 white beans were collected, then 14 remain, and you need to add another 14 white beans to the area. Repeat with the other three colours.
6. Repeat for two further generations so that only one tribe is left.

Inquiry

What if the habitat of bean prey was changed?

- Write a hypothesis (If … then … because …) for your inquiry.
- Identify the (independent) variable that you will change from the first method.
- Identify the (dependent) variable that you will measure and/or observe.
- Identify two variables that you will need to control to ensure a valid test. Describe how you will control these variables.
- Identify the materials that you will need for your experiment.
- Write down the method you will use to complete your investigation in your logbook.
- Draw a table to record your results.
- Show your teacher your planning for approval before starting your experiment.

Results

Copy and complete Table 1 to record your results for generation 1.

Table 1 Results for generation 1

	Knife tribe	Spoon tribe	Hand tribe	Sticky-tape tribe	Glove tribe	Totals
Red-butted beans						
Long-toothed yellow beans						
Panther-toothed black beans						
Wicked white beans						
Totals						

Create two more tables for the next two generations.

Discussion

1. Identify the tribes that became extinct first. Describe the selection pressures that contributed to their extinction.
2. Explain why the bean prey numbers doubled after each generation.
3. Identify the beans that were selected against in the first generation.
4. Use the mechanism of natural selection to explain the change in bean prey numbers.
5. Identify a similar example to this experiment that might occur in nature.

Conclusion

Describe how the mechanism of natural selection changes the frequency of alleles in a population.

3.3 Divergent and convergent evolution of big beaks and small beaks

EXPERIMENT

CAUTION! Do not eat or drink in the laboratory.

Aim

To model divergent and convergent evolution in beak size.

Materials

- 6 previously prepared bags of food:
  - North Trayland/Season 1 = 4 handfuls popcorn + 20 kidney beans + 50 marbles
  - North Trayland/Season 2 = 1 handful popcorn + 10 kidney beans + 50 marbles
  - North Trayland/Season 3 = 100 marbles
  - South Trayland/Season 1 = 4 handfuls popcorn + 20 kidney beans + 50 marbles
  - South Trayland/Season 2 = 6 handfuls popcorn + 10 kidney beans + 5 marbles
  - South Trayland/Season 3 = 8 handfuls popcorn
- 20 large bulldog clips
- 20 medium-sized bulldog clips
- 20 small bulldog clips
- 30 plastic cups
- 2 large trays
- 6 plastic bags
- Timer

Method

1. Twelve students will represent a population of birds living on an island. Four students are Giant birds (with a large bulldog clip each). Four students are Midbill birds (with a medium-sized bulldog clip each). The remaining four students are Babybill birds (with a small bulldog clip each)
2. A permanent barrier separates the bird population into two groups (North Trayland and South Trayland), with two birds of each type (2 Giant birds, 2 Midbill birds and 2 Babybill birds) in each. Place the trays at opposite ends of the classroom.
3. Place the first season's food for each population in the tray. The 12 birds have 25 seconds to collect as much food as possible with their bulldog-clip 'beaks' and place it in their cup 'stomachs'.
4. At the end of the time, calculate how many kilojoules each bird has consumed if popcorn = 2 kilojoules, beans = 5 kilojoules, and marbles = 10 kilojoules. Table 1 shows how many kilojoules each type of bird needs to survive.

Table 1 Kilojoules needed by each type of bird

Bird	Kilojoules needed to survive	Kilojoules needed to reproduce
Giant	80	160
Midbill	50	100
Babybill	25	50

5. Birds that do not collect enough kilojoules to survive must leave the island and sit down. Record the number of surviving birds in Tables 2 and 3.
6. If a surviving bird has collected enough kilojoules to reproduce, they should choose another student (who is not already a bird) to be their baby (with the same-sized beak). If a bird has collected enough kilojoules to survive but not enough to reproduce, they continue in the next round but do not have a 'baby'.
7. Remove any remaining food from the trays and place it back into the plastic bags. Place the food for season 2 in each tray. Repeat steps 3–6.
8. Remove any remaining food from the trays and place the food for season 3 in each tray. Repeat steps 3–6.
9. Clean up any remaining food.

Results

Copy and complete Tables 2 and 3.

Table 2 North Trayland

Bird	Before isolation	Season 1	Season 2	Season 3
Giant	2			
Midbill	2			
Babybill	2			

Table 3 South Trayland

Bird	Before isolation	Season 1	Season 2	Season 3
Giant	2			
Midbill	2			
Babybill	2			

Discussion

1. Identify if this activity is a case study, modelling/simulation, quantitative analysis or a controlled experiment. Justify your reasoning (by identifying the key characteristics of the activity and comparing these with the definition of the term you chose).
2. Explain why the starting population of each bird did not have a single bird of each Bill type.
3. Describe what happened to the North Trayland population of birds after they were isolated from South Trayland for three generations.
4. Describe what happened to the South Trayland population of birds after they were isolated from North Trayland for three generations.

Conclusion

Use the terms 'natural selection' and 'selection pressures' to explain the type of evolution that occurred between the two species.

3.4 Popcorn dating

EXPERIMENT

CAUTION! Do not eat or drink in the laboratory.

Aim

To determine the absolute date of an unknown sample of popped popcorn.

Materials

- Previously prepared bags of microwave popcorn (unbuttered):
  - Bag A: stop microwave 10 seconds after first pop (record the actual time)
  - Bag B: stop microwave 30 seconds after first pop (record the actual time)
  - Bag C: stop microwave 10 seconds after last pop (record the actual time)
  - Bag D: mystery fossil bag (your teacher will have microwaved this bag for a time between bag A and bag C)
- 4 large trays

Method

1. Open bag A and count how many corn kernels have popped and how many have not popped.
2. Determine the percentage of popped kernels using the following equation.

$$\text{Percentage of popped kernels} = \frac{\text{number of popped kernels}}{\text{total number of kernels}} \times 100$$

3. Repeat steps 1 and 2 with bags B and C.
4. Graph the percentage of popped kernels against the time spent in the microwave oven.
5. Repeat steps 1 and 2 with bag D. Use your graph to determine how long bag D was in the microwave oven.

Results

Copy and complete Table 1, and draw a graph of your results.

Table 1 Results from the experiment

Bag	Time in the microwave	Number of popped kernels	Number of un-popped kernels	Percentage of popped kernels
A				
B				
C				
D				

Discussion

1. Define the term 'half-life'.
2. Calculate the half-life of your popcorn kernels.
3. Identify how long the mystery bag D was heated in the microwave.
   a. Compare your answer with that of other students.
   b. Compare your answer with the actual time provided by your teacher.
4. Explain why the relative age of a fossil is always a range of years (e.g. 350–450 years ago) rather than a single date (401 years ago).
5. Evaluate the accuracy of this model of a half-life (by describing how a half-life is used to determine the age of fossils, comparing this description with the popcorn model, and deciding whether the model was an accurate representation).

Conclusion

Explain how radioactive materials are used to determine the absolute age of fossils.

3.6 Who is my cousin?

EXPERIMENT

Aim

To determine the evolutionary relationship between different species.

Materials

> DNA sequences, listed below
- Hippo AGTCCCCAAAGCAAAGGAGACTATCCTTCCTAAGCATAAAGAAATGCCCTTCTCTAAATC
- Giraffe AGTCTCCAAATGAAAGGAGACTATGGCTCCTAAGCACAAAGAAATGCCCTTCCCTAAATA
- Rhino AGTCCTCCAAACTAAGGAGACCATCTTTCCTAAGCTCAAAGTTATGCCCTCCCTTAAATC
- Pig AGATTCCAAAGCTAAGGAGACCATTGTTCCCAAGCGTAAAGGAATGCCCTTCCCTAAATC
- Cow AGTCCCCAAATGAAAGGAGACTATGGTTCCTAAGCACAAGGAAATGCCCTTCCCTAAATA

Method

1 Compare the DNA sequences with each other and determine the number of differences between each pair.

2 Write your results in Table 1.

Results

Copy and complete Table 1 to show the number of differences between the animals' DNA sequences.

Discussion

1 a Identify the animal that has the least number of differences in DNA sequence when compared with a cow.

b Describe what this suggests about the evolutionary relationship between these two animals.

2 a Identify the animal that has the most number of differences in their DNA sequence when compared with a cow.

b Describe what this suggests about the evolutionary relationship between these two animals.

3 Use your answers to questions 1 and 2 to complete the phylogenetic tree in Figure 1.

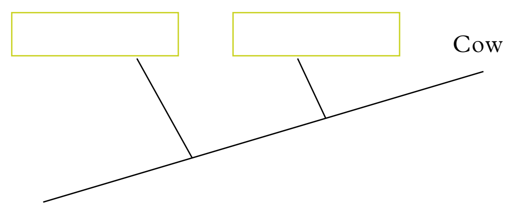


Figure 1 Phylogenetic tree

4 Evaluate the repeatability and reproducibility of this activity (by defining the terms 'repeatability' and 'reproducibility', describing the similarity of DNA between different organisms of the same species, explaining how these similarities or differences affect the repeatability and reproducibility, and deciding whether the activity is repeatable and reproducible).

Conclusion

Describe how DNA sequences can be used to determine the evolutionary relationships between different organisms.

Table 1 Comparison of molecular differences in DNA sequences between animals

Hippo				
Cow				
Giraffe				
Rhino				
	Pig	Hippo	Cow	Giraffe

3.7 Selective breeding of dogs

CHALLENGE

Aim

To examine how selective breeding for chosen characteristics can develop a new breed of dog.

What you need:

Counter, permanent marker

What to do:

1 You are a scientist who studies small mammals in the bush. You need a dog to find and retrieve the mammals without causing them unnecessary stress. This will allow you to tag and release the mammals. Table 1 shows a list of possible traits of dogs.

Table 1 Possible traits of dogs

Trait	Desired form			
Trainability	High	Moderate	Low	Any
Temperament	Vicious	Friendly	Timid	Any
Bark	Very loud	Moderate	Quiet	Any
Coat colour	Black	Brown	Caramel	Any
Hair length	Long	Moderate	Short	Any
Smell	High ability	Moderate	Low ability	Any
Sight	High ability	Moderate	Low ability	Any
Hearing	High ability	Moderate	Low ability	Any
Speed	Fast	Moderate	Low	Any
Endurance	High	Moderate	Low	Any

2 Identify which two traits are most important for your new breed to inherit.

3 Using Table 2, choose which dogs you need to breed to achieve your desired traits.

4 Choose dogs to be the mother and the father. Write an 'M' for mother on one side of the counter and an 'F' for father on the other side of the counter.

5 Flip the counter for each trait. If it lands with the 'M' side up, then the puppy will inherit the mother's trait. An 'F' indicates that puppy inherits the father's trait. Write your results in Table 3.

6 Flip the counter three times for each trait because each pair will have three puppies.

Results

Copy and complete Table 3.

Table 3 Results from the experiment

Trait	Puppy 1	Puppy 2	Puppy 3
Trainability			
Temperament			
Bark			
Coat colour			
Hair length			
Smell			
Sight			
Hearing			
Speed			
Endurance			

Discussion

1 Explain why all three puppies were not identical.

2 Identify the puppy best suited to your original needs. Justify your answer (by comparing the two original traits that you identified with the traits of the puppy you chose).

3 If you were to breed the dogs for another generation, identify the puppies you would select to be the parents. Justify your answer.

4 Evaluate whether your puppies are a new species (by defining the term 'species', comparing your definition with your puppies, and deciding whether they are a new species).

5 Evaluate whether your chosen traits would be beneficial to the species (by describing your chosen traits, explaining how each of these traits would affect the survival of your puppy without humans, and deciding whether each trait would be beneficial to the survival of the species).

Conclusion

Explain how selective breeding can affect the survival of a species.

Table 2 Traits of different dog breeds

Breed	Animo	Bax	Coota	Dallie	Enos	Favious
Trainability	Moderate	Moderate	High	Low	Moderate	High
Temperament	Timid	Timid	Vicious	Timid	Friendly	Vicious
Bark	Moderate	Very loud	Moderate	Quiet	Very loud	Moderate
Coat colour	Black	Brown	Caramel	Caramel	Black	Brown
Hair length	Long	Moderate	Long	Short	Moderate	Long
Smell	High ability	Moderate	Low	Low	Moderate	High
Sight	Moderate	Moderate	Moderate	High	High	Low
Hearing	High ability	Moderate	Moderate	High	High	Moderate
Speed	Moderate	Fast	Fast	Fast	Low	Moderate
Endurance	Low	Moderate	High	Moderate	High	Low

3.8 Selecting for sickle cell anaemia

EXPERIMENT

Aim

To examine how malaria selects for sickle cell anaemia.

Materials

- 75 dried red kidney beans (These are the sex cells carrying 'H', the unaffected normal haemoglobin allele.)
- 25 white beans (These are the sex cells carrying 'h', the affected sickle cell allele.)
- 5 containers
- Coin or counter (for flipping heads or tails)
- Permanent marker

Method

1. Place all the beans in a container and mix them thoroughly. This container represents the total 'gene pool' of your population.
2. Label the remaining containers:
   - HH: No sickle cell disease
   - Hh: No sickle cell disease
   - hh: Sickle cell disease
   - Dead
3. Without looking, randomly select two beans from the gene pool. This represents the two alleles that are present in a baby of the next generation.
4. Flip the coin to determine whether the baby catches malaria. Heads means the baby is infected; tails means it does not become infected. Use Table 1 to determine whether the individual lives or dies.

Table 1 The possible consequences of the genotype for sickle cell disease

Alleles present (bean colour)	Presence of sickle cell anaemia?	Heads – infected with malaria	Tails – not infected with malaria
HH (red – red)	No sickle cell anaemia Susceptible to malaria	Individual dies. Place beans in dead container.	Individual lives. Place beans in HH container.
Hh (red – white)	No sickle cell anaemia Resistant to malaria	Individual lives. Place beans in Hh container.	Individual lives. Place beans in Hh container.
hh (white – white)	Sickle cell anaemia	Individual dies. Place beans in dead container.	Individual dies. Place beans in dead container.

5. Repeat steps 3 and 4 until the gene pool is empty.
6. Record your results in Table 2.
7. Place all the survivors in HH and Hh back into the gene pool and continue breeding for a second and third generation.
8. Combine the class results to ensure that you have a large sample size.
9. Determine the percentage of each allele present in each generation from the following formulas:

$$\text{Percentage of H alleles present} = \frac{\text{number of red kidney beans}}{\text{total number of beans}} \times 100$$

$$\text{Percentage of h alleles present} = \frac{\text{number of white beans}}{\text{total number of beans}} \times 100$$

Results

Copy and complete Table 2.

Table 2 Surviving alleles

Generation	Number of red kidney beans (H)	Number of white beans (h)
1	75	25
2		
3		

Discussion

1. Describe the trend in the percentage of 'H' (normal) alleles present in the gene pool.
2. Describe the trend in the percentage of 'h' (sickle cell) alleles present in the gene pool.
3. The hh combination is deadly, and people with this are likely to die before reproducing. Explain why the 'h' allele has not been removed from the population.
4. If people with sickle cell anaemia were able to survive and reproduce, describe what you would expect to happen to the percentage of people carrying the 'h' allele in the population.
5. Evaluate the validity of this model (by explaining how this model relates to the real world, identifying other factors that may change the outcomes in the real-world example, and deciding whether the model is a valid representation of the real world).

Conclusion

Explain how malaria selects for carriers of sickle cell anaemia.

4.1 Making a simple barometer

CHALLENGE

Aim

To make a simple barometer.

What you need:

Glass jar, balloon, rubber band, straw, sticky tape, sheet of thick paper with a scale marked on it

What to do:

1 Cut a section from the balloon large enough to cover the opening of the jar.
2 Secure the balloon over the jar with the rubber band.
3 Tape the straw onto the balloon.
4 Place the paper with the scale near the end of the straw and mark on the scale where the straw is.
5 Check the position of the straw on the scale each day for a week. Mark each position of the straw on the scale and record the date next to the mark (Figure 1).
6 Record the air pressure of your area each day for a week.

Discussion

1 Describe how the balloon would change if the air pressure surrounding the jar was decreased. Describe how this would affect the movement of the straw.

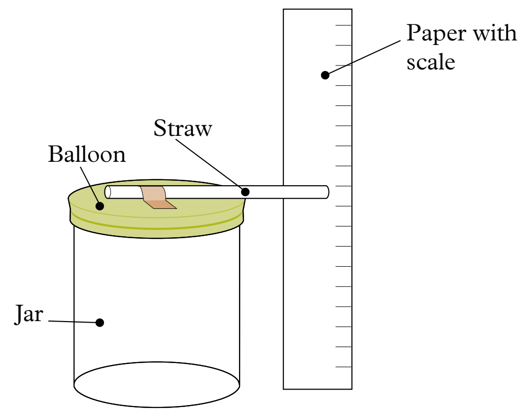


Figure 1 Experimental set-up

2 Describe how the balloon would change if the air pressure surrounding the jar was increased. Describe how this would affect the movement of the straw.
3 Compare the changes in the balloon (indicated by the position of the straw on the scale) with the recorded air pressure each day.
4 Use the particle model of air to explain why the balloon gets pushed in or out of the jar by the surrounding air.
5 Explain why this 'barometer' will also respond to changes in temperature in addition to changes in air pressure.

4.2 Using computer simulations

CHALLENGE

Aim

Use a computer to simulate the temperature at the deepest point of Earth's mantle, 2800 km below Earth's surface.

Scientists can't always find answers to big questions by doing experiments. Often the risks are too great or the experimental method is outside the limits of current technology. Answers to problems like this can sometimes be found using computer simulations.

A computer simulation takes an established pattern and extends it to make a prediction about further events. A simulation is a type of model and, just like other models, it isn't always accurate, but it is the best possible inference or answer to a big question that cannot be tested in any other way. Computer simulations can also be used for experiments that require a lot of repetition that would take a scientist a long time to complete manually, or to infer data about places we can't go to, such as other planets or below the crust of our own planet.

Scientists know that the Earth's mantle is 2800 km thick and that the temperature near the point where the crust and mantle meet is approximately 500°C. Your job is to find out the temperature of the mantle at its deepest point: 2800 km below the Earth's surface.

What to do:

1 Enter the information from Table 1 into a spreadsheet program, such as Microsoft Excel or similar.

Table 1 The temperature of the Earth at different depths below the surface.

Depth under mantle (km)	Temperature (°C)
100	500
200	598
300	696
400	794
500	892
600	990

2 Create a scatter graph of this information using the graphing function of the computer program. Make sure that temperature is on the *y*-axis and depth is on the *x*-axis.

3 Extend the data in the table until you reach a 'Depth under mantle' of 2800 km. Do this by using the 'fill handle' tool (select the cells in the Excel worksheet, and click and drag the small square that appears in the lower right corner of the selection).

4 Update your graph to represent this new data.

Discussion

1 Compare the temperature at a depth of 2800 km obtained from your graph with the information you have read here. Explain why there is a variance.

2 The process you have just followed only works for 'linear' data, which is data that increases or decreases at a constant level. Describe another experiment you have conducted this year that you could have completed using this process.

3 Similar modelling is conducted using data about weather and climate. Define the terms 'weather' and 'climate'.

4 Describe the predictions that scientists would make by using weather and climate data.

5 Evaluate the accuracy of these predictions (by recording weather observations for a week, comparing the weather predictions made with the observed weather conditions, and deciding whether they were accurate).

Figure 1 Computer modelling can be used to represent data from a table.

4.3A Melting ice and its effect on sea levels

EXPERIMENT

Aim

To observe the effect of melting sea and sheet ice on global sea levels.

Materials

- Ice cubes
- 50 mL beakers
- Spatula
- Clay or Plasticine
- Marker pen

Method

Part A: Sea ice

Sea ice is floating ice, like the ice found in icebergs. Design an experiment using the listed materials that shows the effects of melting sea ice on water level (e.g. an ice cube floating on water).

Part B: Sheet ice

Sheet ice is ice resting on land. Approximately 98 per cent of Antarctica is covered by sheet ice and the Antarctic ice sheet is one of two polar ice sheets. Design an experiment using the listed materials that shows the effects of a melting ice sheet on water level (e.g. an ice cube resting on clay).

Results

Present your results for each experiment in an appropriate format.

Discussion

1 Compare the water level changes caused by melted sea ice and melted sheet ice.
2 Explain the differences you noticed between the water levels for each type of ice.
3 Evaluate the validity of this experiment (by explaining how this model relates to the real world, identifying other factors that may change the outcomes in the real-world example, and deciding whether the model is a valid representation of the real world).

Conclusion

Describe how melting sea ice or melting sheet ice will affect sea levels.

Figure 1 Antarctica is home to both sheet and sea ice (pictured).

4.3B Salt water density

CHALLENGE

Aim

To determine how salt affects the density of water.

What you need:

Salt, water, large spatula or plastic teaspoons, food colouring (4 different colours), test tube and test-tube rack, 4 × 200 mL beakers, plastic disposable pipette

What to do:

1 Add 150 mL of water to each beaker. Label the beakers 1–4.
2 Add 1 teaspoon of salt to beaker 2 and mix thoroughly.
3 Add 2 teaspoons of salt to beaker 3 and mix thoroughly.
4 Add 3 teaspoons of salt to beaker 4 and mix thoroughly.
5 Add a different food colour to each beaker.
6 Use the pipette to add 2 cm of salty water from beaker 4 to the bottom of the test tube.
7 Carefully use the pipette to add 2 cm of the salty water from beaker 3 so that it runs down the sides of the test tube. Be careful not to mix the two solutions.
8 Repeat the previous step with beaker 2 and then beaker 1 so that you achieve a test tube with different coloured layers.

Discussion

1 Define the term ‘density’.
2 Use evidence from your results to identify which solution has the greatest density – the solution in beaker 1 or beaker 4.
3 Use evidence from your experiment to describe how the fresh water from rivers will behave as it enters the ocean.
4 Water from melted ice is often denser than the salt water ocean. Use a diagram to describe how the icy fresh water will behave when it enters the ocean.
5 Describe how the density of water can cause ocean currents.

5.1 Flame tests

EXPERIMENT

CAUTION! Wear safety goggles and a lab coat. Ensure hair is tied back and loose clothing is removed or tucked away. Wire loops and flames are hot. Be careful not to burn yourself. 1 M hydrochloric acid can give a small chemical burn. Wash skin with tap water immediately.

Aim

To observe the coloured light emitted when certain substances are heated in a flame.

Materials

- Solid samples of sodium carbonate, copper carbonate, potassium carbonate and strontium carbonate
- 1 M hydrochloric acid
- Bunsen burner
- Heatproof mat
- Wire loops

Method

1. Set up your Bunsen burner, observing safety instructions, and light your Bunsen burner on the (red) safety flame.
2. Adjust your Bunsen burner to the blue flame. Take a wire loop and dip it in a small beaker of 1 M hydrochloric acid. Flame the loop. This will clean the loop, ready for your solid sample. Avoid getting too close to the flame. Stand back a little.
3. Take a loop of solid chemical and place it in the flame. Observe the colour of the flame. Try not to lose the solid down the Bunsen burner barrel. This could block the burner and contaminate the flame, changing the colour.
4. Once you have finished your observation, dip the loop in the 1 M hydrochloric acid again and re-flame it. This will clean the loop for the next sample.
5. Repeat steps 3 and 4 for the other samples.

Results

Include your results in a table.

Discussion

1. Explain why the loop was treated with hydrochloric acid before any carbonates were tested.
2. Explain why the flame colour changed in the different chemicals.
3. Evaluate whether the colour change is a chemical change or a physical change (by defining chemical change, defining physical change, comparing the change in the chemicals to these definitions and deciding the type of change).
4. Explain why electrons in different elements produce different colours.
5. Identify whether the colour change is caused by the metal or the carbonate part of the powder. Justify your answer (by describing the differences between the chemicals tested and describing how these differences caused the colour changes).

Conclusion

Describe what you know about the different coloured flames produced by different elements.

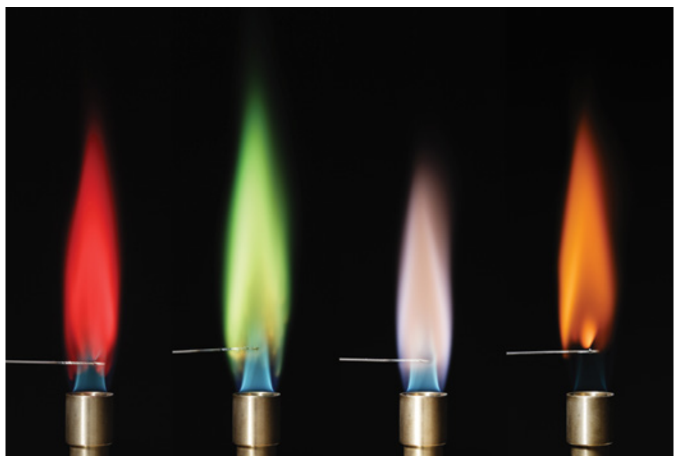


Figure 1 Flames can change colour depending on what substances are heated.

5.2 Reactivity of metals

EXPERIMENT

CAUTION! Wear safety glasses, lab coat and gloves when working with chemicals.

Aim

To compare the reactivity of various metals by observing their reaction with hydrochloric acid.

Materials

- 2 M hydrochloric acid
- Detergent
- 0.5 cm pieces of magnesium, aluminium, iron, zinc and copper
- Steel wool
- Test tubes and test-tube rack
- Ruler
- Timer
- Bench mat
- Plastic disposable pipette

Method

1 Clean the surface of the magnesium with a piece of steel wool.
2 Place the magnesium into a test tube.
3 Add 3 drops of detergent to the test tube.
4 Add 2 cm of hydrochloric acid to the test tube and place the test tube into the test-tube rack. Set the timer for 5 minutes and record your observations, including the height of the foam produced, in Table 1.
5 Repeat the process for the remaining metals.
6 Record your observations over 30 minutes.
7 This equipment can be left set up overnight to observe any further changes.

Results

Copy and complete Table 1.

Table 1 Observations from the experiment

Metal	Observations	Height of foam (cm)
Magnesium		
Aluminium		
Iron		
Zinc		
Copper		

Discussion

1 Identify the metal that was the most reactive.
2 Identify the metal that was the least reactive.
3 Explain why the metals were cleaned with steel wool before being exposed to the acid.
4 Explain why the detergent was added to the test tubes with the hydrochloric acid.
5 Describe the link between the reactivity of the metals and where they are located in the periodic table.
6 Identify other properties that the most reactive metal may exhibit. Justify your answer (by comparing your answer to the previous question with the properties you identify).
7 Describe the reliability of this experiment (by identifying other variables that may affect the outcome of the experiment, describing how these variables are or are not controlled, and explaining whether the experiment is repeatable and reproducible).

Conclusion

Explain how the reactivity of metals can vary across the periodic table.

5.3 Identifying patterns in the periodic table

CHALLENGE

Aim

To identify patterns in the periodic table.

What you need:

A3 sheet of paper, pens, highlighter pens

What to do:

1 On an A3 sheet of paper, make a copy of the periodic table up to element 20. Leave a gap for the block of transition metals. Ensure that the size of the box for each element will fit the information you need to insert, as detailed in steps 3–5.
2 Use highlighters to colour hydrogen red, metals blue, noble gases purple and other non-metals green. Place a suitable key under your periodic table.
3 Identify the elements that will not gain or lose electrons in a reaction because their uncharged atoms are already very stable. Beneath them, write:
   - already a stable structure
   - does not form an ion.
4 Identify the elements that will not gain or lose electrons in a reaction, because this would require them to gain or lose more than three electrons. Beneath them, write:
   - needs to gain or lose more than three electrons for a more stable structure
   - does not form an ion.
5 Complete the box for each of the other elements listed, except for the metalloids and hydrogen, by stating how many electrons the element needs to gain or lose to achieve a more stable structure, and hence what charge its ion should have. As an example, chlorine (Cl) has the following properties:
   - needs to gain one electron
   - charge on ion = 1–

Discussion

1 Describe the patterns in the alkali metal group.
2 Describe the patterns in the alkaline earth metal group.
3 Describe the patterns that apply to all the metals listed.
4 Describe the patterns in the halogen group.
5 Describe the patterns in the group 16 elements.
6 Describe the patterns that apply to the non-metals, except for hydrogen and the noble gases.
7 In general, describe what you expect to happen when a metal atom and a non-metal atom meet. Identify the groups of non-metals that will not react in this way. Justify your answer (by explaining the properties of the group of non-metals you chose).
8 Predict what might happen if:
   a a potassium atom and a fluorine atom meet
   b a calcium atom and an oxygen atom meet.

   Justify your predictions (by drawing shell diagrams of the atoms and describing what happens in the reaction).
9 Explain why hydrogen and the metalloids were not considered in this activity.

5.5A Conductivity of ionic compounds

EXPERIMENT

Aim

To investigate the electrical conductivity of two ionic compounds as a solid and in aqueous solution.

Materials

- Large sodium chloride crystals
- Coarse sea salt crystals
- Small Petri dish
- 4 V battery or other 4 V DC power supply
- Ammeter
- Wires with alligator clips (for solids)
- 2 graphite electrodes (for liquids)
- 3 × 100 mL beakers
- Large spatula
- Glass stirring rod
- Paper towel

Method

1 Set up the electrical circuit as shown in Figure 1. Have your teacher check that it is correct before proceeding. Ensure that you know how to use the ammeter and its scales correctly.

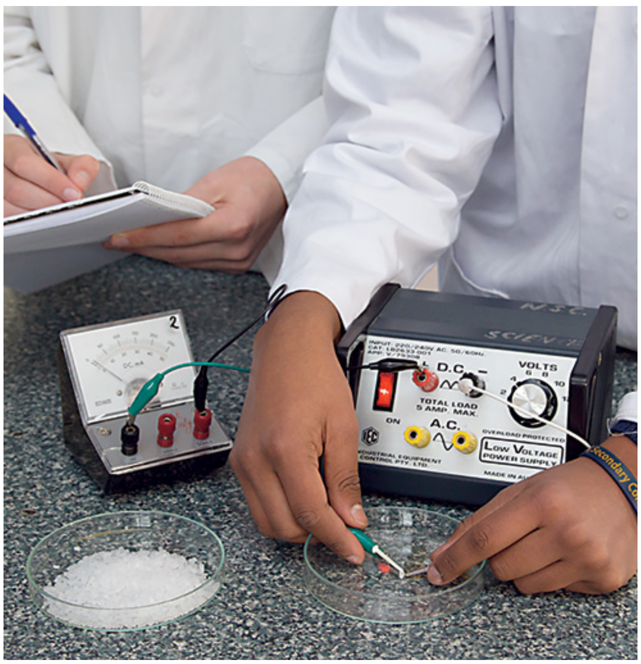


Figure 1 Experimental set-up

2 Using the spatula, place the largest sodium chloride crystal onto the Petri dish, then touch each end with an electrode, making sure that the two electrodes do not touch each other. If the crystal does not appear to conduct electricity, connect the wire to the more sensitive scale on the ammeter to check further. Record your result.

3 In a 100 mL beaker, place half a large spatula of sodium chloride crystals and add 50 mL of water. Stir to dissolve the crystals.

4 Attach the graphite electrodes to the alligator clips and place the ends of the electrodes into the solution, ensuring they do not touch each other. If the crystal does not appear to conduct electricity, connect the wire to the more sensitive scale on the ammeter to check further. Record your result.

5 Turn off the power supply and rinse the electrodes with fresh tap water, then dry them with a paper towel.

Inquiry

What if large coarse sea salt was used?

- Write a hypothesis (If … then … because …) for your inquiry.
- Identify the (independent) variable that you will change from the first method.
- Identify the (dependent) variable that you will measure and/or observe.
- Identify two variables that you will need to control to ensure a valid test. Describe how you will control these variables.
- Identify the materials that you will need for your experiment.
- Write down the method you will use to complete your investigation in your logbook.
- Draw a table to record your results.
- Show your teacher your planning for approval before starting your experiment.

Results

Create a simple table or spreadsheet in which to record your results.

Discussion

1 Sea salt is a mixture of different ionic compounds, including sodium chloride. Describe your conclusions about the ability of solid ionic compounds to conduct electricity.

2 Describe how dissolving an ionic compound in water changes its ability to conduct electricity.

3 Explain why a substance must have charged particles that can move about before it can conduct electricity.

4 The melting point of sodium chloride is 801°C, so it is not practical to melt it in the school laboratory. Predict whether molten sodium chloride would conduct electricity. Justify your answer (by describing the essential property necessary for a material to conduct electricity and identifying whether this property would be present in molten sodium chloride).

Conclusion

Describe what you know about the conductivity of ionic compounds.

5.5B Ionic compounds

SKILLS LAB

Aim

To identify the ionic formulas of a selection of compounds.

Ionic compounds are those formed from the bonding of ions. Consider sodium chloride, which is produced when sodium and chlorine meet and react. In this compound, the metal sodium is present in the form of positively charged ions (Na^+) and the non-metal chlorine is present as negatively charged ions (Cl^-). Notice that the:

- metal is named first and its name is not changed
- non-metal is named second and the end of its name is changed from -ine to -ide.

This obeys the following standard naming convention.

The positively charged ion (cation) in the compound is written first and keeps the name of the metal from which it was formed.

The negatively charged ion (anion) in the compound is written second. The end of the name of the non-metal from which it was formed is replaced with -ide.

Some transition metals can form more than one ion. In these cases, a Roman numeral is used to show the charge on the ion.

Table 1 Formulas of some common cations

Cations	
Name	**Formula**
Lithium	Li^+
Sodium	Na^+
Potassium	K^+
Magnesium	Mg^{2+}
Calcium	Ca^{2+}
Aluminium	Al^{3+}
Silver	Ag^+
Zinc	Zn^{2+}
Copper(II)	Cu^{2+}
Iron(II)	Fe^{2+}
Iron(III)	Fe^{3+}

Table 2 Formulas of some common anions

Anions	
Name	**Formula**
Fluoride	F^-
Chloride	Cl^-
Bromide	Br^-
Iodide	I^-
Oxide	O^{2-}
Sulfide	S^{2-}
Nitride	N^{3-}

For example, copper forms two ions: one with a 1+ charge and one with a 2+ charge. These ions are called copper(I) and copper(II), respectively.

The names and formulas of some common ions are listed in Table 1.

The formula for sodium chloride is NaCl, whereas the formula of magnesium chloride is $MgCl_2$. The formula NaCl means that the cations and anions are present in a ratio of 1 : 1. That is, for every Na^+ ion present in a sodium chloride crystal, there is one Cl^- ion present. The formula $MgCl_2$ means that the cations and anions are present in a ratio of 1 : 2. That is, for every Mg^{2+} ion present in a magnesium chloride crystal, there are two Cl^- ions present. This is necessary to achieve an overall neutral charge.

We can use this principle to determine the formula of an ionic compound.

1. Use tables 1 and 2 to list the formulas for the cations and anions present.
2. Work out the simplest ratio they need to be in so that the total positive charge and total negative charge are equal.

Note: The worked example will assist you in your calculations.

Worked example

Identify the formula for the following compounds.

a iron(II) oxide

b silver sulfide

Solution

a Iron(II) oxide

- The ions are Fe^{2+} and O^{2-}.
- Because the charges 2+ and 2– are equal, the ions only need to be in a ratio of 1 : 1.
- Therefore, the formula is FeO.

b Silver sulfide

- The ions are Ag^+ and S^{2-}.
- Because the charges are 1+ and 2–, the ions need to be in a ratio of 2 : 1 (making it a total of 2+ and 2–).
- Therefore, the formula is Ag_2S.

Discussion

1. Write the formulas for:
   a lithium bromide
   b iron(III) chloride
   c sodium nitride
   d aluminium oxide.
2. Identify the charge of elements in:
   a group 1
   b group 2
   c group 6
   d group 7.
3. Explain why elements in group 8 do not usually form ions.

5.6 Modelling covalent molecules

CHALLENGE

Aim

To model the sharing of electrons in covalent molecules.

What you need:

Molecular modelling kits (or use different coloured marshmallows and toothpicks)

What to do:

1 Choose three different colours to represent carbon, hydrogen and oxygen.

2 For each of the molecules shown in Table 1:

a state the numbers of each atom

b make and draw a model of the molecules

c draw the number of electrons in the valence shell of each atom, including the shared electrons.

Results

Copy and complete Table 1.

Table 1 Atomic modelling

Molecule	Atoms present	Numbers of each atom	Drawing of model	Electron dot diagram
H_2				
H_2O				
CH_4				
CO_2				
$CHCl_3$				

Discussion

1 Identify and describe the type of bond that occurs between a metal and a non-metal.

2 Identify and describe the type of bond that occurs between two non-metals.

3 Define the term 'valence shell'.

4 Explain the meaning of the term 'sharing electrons' in covalent bonds.

Conclusion

Describe a covalent bond and the types of elements that form this bond.

Figure 1 The structural arrangement of molecules can be modelled.

5.7 Modelling alloys

CHALLENGE

Aim

To compare the properties of model alloys.

What you need:

4 different colours of softened Plasticine or play dough (35 g of each), sand (12 g), newspaper, balance, magnifying glass

What to do:

1 Weigh 2 g of sand onto the newspaper.
2 Work one of the Plasticine colours until it is soft and malleable. Roll it out into a 0.5 cm layer.
3 Sprinkle the sand onto the Plasticine and work the Plasticine until the sand is spread through it evenly.
4 Repeat steps 2 and 3 with 4 g and 6 g of sand.
5 Roll out each of the four pieces (one of which contains no sand). In your results table, note which piece was easiest to roll out.
6 Work the four pieces of Plasticine (one of which will contain no sand) until they are at room temperature.
7 Form each piece of Plasticine into a long, thin cylinder ('wire') of the same size and length.
8 In your results table, note which piece was easiest to draw out into a long, thin cylinder ('wire').
9 Hold the ends of one Plasticine cylinder firmly and pull it apart.
10 Repeat the pull test for each Plasticine cylinder.
11 In your results table, note which piece snapped soonest.
12 Use the magnifying glass to examine the broken ends of each cylinder.
13 In your results table, estimate the surface area of the broken ends.

Figure 1 Use Plasticine and sand to model alloys.

Results

Record your observations in an appropriate table.

Discussion

1 Identify the 'alloy' that was most malleable (able to be rolled out easily when cold).
2 Identify the 'alloy' that was most ductile (able to be drawn out into a 'wire' shape easily).
3 Identify the 'alloy' that was most brittle (snapped quickly).
4 Identify one other variable in this model that could affect the properties of the Plasticine 'alloy'. Describe how the properties of the 'alloy' could be affected by this variable. Describe how this variable was or could be controlled.
5 Evaluate how the amount of sand in the 'alloy' affected the size of the largest fracture surface (by comparing the amount of sand and the size of the surface area of the broken end for each amount of sand and summarising your findings in a single sentence: 'As the amount of sand in the 'alloy' increases, the fracture surface …').

Conclusion

Describe how the alloying of metal affects its properties.

6.1A Direct synthesis with a 'pop'

EXPERIMENT

CAUTION! Wear protective clothing and safety glasses throughout this experiment. Avoid contact with hydrochloric acid.

Aim

To produce water by direct synthesis.

Materials

- Magnesium ribbon
- Dilute hydrochloric acid (1 M)
- 2 test tubes and test-tube rack
- Rubber stopper
- Wooden splint
- Matches
- Bench mat
- Timer

Method

1 For this reaction, you require a test tube containing hydrogen gas. The easiest way to produce this is to place three 1 cm lengths of magnesium ribbon in a test tube and add 10 mL dilute hydrochloric acid (Figure 1).

Figure 1 Magnesium ribbon is reacted with 10 mL of HCl.

2 Place the other test tube (make sure it is dry) upside down over the top of the first test tube so that any hydrogen gas produced enters the second test tube (Figure 2).

Figure 2 A second test tube is used to trap the hydrogen gas.

3 After 15 seconds, place a rubber stopper over the end of the second test tube to trap the hydrogen gas – you now have a test tube of hydrogen gas.

4 Place the sealed test tube containing the hydrogen gas into the test-tube rack.

5 Light the wooden splint. Remove the rubber stopper and carefully hold the burning splint close to the top of the test tube.

6 Observe the reaction that occurs and examine the inside of the test tube closely.

Results

Record your observations in an appropriate format.

Discussion

1 Describe the evidence that water was formed in the reaction.

2 Write a balanced chemical equation for the reaction, remembering that no atoms are created or destroyed in the process.

3 Explain why heat was required to start the reaction.

4 Apart from synthesis, identify another way this reaction could be classified. (HINT: Think about the energy involved in this reaction.)

Conclusion

Describe the direct synthesis of water that occurred in this reaction.

6.1B Decomposing a carbonate

EXPERIMENT

CAUTION! Wear safety glasses, lab coat and gloves when working with chemicals. Ensure the open end of the test tube is facing in a safe direction while heating.

Aim

To use heat to decompose copper(II) carbonate to produce copper oxide and carbon dioxide.

Materials

- Copper(II) carbonate
- Pyrex (high-strength) test tube
- Test-tube rack
- Test-tube holder
- Bunsen burner
- Matches
- Spatula
- Gloves and safety glasses
- Heatproof mat

Method

1 Describe the appearance of copper(II) carbonate.
2 Carefully place one spatula of copper(II) carbonate into the test tube.
3 Hold the test tube at an angle of approximately 45° towards the wall, and gently heat the bottom of the test tube by moving it carefully in and out of a Bunsen burner flame (Figure 1).
4 Carefully observe the changes that occur.

Figure 1 Point the test tube away from you as you move it in and out of the Bunsen burner flame.

Figure 2 Copper carbonate is a green powder before it is heated.

Results

Record your observations in an appropriate format.

Discussion

1 Describe the evidence that copper(II) oxide was formed in the reaction.
2 Describe the evidence that a gas was produced in the reaction.
3 Write a chemical equation for the reaction, including the state of matter symbols.
4 Apart from decomposition, identify another way this reaction could be classified.
5 Describe the precautions you took to ensure the safety of other people in the room.

Conclusion

Describe the decomposition reaction that occurred.

Further investigation

Redesign this experiment to provide evidence that carbon dioxide gas is produced in the reaction. Write an experimental method, including labelled diagrams, and list any additional equipment you will need. Show your design to your teacher and, if it is safe, try your method using copper(II) carbonate.

6.2 Precipitation reactions

EXPERIMENT

CAUTION! Wear safety glasses, lab coat and gloves when working with chemicals.

Aim

To determine which compounds form precipitates and to write equations for the reactions occurring.

Materials

> Plastic document sleeve or spotting tile

> Dropper bottles containing 0.1 M solutions of:

– Group A: calcium nitrate ($Ca(NO_3)_2$), copper(II) nitrate ($Cu(NO_3)_2$), magnesium nitrate ($Mg(NO_3)_2$), silver nitrate ($AgNO_3$), copper(II) sulfate ($CuSO_4$)

– Group B: sodium chloride (NaCl), sodium hydroxide (NaOH), sodium sulfate (Na_2SO_4), sodium carbonate (Na_2CO_3)

Method

1 Draw up a large table with group B solutions listed across the first row and group A solutions in the first column, as shown in Table 1.

Table 1 Results from the experiment

	NaCl	NaOH	Na_2SO_4	Na_2CO_3
$Ca(NO_3)_2$				
$Cu(NO_3)_2$				
$Mg(NO_3)_2$				
$AgNO_3$				
$CuSO_4$				

2 Make a copy of your results table on a piece of A4 paper and place this table into the plastic document sleeve. Place this on the laboratory bench. This is your working area for the experiment. You will add drops of the solutions to the corresponding cells on the results table, which is now protected by the plastic sleeve.

3 Place 1 drop of each of the group A solutions in each cell of the results table in the correct rows.

4 Add 1 drop of each of the group B solutions to the drops of group A solutions in the correct columns. Do not touch the tip of the dropper bottles to the group A solutions already resting on the plastic sleeve.

Results

1 Using your other copy of the results table, describe any precipitate that forms.

2 Use Table 1 (page 144) to help you answer the following questions. For each precipitate formed:

a identify the ions that have combined to form the precipitate and write the formula of the ions

b write the formula of the precipitate

c write a word equation for the reaction.

Discussion

1 The sets of compounds tested included a range of anions: NO_3^-, OH^-, CO_3^{2-}, Cl^- and SO_4^{2-}. Of these, identify which:

a did not form any precipitates

b only formed precipitates with one or two cations.

2 The sets of compounds tested included a range of cations: Na^+, Ag^+, Cu^{2+}, Ca^{2+} and Mg^{2+}. Of these, identify which:

a did not form any precipitates

b formed precipitates with only one or two anions.

3 Compare the precipitation reactions you observed with the predictions from Table 1 on page 144. Explain any discrepancies (differences).

4 Write balanced chemical equations for the reactions between:

a silver nitrate and sodium chloride

b magnesium nitrate and sodium hydroxide.

5 Explain why it was important not to touch the tip of the dropper bottles to the top of the solution already on the plastic sleeve.

6 Identify other factors that may affect the outcome of these precipitation reactions. Explain how each of these factors would affect the outcome of the experiment.

Conclusion

Describe what you know about predicting the formation of a precipitate in a chemical reaction.

6.3A Testing with pH paper

CHALLENGE

What you need:

pH paper and pH colour chart or universal indicator, white tile, variety of laboratory acids and bases, vinegar, milk, toothpaste, lemon juice

What to do:

1 Tear off about 1 cm of pH paper and place it on the white tile.
2 Place a drop of a laboratory acid on the paper.
3 Compare the colour of the wet spot on the pH paper with the pH colour chart.
4 Repeat for the laboratory bases and the other substances.
5 For each substance, record the pH colour and number and note whether the substance is an acid, a base or neutral.
6 Dilute some of the substances with water and measure the pH of the diluted solutions with more indicator paper.

Discussion

1 Identify which substance was the most acidic solution that you tested (lowest pH).
2 Identify which substance was the most basic solution that you tested (highest pH).
3 Describe what happens to the pH of an acid when the acid is diluted in water.
4 Use your answer to question 3 to describe a way of treating a burn caused by acid.

Figure 1 pH paper and colour chart

6.3B What if plants were used to create an indicator?

EXPERIMENT

Red cabbage contains a water-soluble pigment called flavin, which is also found in plums, poppies, grapes and apple skin. Very acidic solutions will turn flavin red, neutral solutions result in a purplish colour and alkaline solutions appear greenish yellow if flavin is added to them.

Aim

To make an indicator from red cabbage and demonstrate how it can be used to identify acids and bases.

Materials

> 2 leaves from a fresh red cabbage (shredded)
> 0.1 M sodium hydroxide
> Water
> Stirring rod
> 250 mL beaker
> Strainer
> 0.1 M hydrochloric acid
> Hotplate or Bunsen burner, tripod and gauze mat
> Test tubes and test-tube rack
> Variety of products for testing e.g. shampoo, vinegar, baking soda

Method

1 To make the indicator:
   a Cut a few red cabbage leaves into smaller pieces and place in a beaker.
   b Cover the cabbage leaves with water and boil the mixture until the water is purple.
   c Cool the liquid and then strain it, discarding the cabbage leaves.
2 To test the indicator:
   a Add a small amount of hydrochloric acid to a test tube and then add a few drops of red cabbage indicator.
   b Record any colour change in a table.
   c Add a small amount of water (neutral solution) to a test tube and then add a few drops of red cabbage indicator.
   d Record any colour change in your table.
   e Add a small amount of sodium hydroxide (basic solution) to a test tube and then add a few drops of red cabbage indicator.
   f Record any colour change in your table.
3 Test a variety of products, such as shampoo, vinegar and baking soda, by adding a few drops of red cabbage indicator solution to them.
4 Record the colour changes and determine which products are acids and which are bases.

Inquiry

What if another plant, flower or fruit was used to create an indicator?

> Write a hypothesis (If ... then ... because ...) for your inquiry.
> Identify the (independent) variable that you will change from the red cabbage method.
> Describe how you will measure whether the plant, flower or fruit (dependent variable) is an indicator. Predict the colour changes you might expect.
> Name two variables that you will need to control to ensure a valid test. Describe how you will control these variables.
> Identify the materials you will need for your experiment.
> Write down the method you will use to complete your investigation in your logbook.
> Draw a table to record your results.
> Show your teacher your planning for approval before starting your experiment.

Results

Include your table of observations.

Discussion

1 Identify a colour change that can be used to determine the pH of a substance added to red cabbage.
2 Identify the colour that the extract from your plant becomes in:
   a an acid
   b a base
   c water.
3 Describe any limitations of your experiment (by describing where your extract will become inaccurate, describing the sensitivity of your extract or if it can determine the difference between pH 1 and pH 2, and how expensive your extract would be to produce for chemical laboratories or manufacturing chemicals).

Conclusion

Describe what you know about indicators and how they are produced.

Figure 1 Many plants, including red cabbage, can be used to make an indicator.

6.4 Acid titrations

EXPERIMENT

CAUTION! Wear safety glasses, lab coat and gloves when working with chemicals.

Aim

To compare the reactions of a strong acid (hydrochloric acid) and a weak acid (ethanoic acid, common name acetic acid).

Materials

> Dropper bottles containing:
  – 0.1 M hydrochloric acid (HCl)
  – 0.1 M ethanoic acid (acetic acid) (CH_3COOH)
  – 0.1 M sodium hydroxide (NaOH)
  – 1 M hydrochloric acid (HCl)
  – 1 M ethanoic acid (acetic acid) (CH_3COOH)
  – Universal indicator solution
> pH colour chart
> Small pieces of magnesium ribbon
> 4 test tubes and test-tube rack
> Pipette
> Matches
> Bench mat

Method

Part A

1 Draw up a table to record each test and the results for each acid.
2 Place 2 mL of 0.1 M hydrochloric acid in one test tube and add 2 drops of universal indicator solution. Record the colour of the indicator and the corresponding pH from the colour chart.
3 Repeat step 2 with 0.1 M ethanoic acid, using a fresh test tube.
4 To the first test tube add 0.1 M sodium hydroxide drop by drop, counting the drops, until the solution is neutral (i.e. pH = 7).
5 Repeat step 4 with the ethanoic acid.

Part B

1 Add 2 mL of 1 M hydrochloric acid to a fresh test tube.
2 Add a small piece of magnesium ribbon to the test tube and invert a clean test tube over the top.
3 Record your observations.
4 Lightly touch the base of the bottom test tube. Record your observations of the temperature of the mixture.
5 When the reaction has ceased, light a match and hold it just inside the inverted test tube. Do you hear a loud popping sound? This is evidence of hydrogen gas being produced.
6 Repeat steps 1–6 with 2 mL of 1 M ethanoic acid.

Results

Record your results in an appropriate table.

Discussion

1 When you tested the pH of the two acids, you used the same concentration (0.1 M).
  a Explain why the reactions were compared at the same concentration.
  b Compare concentration of an acid with the strength of the acid. Identify which (strength or concentration) is related to the pH of the acid.
  c Compare the strength of ethanoic acid with the strength of hydrochloric acid.
2 Define the term 'neutralisation'.
3 Write a balanced equation for each neutralisation reaction.
4 The pop test is the standard test for hydrogen gas. The 'pop' sound is a mini-explosion due to the combustion of hydrogen gas in air, which is a very exothermic (heat producing) reaction.
  The equation for the reaction is:
  $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$ + energy
  a Identify whether hydrogen gas was produced in your reactions.
  b Compare the rate of the reactions with the two different acids. Provide an explanation for any differences observed.
5 Write a balanced chemical equation for the reaction between the two acids and the magnesium ribbon.
6 Evaluate the reliability of this experiment (by identifying any random errors or systematic errors that could have occurred, describing how the results may or may not change if the experiment was repeated in the same laboratory by the same scientist, describing how the results may change if the experiment was repeated by another scientist in another laboratory, and deciding whether the experiment was reliable).

Conclusion

Explain what you know about:
> neutralisation reactions
> reactions between metals and acids
> the difference between strength and concentration of acids.

6.5 Combustion of wire wool

EXPERIMENT

CAUTION! Wear a laboratory coat and safety glasses throughout this experiment. The wire wool becomes very hot. Use a non-flammable bench mat. Do not touch the wool until it has cooled.

Aim

To observe the oxidation of wire wool.

Materials

- Wire wool
- 9 V battery
- Crucible
- Heatproof mat
- Balance
- Small spatula

Method

1 Make a small ball out of the wire wool and place it in the crucible.
2 Record the weight of the crucible and wire wool.
3 Place the crucible in the centre of the heatproof mat.
4 Quickly touch both terminals of the 9 V battery to the wool and then pull them away (Figure 1). (If the wool sticks to the battery, use a small spatula to separate them.)
5 Write your observations of the reaction.
6 When the wire wool has stopped reacting, weigh the crucible and contents a second time.

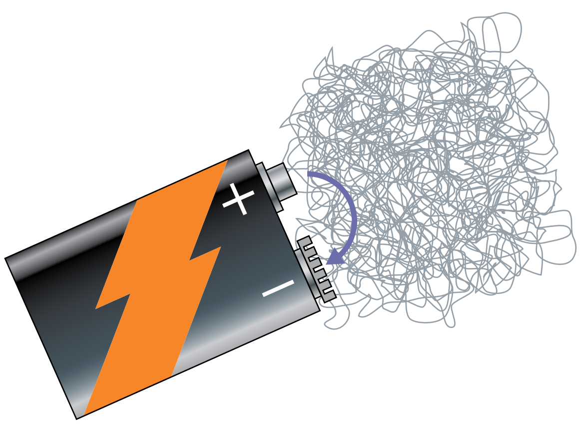


Figure 1 Experimental set-up

Results

Record your masses and observations in an appropriate table.

Discussion

1 Identify this reaction as an exothermic or endothermic reaction. Justify your decision (by comparing the reaction you completed with the definition of the term you chose).
2 Compare the mass of the reactants with the mass of the products. Explain any discrepancies (differences).
3 Write a word equation for this reaction.
4 Write a balanced chemical equation for this reaction.
5 Evaluate the validity of this experiment (by describing a real-world example of this reaction, identifying other factors in the real world that might change this reaction, describing how these factors were controlled in this experiment, and deciding whether the experiment is valid).

Conclusion

Describe what you know about the oxidation of wire wool.

6.6 Polymerisation of casein

EXPERIMENT

Milk contains a protein called casein. When milk is heated and mixed with an acid, such as the ethanoic acid in vinegar, the casein monomers bond with each other to form long polymers. Before the Second World War, casein plastic was used to make buttons, beads and jewellery.

Aim

To form polymers of casein monomers.

Materials

- 100 mL full cream milk
- 5 mL vinegar (CH_3COOH)
- Bunsen burner
- Matches
- Tripod
- Thermometer
- Gauze mat
- Heatproof mat
- Spatula
- Filter paper
- Funnel
- 250 mL beaker
- Conical flask
- Heatproof gloves
- Timer

Method

1. Place 100 mL of milk in a beaker and heat it over the Bunsen burner until it is above 49°C and no hotter than 80°C.
2. Remove the beaker of milk from the Bunsen burner and place it on the bench mat.
3. Add 5 mL of vinegar to the milk, stirring gently for 5 seconds. The milk will separate into curds.
4. Place the filter paper in the funnel and put into the conical flask. Filter the casein polymer curds from the whey.
5. Weigh the casein polymer you obtained as a measure of the effectiveness of the reaction.
6. Mould the casein plastic into a shape of your choice.

Inquiry

Choose one of the following questions to investigate.

- What if low-fat milk was used?
- What if more vinegar was used?
- What if less vinegar was used?

Answer the following questions in relation to your inquiry.

- Write a hypothesis (If … then … because …) for your inquiry.
- Identify the (independent) variable that you will change from the first method.
- Identify the (dependent) variable that you will measure and/or observe.
- Identify two variables that you will need to control to ensure a valid test. Describe how you will control these variables.
- Identify the materials that you will need for your experiment.
- Write down the method you will use to complete your investigation in your logbook.
- Draw a table to record your results.
- Show your teacher your planning for approval before starting your experiment.

Results

Record your observations and measurements in a table.

Discussion

1. Identify the reactants that were used.
2. Identify and describe the products that were produced.
3. Describe the type of reaction that has occurred.
4. Identify the polymer you created as a thermoplastic polymer or a thermosetting polymer. Justify your decision (by defining both terms and comparing the properties of the plastic you produced with the definition of the term you chose).
5. Describe a use for this polymer and identify the properties that make it suitable for that use.

Conclusion

Describe what you know about polymerisation.

6.7 Factors affecting reaction rate

EXPERIMENT

CAUTION! Wear protective gloves, lab coat and safety glasses throughout this experiment. Avoid contact with the acid solutions because they are corrosive. If acid comes into contact with your skin, wash it with water immediately.

Aim

To investigate the rates of a reaction between hydrochloric acid and calcium carbonate.

Materials

- 30 g small marble chips (calcium carbonate) of similar size
- 20 mL of 0.5 M hydrochloric acid (HCl)
- 20 mL of 1.0 M HCl
- 20 mL of 2.0 M HCl
- Electronic balance
- Stopwatch
- 25 mL measuring cylinder
- 3 × 100 mL conical flasks

Method

1. Place a conical flask on the electronic balance and tare the balance so it reads zero. Weigh approximately 10 g of identical-sized marble chips into the flask.
2. Using a measuring cylinder add 20 mL of 0.5 M HCl to the conical flask still sitting on the electronic balance. Immediately tare the balance once so that it returns to zero briefly, and start the stopwatch. The numbers on the balance will move into negative readings from zero, as gas is given off.
3. Record in your results table the mass loss in grams at 30 seconds, 1 minute and then every minute until 8 minutes.

Inquiry

Choose one of the following questions to investigate.

- What if the marble chips were smaller?
- What if the acid was more concentrated?
- What if the temperature of the acid was increased?

Answer the following questions in relation to your inquiry.

- Write a hypothesis (If … then … because …) for your inquiry.
- Identify the (independent) variable that you will change from the first method.
- Identify the (dependent) variable that you will measure and/or observe.
- Identify two variables that you will need to control to ensure a valid test. Describe how you will control these variables.
- Identify the materials that you will need for your experiment.
- Write down the method you will use to complete your investigation in your logbook.
- Identify the potential hazards in the experiment (e.g. heating the acid).
- Describe how you will remove or limit these risks.
- Draw a table to record your results.
- Show your teacher your planning for approval before starting your experiment.

Results

Copy and complete Table 1 and plot a graph of the mass loss by minutes.

Discussion

1. Write a balanced chemical equation for the chemical reaction.
2. Describe the relationship between your independent variable and dependent variable as shown by your graph.
3. Compare your hypothesis with the results you obtained.
4. Identify a random error and a systemic error in your experiment. Describe how you could prevent or minimise these errors to make this experiment more reliable.
5. Evaluate the validity of this experiment (by describing a real-world example of this reaction, identifying other factors in the real world that might change this reaction, describing how these factors were controlled in this experiment, and deciding whether the experiment is valid).

Conclusion

Write a conclusion for your experiment that includes a general statement that summarises the evidence that supports your hypothesis.

Table 1 Results from the experiment

Experiment	30 s	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min
Control (from the Method)									

6.8 Using a catalyst

EXPERIMENT

The reaction used in this experiment is the decomposition of hydrogen peroxide:

$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$

CAUTION! Wear protective gloves, lab coat and safety glasses throughout this experiment. Avoid contact with hydrogen peroxide.

Aim

To investigate the effect of adding a catalyst to a reaction.

Materials

- 3 per cent hydrogen peroxide (H_2O_2) solution (10 mL)
- Manganese dioxide (MnO_2) powder
- Test tubes and test-tube rack
- Spatula (small)
- 10 mL measuring cylinder

Method

1 Using a measuring cylinder, measure 5 mL of hydrogen peroxide solution into two separate test tubes.
2 Allow one of the tubes to stand; add a small amount of manganese dioxide to the other test tube using a spatula.
3 Observe and describe the changes that occur in the two test tubes.

Results

Record your observations in an appropriate format.

Discussion

1 Identify whether your observations were quantitative or qualitative.
2 Evaluate the statement 'There was no reaction in the test tube that had no manganese dioxide' (by defining the phrase 'rate of a reaction' and comparing the decomposing rate of hydrogen peroxide with or without manganese dioxide).
3 Describe how manganese dioxide changed the rate of a reaction.
4 Define the term 'catalyst'.
5 Identify whether manganese dioxide is a catalyst. Justify your answer.
6 Describe two ways in which the rate of hydrogen peroxide decomposition could be increased further.

Figure 1 Hydrogen peroxide

Conclusion

Describe how a catalyst affects the rate of a reaction.

7.1A Using a star chart

SKILLS LAB

Planispheres or star charts are very useful maps for locating various stars in the night sky. A sky chart can be easily downloaded each month from the Skymaps website. A sky chart and calendar are given on page 1, whereas page 2 has various notes and explanations about the objects you can see.

Aim

To use a star chart to identify the position of a star or constellation.

What you need:

A copy of this month's sky chart (Make sure you click on the southern hemisphere option.)

What to do:

1 Read the instructions on how to use the sky chart. These are printed around the outside of the circular chart, along with other useful information about the chart.

2 Find the south celestial pole (SCP), which is marked a few centimetres above south on the chart. This is just a place in the sky; there is no star nearby. Over the course of a night, the stars appear to rotate around this point. In the northern hemisphere, the North Star is located at the north celestial pole (NCP) and so it is used in navigation to find north.

3 Look at the bottom right-hand corner of the chart, which gives a key to the symbols on the chart. The star magnitudes give the brightness of the stars as viewed from the Earth.

Discussion

1 Identify the location of the brightest star in the sky (Sirius).

2 Identify the star that is the second brightest in the sky.

3 Identify which star is brighter – Alpha Centauri or Beta Centauri.

4 Use your star chart to observe the night sky. Circle the stars and constellations you were able to identify.

Figure 1 What constellations can you see?

7.1B Modern-day Australian astronomers

CHALLENGE

Two prominent astronomers currently practising in Australia are Penny Sackett and Brian Schmidt (Figure 1).

Figure 1 Penny Sackett and Brian Schmidt

Aim

To determine the role of Penny Sackett and Brian Schmidt in astronomy.

What to do:

Below are some jumbled facts about these two scientists. Carry out some research to help you match the facts to the correct scientist. Answer any of the following questions and add any other interesting or up-to-date facts about each person. Find some images to go with your information.

- Conducted major research into extrasolar planets. (What are these?)
- Headed the SkyMapper project. (What is this?)
- Was a member of the High-Z SN search team. (What did this team do?)
- Served on the Board of Directors of the Giant Magellan project. (What is this?)
- Born in 1967 in the USA.
- Has worked as a science reporter for *Science News*.
- Born in 1956 in the USA.
- Made a major scientific breakthrough in 1998. (What was it?)
- Worked as Director of the ANU Research School of Astronomy and Astrophysics. (When?)
- Worked mainly with exploding stars called supernovas.
- Appointed as the Chief Scientist of Australia. (When?)
- Been jointly awarded the US$1 million Shaw prize for astronomy. (When and why?)

7.2A Understanding parallax

CHALLENGE

Aim

To model the parallax movement of stars.

What you need:

Whiteboard, whiteboard marker

What to do:

1 Position a student in front of the class approximately 2–4 m in front of the whiteboard (if possible).
2 Write a series of numbers across the whiteboard at the same height as the student.
3 Ask each member of the class to decide which number is in line with the student.

Discussion

1 Explain why most members of the class see a different alignment of the student and the numbers on the whiteboard.
2 Relate this activity to the night sky. Explain what the:
   a numbers represent
   b students represent
   c members of the class represent.
3 Explain how the results of this demonstration would be different if the student stood approximately 30 cm in front of the whiteboard.

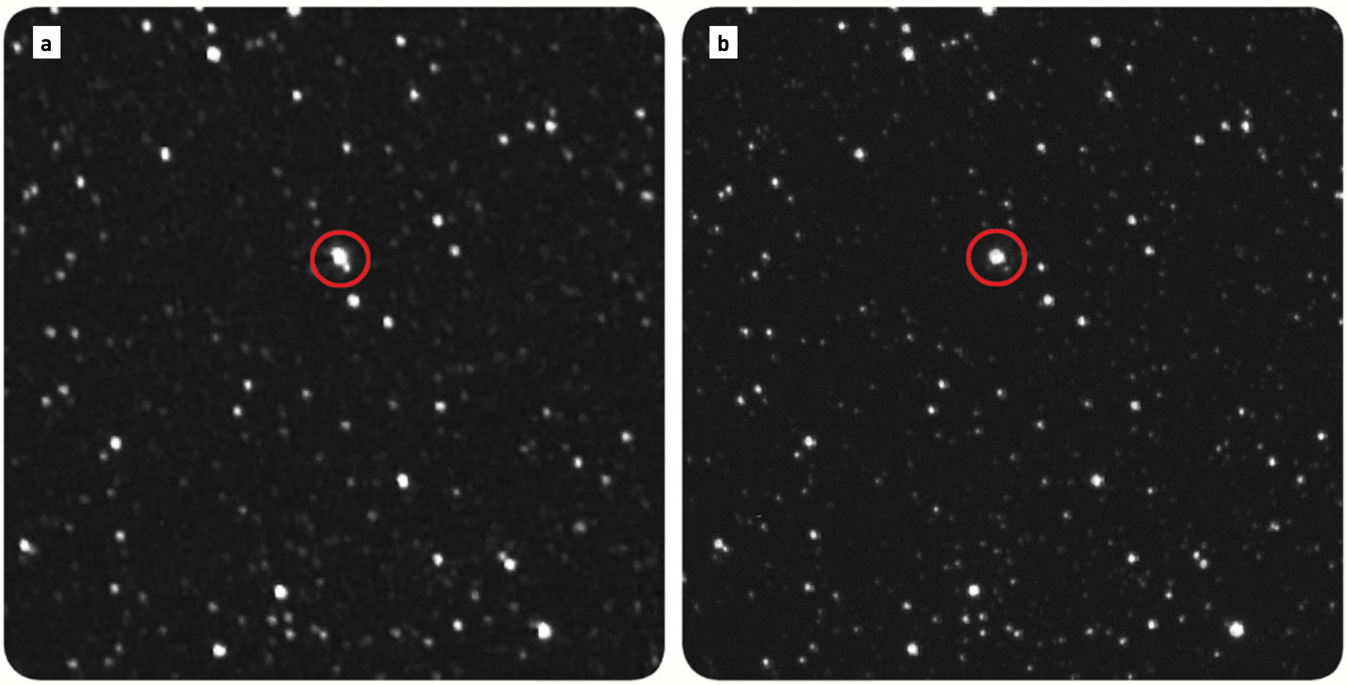


Figure 1 These images show two views of the star Proxima Centauri (circled). Image **a** was taken by a spacecraft 7 billion kilometres from Earth and image **b** was taken from Siding Spring Observatory in Australia. You can see that the star appears to be in a different position in each image. This is because of the parallax effect.

7.2B Calculating the distance to the Sun

EXPERIMENT

Aim

To determine a value for the distance from the Earth to the Sun using a pinhole screen, and to compare this with the known value.

Materials

- Metre ruler
- Retort stand (about 76 cm in height)
- Clamp
- Coat hanger
- Sticky tape
- Needle or pin
- 2 × A4 sheets of paper
- Calculator
- Sun visible in the sky

Theory

This experiment uses ratios to determine the distance from the Earth to the Sun. If you know the distance from the pinhole to the image of the Sun, the diameter of the Sun's image and the diameter of the Sun, you can calculate the unknown – the distance to the Sun.

You will use the following symbols:

- length from pinhole to Sun's image, L_i
- distance to the Sun, L_S
- diameter of Sun's image, d_i
- diameter of the Sun, d_S

You can write an equation using these four quantities. Try writing this equation or ask your teacher for help. It can be written in either fraction or ratio form.

Method

1 Wrap a sheet of A4 paper around the coat hanger and tape securely into place to form a screen.

2 Make a tiny pinhole in the centre of the screen covering the coat hanger.

3 In the centre of the other sheet of paper, draw two lines approximately 7 mm apart and measure the distance as accurately as possible. It doesn't matter if they are not 7 mm apart, but measure them as carefully as possible and record this value.

4 Tape the A4 paper with the two lines to the top of the base of the retort stand, making sure that the two lines are centred on the base horizontally.

5 Clamp the pinhole screen horizontally so it is facing the screen on the base of the stand and is about 40 cm away from the base.

6 Go outside and point the screen with the pinhole at the Sun. Adjust the position of the pinhole screen along the rod so that the circle of light from the Sun through the pinhole falls exactly between the two lines you drew on the base of the retort stand. The circle of light needs to fill the two lines by just touching both lines.

Results

1 Measure and record the distance between the two lines on the screen. This is d_i in the equation.

2 Measure and record the distance between the two screens in millimetres. This is L_i in the equation.

3 The accepted value of the diameter of the Sun, d_S, is 1 392 000 km.

4 Use the equation to perform a calculation based on the measurements to determine a value for L_S.

Discussion

1 The correct value for the distance to the Sun is approximately 149 600 000 km. Calculate the difference between L_S and this value. Record this value as the 'difference'.

2 Divide the difference by the correct value and multiply by 100. This converts it to a percentage and is called the percentage error. Round it off to the nearest whole number.

3 Identify two factors that contributed to this error. (HINT: Which measurements were not exact?)

4 Describe how these errors could have been minimised.

Conclusion

Write a conclusion for this experiment that relates the findings to the aim. Describe the size of the percentage error.

7.4A Exploring the Doppler effect

CHALLENGE

Aim

To explore the Doppler effect.

What you need:

Source of sound that can be spun on a rope (known as a Doppler effect apparatus)

What to do:

1 Switch on the sound source and spin it around, making sure no one is in its path (Figure 1).

2 Listen carefully to the pitch of the sound.

Discussion

1 Describe what happened to the pitch of the sound as the Doppler effect apparatus spun around.

2 Identify when the pitch was:

a higher

b lower.

3 Compare this demonstration with red shift and blue shift that are seen with starlight.

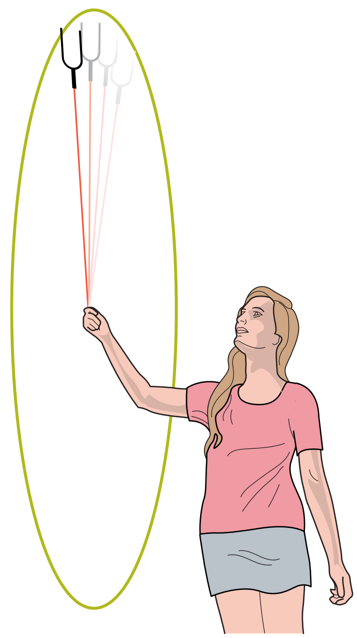


Figure 1 Using the Doppler effect apparatus

7.4B Investigating emission spectra

EXPERIMENT

CAUTION! Discharge tubes will get hot when in use. Do not touch. Turn off when not in use and allow to cool before handling. Keep electrical equipment away from water.

Aim

To use spectroscopy to investigate the light emitted by various elements.

Materials

- Spectroscope
- Discharge tubes for different elements – hydrogen, helium and neon
- Power supply for discharge tubes

Method

1. Connect the equipment and darken the room.
2. Aim the spectroscope at the discharge tube and observe the emission spectrum.
3. Repeat for each tube.

Results

Record the position and colour of the emission lines for each element. Present the results in a table.

Discussion

1. Compare the emission spectrum with the absorption spectrum.
2. Each element has a distinct emission spectrum. Describe how this is used to identify the elements present in the universe.
3. Some light from a distant nebula can have lines missing from its spectrum. Explain the cause of these missing lines, and identify the information that scientists obtain from this information.

Conclusion

Explain how the light emitted from different elements varies.

7.5 The expanding universe

CHALLENGE

Aim

To model how the universe expands.

What you need:

Balloon, permanent marker, tape measure, balloon pump

What to do:

1. Use the ruler to mark three crosses on the side of the balloon, 1 cm apart. Mark the centre cross as the origin (O).
2. Inflate the balloon using a balloon pump. Measure the distance of each cross from the origin (O).

Figure 1 Use a balloon to model the expansion of the universe.

Discussion

1. Compare the distance between each cross before and after the balloon was inflated.
2. Predict what would happen to the distance between the crosses if you added more air into the balloon.
3. Use the information gained from this model to explain the movement of galaxies as the universe expands.

8.1 Bringing graphs to life

CHALLENGE

Aim

To model movement from a displacement–time graph.

What you need:

Clear space (maybe outside), tape measure, stopwatch, masking tape, marker pen

What to do:

Working in pairs, act out the displacement–time graph in Figure 1.

1 Lay out a 4 m piece of masking tape on the floor and mark it at intervals of 1 m.
2 Rehearse the motion shown in Figure 1 by discussing it with your group. You could even do a walk-through rehearsal.
3 Start the stopwatch and try to match your motion to the graph. The person timing you will give you feedback on how you went.
4 Swap roles and repeat the activity until everyone in your group has had a turn.
5 Repeat the activity with another piece of masking tape on the floor going 4 m in the opposite direction.

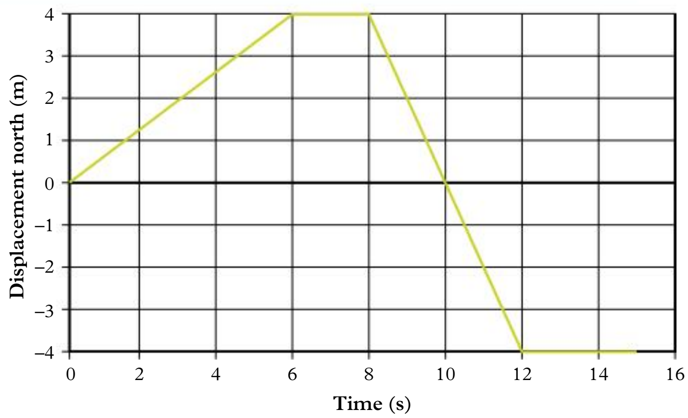


Figure 1 A displacement–time graph

Discussion

1 Describe the motion completed by your group that was matched to the graph.
2 Describe the common errors made by the group when completing this activity.
3 Draw your own displacement–time graph.
4 Describe the motion that is illustrated in the graph.

8.2A The ticker timer

EXPERIMENT

Aim

To learn how a ticker timer operates and to use it to produce a speed–time graph.

Materials

- Ticker timer
- Scissors
- 2–12 V DC power supply
- Graph paper
- 2 electrical wires
- Glue
- Ticker tape
- Carbon circles
- Ruler

Method

1 Connect the ticker timer to the AC terminals of the power supply using the two electrical wires (Figure 1). Set power source at 6 V. Adjust as required.

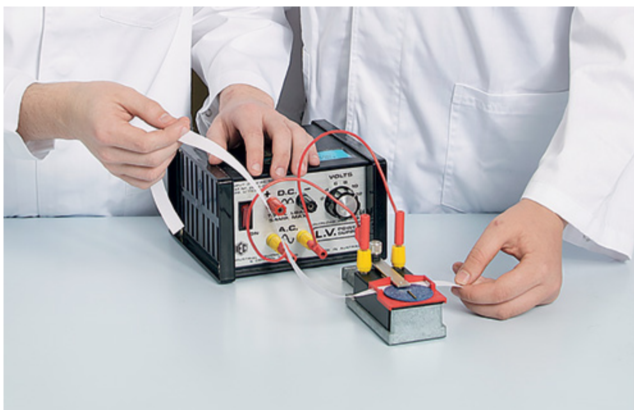


Figure 1 Connecting the ticker timer

2 Thread a 30 cm length of ticker tape through the slots in the ticker timer. Turn on the power and pull the tape through the timer. Examine the tape to see if the dots are clear (Figure 2).

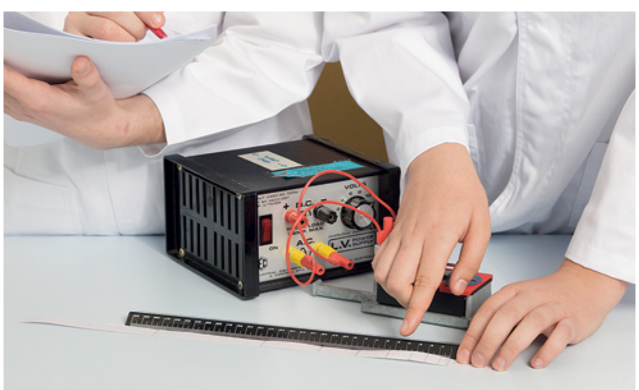


Figure 2 Examining the ticker tape

3 If the dots are too faint, adjust the equipment by increasing the voltage of the power supply. A new carbon disc may be required if this doesn't solve the problem. It can also help to loosen or tighten the screw holding the 'arm' of the ticker timer.

4 Repeat with a 1 m length of ticker tape. As you pull the ticker tape through, adjust your pulling speed so that there is a very slow section, a medium speed section and a very fast section, in any order.

Results

1 Start your analysis by finding the first clear dot. Number this dot '0'. Count along another five dots and rule a line right through the middle of the fifth dot. This gives a five-'gap' section of tape. The gap between successive dots is 0.02 seconds, so five gaps equals 5 × 0.02 or 0.1 seconds.

2 Divide the rest of your tape into five-gap sections by ruling lines through the middle of every fifth dot.

3 Number the sections of your tape and cut along the lines.

4 Glue each section of tape onto your graph paper, side by side, to form a column graph.

5 Add axes to your graph (speed on the *y*-axis and time on the *x*-axis) and work out a scale for each axis.

Discussion

1 Compare speed with velocity.

2 Explain why the length of each tape column indicates the speed.

3 Describe how you could determine the average speed of each section.
(HINT: Average speed = distance ÷ time)

4 Explain why the lengths of tape are the 'average' speed and not the instantaneous speed (by defining average speed, defining instantaneous speed, and comparing your chosen definition with the length of the tape).

5 Design another experiment you could do using a ticker timer. Ask your teacher for permission to carry out your experiment.

Conclusion

Describe the information you can determine using a ticker timer.

8.2B Using a motion sensor

EXPERIMENT

Aim

To become familiar with the operation of a motion sensor and to use it to produce motion graphs.

Materials

- Motion sensor
- Dynamics trolley
- Laptop computer
- Cardboard reflector

Method

1 Connect the laptop to the motion sensor and open the appropriate software for your motion sensor on the laptop.
2 Position the motion sensor several metres in front of the dynamics trolley and push the trolley towards the sensor. (You may need to attach a cardboard reflector to the front of the trolley to reflect the signal from the motion sensor back to the sensor.) Ensure the trolley does not contact the motion sensor.

Results

Analyse the data on the laptop to produce a displacement–time graph (and a speed–time graph, and even an acceleration–time graph if possible).

Discussion

1 Describe what each graph is showing you.
2 Compare the graphs with the actual motion of the trolley.
3 Evaluate the accuracy of the graphs produced by the motion sensor (by comparing it with the measurements produced by the ticker timer in Experiment 8.2A and deciding which is more accurate).
4 Design another experiment you could perform with the motion sensor.

Conclusion

Describe the information that can be gained from graphs created by a motion sensor.

Figure 1 Motion sensors can be used to measure displacement, speed, velocity and acceleration.

8.3 Measuring acceleration by timing or using a motion sensor

CHALLENGE

CAUTION! Never drop objects from high places without looking below to make sure the area is clear.

Aim

To measure the acceleration of a falling object.

What you need:

Ball, stopwatch, tape measure, motion sensor

What to do:

1. Measure how long it takes to drop a ball from one storey in seconds (t).
2. Measure the distance the ball fell in metres (h).
3. For more accuracy, or as a comparison, you could use a motion sensor connected to a computer to measure the acceleration directly.

Discussion

1. Use the results to calculate the acceleration due to gravity in units of m/s^2. The formula that describes this situation is:

   $h = at^2$

   (HINT: Rearrange the formula to make a (acceleration) the subject and substitute your values for h and t.)
2. The resulting value for a is the acceleration due to gravity (although it usually has the symbol g). Compare your calculated value with the known true value of 9.8 m/s^2 near the Earth's surface.
3. Identify whether this activity is a case study, modelling/simulation, quantitative analysis or a controlled experiment. Justify your decision (by identifying the key characteristics of the activity and comparing these with the definition of the term you chose).

8.4A Make an accelerometer

CHALLENGE

Aim

To make an accelerometer.

What you need:

Small glass jar and lid, paperclip, short length of cotton, sticky tape, water, scissors

What to do:

1. Tie one end of the cotton to the paperclip.
2. Stick the other end of the cotton to the underside of the lid so the paperclip hangs vertically inside the jar without touching the bottom.
3. Fill the jar with water and screw the lid on.
4. Test your accelerometer by pushing it slowly along a table, then speed it up, move it at constant speed, and finally slow it down.
5. Take your accelerometer with you in the car, bus or train and observe the position of the cotton and paperclip when the vehicle:
   - starts moving
   - slows its movement
   - travels at constant speed in a straight line.

Discussion

1. Use Newton's first law of motion to explain why the paperclip resists moving when the jar starts moving.
2. Use Newton's first law of motion to explain why the paperclip keeps moving forwards when the jar comes to rest.
3. Describe what happens to the paperclip when the jar is moving at a constant speed.
4. Use Newton's first law of motion to explain your answer to question 3.
5. Explain how our own bodies tell us we are accelerating, decelerating or travelling around a corner.

8.4B How do you like your eggs?

CHALLENGE

CAUTION! Some students may be allergic to eggs. Do not eat or drink in the laboratory.

Aim

To use Newton's laws to identify an object full of liquid.

What you need:

2 eggs in their shells – one fresh and one hard-boiled, with no indication of which is which (NOTE: Use half-full water bottles if egg allergies are a concern.)

What to do:

1 Spin both eggs on a flat surface.
2 Stop the eggs gently by placing your finger momentarily on top of the spinning egg, then release the egg by lifting your finger off it. Does it stay stopped or keep spinning?

Figure 1 Which egg is fresh (full of liquid) and which is hard boiled?

Discussion

1 Compare the motion of the two eggs.
2 Describe how the contents of a fresh egg will move when it is spun.
3 Describe how the content of a fresh egg will change its movement when the egg is stopped.
4 Describe how the content of a boiled egg will change its movement when the egg is stopped.
5 Predict which egg is fresh and which is boiled. Open the shells (over a rubbish bin or sink). Describe the accuracy of your prediction.
6 Use Newton's first law to describe the motion of a fresh egg and a boiled egg.

8.5A Resultant forces

EXPERIMENT

Aim

To investigate the addition of vectors using three spring balances.

Materials

- 3 spring balances (0–10 N or 0–20 N are best)
- 2 rubber bands
- Graph paper
- Masking tape
- Scissors

Method

1 Test to see that each spring balance reads zero with no force exerted on its hook. (This is known as checking the 'calibration'.) If not, adjust it so it does.

2 Tape a piece of graph paper to the bench and draw a large dot in the centre of the paper.

3 Tie one rubber band to the centre of the other to create three 'loops' with a knot in the centre.

4 Hook each spring balance onto the loops lying flat on the paper and position the knot so that it stays directly above the dot on the graph paper (Figure 1).

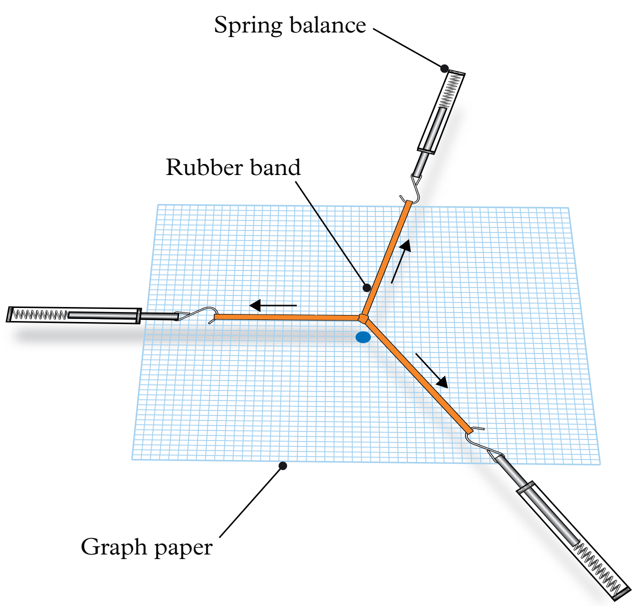


Figure 1 Experimental set-up

5 Pull on the spring balances in different directions so that the knot stays directly over the dot.

6 Record the force reading on each spring balance, and draw the direction of the force on the graph paper. This can be done by drawing a line directly below the rubber bands.

7 Repeat the experiment twice more using different-sized forces and different directions.

Results

1 Drawing a force diagram: Remove the graph paper and create a force diagram by choosing an appropriate scale (usually 1 cm = 1 N) and drawing the three forces acting from the dot in the correct directions. The forces are drawn as lines with arrowheads. The direction of the arrowhead shows the direction of the force. The length of the line shows the size of the force.

2 Drawing a vector diagram: To convert the force diagram into a vector diagram, leave one of the force arrows in position where it is, then 'slide' the other two force arrows so that all three join head to tail with each other. When all three forces are added, determine the net force by drawing a line from the start to the end and head-to-head and tail-to-tail. This shows the result of the three individual vectors, which should be very small or even non-existent if you did the experiment correctly.

Discussion

1 Contrast a force diagram and a vector diagram.

2 Define the term 'net force'.

3 Describe the net force on a stationary object.

Conclusion

Describe the vector forces on the three spring balances.

8.5B Accelerating masses

EXPERIMENT

Aim

To determine the relationship between mass and acceleration.

Materials

- Dynamics trolley
- String
- Mass hanger and brass 50 g masses
- Several 1 kg masses
- Desk-mountable pulley wheel with clamp
- Motion sensor or stopwatch
- Tape measure or ticker timer
- 2–12 V power supply
- Ticker tape
- Cushioning material

Method

1 Clamp the pulley wheel to the edge of the desk. Try to arrange the largest height possible above the floor (Figure 1).

Figure 1 Clamping the pulley wheel to the desk

2 Attach one end of the string to the dynamics trolley and the other end to the mass hanger, carrying a total of approximately 200 g of mass (Figure 2).

Figure 2 Attaching string to the dynamics trolley and the mass hanger

3 Hang the masses over the pulley so they can pull the trolley along as they fall to the floor. Place the cushioning material under the weights to reduce impact.

4 Record the motion of the trolley as the masses fall, by using a motion sensor, timing with a stopwatch or recording the motion on ticker tape (Figure 3).

Figure 3 Recording the motion of the trolley

5 Successively add 1 kg masses to the trolley and repeat your measurements several times.

Results

1 Determine the acceleration of the trolley using one of the following methods.

a If you used a motion sensor, use software (see Experiment 8.2B) to determine the acceleration directly or from the gradient of a velocity–time graph.

b If you used a stopwatch, calculate the acceleration as (2 × the distance travelled ÷ time squared).

c If you used a ticker timer, use the 'every fifth dot method' (as per Experiment 8.2A) to divide the tape into sections. Determine the speed of each section by dividing the distance covered by 0.1. Plot a speed–time graph and determine the acceleration from the gradient of the graph.

2 Plot a graph of acceleration versus total mass. This should give a truncated, or inverse, graph.

Discussion

1 Define the term 'acceleration'.

2 Define the term 'mass'.

3 Describe how increasing the mass on the trolley affected the acceleration of the trolley.

4 Use Newton's second law of motion to explain the effect mass has on acceleration.

5 Describe a real-world example in which the mass can affect the motion of a moving object.

Conclusion

Describe the relationship between mass and acceleration.

8.6 What if forces were changed on Newton's rocket?

EXPERIMENT

Aim

To examine the action and reaction of a balloon rocket.

Materials

- Balloon and balloon pump
- Drinking straw
- Sticky tape
- Fishing line
- Timer
- Measuring tape

Method

1 Thread the fishing line through the straw.
2 Tie the ends of the fishing line to two fixed points across the room.
3 Inflate the balloon and hold it shut. Measure the diameter of the balloon.
4 Use the sticky tape to tape the inflated balloon to the straw (Figure 1).
5 Release the end of the balloon and measure the distance the balloon travels and the time it takes to come to a complete stop.
6 Reinflate the balloon to the same diameter. Repeat step 5.
7 Repeat steps 5 and 6 several more times.
8 Determine the mean, median and mode speed of the balloon.

Results

Record your results in an appropriate table.

Inquiry

Choose one of the following questions to investigate.

- What if the amount of air in the balloon was increased?
- What if a string with more friction was used?

Answer the following questions in relation to your inquiry.

- Write a hypothesis (If … then … because …) for your inquiry.
- Identify the (independent) variable that you will change from the first method.
- Identify the (dependent) variable that you will measure and/or observe.
- Identify two variables that you will need to control to ensure a valid test. Describe how you will control these variables.
- Identify the materials that you will need for your experiment.
- Write down the method you will use to complete your investigation in your logbook.
- Draw a table to record your results.
- Show your teacher your planning for approval before starting your experiment.

Discussion

1 Explain why the balloon moves forward.
2 Draw a picture of the balloon rocket with all the forces that are acting on it.
3 Describe the action and reaction that occurs in the balloon rocket.
4 Explain how you would expect the average speed to change if the balloon was inflated less.
5 Compare the mean, median and mode values you obtained. Evaluate which value could be considered the most accurate. Justify your answer (by describing how each value was determined, comparing the effect an added outlier would have on the values, and deciding which value could be considered most accurate).

Conclusion

Describe how Newton's third law applies to your balloon rocket.

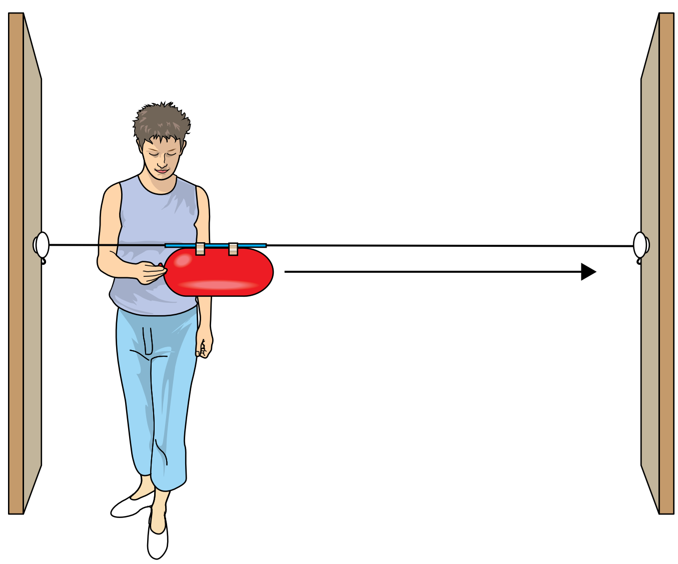


Figure 1 Experimental set-up

8.7 Colliding trolleys

EXPERIMENT

Aim

To investigate whether total momentum is conserved during a collision.

Materials

- 2 dynamics trolleys
- Metre ruler
- Ruler
- Several 1 kg masses to add to the trolleys
- 2 rubber bands tied together that will stretch to 20 cm quite easily
- Level benchtop
- Piece of A4 paper
- Masking tape

Method

1. Attach the piece of A4 paper to the benchtop with masking tape. Rule two parallel lines on the paper, 20 cm apart (Figure 1).

Figure 1 Setting up the paper

2. Link the two trolleys with the rubber bands (Figure 2).

Figure 2 Linking the trolleys

3. Pull the trolleys apart and hold them with their front ends on the two lines (Figure 3).

Figure 3 Pulling the trolleys apart

4. Release the trolleys. The trolleys will accelerate towards each other and collide. How far the trolleys travel in a given time is proportional to their relative velocities. Determine where the trolleys collide and mark the collision point on the paper.
5. Measure the distance from one line to the collision point (d_1) and the same for the other line (d_2). Because the trolleys collide at the same time, there is no need to measure the times because the distances are proportional to the collision speeds.
6. Add various masses to one (or both) of the trolleys and repeat the experiment. Test approximately five different mass combinations.

Results

Record the results listed in the header row of Table 1 in a spreadsheet or table.

Table 1 Results from the experiment

m_1 = mass of trolley 1	d_1 (in m)	$m_1 \times d_1$	m_2 = mass of trolley 2	d_2 (in m)	$m_2 \times d_2$	$(m_1 \times d_1) - (m_2 \times d_2)$

The final column gives a measure of the total momentum of the two trolleys just prior to the collision. The negative sign is used because the two trolleys are travelling in opposite directions and therefore one momentum is negative.

Discussion

1. Define the term 'momentum'.
2. Use an example to explain the law of conservation of momentum.
3. Explain why the trolleys travel towards each other for the same period of time when they are released.
4. Describe the magnitude of the force acting on each trolley.
5. If both trolleys come to a stop after the collision, explain the final total momentum of the 'system'.
6. Use the last column of results to calculate the initial total momentum of the 'system'.

Conclusion

Describe what this experiment demonstrated about the total momentum before and after a collision.

9.1A Neuroscientist interview

CHALLENGE

Aim

To explain the function of different brain areas and what happens if these areas are damaged.

What you need:

Writing device (notebook or computer), access to the internet

What to do:

1. Imagine you are a neuroscientist explaining different areas of brain damage to patients, and the impact it will have on their ability to function. Use your understanding of the roles of the areas of the brain presented in Table 1 to create your explanation.
2. Select one of the areas of the brain from Table 1. Prepare a 2 minute presentation to explain the role of the area and the possible effects of damage to this area.

Figure 1 What is the impact of damage to the different areas of the brain?

Table 1 Areas of the brain

Area of brain damaged	Role of this area of the brain	Explanation to patient (What is the impact of this brain damage on the person's ability to function?)
Hippocampus		
Amygdala		
Cerebellum		
Frontal lobe of cerebral cortex		
Parietal lobe of cerebral cortex		
Occipital lobe of cerebral cortex		
Temporal lobe of cerebral cortex		

9.1B Modelling neural pathways

CHALLENGE

Aim

To model neural pathways using pipe cleaners.

What you need:

Pipe cleaners (3 each of 5 different colours per group), A3 paper, glue, glitter

What to do:

1 Collect materials to create your own colourful neurons.
2 Each pipe cleaner colour will be used for a different neuron part. Use the same colours for each neuron part. For example:
   > dendrites (blue)
   > soma (cell body) and cell nucleus (green)
   > axon (yellow)
   > myelin sheath (red)
   > axon terminals (black).
3 Use the diagram of a typical neuron to create two neurons. Wind the pipe cleaners to create the different parts.
4 Arrange the two neurons on the A3 paper and glue them down. Make sure you join them end-to-end (axon terminals to dendrites). Ensure the two neurons are not touching – there is a gap between each pair of neurons (called the synapse).
5 Between the two neurons, use glue and glitter to create a sparkly synapse. The glitter represents the neurotransmitters.
6 The two neurons placed end-to-end with glitter at the synapse are now a mini neural pathway.
7 Create a class neural network by placing all the mini neural networks onto a display board or whiteboard. Take care to make sure that only dendrites and axons are connected with each other and that neurons are not touching each other.

Discussion

1 Describe the function of a neuron.
2 Use the following terms to explain how the neurons communicate with each other: dendrites, axons, electrical message, axon terminals, synapse, neurotransmitter.

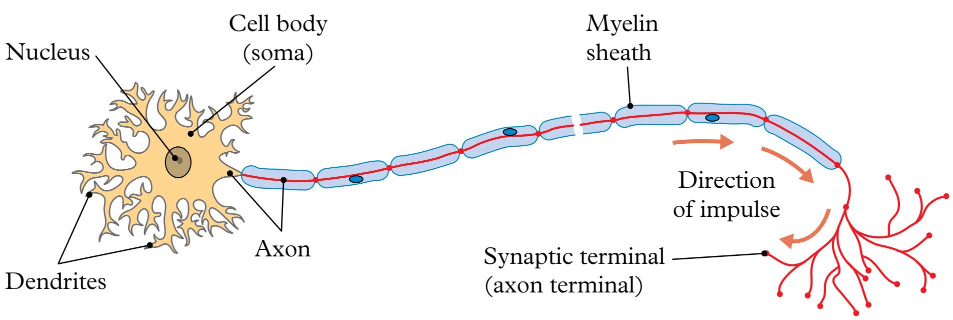


Figure 1 A typical neuron

9.1C Modelling brain structure and function

SKILLS LAB

Aim

To create a model of the different parts of the brain involved in learning and memory.

What you need:

5 different colours of play dough, A3 paper, coloured marker pens

What to do:

1 Break into small groups. Each group should have an equal amount of each play dough colour.
2 Create a model of the brain to illustrate the following key structures involved in memory and learning.
   > cerebral cortex (each lobe: frontal, parietal, occipital, temporal)
   > hippocampus
   > amygdala
   > cerebellum

   Your model should represent both internal and external structures. You may want to do some research on the internet or use the figures on this page to assist you.
3 Build your model on the A3 paper.
4 Label each of the key parts of the brain.
5 Share your model of the brain with the class.

Discussion

1 Describe the function of each of the following parts of the brain:
   a amygdala
   b cerebellum
   c hippocampus.
2 Describe one way you could improve your memory of the different structures of the brain.

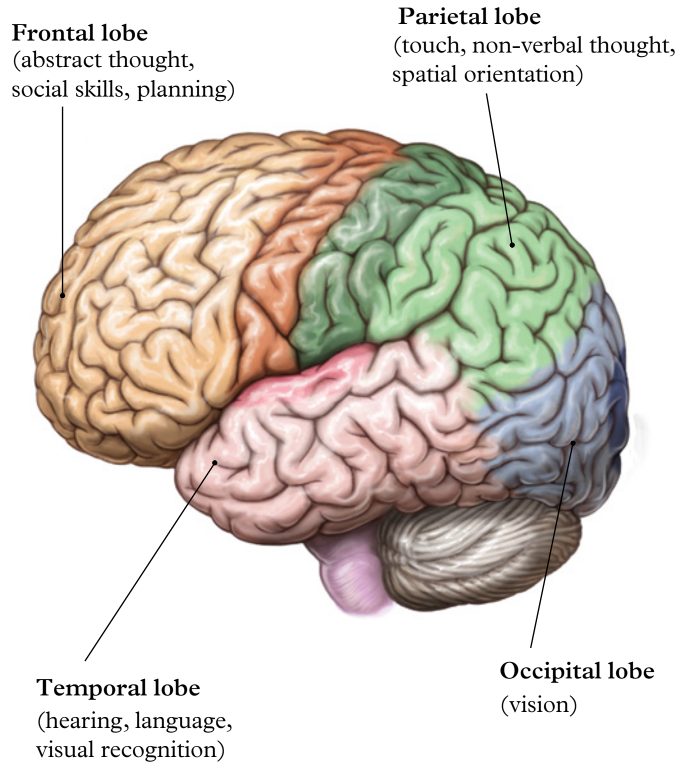


Figure 1 Lobes of the cerebral cortex

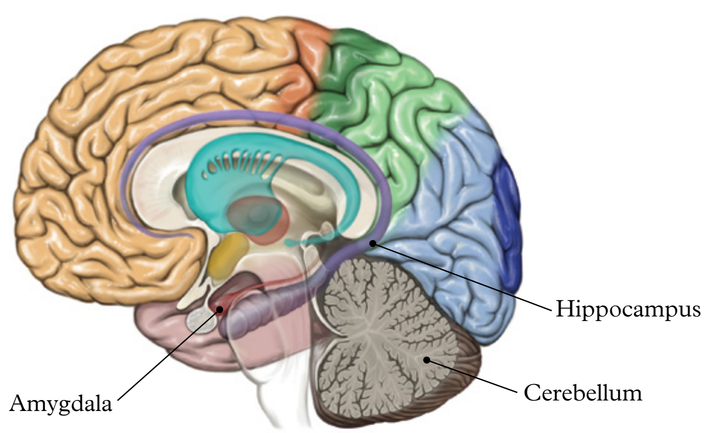


Figure 2 Parts of the brain

9.5 Improving memory recall

EXPERIMENT

Aim

To use the mnemonic strategy of chaining to improve recall of 15 words.

Materials

- 2 lists of 15 unrelated words (List A and List B, below)
- Pens
- 2 pieces of paper per student

List A

Pen, chair, knife, pot, teacup, lamp, jumper, bottle, box, ruler, apple, balloon, stylus, phone, glasses

List B

Bed, runners, dumbbell, table, bagel, headphones, notebook, mouse, speaker, vase, frame, flower, vacuum, candle, book

Method

1 One student is to access List A and List B via the obook pro.
2 Remaining students are assigned two pieces of paper. At the top of one page, students are to write List A, and at the top of the other page students should write List B.

List A

1 The teacher tells the students they will hear a list of words. They should not use any strategy for aiding retention, but simply repeat each word as it is read out.
2 The teacher reads List A to students with a 3 second break in between each word.
3 Once each word on List A has been read aloud, students write down all the words they remember from the 15 words in the order they were presented.
4 The teacher then reads List A aloud again. Students self-correct their list of recalled words, then turn their list face down so they cannot see the List A words.

List B

1 The teacher tells the students they will hear a new list of words. They must create a story with each word from List B as it is presented. They should not use any other strategy for aiding retention – only chaining.
2 The teacher then reads List B to students with a 3 second break in between each word.
3 Once each word on List B has been read aloud, students write down all the words they remember from the 15 words in List B in the order they were presented.
4 The teacher then re-reads List B. Students self-correct their list of recalled words.
5 Students look at their lists of recalled words and record how many words they recalled correctly for List A and for List B.

Results

1 Copy and complete Table 1 with the results of each student in the class.

Table 1 Student recall

Student	List A (number recalled out of 15)	List B (number recalled out of 15)
1		
2		
3		
4		
5		
…		

2 Calculate the mean, median and mode for List A, and then for List B.
3 Create a graph that represents the class mean for List A and for List B. Label the axes of your graph appropriately and give your graph a suitable title.

Discussion

1 Suggest what your class mean data suggests about the effectiveness of chaining as a mnemonic strategy to improve recall for a list of 15 words. Compare the data for List A and List B to support your reasoning.
2 Explain your results with reference to elaborative rehearsal and long-term memory.
3 Compare your individual data with the class data. Do they compare? Provide reasoning for any similarities or differences.
4 Extraneous variables are factors that were not tested but may have influenced the data. Identify three extraneous variables that may have unintentionally influenced your class results.
5 Suggest a specific recommendation based on this experiment that you could make to students in your school to help them improve their recall.

Conclusion

Write a brief conclusion about the effectiveness of chaining as a strategy for improving the recall of 15 words.

[STEAM project 1]

How can we use technology so that we improve the lives of people in the world's poorest nations?

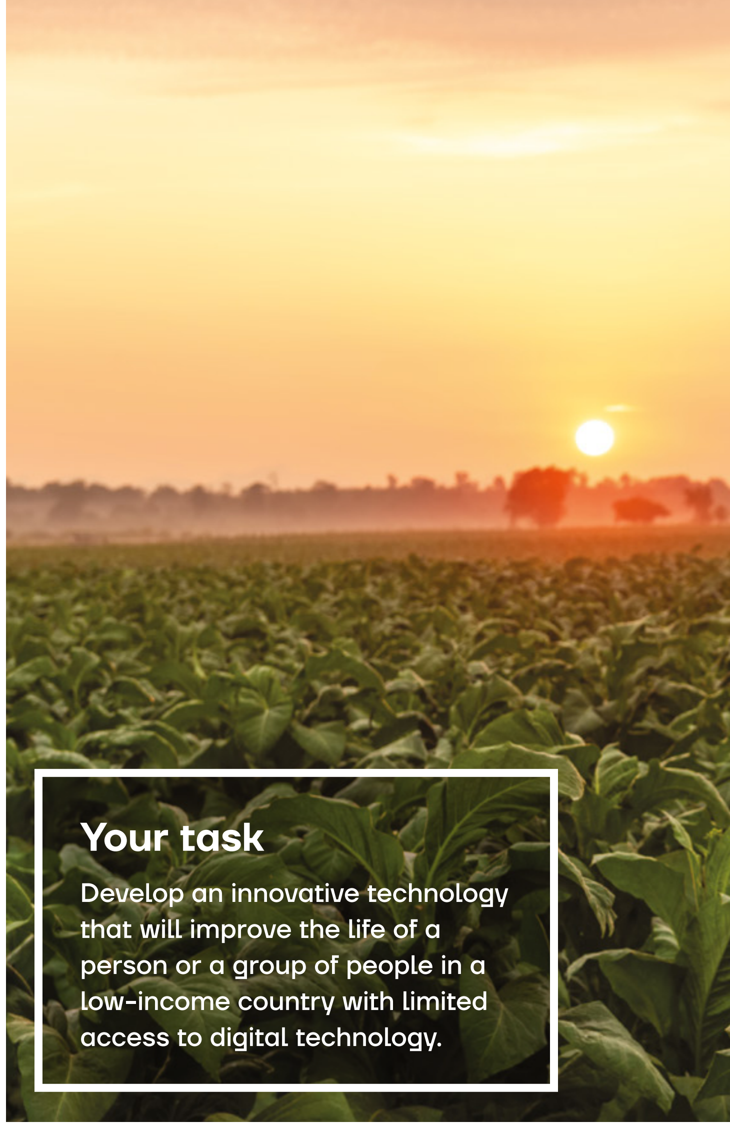
In Australia we are surrounded by technology every day. It is in the phones we use, the televisions we watch and the cars we drive. The term 'technology' is used for any machinery or equipment that applies the scientific knowledge we have discovered. Wheels and computers are both examples of technology.

In high-income countries, emergency response teams often rely on technological data supplied by electronic sensors to respond to natural disasters such as storms, fires and plagues. Drones might be used to conduct search and rescue operations. Doctors can use technology to remotely diagnose people who are sick and to perform operations that save lives.

At the end of 2017, the number of high-speed mobile phone subscriptions in member countries of the Organisation for Economic Co-operation and Development (OECD) reached a milestone: more subscriptions than the number of people. These mobile phones have been used to alert people to natural disasters, or to call for help in the event of floods and fires.

Technology is not just used for communication during natural disasters. It is also used to create medicine, improve farming practices and for education.

However, not everyone has access to technology.



Your task

Develop an innovative technology that will improve the life of a person or a group of people in a low-income country with limited access to digital technology.

Figure 1 Technology can be used to enhance and improve agricultural practices.

The digital divide

The term 'digital divide' is used to describe the gap between those who have access to digital technology – such as mobile phones, computers and the internet – and those who do not. The Australian Bureau of Statistics has identified that almost 2.6 million Australians do not use the internet and cannot access technology in an emergency. Access is even lower in lower-income countries throughout Africa and Asia.

The OECD has identified that targeted innovation that uses technology can boost productivity, increase economic growth and help solve problems in society.

Figure 2 Technology has made attending a doctor's appointment easier and more accessible for people who may have difficulty attending in person.

HUMANITIES

In Geography this year, you will be learning about the spatial variations in human wellbeing globally. You will need to explore a range of factors that lead to inequalities, such as social, political, economic and technological differences. In Economics and Business, you will explore variations in living standards between countries, and how living standards can be improved.

To complete this task successfully, you will need to research the initiatives of international governments and non-government organisations (NGOs) aimed at improving human wellbeing, particularly regarding health. You should consider how technology could be effectively accessed, resourced and used by a group of people to address their health concerns.

You will find more information on this in Chapter 5 'Inequalities in wellbeing' and Chapter 13 'Living standards' of *Oxford Humanities and Social Sciences 10 Australian Curriculum*.

MATHS

In Maths this year, you will extend your skills in representing, comparing and interpreting data. You will use digital technology to work with data, but also perform calculations by hand.

To complete this task successfully, you will need to find data to quantify the problem, to cost your interventions and to calculate a quantitative, evidence-based estimate of the likely benefits of your interventions. You will need to use skills in performing proportionality and other calculations with very large numbers, using scientific notation.

You will find relevant mathematical and statistical concepts in Chapter 9 'Statistics' of *Oxford Maths 10 Australian Curriculum*.

SCIENCE

In Science this year, you will learn how an understanding of evolution can contribute to the selection of desired traits (such as drought resistance) in plants and animals. You will also learn how genetic engineering can be used to develop medicines that will cure cancers and prevent disease.

To complete this task successfully, you will need to consider how the values and needs of different societies can influence the focus of scientific research. You will also need to consider the ethics of the technology that you will be offering to your selected individual or group of people.

You will find more information on this in Chapter 2 'Genetics' and Chapter 3 'Evolution' of *Oxford Science 10 Australian Curriculum*.

The design cycle

To successfully complete this task, you will need to complete each of the phases of the design cycle.

Discover

When designing solutions to a problem, you need to know who you are helping and what they need. The people you are helping, who will use your design, are called your end-users.

Consider the following questions to help you empathise with your end-users:

- Who am I designing for?
- What problems are they facing? Why are they facing them?
- What do they need? What do they not need?
- What does it feel like to face these problems? What words would you use to describe these feelings?

To answer these questions, you may need to investigate using different resources, or even conduct interviews or surveys.

Define

Before you start to design your innovative technology, you need to define the parameters you are working towards.

Define your version of the problem

Rewrite the problem so that you describe the group you are helping, the problem they are experiencing and the reason it is important to solve it. Use the following phrase as a guide.

'How can we help (the group) to solve (the problem) so that (the reason)?'

Determine the criteria

1 Describe the limitations in energy, communications, transport and support personnel that will need to be considered as part of the solution.
2 Describe how many copies of the solution prototype will need to be made to make a difference in the country you have chosen.
3 Identify who could pay for the construction of the solution prototypes.
4 Describe the social culture that is experienced by the individuals and groups who are affected by the problem. Why might some technologies be viewed as unwanted or even dangerous?

Ideate

Once you know who you're designing for, and you know what the criteria are, it's time to get creative!

Outline the criteria or requirements your technological design must fulfil (i.e. cost, size and weight for transportation, and cultural appropriateness).

Brainstorm at least one idea per person that fulfils the criteria.

Remember that there are no bad ideas at this stage. One silly thought could lead to a genius innovation!

Build

Each group member should select one design to draw. Label each part of the design. Include the material that will be used for its construction.

Include in the individual designs:

a a detailed diagram of the design

b a description of how it will change the life of your selected individual or group

c an outline of any similar designs that are already available to buy

d an outline of why your idea or design is better than others that are already available.

Present your design to your group.

Build the prototype

Choose one solution and build two or three prototypes. The prototype may be full size, or it may be a scale model (10 cm = 1 m).

Use the following questions as guidelines for your prototype solution.

- What materials or technology will you need to build or represent your prototype solution?
- What skills will you need to construct your prototype design? Does your group have these skills, or who can teach you those skills?
- How will you make sure your prototype design is able to be used by your selected individual or group? Will they need training?
- How will you display or describe the way the prototype design will work?

Test

Prototype 1

Use the scientific method to design an experiment that will test the effectiveness and strength of your first prototype solution. You will test the prototype more than once to compare results, so you will need to control your variables between tests.

What criteria will you use to determine the success of your prototype? Conduct your tests and record your results in an appropriate table.

Prototype 2

If your prototype will be used to help an individual, then you will need to generate a survey to test whether the prototype is appropriate for their use. (How would they use it? Would it make their work easier or harder? Would they consider buying it?)

Prototype 3

Use the information you have obtained from testing the first two versions to adapt your last prototype to be more effective and usable for the group you are helping. You may want to use the first two prototypes to demonstrate how the design has been improved over time.

Communicate

Present your design to the class as though you are trying to get your peers to invest in your designed solution.

In your presentation, you will need to:

- outline the situation of the country in which your selected individual or group lives
- outline the challenges faced by your selected individual or group
- include a working model or a detailed series of diagrams with a description of how the prototype of the solution will be used
- include a description of how you changed your design prototype as a result of testing or feedback
- include a description of how the design prototype will improve the lives of your selected individual or group.

Check your Student obook pro for the following digital resources to help you with this STEAM project:

Student booklet
This helpful booklet will guide you step-by-step through the project.

What is the design cycle?
This video will help you to better understand each phase in the design cycle.

How to manage your project
This 'how-to' video will help you to manage your time throughout the design cycle.

How to pitch your idea
This 'how-to' video will help you with the 'Communicate' phase of your project.

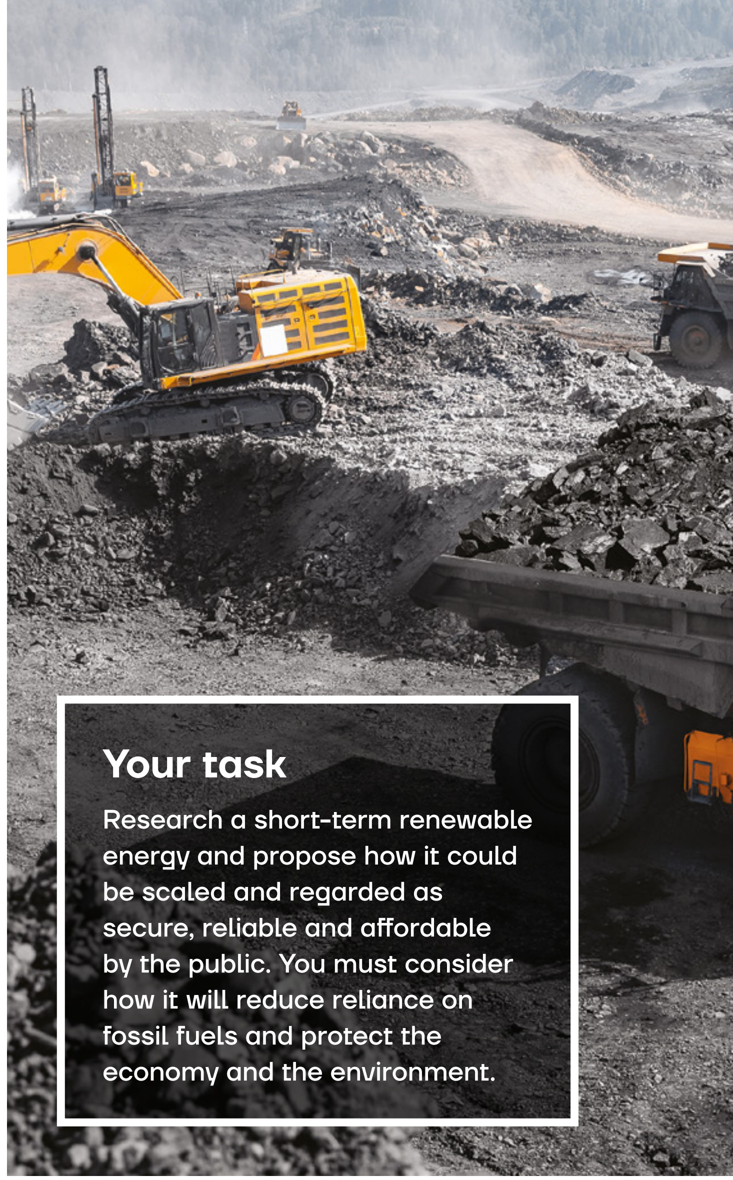
[STEAM project 2]

How can Australia reduce its reliance on fossil fuels so that we protect the environment and the economy?

Fossil fuels such as coal, oil and gas are made from fossilised, decomposed organisms that aged over millions of years in the Earth's crust. They contain carbon, which can be burned for energy. Due to the length of time it takes for these fuels to form as part of the carbon cycle, they are classified as long-term renewable sources of energy, sometimes called non-renewable.

Australia is a major user, producer and exporter of fossil fuels. Nearly 80 per cent of Australia's electricity is generated from coal and gas. Seventy-five per cent of coal mined in Australia is exported, making Australia the largest net exporter of this fuel in the world. In 2019, it was reported that Australia was the world's third-largest exporter of fossil fuels. Economically, the production and export of fossil fuels contributes hugely to Australia's GDP, and the mining industry is an important employer.

Coal emits higher amounts of carbon dioxide (CO_2) than oil or gas when used to produce energy. Measuring fossil fuel exports according to their potential to emit CO_2 makes Australia's carbon footprint per capita one of the largest in the world. This is contentious globally, particularly for nations most affected by a changing climate.



Your task

Research a short-term renewable energy and propose how it could be scaled and regarded as secure, reliable and affordable by the public. You must consider how it will reduce reliance on fossil fuels and protect the economy and the environment.

Figure 1 Most of Australia's energy is generated from coal. Almost 80 per cent of the coal produced in Australia is from open-cut mines.

Renewable alternatives

To protect both the environment and the economy, Australia needs to focus more on short-term renewable energy. When deciding on energy alternatives, it is important that energy supply be secure, reliable and affordable.

Short-term renewable energy sources include hydropower, solar power, wind power, bioenergy and ocean energy. Australia's landscape is suitable for many of these alternatives, but large investments in technology are required. As we invest more in the technology that makes short-term renewable energy possible, the better we get at making it, the more affordable it becomes and the more demand for renewable energy grows (a cyclical process).

Figure 2 A solar farm in Canberra. Solar energy is a source of renewable energy.

HUMANITIES

In Geography this year, you will learn about environmental change and management. You will explore the environmental, technological and economic factors that have influenced the change and the consequences of human actions on the sustainability of the environment.

In Economics and Business, you will investigate how the performance of Australia's economy is measured and how Australia's economic growth has depended on natural resources. You will explore the impact that environmental policies can have on Australia's economy and living standards.

To complete this task successfully, you will need to understand how stakeholders such as governments, communities and businesses can work together to initiate environmental change and management plans that protect both the environment and the economy.

You will find more information on this in Chapter 2 'Changing and managing the environment' and Chapter 13 'Economic growth and productivity' of *Oxford Humanities and Social Sciences 10 Australian Curriculum*.

MATHS

In Maths this year, you will extend your skills in representing and interpreting data, including univariate, bivariate and multivariate data sets. This will include critical consideration of media reports that use statistics and present graphs. You will use digital technology to work with data but also perform calculations by hand.

To complete this task successfully, you will need to find data to quantify the problem, to cost your interventions and to calculate a quantitative, evidence-based estimate of the likely benefits of your interventions. You will need to have skills in performing proportionality and other calculations with very large numbers, using scientific notation.

You will find relevant mathematical and statistical concepts in Chapter 9 'Statistics' of *Oxford Maths 10 Australian Curriculum*.

SCIENCE

In Science this year, you will learn about the impacts of fossil fuel combustion reactions in the production of carbon dioxide and carbon monoxide. You will also examine how increased reliance on this form of energy has affected the way carbon cycles through Earth's spheres, and how the resulting increase in greenhouse gases (including carbon dioxide) has led to enhanced global warming, which is contributing to melting sea ice and permafrost, rising sea levels and an increased number of extreme weather events.

To complete this task successfully, you will need to consider how energy that is generated can be used efficiently.

You will find more information on this in Chapter 4 'Climate change' of *Oxford Science 10 Australian Curriculum*.

The design cycle

To successfully complete this task, you will need to complete each of the phases of the design cycle.

Discover

When designing solutions to a problem, you need to know who you are helping (your end-users) and what they need.

Consider the following questions to help you empathise with your end-users:

- Who am I designing for? Will I be helping the government or members of the public?
- What problems are they facing? Why are they facing them?
- What do they need? What do they not need?

To answer these questions, you may need to investigate using different resources, or even conduct interviews or surveys.

Define

Before you start to design your solution for the potential replacement of fossil fuels, you need to define the parameters you are working towards.

Define your version of the problem

Rewrite the problem so that you describe the group you are helping, the problem they are experiencing and the reason it is important to solve it. Use the following phrase as a guide.

‘How can we help (the group) to solve (the problem) so that (the reason)?’

Determine the criteria

1 What type of energy source are you trying to replace? How much of it is currently used and how is it used?
2 How will the renewable energy be used? Will it be easy for the user to access?
3 Will the renewable energy require many changes in the vehicles or equipment being used? Who will pay for this change in infrastructure? How much will it cost?
4 How long will it take to generate the resources needed to make this renewable energy resource accessible and affordable for most people?

Ideate

Once you know who you’re designing for, and you know what the criteria are, it’s time to get creative!

Outline the criteria or requirements your design must fulfil (i.e. type of equipment, number and amount of materials, area that needs to be covered).

Brainstorm at least one idea per person that fulfils the criteria.

Remember that there are no bad ideas at this stage. One silly thought could lead to a genius innovation!

Build

Each team member should draw one individual design. Label each part of the design. Include the material that will be used to construct a model of the design.

Include in the individual designs:

a a description of what you see as the biggest problem with the energy source that you are replacing
b a description of the renewable energy that you propose could be used instead

c a description of how this renewable energy could be scaled up so that it can be used more effectively.

Present your design to your group.

Build the prototype

As a group, choose one design and plan how to model or build it. You may need to produce two or three to-scale prototypes for your group's design. Keep each iteration so that you can show the progress of your ideas.

Use the following questions as guidelines for your prototype.

- How will you replicate or model the renewable energy source?
- How will you model how the renewable energy will be used?
- What are the limitations of the renewable energy source? Will it produce enough energy for the equipment that currently uses fossil fuels?
- Calculate the number, density or requirements of energy sources in your area. How will your model provide for these demands?

Test

Use the scientific method to design an experiment that will test the limitations of your renewable energy prototype idea. You will need to model and test more than one prototype to compare results, so you will need to consider all variables between tests.

What criteria will you use to determine the success of your renewable energy prototype?

If your prototype will be used by a particular group of individuals, then you will need to generate a survey to test whether the prototype is appropriate for their use. (How would they use the alternative energy source? Would it make their life easier or harder? Would they consider buying it? How much would they be prepared to pay to access this form of energy?)

Conduct your tests and record your results in an appropriate table.

Communicate

Present your design to the class as though you are trying to get your peers to invest in your alternative energy design.

In your presentation, you will need to:

- outline the energy needs of the selected individual or group you are supporting
- outline the energy challenges faced by your selected individual or group
- create a working model or a detailed series of diagrams, with a description of how the design prototype will be used to replace the current energy demands
- describe how you changed your design prototype as a result of testing or feedback
- describe how the renewable energy prototype will improve the life of your selected individual or group
- estimate the cost of production for each element of your energy design
- estimate the number of each element of your energy design required in your local government area
- estimate the total implementation cost to individuals, or to local, state or national government bodies
- compare how this energy system could be implemented in developed and developing countries.

Check your Student obook pro for the following digital resources to help you with this STEAM project:

Student booklet
This helpful booklet will guide you step-by-step through the project.

What is the design cycle?
This video will help you to better understand each phase in the design cycle.

How to manage your project
This 'how-to' video will help you to manage your time throughout the design cycle.

How to define a problem
This 'how-to' video will help you to narrow your ideas down and define a specific problem.

GLOSSARY

A

absolute dating
a method of determining the age of a fossil, by measuring the amount of radioactivity remaining in the rock surrounding the fossil

absolute magnitude scale
a scale for measuring the brightness (luminosity) of objects from the same distance

absorption spectrum
a spectrum with dark bands missing from the pattern, where the element has absorbed characteristic light wavelengths; the opposite of an emission spectrum

acceleration due to gravity
acceleration of an object due to a planet's gravitational field; on Earth, $g = 9.8\ \text{m/s}^2$

achondroplasia
a genetic (inherited) disorder of bone growth resulting in abnormally short stature and short limbs

acid
a hydrogen-containing substance that has the ability to donate a proton

active site
the region of an enzyme that substrates can bind to

adaptation
a characteristic or behaviour of a species that allows it to survive and reproduce more effectively

alkali
a base that dissolves in water

alkali metal
an element in group 1 of the periodic table

alkaline earth metals
elements with similar properties found in group 2 of the periodic table

alkaline solution
a solution that consists of a base dissolved in water

allele
a version of a gene; a person inherits two alleles for each gene, one coming from each parent

amino acids
small molecules that make up proteins

amygdala
a part of the brain responsible for encoding the emotional part of a memory

analogous structures
structures in organisms of different species that have the same function but are structurally different, because they evolved independently; for example, wings in birds and bats

anion
a negatively charged ion formed when an atom gains electrons

antigen
a molecule that will cause the body's immune system to react

apoptosis
programmed cell death

apparent magnitude scale
a scale for measuring the brightness of an object when viewed from Earth

artificial selection
when humans breed organisms that have desirable traits, increasing the likelihood of that trait occurring in the next generation

atomic number
the number of protons in an atom

autosome
a chromosome that does not determine the sex of an organism

B

base
a substance that has the ability to accept a hydrogen proton

Big Bang theory
the theory that the universe began as a hot, dense, single point at some time in the past, and since then has expanded and will continue to expand into the future

binary fission
a form of asexual reproduction used by bacteria; the splitting of a parent cell into two equal daughter cells

biochar
a lightweight residue containing carbon and ash that is formed from the slow burning of biomass

biodiversity
the variety of life; the different plants, animals and micro-organisms and the ecosystems they live in

bioplastic
plastic produced from renewable biomass sources

black dwarf
a remnant formed when a white dwarf star cools and gradually fades away

black hole
a region in space of infinite density where gravity is so strong that nothing, not even light, can escape from it

blind study
when the participants do not know if they are receiving the treatment or a placebo

blue shift
the apparent increase in frequency (towards the blue end of the spectrum) of light from galaxies that are moving towards the Earth

Bohr model
a model of the atom in which electrons orbit the nucleus in a series of defined orbits known as shells

C

carbon nanotube
a very small tube of carbon atoms, made synthetically

carrier
a person who has the allele for a recessive trait that does not show in their phenotype

catalyst
a substance that increases the rate of a chemical reaction without undergoing any permanent chemical change

cation
a positively charged ion that results from an atom losing electrons

cerebellum
a small lobe at the lower rear of the brain responsible for fine motor movement, balance and coordination

cerebral cortex
the outer layer of the brain that is responsible for conscious thought

chromatid
one side of the X-shaped chromosome that contains a double helix of DNA

chromosome
the form of DNA that is tightly wound around proteins before replication

classical conditioning
a learned behaviour that is linked to a previously neutral stimulus

climate
the weather conditions at a particular place, averaged over a long period of time, based on collection and analysis of large amounts of data

climate change
periodic change in the Earth's climate

climate change adaptation
coping adjustments made in response to the effects of climate change

climate change mitigation
efforts that aim to reduce or prevent greenhouse gas emission

co-dominant
two different alleles that can both appear in the phenotype at the same time; both can appear with a single allele

codon
a group of three nucleotides on mRNA

cognition
mental processes that are involved in acquiring, storing, manipulating and retrieving information

cognitive verb
a doing word that requires you to perform a specific thinking task

complementary base
a nucleotide base that pairs with its partner nucleotide on the alternative DNA strand; adenine pairs with thymine, cytosine pairs with guanine

concentration
the number of active molecules in a set volume of solution

confirmation bias
when a scientist selects a method that will support the outcome they want

confounding variable
a variable that impacts both the independent and dependent variables

constellation
a group of stars that form a pattern or picture

continental drift
the continuous movement of the continents over time

control group
a group of organisms, chemical reactions or physical conditions that can be compared to the group that has had the independent variable changed

controlled variables
variables that remain unchanged during an experiment

convergent evolution
the process whereby unrelated organisms evolve to have similar characteristics as a result of adapting to similar environments

Coriolis effect
the influence of the Earth's rotation on the direction of movement of air or water

cosmic microwave background radiation
remnant electromagnetic radiation left from early stages of the universe

covalent bond
a bond formed when two or more atoms share electrons

cultural norm
the expectation that you should behave according to the values of the people around you

cytokinesis
the splitting of a replicating cell into two cells

D

decomposition
a reaction that involves the breakdown of a compound into simpler substances

delocalised electron
an electron in a molecule that can easily move between atoms

dependent variable
a variable in an experiment that may change as a result of changes to the independent variable

diatomic molecule
a molecule that consists of two atoms

dilute
containing a small number of solute particles in the volume of solution

diploid
containing two complete sets of chromosomes

displacement
the change of position of a moving object in a particular direction

displacement reaction
a reaction resulting in the displacement of an atom or group of atoms

distance
the length of the path travelled by an object

diverge
in relation to two species: to become more different over time due to different selection pressures, possibly becoming reproductively isolated

DNA (deoxyribonucleic acid)
a molecule that contains all the instructions for every job performed by the cell; this information can be passed from one generation to the next

dominant trait
a characteristic that needs only one copy of an allele to appear in the physical appearance of an organism

Doppler effect
the apparent change in wavelength (or frequency) when the source of the waves or the observer is moving; responsible for the red shift of distant stars

double-blind study
when neither the participants nor the treating doctors know if they are receiving the treatment or a placebo

double displacement reaction
when two reactants exchange ions to form new products during a chemical reaction

E

early detection and predictive testing for adults
the testing of chromosomes for the presence of alleles that increase the probability of cancers forming

echoic memory
auditory memory that decays after a few seconds

elaborative rehearsal
a memory technique that involves thinking about the meaning of the term to be remembered

elastomer
long chains of polymers occasionally linked together like a ladder

electron configuration
a numerical way of showing the number of electrons in each electron shell around a particular atomic nucleus

electron shell
a defined area of space in which electrons move around an atom's nucleus

emission spectrum
the pattern of wavelengths (or frequencies) that appear as coloured lines in a spectroscope; it is unique to each element

encoding
the act of information moving into our memory

environmental stimulus
sensory information from the environment (sound, smell, feel) that can start a behaviour

enzyme
a protein-based catalyst

ethics
a set of principles that provide guidance to determine what is morally right and wrong

event horizon
the boundary around a black hole at which no light or matter can escape

evolution
the gradual change in the genetic material of a population of organisms over a long period of time

evolutionary relationship
the way in which two species or populations are related with respect to their evolutionary descent

F

fossil
the remains or traces of an organism that existed in the past

fossilisation
the process of an organism becoming a fossil

frameshift mutation
a type of mutation in which a nucleotide is added or deleted, causing a shift in the reading frame of codons and resulting in a deformed protein

functional magnetic resonance imaging (fMRI)
the use of magnetic fields to show areas of high blood flow in areas of the brain

G

gene
basic unit of genetic material passed on from parents to offspring

gene cloning
the production of identical copies of a gene

gene flow
the flow of genes from one generation to the next, or from one population to the next, as different families or groups in the population choose partners and mate

gene pool
all the genes or alleles in a population

gene therapy
inserting a new healthy allele into an organism to treat a genetic disease

genetic code
the sequence of nucleotides in DNA, inherited from parent organisms

genetic engineering
the deliberate engineering of change in the DNA of an organism

genetically modified organism (GMO)
an organism that has had its DNA changed in a laboratory

genotype
the combination of alleles for a particular trait

greenhouse gas
an atmospheric gas able to absorb and emit solar energy causing a greenhouse effect

group
a vertical list of elements in the periodic table that have characteristics in common

H

half-life
the time it takes the radioactivity in a substance to decrease by half

halogens
the group of elements in group 17 of the periodic table

haploid
containing one complete set of chromosomes in each cell; an example is gametes

Hertzsprung–Russell diagram
a graph displaying star data, with the star's spectral class (temperature) on the *x*-axis and its absolute magnitude (luminosity) on the *y*-axis

heterozygous
having two different alleles for a particular trait; a carrier for a recessive trait

hippocampus
a central part of the brain responsible for encoding memories

homologous structure
structure that is similar in different species, because those species evolved from a common ancestor, but do not necessarily have the same function now; an example is forelimbs in different mammal species

homozygous
having two identical alleles for a particular trait

horizontal transfer
the transfer of genetic material (usually containing antibiotic resistance) from a bacterium to another bacterium that is not its offspring

hydrocarbon
a molecule that contains only carbon and hydrogen atoms

hydrogen bond
a type of weak chemical bond between two groups of atoms; the bond between two nitrogen bases in the DNA helix

hydrostatic equilibrium
in relation to Earth's atmosphere: a state of stability, with upward forces balanced by downward forces

I

iconic memory
visual memories that decay in less than 1 second

imprinting
a form of learning where a baby rapidly encodes a memory that identifies a parent or object

independent variable
a variable (factor) that is changed in an experiment

indicator
a substance that changes colour in the presence of an acid or base

inertia
the tendency of an object to resist changes in its motion while either at rest or in constant motion

informed consent
a decision that is made by a person who has had the procedure and possible effects explained to them

innate behaviour
a common behaviour that all members of a species are born with

interphase
a phase of cell life where normal functioning occurs

intrusion
when upwelled waters do not reach the surface

ion
an atom that is charged because it has an unequal number of electrons and protons

ionic bond
a bond between a negatively charged anion and a positively charged cation

ionic compound
a substance made up of a negatively charged anion and a positively charged cation

isobar
a line drawn on a weather map that joins places of equal air pressure

isolation
the division of a population into two groups

K

karyotype
a way of representing a complete set of chromosomes, arranged in pairs, in order of decreasing size

kinetic energy
the energy an object or particle has due to its motion

L

law of conservation of momentum
a scientific rule that states that the total momentum in an isolated system does not change during a collision

light-year
the distance that light travels in one year

linear polymer
long single chains of polymers

litmus paper
a paper containing an indicator that turns red when exposed to an acid and blue when exposed to a base

living fossil
an existing species of ancient lineage that has remained unchanged in form for a very long time

long-term memory (LTM)
memory that stores information for an unlimited period of time

luminosity
the actual brightness of a star (amount of energy it radiates); measured using the absolute magnitude scale

M

machinability
ability of a metal to be cut and shaped

magnetic resonance imaging (MRI)
the use of magnetic fields and radio waves to produce detailed images of the organs and tissues of the body

magnitude
the size or extent of something

maternal serum screening (MSS)
the genetic testing of fetal DNA found in the mother's blood

maturation
the process of becoming an adult

meiosis
the process that results in the formation of gametes with half the genetic material of the parent cell

metalloids
a small collection of elements that have characteristics of metals and non-metals

metals
elements on the left-hand side of the periodic table; they are malleable, lustrous, ductile and highly conductive

methodology
the rationale (why) and approach (how) used by the scientist to investigate the scientific question

mitosis
the process of cell division that results in genetically identical daughter cells; allows growth and repair

mnemonic
a learning strategy of using a song, rhyme or visual image to help in the encoding, storage and recall of a memory

molecular compound
a molecule that contains two or more different atoms bonded together

molecule
group of two or more atoms bonded together (e.g. a water molecule)

momentum
the product of an object's mass and velocity

monomer
a small molecule from which polymers are made

mutagen
a chemical or physical agent that causes a change in genetic material such as DNA

mutation
a permanent change in the sequence or amount of DNA

N

nanotechnology
the manipulation of individual atoms to form structures

natural selection
when the natural environment selects for or against a physical characteristic

nebula
a cloud of gas and dust in space

negative control
an individual test that checks that a negative result is possible in an experiment

net force
the vector sum of all the forces acting on an object; also known as resultant force

neuroimaging
the creation of an image of brain structures or brain activity

neuron
a nerve cell

neuroscience
the study of how the brain works to improve learning and memory

neutral
having a pH of 7, so neither an acid nor a base; an example is water

neutralisation
a reaction in which an acid and a base combine to produce a metal salt and water

neutron star
a small, highly dense star made mostly of neutrons

newborn screening
the testing of chromosomes in a baby's white blood cells for the presence of a genetic disease

noble gases
the stable gaseous elements in group 18 of the periodic table

non-disjunction
the failure of one or more chromosomes to separate during meiosis; can result in an abnormal number of chromosomes in the daughter cells

non-metals
elements on the right-hand side of the periodic table

nuclear fusion
a reaction in which two lighter atomic nuclei fuse to form a heavier nucleus, releasing energy

nucleotide
a subunit of a nucleic acid

O

objective
uninfluenced by personal opinions and interests

observational learning
when an animal learns from watching others

operant conditioning
a way of learning that some behaviours result in a reward and other behaviours result in a punishment

operationalising
a way to break a large science question into smaller measurable questions

P

pedigree
a chart showing the phenotypes for an individual and their ancestors, usually over several generations; also known as a family tree diagram

period
in chemistry: a horizontal list of elements in the periodic table

pH scale
a scale that represents the acidity or basicity of a solution; pH < 7 indicates an acid, pH > 7 indicates a base, pH 7 indicates a neutral solution

phenotype
the physical characteristics that result from an interaction between the genotype and the environment

phylogenetic tree
a branching tree-like diagram showing relationships between different taxonomic groups

placebo
a substance or treatment that is designed to have no effect

planetary nebula
a glowing shell of gas formed when a star dies

polyatomic ion
a charged ion that consists of two or more atoms bonded together

polymer
a long-chain molecule formed by the joining of many smaller repeating molecules (monomers)

polymerisation
the process of joining smaller units (monomers) to form a long-chain molecule (polymer)

positive control
an individual test that checks that a positive result is possible in an experiment

positive reinforcement
a positive result or consequence of a behaviour

positron emission tomography (PET)
the use of radioactive glucose to produce an image of the highly active areas of the brain

precipitate
a solid, insoluble compound formed in a precipitation reaction

precipitation reaction
a reaction used to produce solid products from solutions of ionic substances

primary data
data collected by the person writing the report

protein
a chain of amino acids; an essential part of cells

punishment
a negative result or consequence of a behaviour

Punnett square
a diagram used to predict the outcome of breeding organisms

R

random error
when an unpredictable variation in measurement occurs, resulting in an outlier result

randomised
when people or objects are selected at random

reaction force
the force acting in the opposite direction to an initial force

reaction rate
how fast or slowly a reaction proceeds

recessive trait
a characteristic that is only expressed in the phenotype when two identical alleles are inherited

red giant
a star that has become large and bright with a cool surface, because it has run out of hydrogen fuel

red shift
the apparent decrease in frequency (towards the red end of the spectrum) of light from galaxies that are moving away from the Earth

reflex response
a behaviour that does not have to be learnt

reforestation
the process of replanting trees and vegetation to restore natural habitat

relative dating
a method of determining the age of an object relative to events that occurred before and after

reliability
when an experiment can be repeated to produce the same results

repeatable
when an experiment can be repeated by the same scientist using the same materials

reproducible
when the experiment can be repeated by another scientist in another laboratory

retrieval
the act of taking a memory out of storage

S

sampling bias
a bias where a group of test subjects do not represent the larger sample group

scalar
having only magnitude (a numeric quantity)

secondary data
data collected by someone else

selection pressure
the environmental factors that affect an organism's ability to survive

semantic networks
a framework that links information in our brain

sensory memory
the ability of our senses to store a specific memory

sex chromosome
a chromosome that determines the sex of an organism

shell diagram
a diagram that shows the number of electrons in each electron shell around a particular atomic nucleus

short-term memory (STM)
a type of memory where we can hold information while we use it or before we transfer it to long-term memory

single displacement reaction
a reaction in which a more reactive element displaces a less reactive element on a molecule

solar radiation
radiant electromagnetic energy from the Sun

solution
a mixture of a solute dissolved in a solvent

somatic cells
the body cells except gametes (egg and sperm)

speciation
the process that results in the formation of a new species

species-specific behaviour
a behaviour that is unique to a single species

spectator ion
an ion that does not take part in a chemical reaction

speed
the distance travelled per unit of time

stellar parallax
a change in the apparent position of a star against its background when viewed from two different positions

stem cell
a cell that can produce different types of cells; adult stem cells can produce a limited number of cell types (e.g. skin stem cells), whereas embryonic stem cells can produce many types of cells

stimulus
any information that the body receives that causes the body to respond

storage
the ability to keep information in the brain

strength
how easily an acid releases a hydrogen ion in a chemical reaction; also describes the bond between different atoms

substitution mutation
a form of mutation where one nucleotide is substituted for another; may or may not result in a deformed protein

substrate
a molecule that reacts with an enzyme

superalloy
high-strength complex metal alloy resistant to extreme temperature and stress

supernova
the explosive death of a star

synthesis
a reaction that involves the building up of compounds by combining simpler substances, usually elements

systematic error
a repetitive error that is not removed by repeating the experiment

T

thermoplastic polymer
a polymer that softens and forms new shapes when heated

thermosetting polymers
polymers that do not melt or change shape when heated

transcription
the process of copying the DNA that makes up a gene to messenger RNA

transgenic organism
an organism that has a gene from another organism inserted into its own chromosomes

transition metals
the elements in groups 3–12 of the periodic table

transitional fossil
a fossil or an organism that shows an intermediate state between an ancestral form and its descendants; also known as a 'missing link'

translation
the formation of a protein from RNA; occurs on a ribosome

U

unbiased
impartial and free from preconceived ideas

universal indicator
a solution that is used to determine the pH (amount of acid or base) of a solution

upwelling
a process in which deep, nutrient-rich cold water moves up towards the surface

V

valence shell
the outermost electron shell in an atom that contains electrons

valid
when the design of the experiment will produce a result that answers the scientific question

vector
having magnitude and direction

velocity
the vector quantity that measures speed in a particular direction

vestigial structure
a structure in an organism that no longer has an obvious purpose

W

weather
the temperature, humidity, rainfall and wind on particular days in a particular place

white dwarf
a small, hot star that forms when a star (e.g. our Sun) runs out of fuel and slowly fades and cools

wind
the sideways movement of air as a result of lower-density warm air rising through the atmosphere

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Notes

Notes

The Earth's systems are in a delicate balance. Mismanagement of the planet's resources can affect this balance and have catastrophic consequences for humans, animals and the environment. This image shows emperor penguins in Antarctica. Emperor penguins are one of many Antarctic species threatened by climate change: the sea ice on which the penguins live is melting. Sea ice also helps to regulate global temperatures. When the ice melts, global temperatures increase further.

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contact customer support at **oup.com.au/help**