



S C I E N C E

OXFORD
SCI
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CE
10

HELEN SILVESTER

SECOND EDITION

V I C T O R I A N
C U R R I C U L U M

OXFORD

S C I E N C E

OXFORD SCIENCE 10

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C U R R I C U L U M

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OXFORD

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UNIVERSITY PRESS

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Published in Australia by
Oxford University Press
Level 8, 737 Bourke Street, Docklands, Victoria 3008, Australia.

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First published 2016

Second edition 2021

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Edited by Penny Drago and Kay Waters

Typeset by Q2A Media Services Pvt. Ltd., Noida, India

Proofread by Kellyanne Martin

Indexed by Max McMaster

Printed in Singapore by Markono Print Media Pte Ltd



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OXFORD SCI EN CE 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

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.

5

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.

6

Global systems

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.

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

Energy

Energy conservation in a system can be explained by describing energy transfers and transformations.

10

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.

11

Experiments



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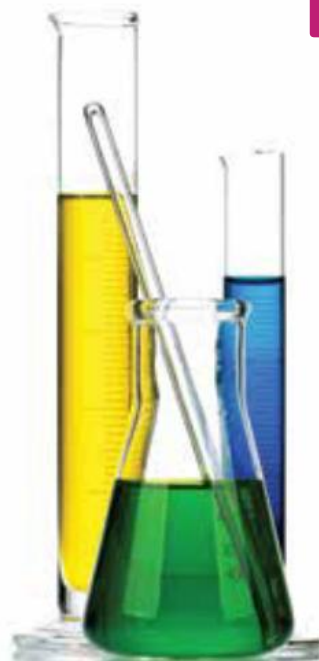
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Oxford Science Victorian Curriculum has been developed to meet the requirements of the *Victorian Curriculum: Science* across Years 7–10. Taking a concept development approach, each double-page spread of Oxford Science represents **one concept, one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

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

- > Student Book
- > Student ebook pro
- > Teacher ebook pro.

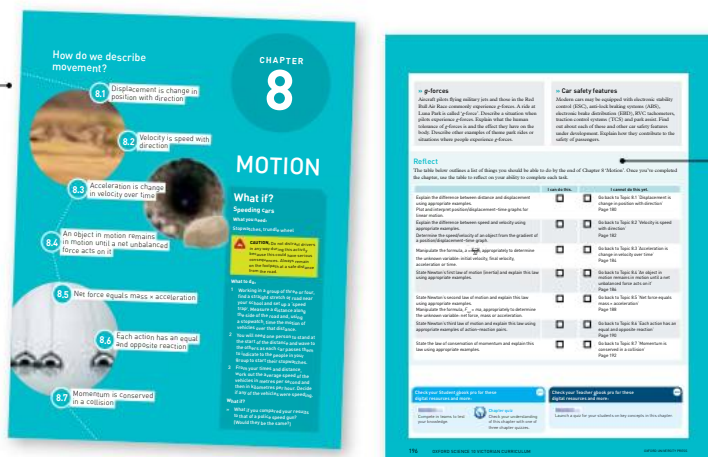
Key features of this Student Book

- > 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 ebook pro.

Focus on concept development

Chapter openers

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



Reflect

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

Concept statements

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

Key ideas

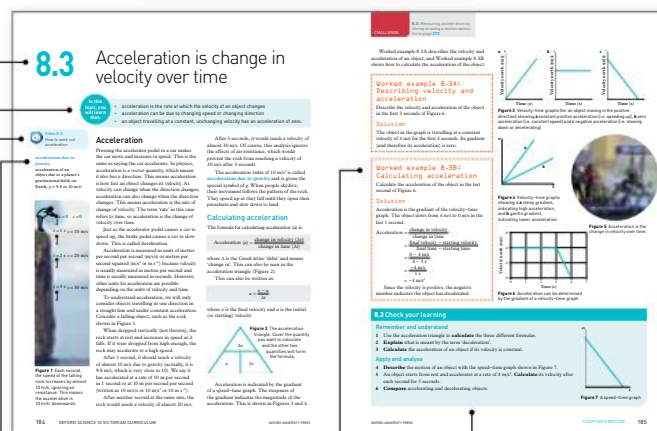
- Key ideas are summarised for each topic in succinct dot points.

Integrated links to engaging digital resources

- Where relevant, digital icons flag engaging resources that can be accessed via Student ebook 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 Bloom's taxonomy. Questions are phrased using bolded task words (also called command verbs), which state what is expected of a student and prepares them for studying VCAA science subjects.

Focus on science inquiry skills and capabilities

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.



Develop your abilities

- 'Develop your abilities' provide scaffolded opportunities for students to apply their science understanding while developing skills and capabilities.

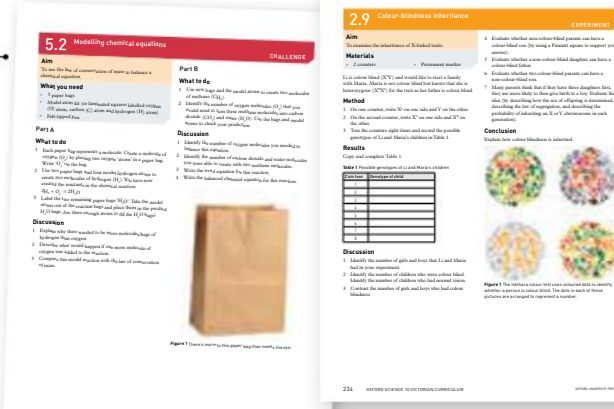
Focus on practical work

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

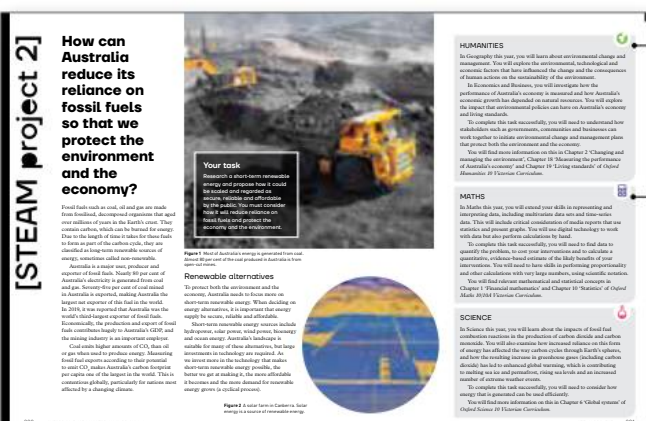
- These activities provide students with opportunities to use problem-solving and critical thinking, and apply science inquiry skills.



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.

obook^{pro}

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

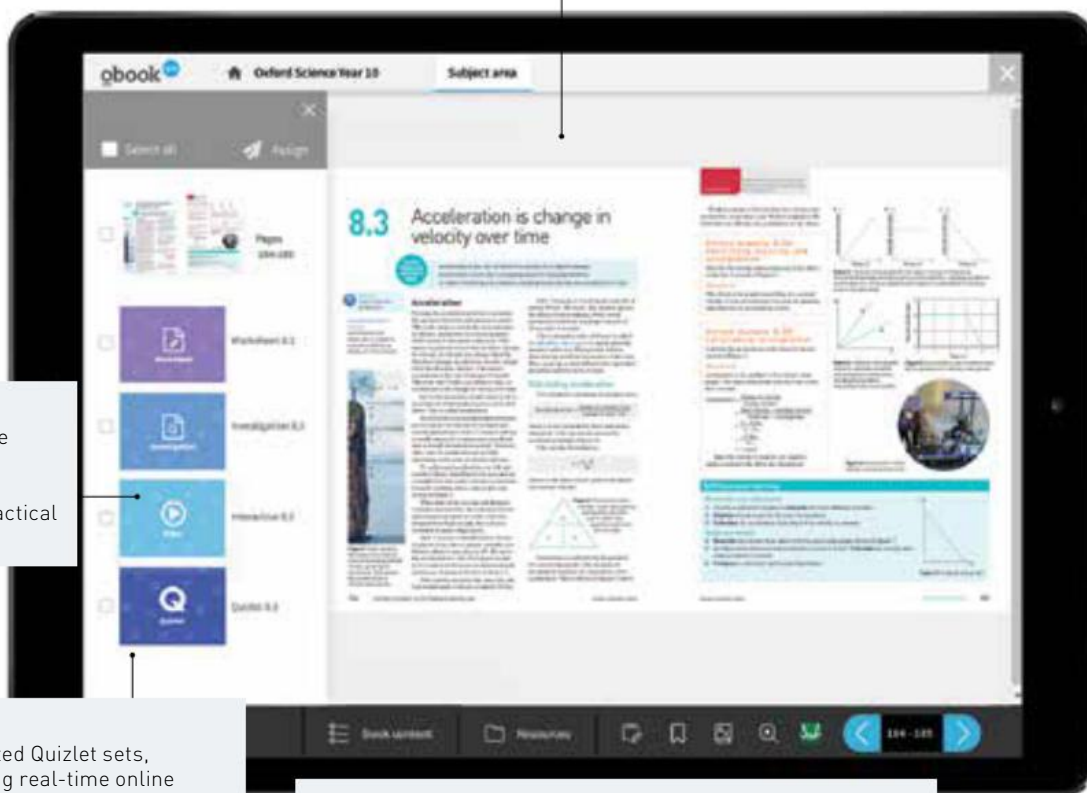
- Integrated Quizlet sets, including real-time online quizzes with live leaderboards, motivate students by providing interactive games that can be played solo or as a class. Quizlet can be used for revision or as a topic is introduced to keep students engaged.

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 are autocorrecting, 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.

- > 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.

**Benefits for
students**



Key features of Teacher obook pro

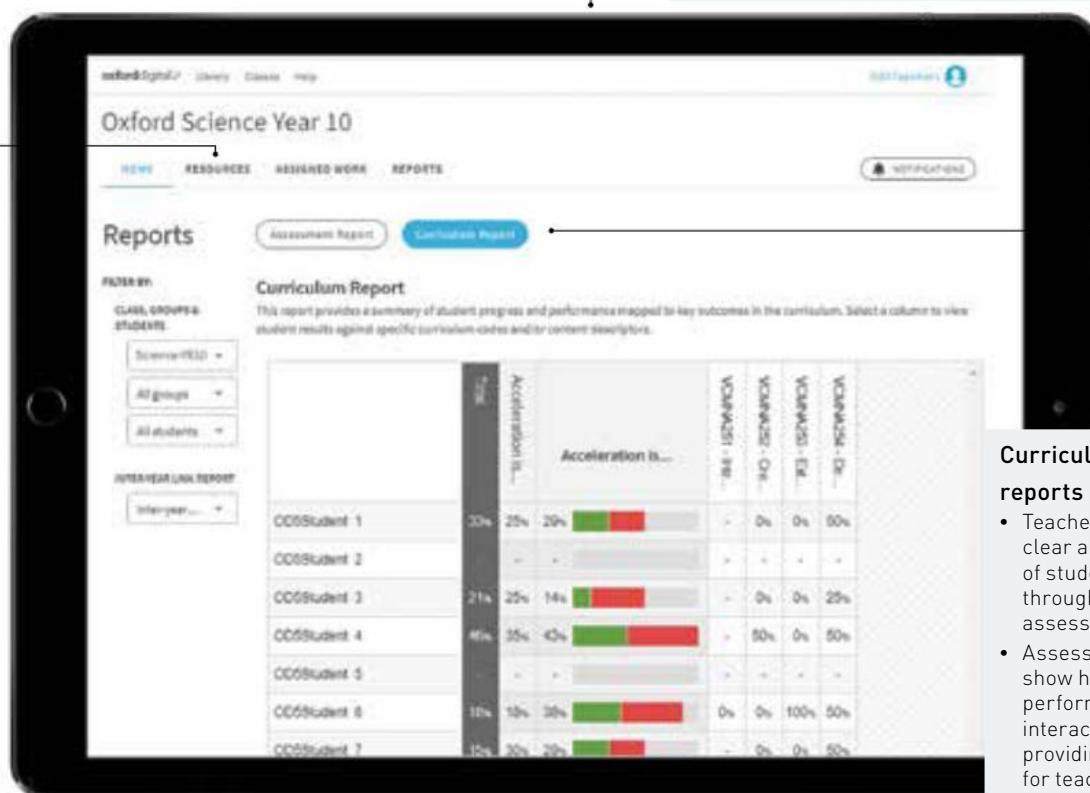
- > Teacher obook pro is a completely digital product delivered via **Oxford Digital**.
- > Each chapter and topic of the Student Book is accompanied by full teaching support. Teaching programs are provided that clearly direct learning pathways throughout each chapter, including ideas for differentiation 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.

pbook^{pro}

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 descriptors and curriculum codes.

Additional resources

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

- > 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.

Benefits for teachers

VICTORIAN CURRICULUM: SCIENCE 10 SCOPE AND SEQUENCE

LEVELS 9 AND 10 DESCRIPTION

In Levels 9 and 10, the curriculum focus is on explaining phenomena involving science and its applications. Students consider both classic and contemporary science contexts to explain the operation of systems at a range of scales. At a microscopic scale, they consider the atom as a system of protons, electrons and neutrons, and understand how this system can change through nuclear decay. They learn that matter can be rearranged through chemical change and that these changes play an important role in many systems. At a macroscopic scale, they explore ways in which the human body as a system responds to its external environment, and investigate the interdependencies between biotic and abiotic components of ecosystems. They develop a more sophisticated view of energy transfer by applying the concept of the conservation of matter in a variety of contexts. They apply their understanding of energy and forces to global systems including continental movement. Students explore the biological, chemical, geological and physical evidence for different theories, including the theories of natural selection and the Big Bang theory. Atomic theory is used to understand relationships within the periodic table of elements. Students understand that motion and forces are related by applying physical laws. Relationships between aspects of the living, physical and chemical world are applied to systems on a local and global scale enabling students to predict how changes will affect equilibrium within these systems.

LEVELS 9 AND 10 CONTENT DESCRIPTIONS

Science as a human endeavour

Chapter 7 Year 9	Scientific understanding, including models and theories, are contestable and are refined over time through a process of review by the scientific community (VCSSU114)
Chapter 2 Chapter 7 Chapter 6 Year 9	Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries (VCSSU115)
Chapter 2 Chapter 6 Year 9	The values and needs of contemporary society can influence the focus of scientific research (VCSSU116)

Biological sciences

Year 9	Multicellular organisms rely on coordinated and interdependent internal systems to respond to changes to their environment (VCSSU117)
Year 9	An animal's response to a stimulus is coordinated by its central nervous system (brain and spinal cord); neurons transmit electrical impulses and are connected by synapses (VCSSU118)
Chapter 2	The transmission of heritable characteristics from one generation to the next involves DNA and genes (VCSSU119)
Chapter 3	The theory of evolution by natural selection explains the diversity of living things and is supported by a range of scientific evidence (VCSSU120)
Year 9	Ecosystems consist of communities of interdependent organisms and abiotic components of the environment; matter and energy flow through these systems (VCSSU121)

LEVELS 9 AND 10 CONTENT DESCRIPTIONS	
<i>Chemical sciences</i>	
Year 9	All matter is made of atoms which are composed of protons, neutrons and electrons; natural radioactivity arises from the decay of nuclei in atoms (VCSSU122)
Chapter 4	The atomic structure and properties of elements are used to organise them in the periodic table (VCSSU123)
Year 9	Chemical reactions involve rearranging atoms to form new substances; during a chemical reaction mass is not created or destroyed (VCSSU124)
Chapter 4 Year 9	Different types of chemical reactions are used to produce a range of products and can occur at different rates; chemical reactions may be represented by balanced chemical equations (VCSSU125)
Chapter 4 Year 9 Chapter 5	Chemical reactions, including combustion and the reactions of acids, are important in both non-living and living systems and involve energy transfer (VCSSU126)
<i>Earth and space sciences</i>	
Year 9	The theory of plate tectonics explains global patterns of geological activity and continental movement (VCSSU127)
Chapter 6	Global systems, including the carbon cycle, rely on interactions involving the atmosphere, biosphere, hydrosphere and lithosphere (VCSSU128)
Chapter 7	The Universe contains features including galaxies, stars and solar systems; the Big Bang theory can be used to explain the origin of the Universe (VCSSU129)
<i>Physical sciences</i>	
Year 9	Electric circuits can be designed for diverse purposes using different components; the operation of circuits can be explained by the concepts of voltage and current (VCSSU130)
Year 9	The interaction of magnets can be explained by a field model; magnets are used in the generation of electricity and the operation of motors (VCSSU131)
Chapter 9	Energy flow in Earth's atmosphere can be explained by the processes of heat transfer (VCSSU132)
Chapter 8	The description and explanation of the motion of objects involves the interaction of forces and the exchange of energy and can be described and predicted using the laws of physics (VCSSU133)
SCIENCE INQUIRY SKILLS	
<i>Questioning and predicting</i>	
Chapter 1 Chapter 11 Year 9	Formulate questions or hypotheses that can be investigated scientifically, including identification of independent, dependent and controlled variables (VCSIS134)
<i>Planning and conducting</i>	
Chapter 1 Chapter 11 Year 9	Independently plan, select and use appropriate investigation types, including fieldwork and laboratory experimentation, to collect reliable data, assess risk and address ethical issues associated with these investigation types (VCSIS135)
Chapter 1 Chapter 11 Year 9	Select and use appropriate equipment and technologies to systematically collect and record accurate and reliable data, and use repeat trials to improve accuracy, precision and reliability (VCSIS136)
<i>Recording and processing</i>	
Chapter 1 Chapter 11 Year 9	Construct and use a range of representations, including graphs, keys, models and formulas, to record and summarise data from students' own investigations and secondary sources, to represent qualitative and quantitative patterns or relationships, and distinguish between discrete and continuous data (VCSIS137)
<i>Analysing and evaluating</i>	
Chapter 1 Chapter 11 Year 9	Analyse patterns and trends in data, including describing relationships between variables, identifying inconsistencies in data and sources of uncertainty, and drawing conclusions that are consistent with evidence (VCSIS138)

ACKNOWLEDGEMENTS

The author and the publisher wish to thank the following reviewers: Professor Bradley Moggridge James Kennedy, Paguiel Meunier, Michelle Moore.

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How do I investigate a question scientifically?

1.1 There are many types of scientific investigations

1.2 Scientists communicate using scientific language

1.3 Experiments must be controlled

1.4 Data can be analysed

1.5 Clinical testing uses the scientific method

1.6 Science as a human endeavour: Scientific investigations must be ethical



CHAPTER

1

SCIENCE TOOLKIT

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

In this topic, you will learn that:

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



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.

operationalising

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

methodology

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

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. 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 may then be broken down into something that is measurable. This is called **operationalising** the 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. It may include a

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



Figure 3 The Commonwealth Scientific and Industrial Research Organisation (CSIRO) completed a detailed study of Port Phillip Bay and used the data to model the effects of nutrients from sewage and industrial plants, run-offs from agricultural land and run-offs from cities.

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, 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 (which is 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 contain the 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 4 Quantitative analysis of pH in soil is important for plant or crop growth.



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

1.1 Check your learning

Remember and understand

- 1 **Explain** the purpose of using a simulation in science.
- 2 **Define** what it means to 'operationalise a question'. Give an example to support your definition.

Apply and analyse

- 3 **Compare** a quantitative analysis and a controlled experiment.
- 4 **Contrast** a methodology and a method.

- 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 Write an operationalised question for this investigation.
 - b Write a hypothesis for this investigation.
 - c **Identify** which methodology the student should use.

Evaluate and create

- 6 Write the method for the experiment described in question 5.

1.2

Scientists communicate using scientific language

In this topic, you will learn that:

- 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 will 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. (2021). <i>Oxford Science 10 Victorian Curriculum</i> (2nd ed.). Oxford University Press.

1.2 Check your learning

Remember and understand

- Explain** why scientists avoid using the first person to describe the results of an experiment.
- Identify** what should be included in the discussion section of a scientific report.

Apply and analyse

- Rewrite the following statements using scientific communication.
 - I measured the speed of a skateboard.
 - The acid made lots of bubbles appear on the side of the metal.

- When I put my hand in the water, it felt very cold. I think it was 15 degrees.
- Contrast** the common or street meaning and the scientific meaning of the word ‘significant’.
 - Compare** the information that is written in the results and discussion sections.
 - When writing a scientific report, a student used the internet to research the definition of the term ‘kinetic energy’. Use an example to **describe** the APA Style of referencing for a website.

1.3

Experiments must be controlled

In this topic, you will learn that:

- 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

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

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 have had the independent variable changed

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 will 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.

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 is claimed 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.



Figure 1 Controlled experiments have all variables the same except for the deliberately changed independent variable.

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. In chemistry, a control group might be a set of chemical reactions that occur at a standard temperature, while the experiment group 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.

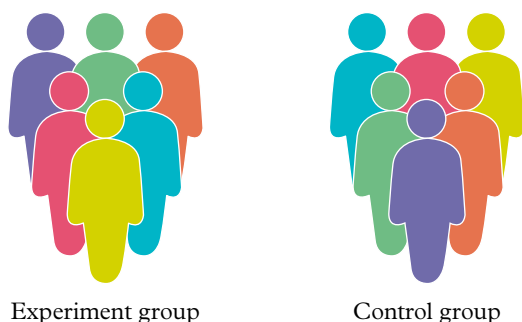


Figure 2 Experiments to determine the effectiveness of dieting require matching participants' ages, sexes, food intake, amount of exercise and general health. Having similar characteristics in each group reduces the number of variables when comparing their results.

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.

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

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.

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

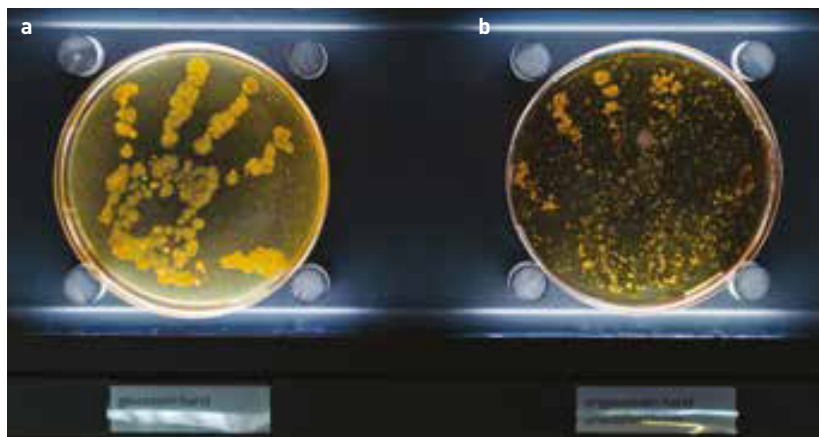


Figure 3 When testing the effectiveness of soap in killing bacteria, **a** the positive control will have bacteria without soap, whereas **b** the negative control will test the soap with no bacteria.

1.3 Check your learning

Remember and understand

- 1 **Define** the term 'valid'.
- 2 **Define** the term 'reliable'.
- 3 **Explain** why a control group should have participants with similar or comparable characteristics to those of the experiment group.

Apply and analyse

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

- 6 **Describe** 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.

Evaluate and create

- 7 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).

1.4

Data can be analysed

In this topic, you will learn that:

- 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.

first-hand data

data collected by the person writing the report

second-hand 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: first-hand data and second-hand data. **First-hand 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 **second-hand data**.

When analysing second-hand 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.

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. 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

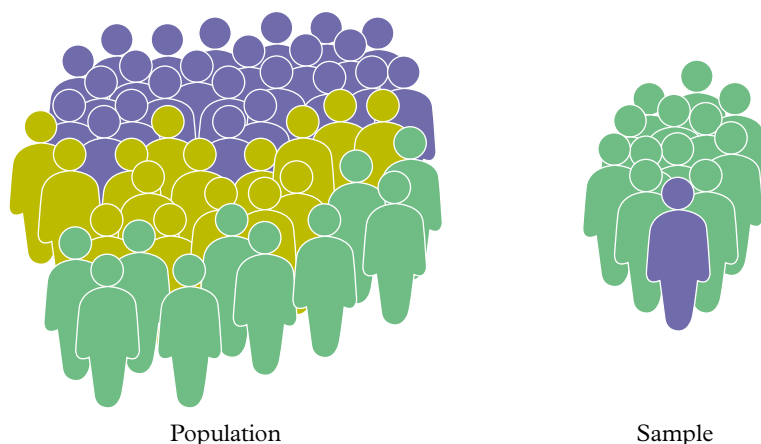


Figure 1 Sampling bias exists when the population of the sample doesn't reflect the actual population.

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, whereas 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.

Scatter graphs 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.

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

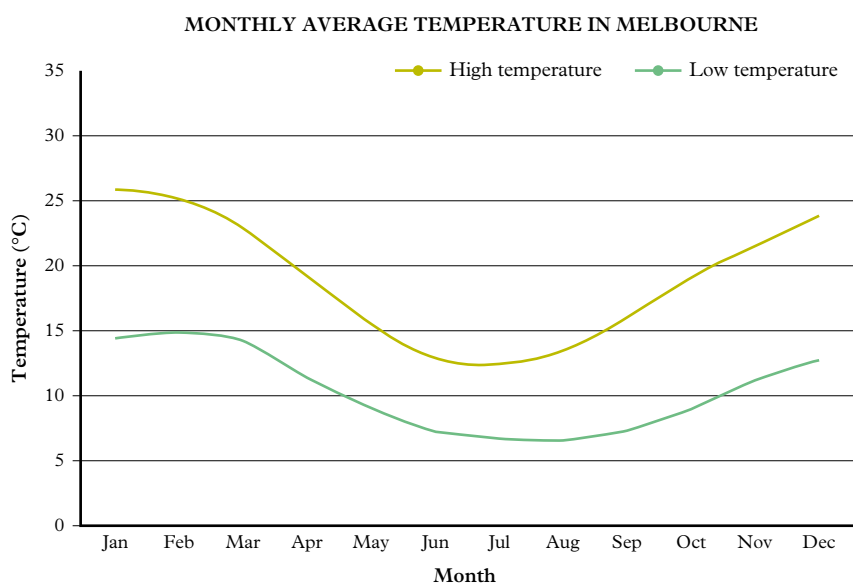


Figure 2 A line graph plots continuous data. In this graph, two data sets are included and are represented by different colours to make it clearer to read.

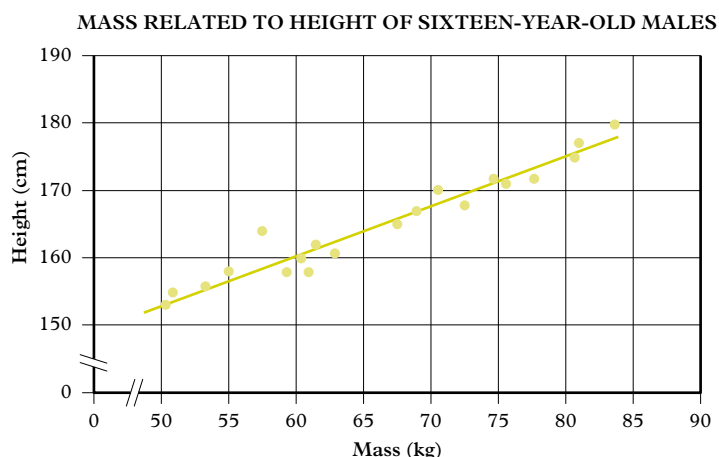
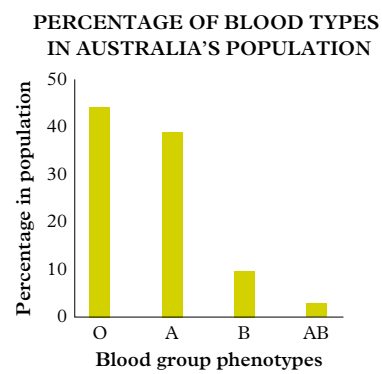


Figure 3 A scatter graph with a line of best fit

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.

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 units (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 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 occurs when equipment has not been calibrated

1.4 Check your learning

Remember and understand

- 1 **Define** the term 'bias'.
- 2 **Define** the term 'placebo'.
- 3 **Compare** (the similarities and differences between) a blind study and a double-blind study.
- 4 **Explain** how a blind study or double-blind study can be used to control variables in an investigation.
- 5 **Contrast** (the differences between) random errors and systematic errors.

Apply and analyse

- 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

- 7 **Explain** 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?

1.5

Clinical testing uses the scientific method

In this topic, you will learn that:

- 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

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.



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

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. 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 the use of a half dose was found to be more effective than the expected full dose, this meant that the phase III trial 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.

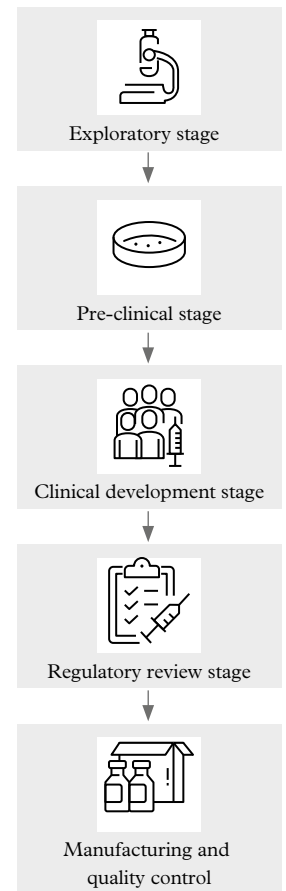


Figure 2 The stages for developing a vaccine



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

1.5 Check your learning

Remember and understand

- 1 **Describe** how a vaccine works.
- 2 **Identify** the regulatory body that is responsible for approving drugs for use in Australia.
- 3 **Identify** what could be used as a placebo in a vaccine trial.

Apply and analyse

- 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.

Evaluate and create

- 6 **Discuss** the importance of 'informed consent' in drug or vaccine trials.
- 7 **Evaluate** the ethics of not including female participants in vaccine trials. **Describe** the benefits and consequences of this.

1.6 Scientific investigations must be ethical

Ethics is a set of principles that provide a way to think when making decisions. There are different frameworks for thinking about ethics. For example, consequentialism 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 make decisions about what is the right course of action, when the answer might otherwise be unclear.

cultural norm

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

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 this research.



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

Ethics

Ethics is 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 consequentialism ethics and deontological ethics.

CONSEQUENTIALISM 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.

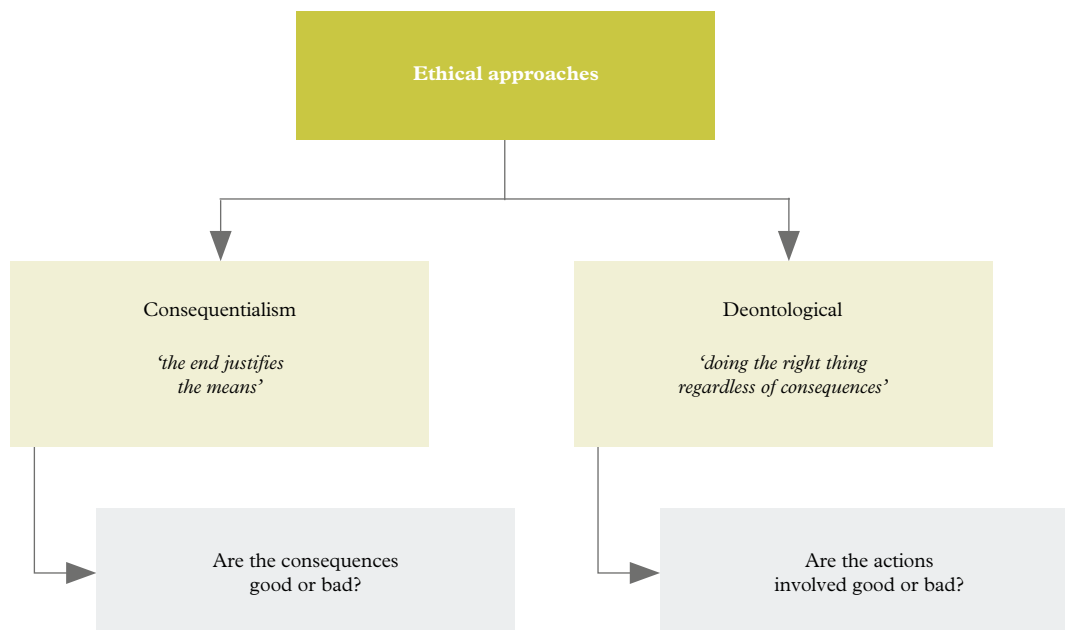


Figure 2 Deontological approaches to ethics consider duties and rules. Consequentialism considers the consequences.

1.6 Develop your abilities

Applying ethics

Using the different ethical approaches can lead to different opinions about what is right or wrong. When this occurs, there is not always a single correct answer to the ethical dilemma. Instead, the consequentialism 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** six ethical problems that occur in science (see the following list). For each problem:

- > use consequentialism 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 the 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?

REVIEW 1

Multiple choice questions

- 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 treatment is 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

Short answer questions

Remember and understand

- 4 **Describe** how a vaccine protects a person from becoming sick from a disease.
- 5 **Explain** why a placebo may be used in a clinical study.
- 6 **Describe** the three phases of the clinical trial for drugs or vaccines.
- 7 **Define** the term 'unconscious bias'.
- 8 **Identify** and **describe** three different types of bias that can occur in scientific investigations.
- 9 **Define** the term 'ethics'.
- 10 Use an example to **explain** the term 'cultural norm' (by defining the term, describing an example and comparing the example to the definition).
- 11 **Define** the terms 'independent variable' and 'dependent variable'.
- 12 **Explain** what is meant by the term 'valid experiment' (by defining 'valid experiment' and describing the factors that affect the validity of an experiment).

Apply and analyse

- 13 **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

- 14 **Compare** (the similarities and differences between) consequentialism ethics and deontological ethics (by defining both terms, describing their similarities and describing their differences).
- 15 **Contrast** (the differences between) methodology and method (by defining both terms and emphasising how they are different).
- 16 **Compare** the methodologies of modelling and case studies.
- 17 **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).
- 18 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.
- 19 Final VCE exams must be marked by someone who does not know the student. Use your knowledge of bias to **explain** the purpose of this rule.
- 20 A manufacturer claimed that their antibacterial wash killed 99 per cent of all bacteria.
 - a Rewrite this claim as an operationalised question.
 - b Write a hypothesis for this question.
 - c **Identify** the 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.



Figure 1 It is important to check a manufacturer's claims.

Evaluate

- 21** 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-old teenagers. **Explain** one way 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).
- 22** **Identify** a potential random error and a systematic error for the investigation you designed in question 20. **Explain** how you could minimise these errors.
- 23** 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).

Social and ethical thinking

- 24** ClassDojo is a popular online tool that allows a teacher to record what occurs in the classroom. This can include the students' marks, how they behave and what they are currently doing. 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).
- 25** A scientist wanted to test whether a particular drug was effective in preventing Alzheimer's disease. He recruited a series of volunteers who had just been diagnosed with the disease and compared them to a control group of volunteers who had no family history of Alzheimer's disease. **Describe** how the scientist should modify this experiment to prevent bias in the test.
- 26** **Describe** what is meant by 'informed consent'. Use a deontological approach to ethics to **explain** why it is considered unethical to include people who have limited capacity to understand the information provided to them, in medical drug trials.

Critical and creative thinking

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



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

- 28** Draw a mind map that identifies the links between each of the glossary terms that are used in this chapter.
- 29** 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 in town.'

Identify who might have written the review. **Explain** what feature of the review suggests that the person who wrote it might be biased.

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.

» Causation versus correlation

The terms 'causation' and 'correlation' can seem very similar. If the independent variable increases when the dependent variable also increases, then the two variables are described as positively correlated. This does not necessarily 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.

» 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 whether 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 bias 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.

Reflect

The table below outlines a list of things you should be able to do by the end of Chapter 1 'Science toolkit'. Once you've completed the chapter, use the table to reflect on your ability to complete each task.

	I can do this.	I cannot do this yet.
Explain how to predict, 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 2
Explain how scientists communicate when writing reports for different audiences.	☐	☐ Go back to Topic 1.2 'Scientists communicate using scientific language' Page 4
Define independent variables, dependent variables and controlled variables. Describe valid experiments, reliable experiments and control groups.	☐	☐ Go back to Topic 1.3 'Experiments must be controlled' Page 6
Recognise that 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 8
Identify and explain the five stages of developing a new vaccine.	☐	☐ Go back to Topic 1.5 'Clinical testing uses the scientific method' Page 12
Describe the deontological and consequentialism 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 14

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Who do I look like?

2.1

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



2.2

DNA consists of a sugar-phosphate
backbone and complementary
nitrogen bases

2.3

Chromosomes carry genetic
information in the form of genes

2.4

DNA holds the code
for building proteins

2.5

Mitosis forms new somatic cells

2.6

Meiosis forms gamete cells

2.7

Alleles can produce dominant
or recessive traits

2.8

Alleles for blood group
traits co-dominate



2.9

Alleles on the sex chromosomes
produce sex-linked traits

2.10

Inheritance of traits can
be shown on pedigrees

2.11

Mutations are changes
in the DNA sequence

2.12

Science as a human endeavour:
Genes can be tested

2.13

Science as a human endeavour:
Genes can be manipulated

2.14

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

CHAPTER

2

GENETICS

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

Scientific understanding is constantly being reviewed, challenged 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. 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 taught maths, but he 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. But Mendel discovered that the different 'factors' could be separated again.

Mendel observed the inheritance of different characteristics in pea plants, such as seed colour, flower shape and height. From his observations he accurately concluded that 'factors' (now called genes) existed in pairs, one from each parent. These gene factors 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. Even 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: the principle of segregation and the principle of 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.

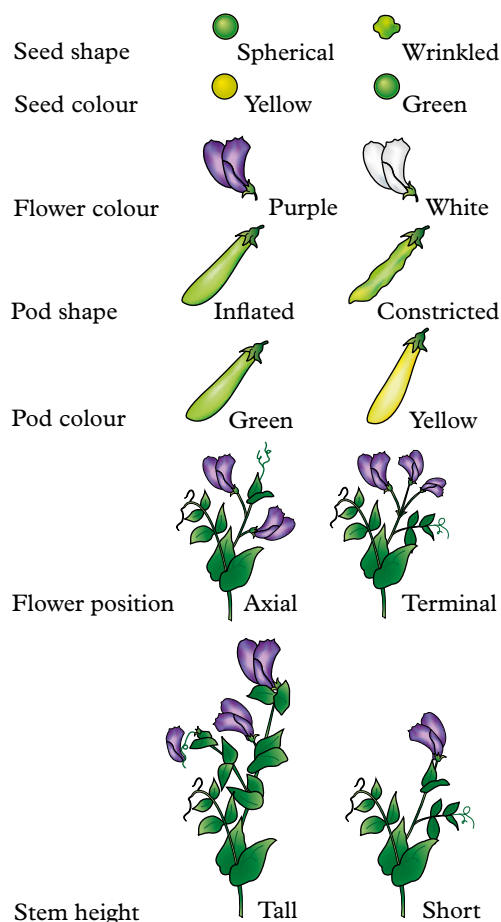
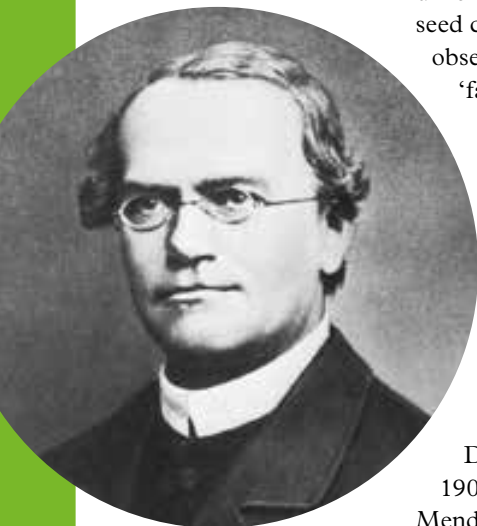


Figure 2 The seven traits, or characteristics, of pea plants studied by Mendel

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



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 are made up of DNA.

The 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. 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 **deoxyribonucleic acid (DNA)**, which they identified as a double helix (two-stranded spiral) in 1953.

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.

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 4). 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 3 Rosalind Franklin



Figure 4 Photograph 51: the X-ray crystallography image of DNA taken by Rosalind Franklin

deoxyribonucleic acid (DNA)

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 Develop your abilities

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 could 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 arise from this discovery by:

- > describing the ethical approach you are using (e.g. consequentialism 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 value.
- 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

In this topic, you will learn that:

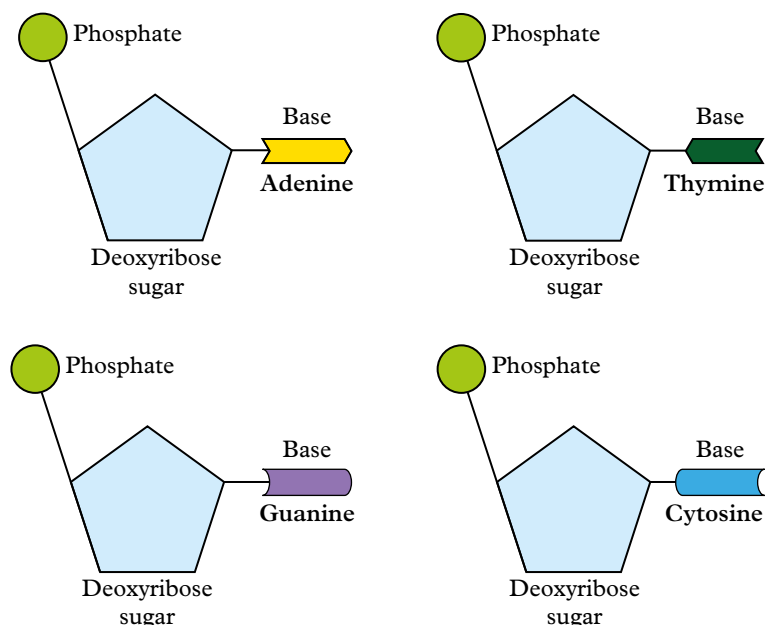
- genes are made of a chemical called deoxyribonucleic acid (DNA)
- the DNA molecule consists of two long, thin strands of complementary nucleotides that are held together by hydrogen bonds
- DNA is a double-helix shape.

nucleotide
a subunit of a DNA molecule

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 in a ladder (Figure 2).

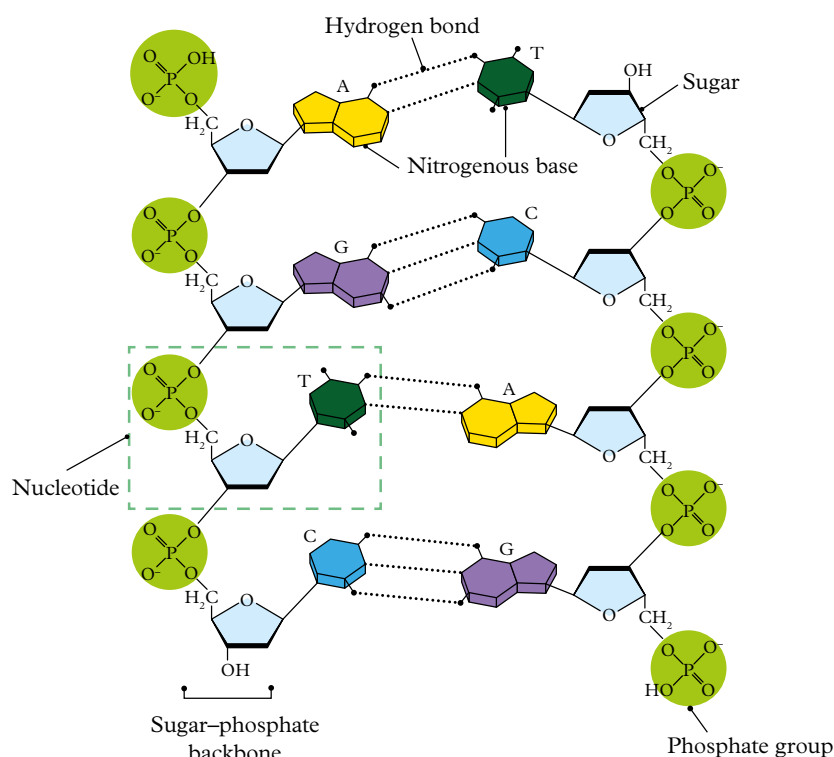


Figure 2 Nucleic acids such as DNA are made of a chain of nucleotides joined together through a sugar-phosphate backbone.

Double helix

The sugar-phosphate backbone of one nucleic chain is attracted to a second nucleic chain, creating a ladder-like structure. 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). These base pairs (G-C and A-T) are called **complementary bases** or complementary base pairs. This means that one nucleic strand will be complementary to the other strand.

The two nucleic chains then wind into a double helix – the twisted ladder (Figure 3).

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.



Figure 4 DNA bases always pair as guanine with cytosine and thymine with adenine.

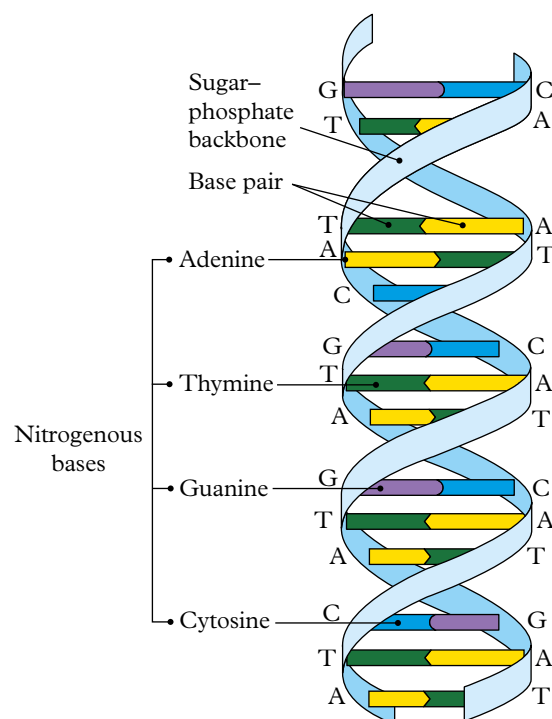


Figure 3 The DNA double helix. If you picture the DNA molecule as a twisted ladder, the sides are sugar and phosphate molecules and the rungs are pairs of nitrogen bases.

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

Remember and understand

- 1 **Define** the term 'nucleotide'.
- 2 **Describe** how nucleotides join together to form polynucleotides.
- 3 **Describe** a double helix.
- 4 **Describe** the part of the nucleotide that varies.
Identify the part that remains constant.
- 5 **Identify** the nucleotide that forms a hydrogen bond with adenine.

Apply and analyse

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

2.3

Chromosomes carry genetic information in the form of genes

In this topic, you will learn that:

- 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

chromatid

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

Chromosomes and genes

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

A human nucleus has 46 chromosomes: 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)

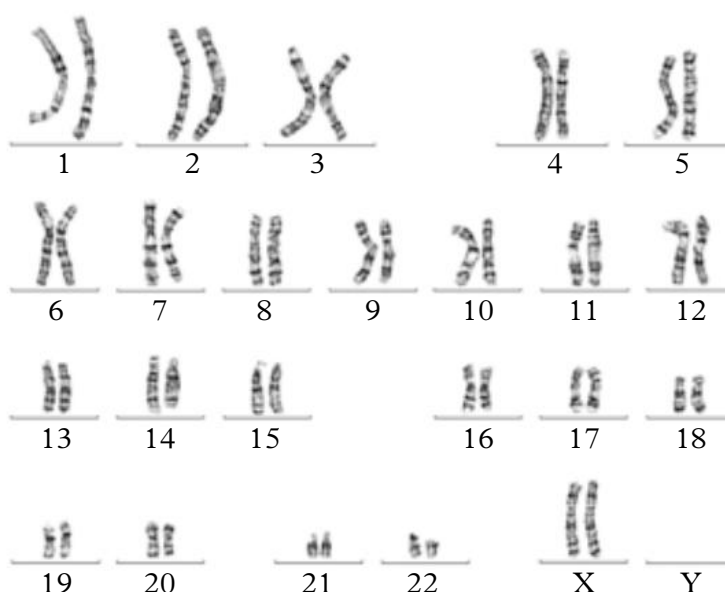


Figure 1 Pairs of chromosomes are often referred to by numbers according to their size – the largest pair is number 1. The last two chromosomes determine the sex of an individual. Human females have two X chromosomes, and males have one X and one Y chromosome. This karyotype is from a female (XX).

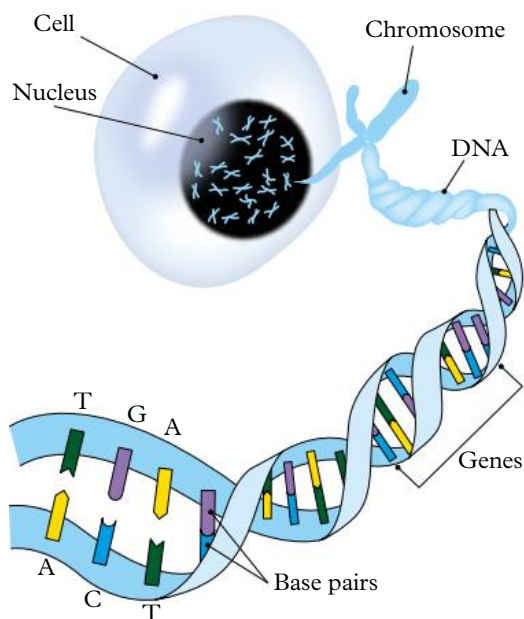


Figure 2 The relationship between DNA and chromosomes

Chromosomes may be a single linear strand of tightly wound DNA or shaped like an X. The two strands of the X are identical to each other. These X-shaped chromosomes are formed during DNA replication so that two identical copies are produced. Each strand of an X-shaped 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

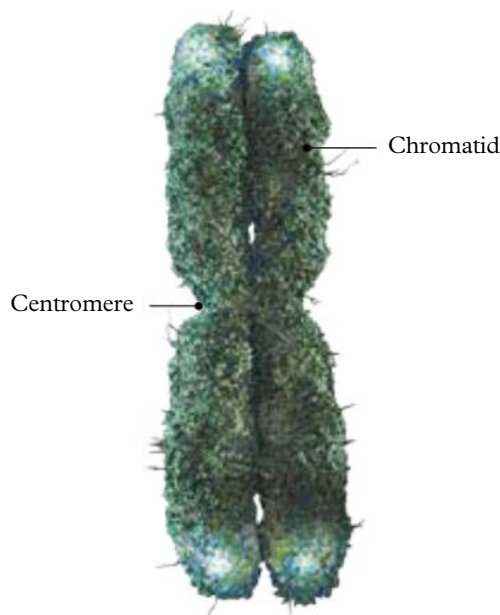


Figure 3 An X-shaped chromosome is made up of sister chromatids joined at the centromere.

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).

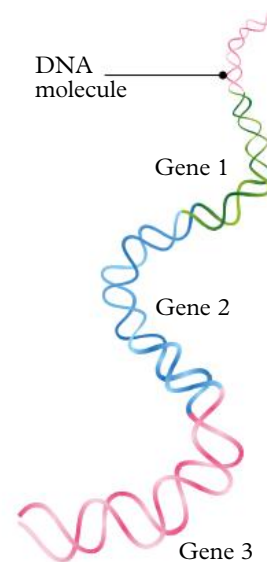


Figure 4 The relationship between DNA and genes

2.3 Check your learning

Remember and understand

- 1 **Identify** the number of chromosomes in each of your cells.
- 2 **Define** the term ‘karyotyping’.
- 3 **Describe** how DNA is like a string of beads.
- 4 **Identify** the names of the nitrogen bases that are represented by the letters A, T, G and C.
- 5 **Identify** the nitrogen bases that are complementary to A, T, G and C.

Apply and analyse

- 6 **Compare** (the similarities and differences between) DNA, chromosomes and genes.

Evaluate and create

- 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).

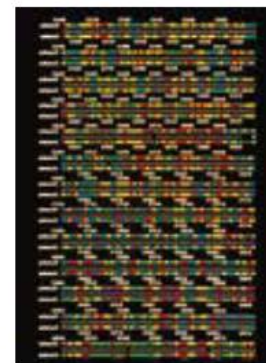


Figure 5 The sequence of bases on DNA is the coding system for life. The sequence of bases shown here comes from the DNA in adenovirus types 5 and 2. These viruses cause a range of illnesses, including colds, sore throats and diarrhoea.

2.4

DNA holds the code for building proteins

In this topic, you will learn that:

- 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

One major feature of DNA is its ability to replicate itself; the other 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.

genetic code

the sequence of nucleotides in DNA, inherited from parent organisms

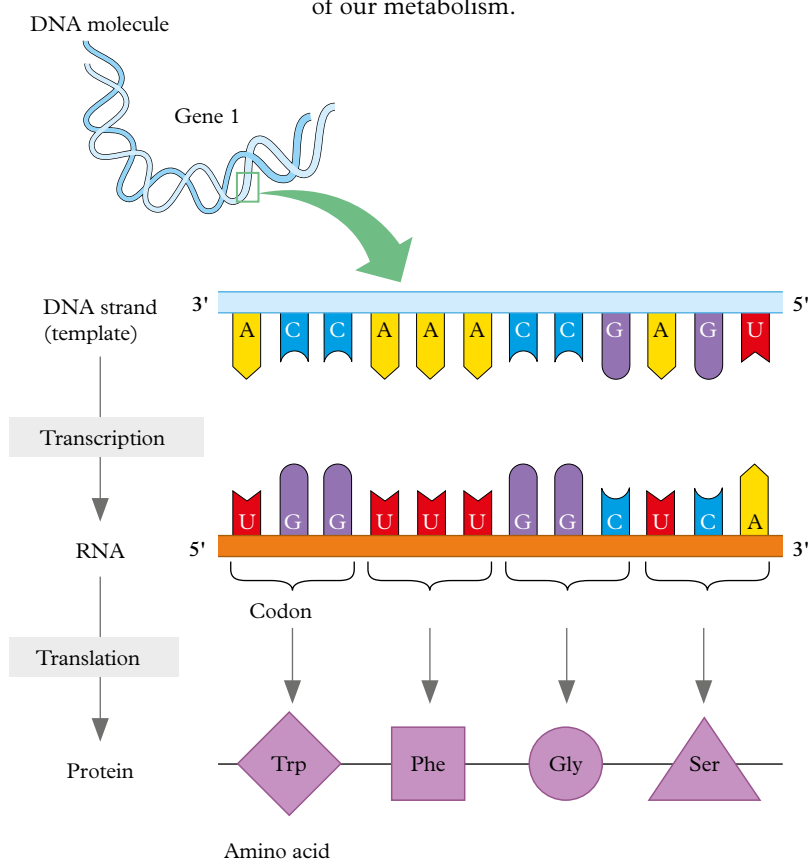


Figure 1 Protein synthesis. A complementary strand of mRNA is made (G-C and A-U). The mRNA leaves the nucleus and is used to form a protein. (Trp = tryptophan; Phe = phenylalanine; Gly = glycine; Ser = serine)

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 that 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.

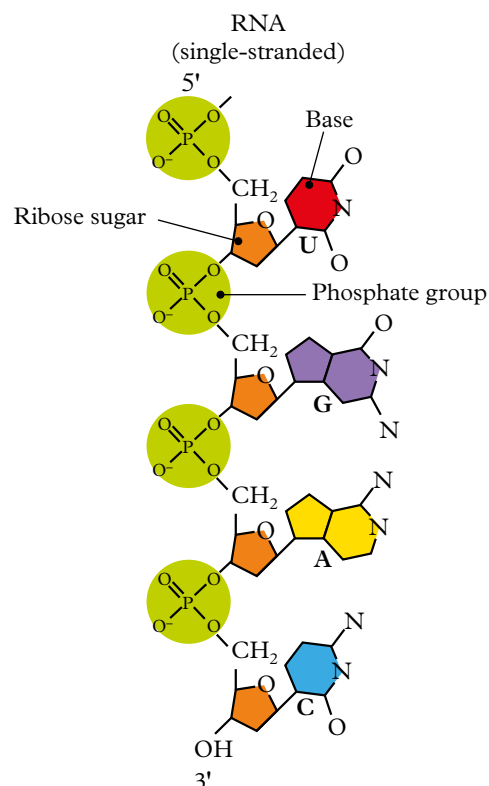


Figure 2 The structure of RNA

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 A special enzyme moves along the DNA strand until it finds the start of a gene. It then joins together free RNA nucleotides (C, G, A, U), which form the strand of mRNA. The mRNA nucleotides are complementary to the DNA nucleotides, with G bonding with C and A bonding to U (instead of T; Figure 1).
- 3 The special enzyme lets go of the DNA once it reaches the end of the gene and the mRNA is complete. The two DNA strands re-join.

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.

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.

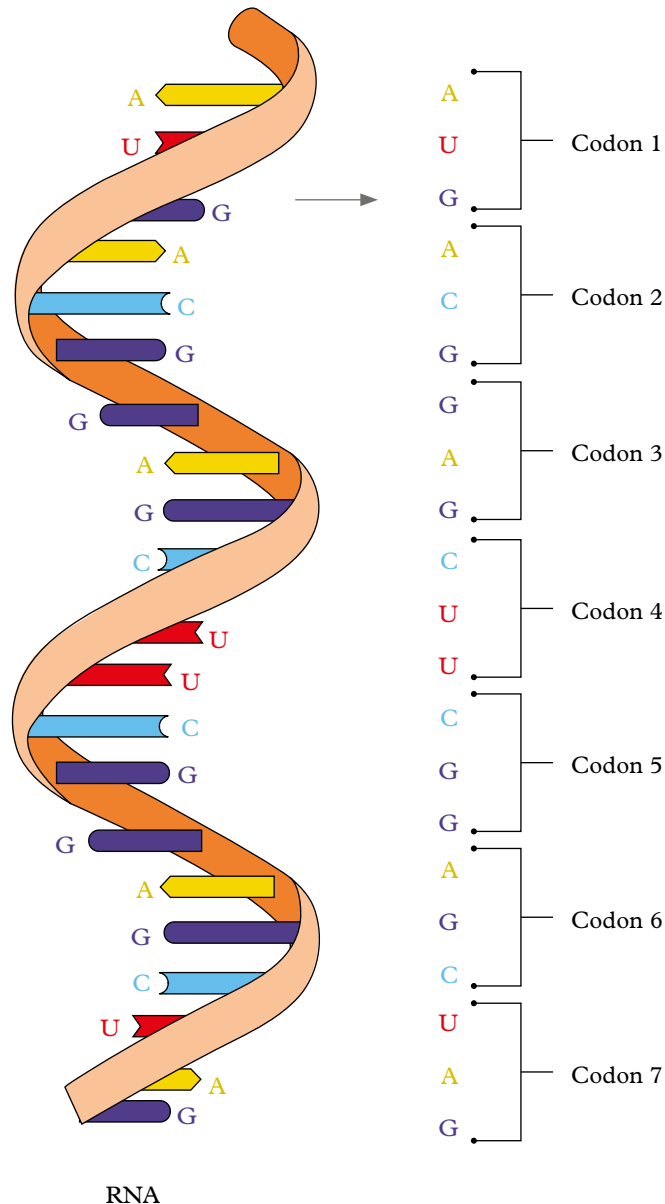


Figure 3 Each codon codes for a specific amino acid. Proteins are made up of long chains of amino acids.

2.4 Check your learning

Remember and understand

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

Apply and analyse

- 3 **Compare** the features of DNA and RNA. (You may like to draw a Venn diagram for this task.)

- 4 **Contrast** (the difference between) transcription and translation.
- 5 **Identify** the mRNA sequence for the template DNA sequence GTTAGCCAGT. (Remember to pair uracil with adenine.)

Evaluate and create

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

transcription

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

translation

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

codon

a group of three nucleotides on mRNA

2.5

Mitosis forms new somatic cells

In this topic, you will learn that:

- 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

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

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** (Figure 3). 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. This doubles the single

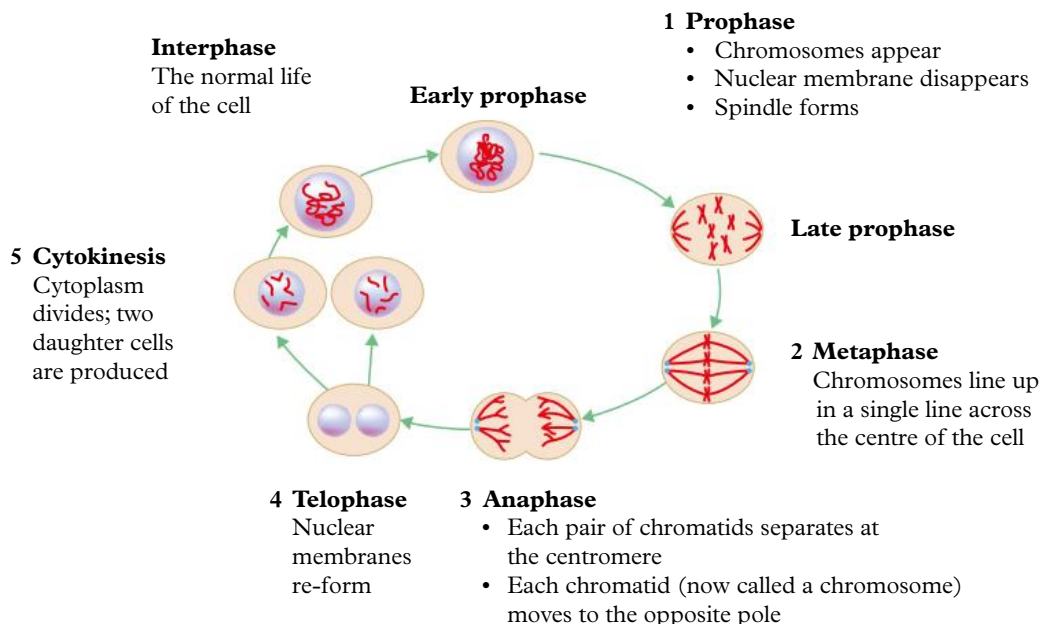


Figure 1 Interphase and the phases of mitosis and cytokinesis

chromosomes to X-shaped chromosomes, connected at the centromere. When the cell undergoes mitosis, the X-shaped 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

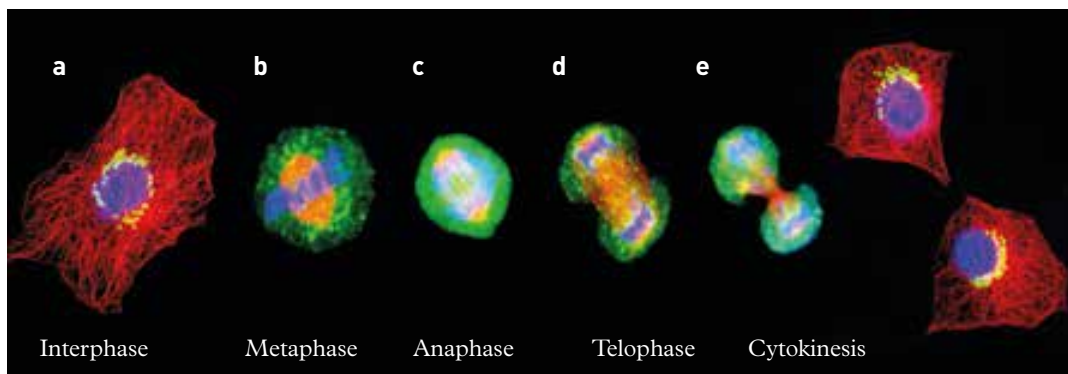


Figure 2 These mitotic cells have been stained with a fluorescent stain to show the separation of DNA. **a** The cell is at the end of interphase – the DNA has been replicated. During prophase, the nuclear membrane breaks down and the red spindle fibres bind to the centromere. **b** The (blue) chromosomes line up along the middle of the cell during metaphase. **c** Anaphase occurs when the spindles contract, separating the two chromatids at the centromere and pulling them to the end of the cell. **d** During telophase, the nuclear membrane re-forms around the two sets of DNA. **e** Cytokinesis occurs when the cell membrane divides in two.

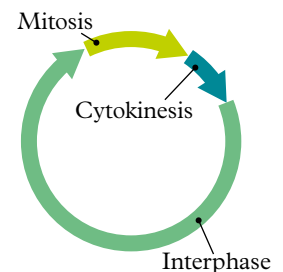


Figure 3 The cell cycle. Cells spend most of their life in interphase, when normal cell functioning occurs.

2.5 Check your learning

Remember and understand

- 1 Explain** why cells need to undergo mitosis.
- 2 Identify** the phase where most cells spend most of their time.
- 3 Describe** what happens in each phase of mitosis.

Apply and analyse

- 4 Contrast** (the difference between) mitosis and cytokinesis.
- 5** A cell that is about to undergo mitosis must double its amount of DNA. **Explain** why this needs to occur.

- 6 Identify** each of the stages of mitosis that are happening in Figure 4.

Evaluate and create

- 7** Write 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.' (HINT: Describe the processes of interphase and mitosis, and decide whether the statement is correct.)

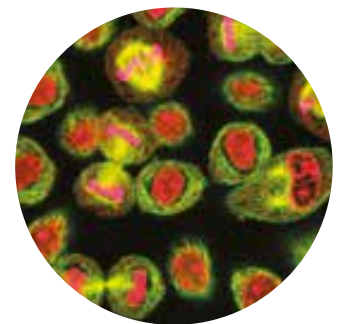


Figure 4 Phases of mitosis

2.6

Meiosis forms gamete cells

In this topic, you will learn that:

- 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.

haploid

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

meiosis

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

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 organism.

Gametes differ from all other body cells because they contain half the number of chromosomes of somatic cells – they are **haploid**. 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 2). When the egg and sperm combine at fertilisation, a diploid somatic cell is produced – 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. 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 X-shaped chromosomes. Once this occurs, the first stage of meiosis can begin.

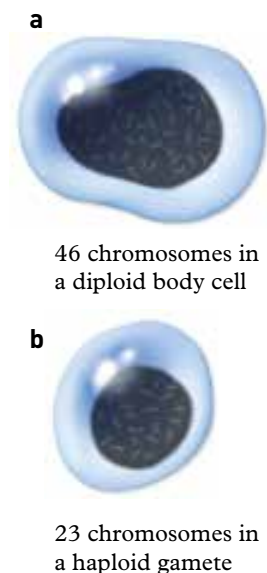


Figure 1 **a** A diploid body cell and **b** a haploid gamete

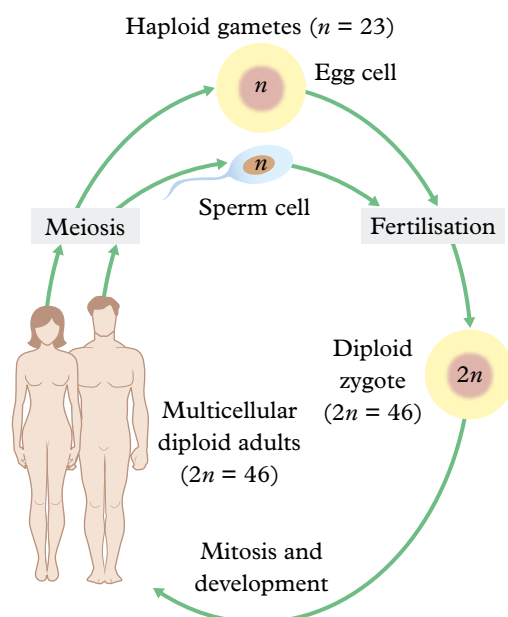


Figure 2 The human life cycle, involving mitosis and meiosis



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

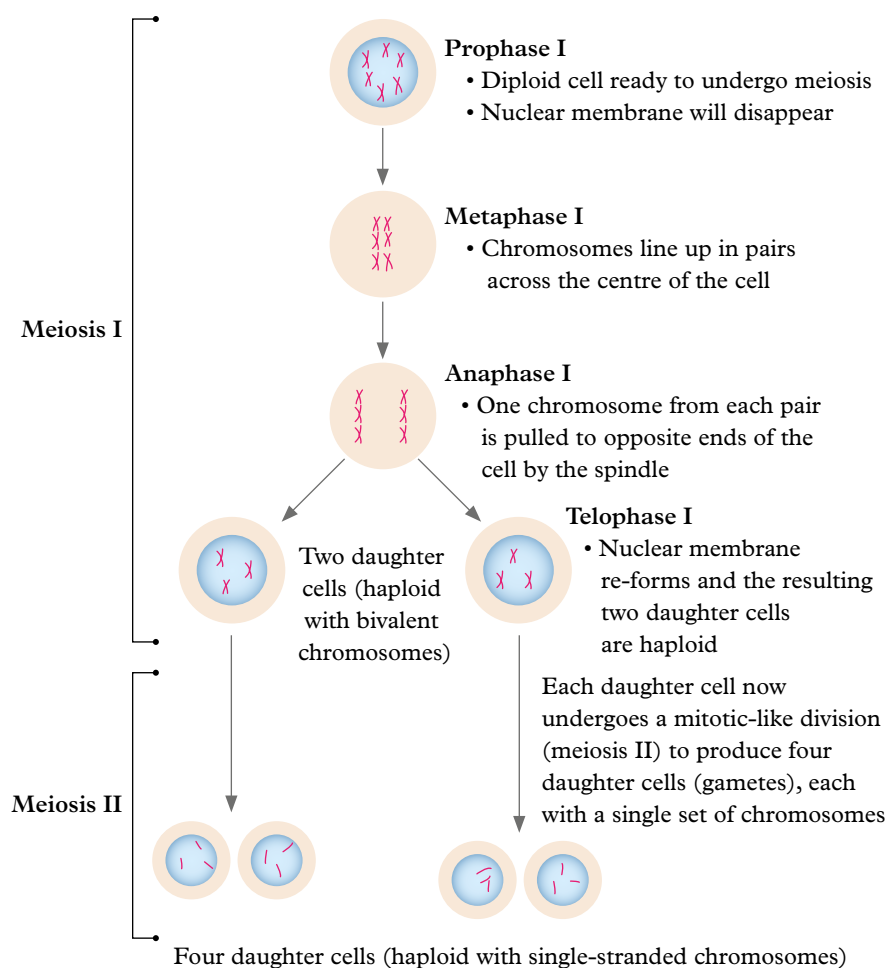


Figure 4 Meiosis consists of two rounds of each phase: prophase, metaphase, anaphase and telophase. If a gamete is fertilised, the chromosomes of the zygote will become diploid again so that the zygote can grow (by mitosis) into an embryo.

2.6 Check your learning

Remember and understand

- Compare** (the similarities and differences between) a haploid cell and a diploid cell.
- Prepare a table comparing mitosis and meiosis.

Apply and analyse

- 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.
- Explain** why the offspring of sexually reproducing organisms are not identical to their parents.
- 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 single or X-shaped chromosomes present at each phase of meiosis shown in Figure 4.

- Explain** why it is essential that the number of chromosomes is halved during meiosis.
- The chromosomes in Figure 5 are separating at the centromere. **Identify** the phase of meiosis that the cell is undergoing.

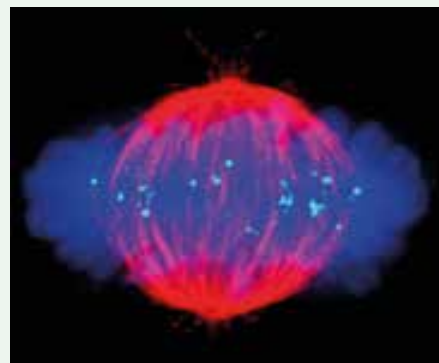


Figure 5 Each stage of meiosis includes prophase, metaphase, anaphase and telophase.

2.7

Alleles can produce dominant or recessive traits

In this topic, you will learn that:

- 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

genotype

the combination of alleles for a particular trait

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. Both genes are for eye colour. 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.

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'.

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.

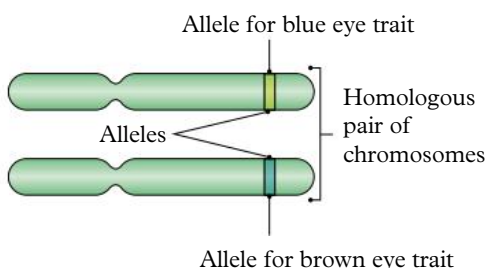


Figure 1 A heterozygous pair of chromosomes

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 (nature), but if you don't get enough food when you are growing, then you will not reach your full height (nurture).

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). 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

Parents' phenotype	Homozygous non-tongue-roller	x	Heterozygous tongue-roller
Parents' genotype	rr	x	Rr
Parents' gametes	r r	x	R r
F₁ genotype (offspring)	Punnett square		

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

F₁ phenotype 50% tongue-rollers
50% non-tongue-rollers

Figure 2 The ability to roll your tongue is inherited.

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.

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

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

Mother has the recessive trait (homozygous) = rr

Then a Punnett square can be constructed.

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

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.

2.7 Check your learning

Remember and understand

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

Apply and analyse

- 3 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).
- 4 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.
- 5 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. **Identify** the genotype of all four individuals and use suitable symbols to justify your answer.

Figure 3 Genetically identical hydrangeas produce different coloured flowers depending on soil conditions.



2.8

Alleles for blood group traits co-dominate

In this topic, you will learn that:

- a gene can make protein enzymes that make the sugar molecules A or B found on the surface of a red blood cell
- the alleles for this gene can be expressed together
- other genes can produce the Rhesus protein.

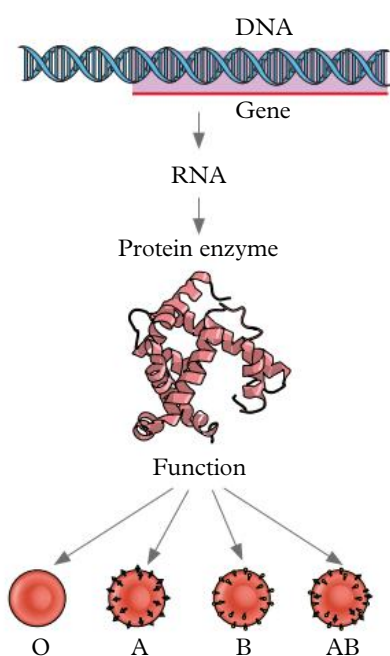


Figure 1 Genes for blood type produce an enzyme that makes a sugar [A or B] on the surface of a red blood cell.

co-dominant

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

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 $I^A I^B$ 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 $I^A i$ or $I^A I^A$ will make sugar molecule A and therefore have blood type A. A person with the genotype $I^B i$ or $I^B I^B$ 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.

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

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: $I^A I^A$ or $I^A i$.

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 ($I^A i$).

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

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 $I^A I^B$: 1 $I^A i$: 1 $I^B i$: 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^A_i	x I^B_i												
Parents' gametes	I^A_i	x I^B_i												
F₁ genotype (offspring)	Punnett square													
	<table><tr><th colspan="2">Ellie's alleles</th></tr><tr><th>I^B</th><th>i</th></tr><tr><th>Greg's alleles</th><td>$I^A I^B$</td></tr><tr><th>i</th><td>$I^A i$</td></tr><tr><td></td><td>$I^B i$</td></tr><tr><td></td><td>ii</td></tr></table>		Ellie's alleles		I^B	i	Greg's alleles	$I^A I^B$	i	$I^A i$		$I^B i$		ii
Ellie's alleles														
I^B	i													
Greg's alleles	$I^A I^B$													
i	$I^A i$													
	$I^B i$													
	ii													

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

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.

2.8 Check your learning

Remember and understand

- Explain** why it is important to know your blood group.
- From Table 1, **identify** the blood group in Australia that is the:
 - most common
 - least common.
- Complete Table 3 to **identify** 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		

Apply and analyse

- Consider** two parents who are both blood group O. **Identify** the blood groups their children could have.
- 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.
- If Vinda and Julie have a second child, **explain** whether the blood group of the first child will affect that of the second. **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).
- Construct** an appropriate graph to present the type of data presented in Table 1.
 - Analyse** the data in the graph and **describe** any pattern you identify in terms of independent and dependent variables.
 - Does the pattern you identified in part a represent correlation or causation? **Justify** your response.

2.9

Alleles on the sex chromosomes produce sex-linked traits

In this topic, you will learn that:

- 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 child
- autosomes are non-sex chromosomes.

autosome

a chromosome that does not determine the sex of an organism

sex chromosome

a chromosome that determines the sex of an organism

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.

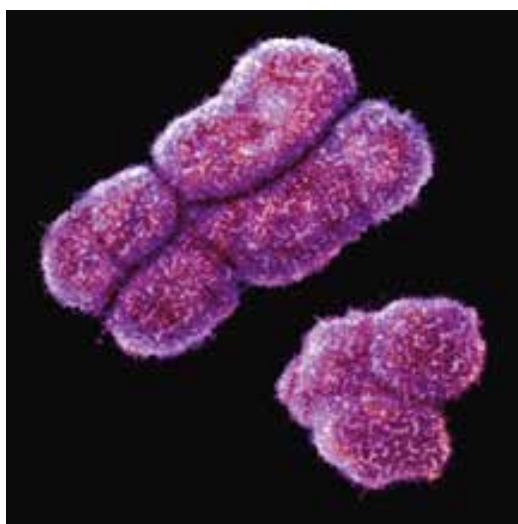


Figure 1 The X chromosome (left) is much larger than the Y chromosome (right) and carries more genetic information.



Figure 2 Most sex-linked genes are situated on the X chromosome. There are only a few Y-linked genes, such as hairy ears. So only males have hairy ears.



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. One allele for this gene is defective and the colour receptors produced do not function properly. This means 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.

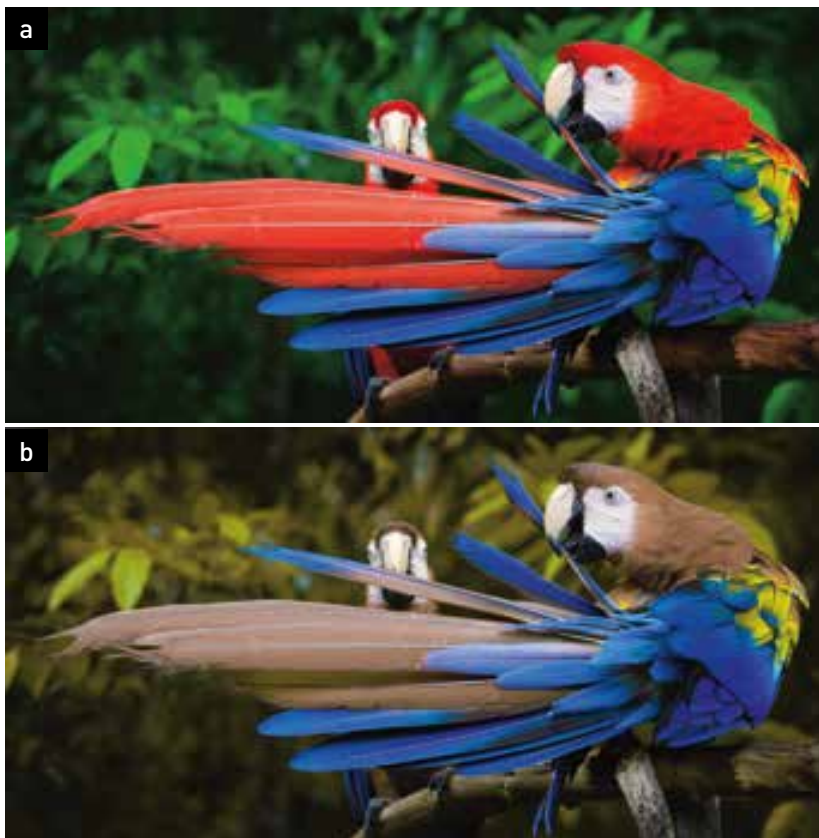


Figure 4 A person with colour blindness will have a very different view of the world. **a** A person with normal vision can see all the colours of these parrots. **b** A person with colour blindness cannot see the red and green feathers.

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,



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

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 (see Figure 6).

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

Queen Victoria $X^H X^h$ x $X^H Y$ Albert

Carrier daughter $X^H X^h$ x $X^H Y$ Her husband

Alexandra $X^H X^h$ (carrier granddaughter) x $X^H Y$ Nicholas II (last Tsar of Russia)

Alexei $X^h Y$ (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.

Remember and understand

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

Apply and 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 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).

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

Evaluate and create

- 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.

Figure 7 A tortoiseshell cat



2.10 Inheritance of traits can be shown on pedigrees

In this topic, you will learn that:

- 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.



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

Pedigree construction and analysis

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

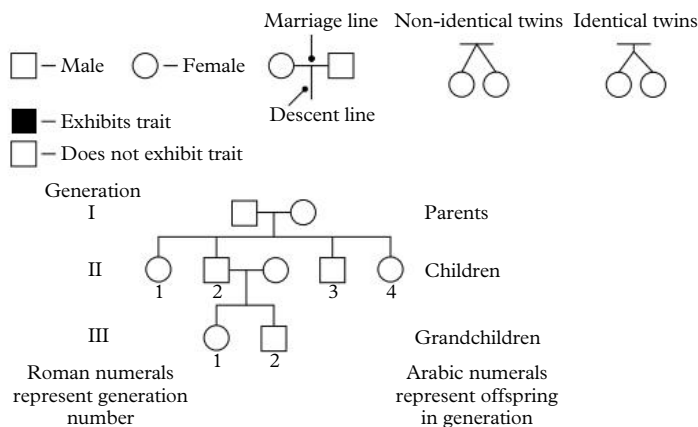


Figure 1 Some symbols used in family tree diagrams.

- > Males are represented by squares and females by circles.
- > A marriage is shown by a horizontal line; a vertical line leads to the offspring.
- > 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 none of their children have it, then the characteristic is dominant (because, if both parents have a characteristic and it is recessive, then all of their children will have that characteristic).

In the pedigree shown in Figure 2, tongue rolling is dominant. This is because individual III1 and her partner can roll their tongues, and some of their offspring can and some cannot. The parents are both heterozygous for tongue rolling.

Analysing pedigrees

Pedigrees can be analysed to determine whether an individual will inherit a disease. There are 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.

Dwarfism

Achondroplasia is the most common form of dwarfism 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

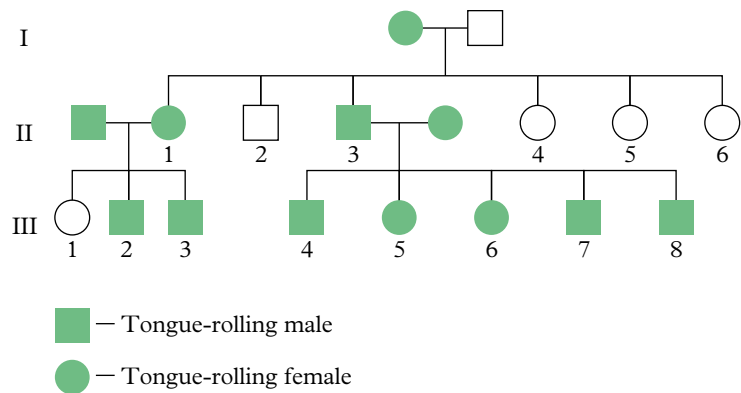


Figure 2 A pedigree for tongue rolling

to the growth factor and will have a dwarf 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. If one parent is affected, there is a 50 per cent chance of the children being affected.

achondroplasia

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

2.10 Check your learning

Remember and understand

- 1 Draw a pedigree symbol that represents the following:
 - a a female with a trait
 - b a male without a trait
 - c non-identical male and female twins without a trait.

Apply and analyse

- 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 3).

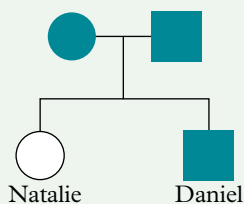


Figure 3 A pedigree showing inheritance of ear lobes

- 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 **identify** 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 4.

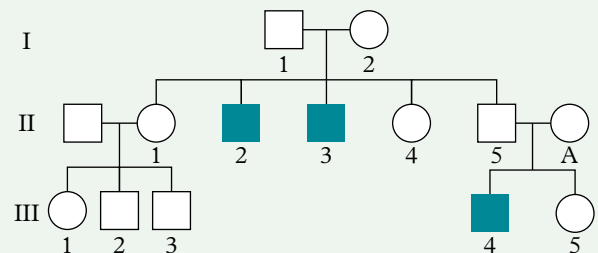


Figure 4 A pedigree showing the inheritance of an X-linked disease

- a Use this pedigree and suitable symbols to show the genotype of individuals I1, I2 and II5. **Identify** the genotype of individual A.
- b **Define** the term 'carrier'. **Identify** one carrier in the pedigree shown in Figure 4.

2.11

Mutations are changes in the DNA sequence

In this topic, you will learn that:

- 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.

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

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 genic or 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.

It was a single nucleotide mutation many thousands of years ago that 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 CARATE 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. The gene that makes part of the haemoglobin molecule, which carries oxygen

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

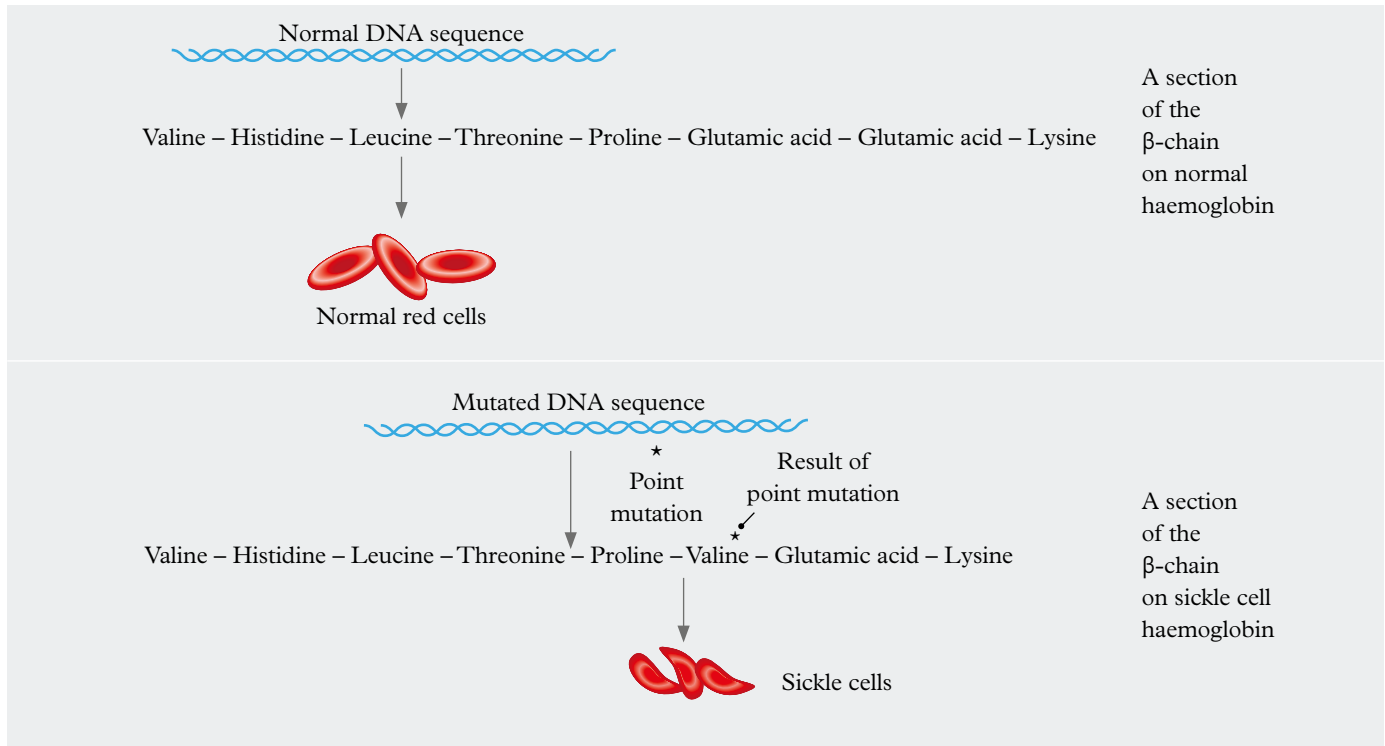


Figure 2 Haemoglobin and sickle cell anaemia – an example of the effects of a point mutation

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, making the red blood cells sickle shaped (Figure 2). People with sickle cell anaemia can feel tired, because the sticky haemoglobin doesn't carry oxygen as effectively.

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 would result in the triplet code becoming:

THE CAA TET HER ATA NDR ANF AR

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

THE CAR TAT ETH ERA TAN DRA NFA R

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

Frameshift mutations have more damaging effects than substitution mutation because they change the entire reading frame of the DNA and RNA, producing a very different protein. If the RNA sequence reads UAC after the mutation, then this is a 'stop codon' and

frameshift

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

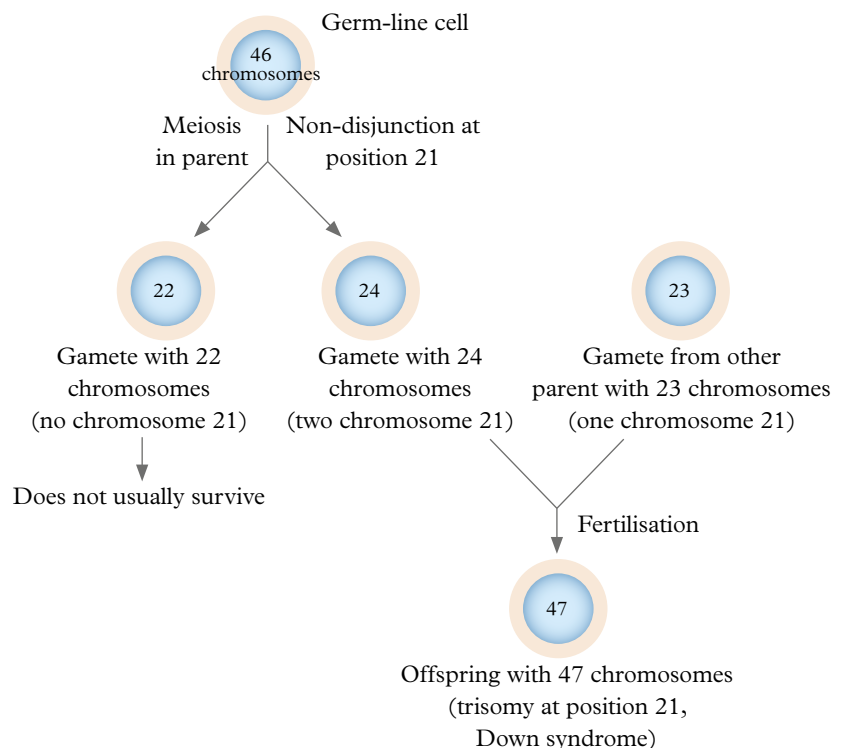


Figure 3 Changes in chromosome numbers due to non-disjunction

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

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.

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 (Figure 5).



Figure 4 This girl has Down syndrome, which is a result of non-disjunction of chromosome 21.

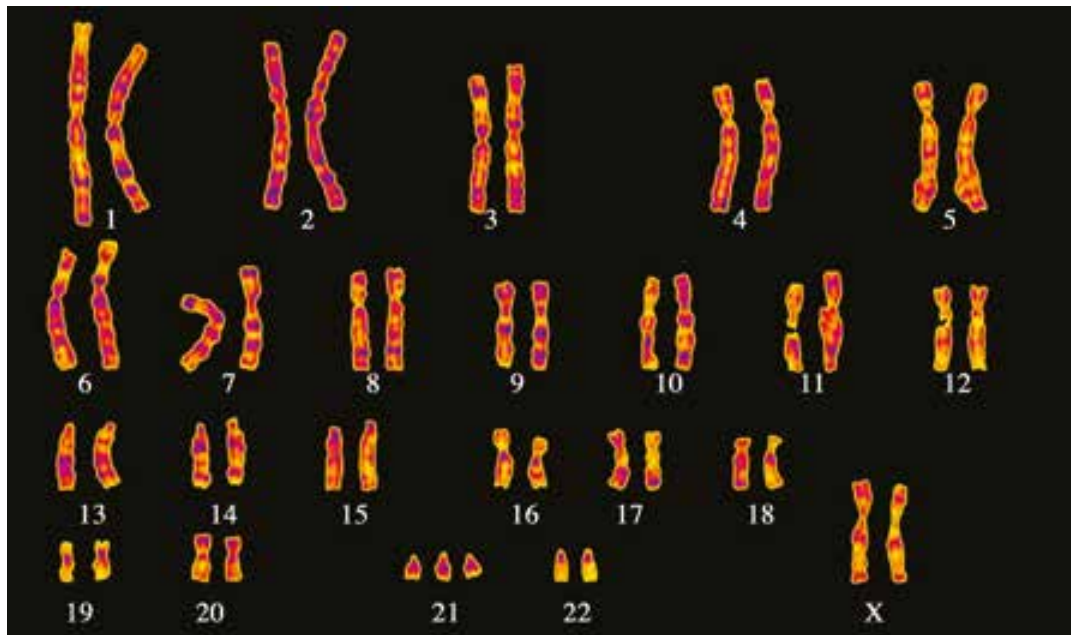


Figure 5 Individuals with Down syndrome have three copies of chromosome 21.

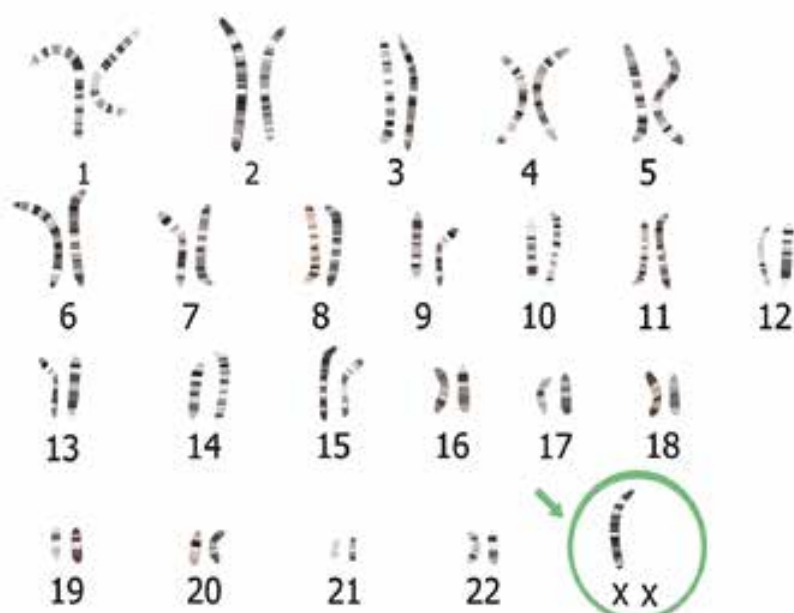


Figure 6 Turner syndrome is a result of non-disjunction of the X chromosome.

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

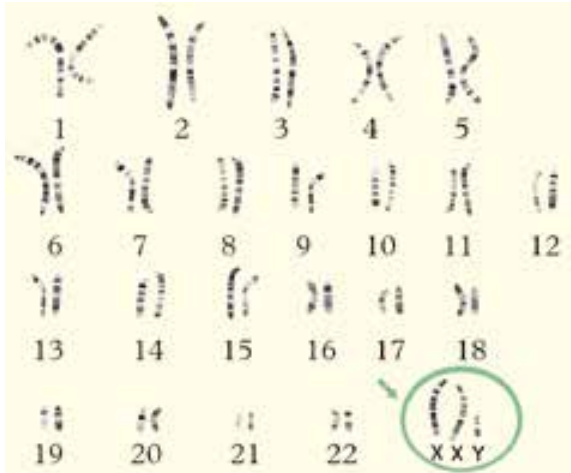


Figure 7 Males with Klinefelter syndrome have an extra X chromosome.

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

This collection of symptoms 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.

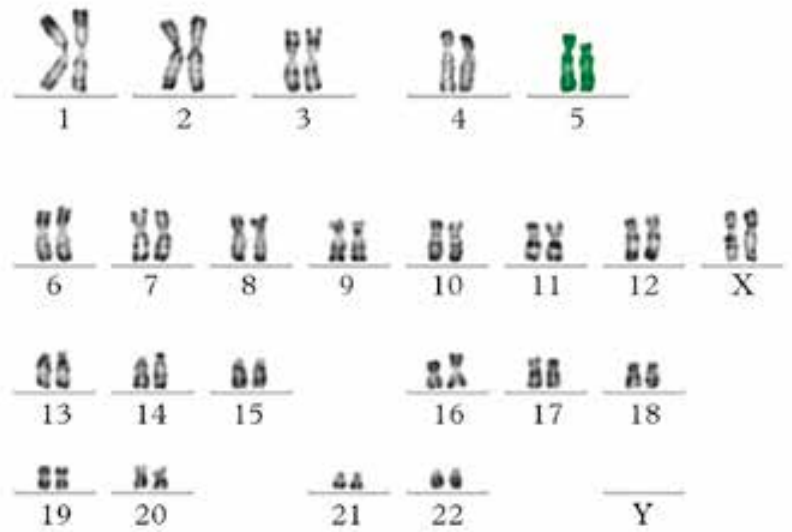


Figure 8 Cri du chat syndrome occurs when part of chromosome 5 is missing.

2.11 Check your learning

Remember and understand

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

Apply and analyse

- 5 **Compare** the causes of Turner syndrome and Down syndrome.

Evaluate and create

- 6 **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).
- 7 Draw a series of diagrams that show non-disjunction occurring in meiosis.
- 8 **Describe** how you would test whether a male had Klinefelter syndrome.

2.12 Genes can be tested

Mutations in genes can be identified by using a probe. Probes are short sections of complementary nucleotides that can bind to the 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 be used to identify individuals at increased risk of developing a disease such as breast cancer, cardiovascular disease or Alzheimer's disease. While this genetic testing has advantages in the treatment of the disease, there are many social and ethical issues that must be considered.

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
- » **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.

Genetic screening can also be used to prevent genetic diseases from being passed on to the next generation. Although 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.



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

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 Develop your abilities

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 (consequentialism 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.

2.13 Genes can be manipulated

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?'



Video 2.13A
A genetically superior bee



Video 2.13B
Genetically modified salmon

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

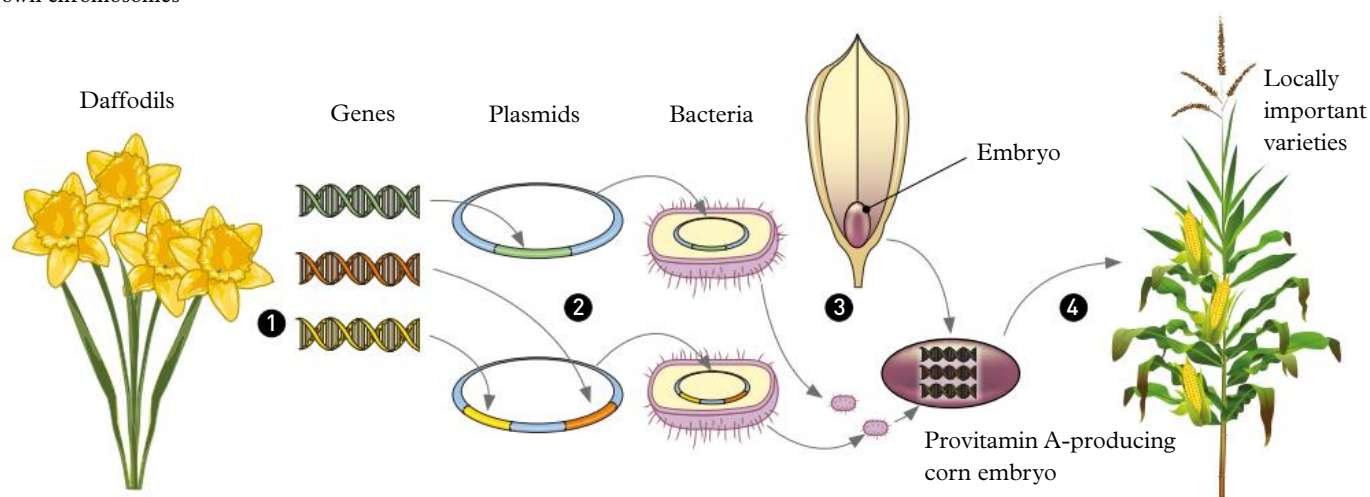
Genetically modified organisms

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 resistance to herbicides or 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 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.

Crops that have been engineered to resist disease need lower amounts of pesticides and herbicides to grow. This reduces production costs and environmental pollution.



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.

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 significant increase in GM plants has only occurred in the past decade or so.

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 non-GM plants. Windborne cross-pollination of GM plants such as herbicide-resistant corn may lead to their pollen being blown onto local, genetically similar weeds. Occasionally, this can result in a hybrid plant that reproduces quickly like weeds and is also resistant to plant-killing herbicides.



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 Develop your abilities

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 **Examine** this example 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.

2.14 Genetic engineering is used in medicine

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



Video 2.14
Genetically modified humans

genetic engineering

the deliberate engineering of change in the DNA of an organism

gene therapy

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

gene cloning

the production of identical copies of a gene

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.

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

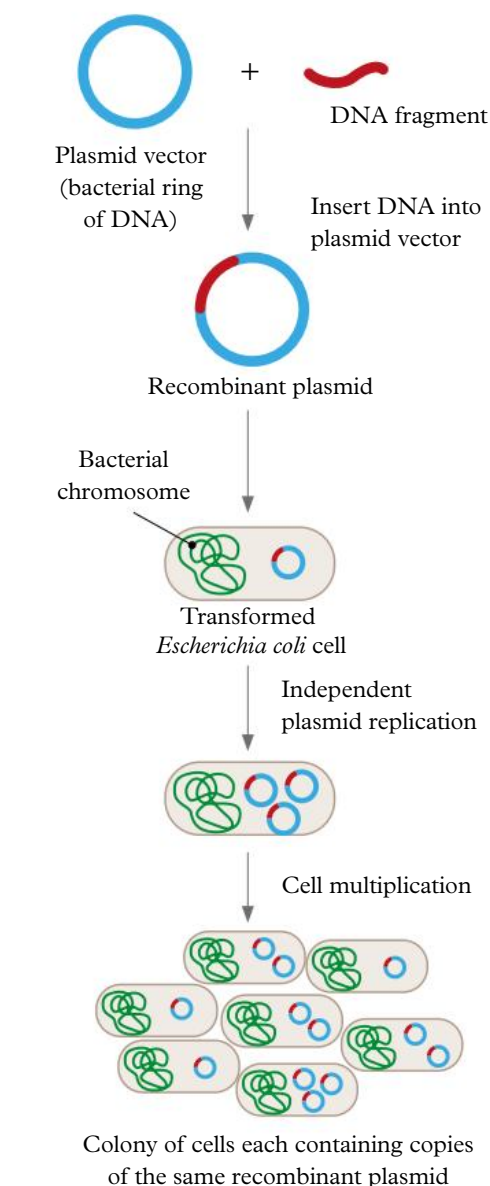


Figure 1 Gene cloning

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. 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

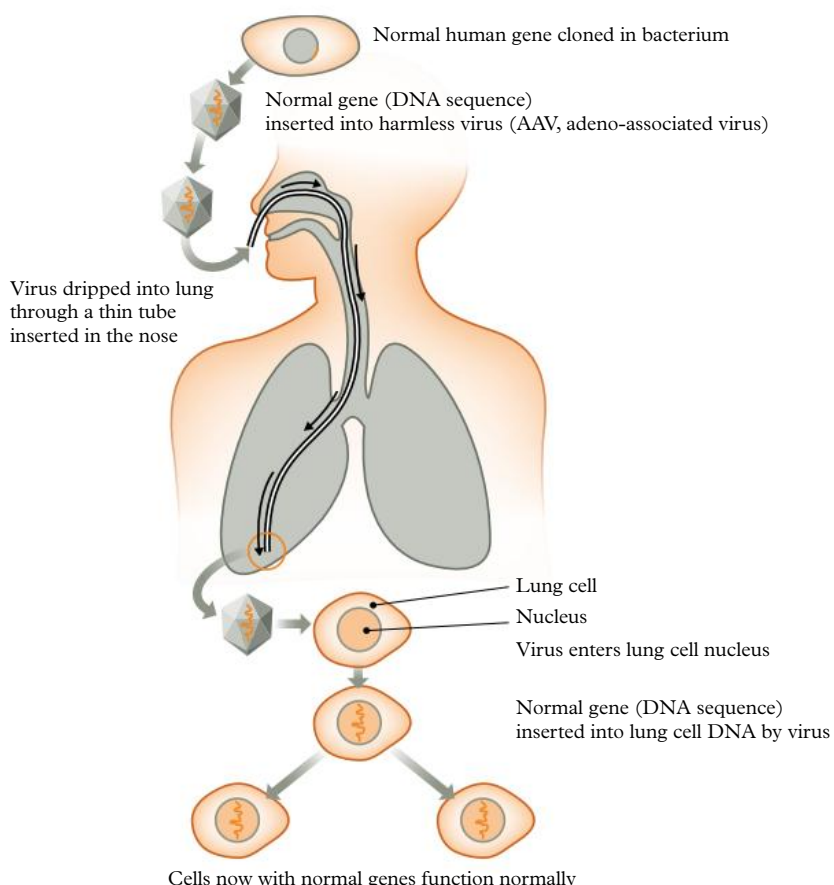


Figure 2 Gene therapy for cystic fibrosis

pluripotent stem cells (like the embryo cells). These cells are called induced pluripotent 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 Develop your abilities

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 (consequentialism 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.

REVIEW 2

Multiple choice questions

- Identify** which is not a smaller part of all nucleotides.
 - deoxyribose
 - nitrogen base
 - adenine
 - phosphate molecule
- Mutations are _____ and mutagens are _____.
 - changes in the gene carried through DNA; a substance that causes permanent change
 - changes in the chromosomes; a substance that causes permanent change
 - a substance that causes permanent change; changes in the chromosomes
 - a change in the genetic structure; substances that causes temporary change
- Pedigrees are:
 - a cross that shows inheritance
 - a diagram to show the inheritance pattern of a trait
 - a particular breed of species
 - a plot of chromosomes.

Short answer questions

Remember and understand

- Identify** the four nitrogen bases found in DNA.
- Use the terms 'gametes' and 'fertilisation' to **explain** how DNA is transferred from one generation to the next.
- Compare** a chromosome and a molecule of DNA.
- Contrast** the structure or function of DNA and RNA.
- Use words and/or diagrams to **contrast**:
 - a nitrogen base and a codon
 - diploid and haploid.
- Define** the term 'monohybrid cross'.
- Describe** Mendel's conclusions from his work on breeding peas.
- Contrast** the following pairs of terms.
 - autosome and sex chromosome
 - gene and allele
 - heterozygous and homozygous
- Explain** what is meant by the following formula:
Phenotype = genotype + environment
- Define** the following terms.
 - GMO
 - transgenic organism

- Explain** the process of:

- gene cloning
- gene therapy.

Apply and analyse

- 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.)
- Identify** which of the following is not a function of mitosis.
 - replenishing the epithelial cells of the small intestine that are shed daily
 - forming new red blood cells to replace those that are worn out
 - forming cells for sexual reproduction
 - repairing cuts and abrasions of the skin
- Describe** the sort of information that can be determined from the pedigree shown in Figure 1.

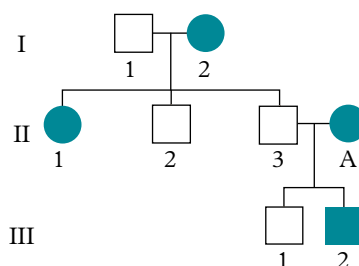


Figure 1 A pedigree

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

- Identify** the genotype and phenotype of Parent 1 and Parent 2.
- Calculate** the chances of Parents 1 and 2 producing offspring with green peas.
- Calculate** the chances of Parents 1 and 2 producing offspring with yellow peas.
- Explain** how you know one of the traits in the Punnett square is dominant.

21 Examine Figure 3.

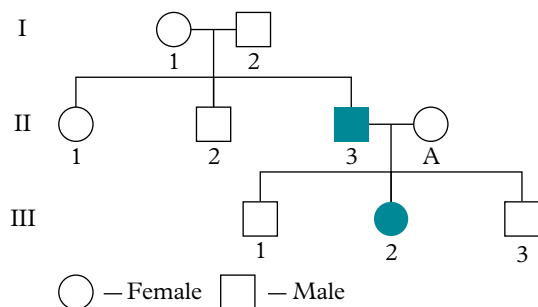


Figure 3 A pedigree indicating the inheritance of a trait

- In this family pedigree, **identify** the characteristic indicated by shading as dominant or recessive. **Justify** your answer.
 - If R represents the allele for the dominant trait and r represents the allele for the recessive trait, **identify** the genotypes for I1, I2 and person A.
 - If A and her partner had another child, **calculate** the chance of the child having the characteristic indicated by shading. Show your working.
- 22** The pedigrees in Figure 4 show the inheritance of two genetic disorders (vision defects and limb defects) in the same family.
- Identify** the allele responsible for the vision defect as dominant or recessive. **Justify** your answer.
 - Identify** the allele responsible for the limb defect as dominant or recessive. **Justify** your answer.

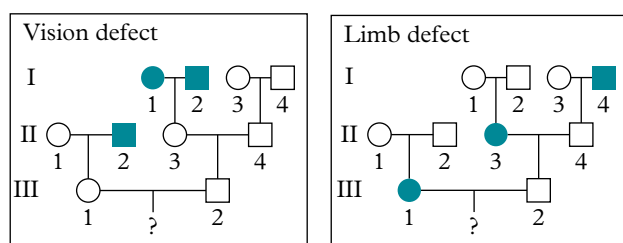


Figure 4 Pedigrees for the inheritance of vision defects and limb defects

Evaluate

- 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. (NOTE: Grey colour is a dominant trait.)
- Contrast** the information provided by a chromosome and a gene.
- If both parents have achondroplasia, **calculate** the chances of their children being unaffected.
- Create** a teaching resource that could be used to teach a Year 7 student about the process of cell division.

Social and ethical thinking

- The debate around embryonic stem cells is heated. **Describe** 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 using embryonic stem cells should be used.
- 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.

Critical and creative thinking

- 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 (gene or chromosomal abnormality), pattern(s) of inheritance, the frequency of the disease in the population, diagnosis, symptoms and treatment.
- Create** a brochure that promotes the benefits of purchasing organic and non-GM foods. Alternatively, produce a brochure promoting the benefits of GM foods.

Research

- 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.

Reflect

The table below outlines a list of things you should be able to do by the end of Chapter 2 'Genetics'. Once you've completed the chapter, use the table to reflect on your ability to complete each task.

	I can do this.	I cannot do this yet.
Describe the contributions of different scientists, including Rosalind Franklin, to 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 20
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 22
Define the terms 'DNA', 'gene' and 'chromosome', and explain the relationship between them.	☐	☐ Go back to Topic 2.3 'Chromosomes carry genetic information in the form of genes' Page 24
Explain the role of DNA and mRNA in the processes of transcription and translation.	☐	☐ Go back to Topic 2.4 'DNA holds the code for building proteins' Page 26
Describe the phases of mitosis. Explain how and why a cell undergoes apoptosis.	☐	☐ Go back to Topic 2.5 'Mitosis forms new somatic cells' Page 28
Describe the phases of meiosis I and meiosis II.	☐	☐ Go back to Topic 2.6 'Meiosis forms gamete cells' Page 30
Explain how combinations of dominant and recessive alleles produce different genotypes and phenotypes in individuals.	☐	☐ Go back to Topic 2.7 'Alleles can produce dominant or recessive traits' Page 32
Describe the different genotypes and phenotypes of human blood groups.	☐	☐ Go back to Topic 2.8 'Alleles for blood group traits co-dominate' Page 34
Explain how and why sex-linked traits are inherited differently in males and females.	☐	☐ Go back to Topic 2.9 'Alleles on the sex chromosomes produce sex-linked traits' Page 36
Analyse and interpret pedigrees to determine whether a trait is dominant, recessive, autosomal or sex-linked.	☐	☐ Go back to Topic 2.10 'Inheritance of traits can be shown on pedigrees' Page 40
Explain how substitution and frameshift mutations alter the nucleotide and amino acid sequences of a protein.	☐	☐ Go back to Topic 2.11 'Mutations are changes in the DNA sequence' Page 42
Describe the purpose of genetic screening and testing.	☐	☐ Go back to Topic 2.12 'Science as a human endeavour: Genes can be tested' Page 46
Give examples of different GMOs and explain the human need for these GMOs to be produced.	☐	☐ Go back to Topic 2.13 'Science as a human endeavour: Genes can be manipulated' Page 48
Explain how gene therapy can be used for the treatment of medical conditions.	☐	☐ Go back to Topic 2.14 'Science as a human endeavour: Genetic engineering is used in medicine' Page 50

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How are humans and chimpanzees related?

3.1

Science as a human endeavour:
Darwin and Wallace were
co-conspirators

3.2

Natural selection is the
mechanism of evolution

3.3

Different selection pressures
cause divergence. Similar selection
pressures cause convergence

3.4

Fossils provide
evidence of evolution



3.5

Multiple forms of evidence
support evolution

3.6

DNA and proteins provide
chemical evidence for evolution



3.7

Humans artificially
select traits

3.8

Science as a human endeavour:
Natural selection affects
the frequency of alleles

CHAPTER

3

EVOLUTION

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?)

3.1 Darwin and Wallace were co-conspirators

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.



Video 3.1
Galapagos

Before evolutionary theory

The generally accepted belief for many thousands of years was that life was 'created' by gods. Even events such as volcanic

Figure 1 These layers of rock are an indication of different time periods. Pale layers can sometimes represent volcanic ash released during an eruption.



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. 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



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.

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 1000 km

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. 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.

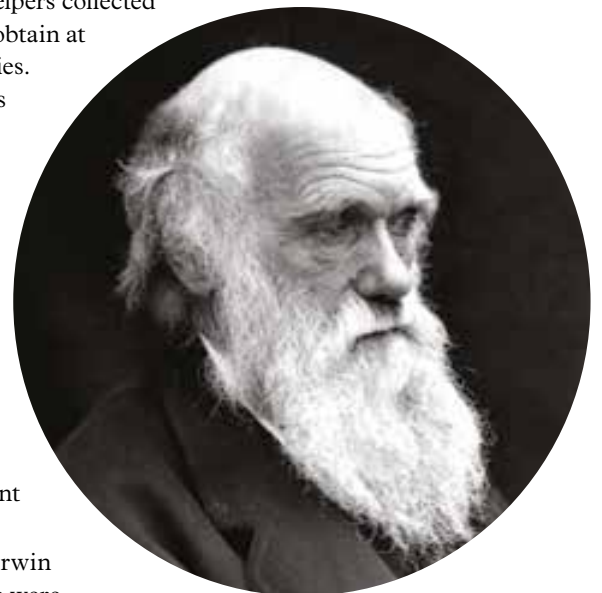


Figure 3 Charles Darwin's theory of evolution was a departure from the traditional view of Creation and attracted much public interest and criticism.



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. Malthus argued in his paper that the human race would completely overrun the Earth if it was not held



Figure 5 Was the plague simply nature's way of keeping the human population in check?

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*.

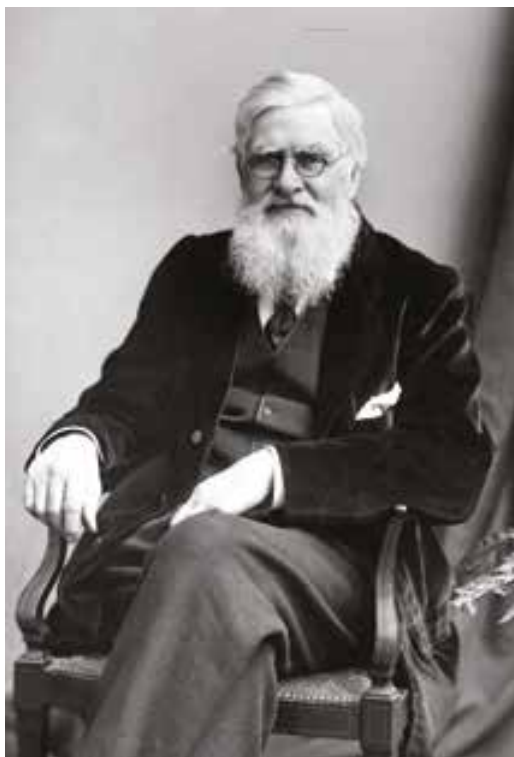


Figure 6 Alfred Russel Wallace formed the same theory as Darwin and at the same time. Wallace’s work was conducted in Asia, whereas most of Darwin’s observations were made in South America. Darwin had the advantage of a wealthy family that could assist him in being published. Perhaps this is why Darwin receives all the credit.

3.1 Develop your abilities

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

In this topic, you will learn that:

- 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).

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.

gene pool

all the genes or alleles in a population

selection pressure

the environmental factors that affect an organism's ability to survive

Figure 1 These Siberian huskies have different versions, or alleles, of the gene for eye colour.



Variations in populations

Natural selection depends on the variation of traits within a population, but where does this variation come from? 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. 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 their environment is called **natural selection**.

Allele frequencies

Populations are always evolving. 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.

Evolution is the permanent change in the frequency of alleles in a population due to natural selection.



Figure 2 Syndactyly is webbing between the fingers and toes. It is common because a foetus has webbing that undergoes 'programmed cell death', or apoptosis, to remove it prior to the baby being born. Syndactyly is biologically neutral, because the webbing is usually neither an advantage nor a disadvantage. However, there are situations in which it may be beneficial. Imagine a career as an Olympic swimmer!

Mutating moths

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.



Figure 3 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.

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

Remember and understand

- 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 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.
- 3 **Describe** the selection pressures that caused the allelic frequency of light-grey moths to decrease in England in the 1950s.

Apply and analyse

- 4 In your own words, **describe** the mechanism by which natural selection can influence the frequency of alleles in a population.
- 5 **Explain** why natural selection cannot increase or decrease the frequency of some mutations in a population.

Evaluate and create

- 6 **Create** a diagram that illustrates the process of natural selection of the moths in England.

3.3

Different selection pressures cause divergence. Similar selection pressures cause convergence

In this topic, you will learn that:

- 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 structures

structures that are 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's 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 different 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 – **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 (i.e. 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. All tetrapods (four-limbed land animals) 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

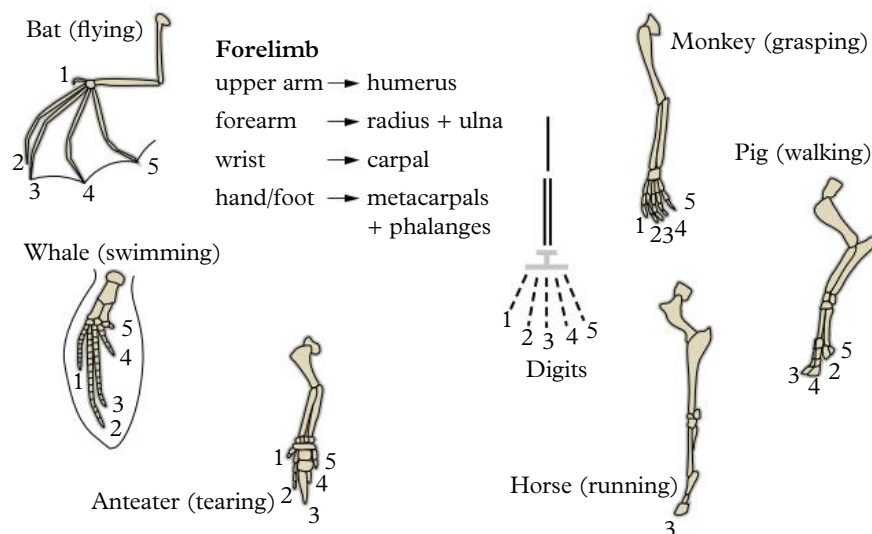


Figure 1 The homologous forelimbs of different mammals show the same basic structure, with a single upper bone, two lower limb bones, small wrist or ankle bones and five digits that are adapted to different uses.



Figure 2 The wings of a bird and the wings of a butterfly are analogous structures: they perform the same function but have significantly different structures.

3.3 Check your learning

Remember and understand

- 1 Use an example to **describe** how a permanent barrier could create a new species.
- 2 **Define** the term 'homologous structures'.
- 3 **Identify** an example of an analogous structure.
- 4 **Define** the term 'speciation'.

Apply and analyse

- 5 **Describe** how gene flow influences the process of speciation.
- 6 **Compare** an adaptation of an organism and an adaptation of a species.
- 7 **Describe** how the land ancestors of dolphins evolved to become the streamlined mammals we see now.

3.4

Fossils provide evidence of evolution

In this topic, you will learn that:

- 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.

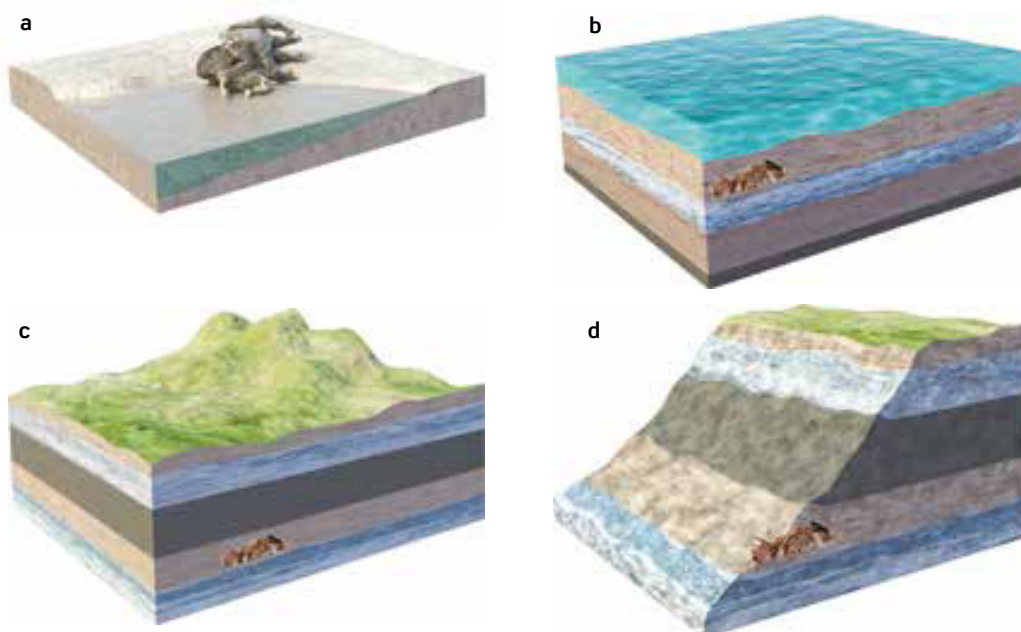


Figure 1 Formation of a fossil. **a** and **b** If an organism dies near water, it has a greater chance of being covered by sediment. The sediment protects the body from predators and weathering. **c** Over millions of years, more sediment is deposited, replacing the remains so they are transformed gradually 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. If scientists know the length of an



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).

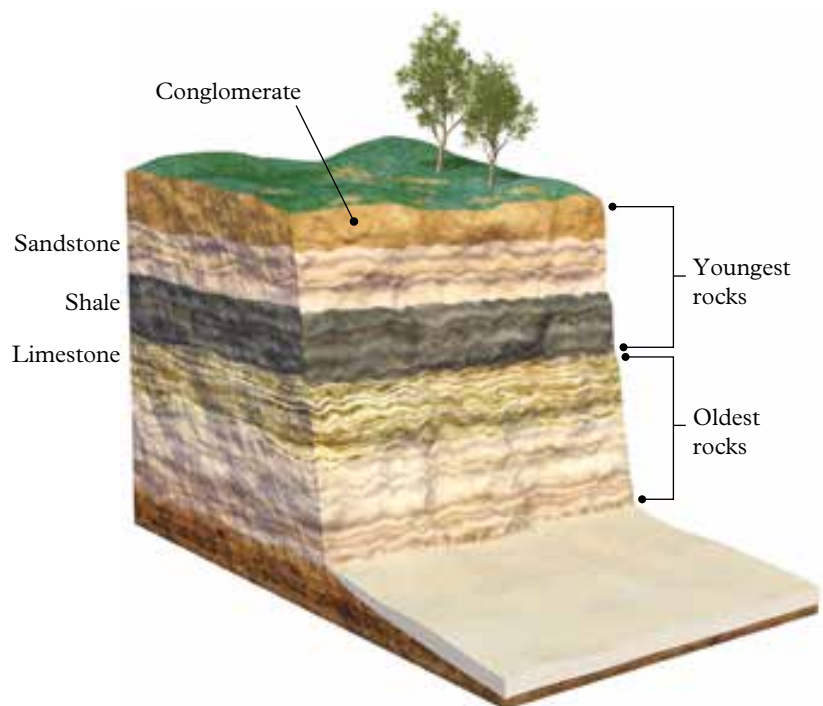


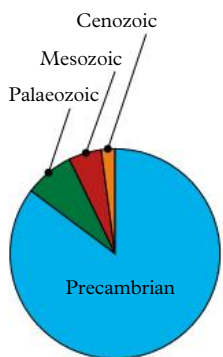
Figure 3 Relative dating is used to work out the age of rocks and fossils. Older rocks are found below younger rocks.



Figure 4 This fossil of *Triceratops horridus* is 65 million years old.

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.

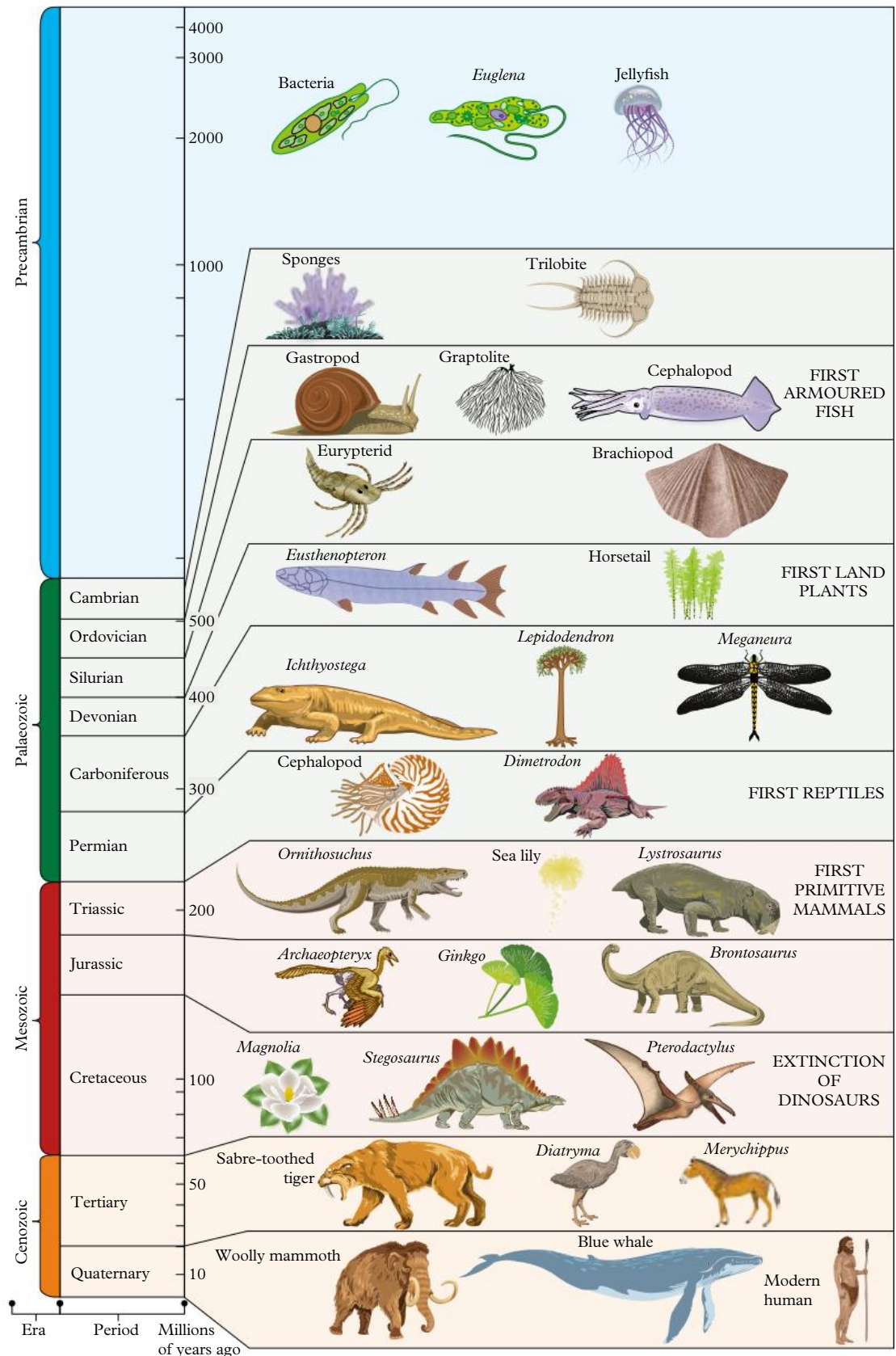


Figure 5 The history of living things (mya = million years ago), as determined by palaeontology (the study of fossils)

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 determine that the fossil has $\frac{1}{8}$ of radioactive carbon-14 remaining.

- Calculate the number of half-lives that have passed in the fossil.
- If 1 half-life = 5000 years, calculate the age of the fossil.

Solution

- 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.

- 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 (e.g. coelacanths, Figure 6).

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**Remember and understand**

- Identify** which parts of an organism are most likely to be found as fossils. **Justify** your answer (by describing how fossils form and describing what features of the fossil are more likely to survive this process).
- Describe** the process of relative dating a fossil.
- Define** the term 'transitional fossil'.
- 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.

Apply and analyse

- 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.

- Contrast** relative dating and absolute dating.
- Fossils were found at four locations (Figure 6). Use relative dating to **determine** which location had the oldest fossils.

Evaluate and create

- 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).

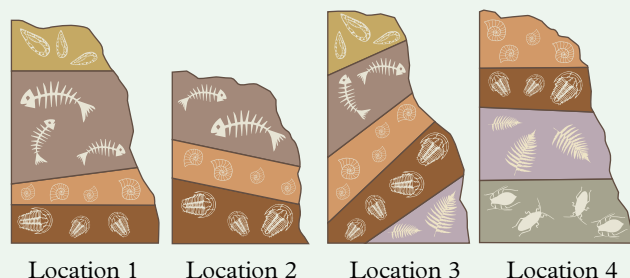


Figure 6 Fossils found at four different locations

3.5

Multiple forms of evidence support evolution

In this topic, you will learn that:

- 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.



Video 3.5

Horses and rhinos share an ancestor

continental drift

the continuous movement of the continents over time

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. This theory



Figure 1 The jigsaw fit of Africa and South America supports the theory of continental drift.

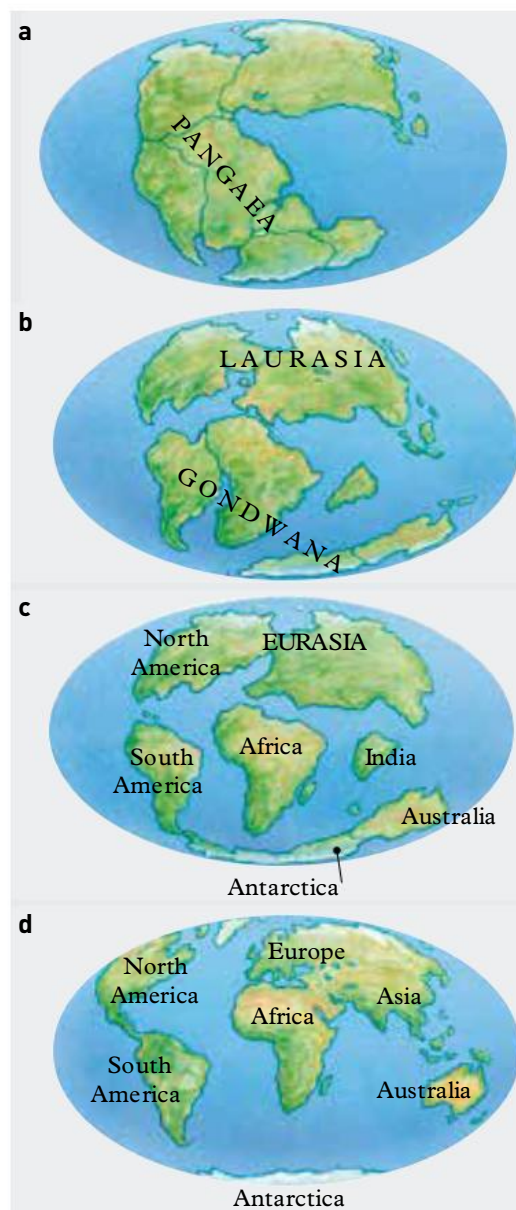


Figure 2 How the continents have drifted: **a** 220 million years ago; **b** 135 million years ago; **c** 65 million years ago; and **d** today

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 on the continents of 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.

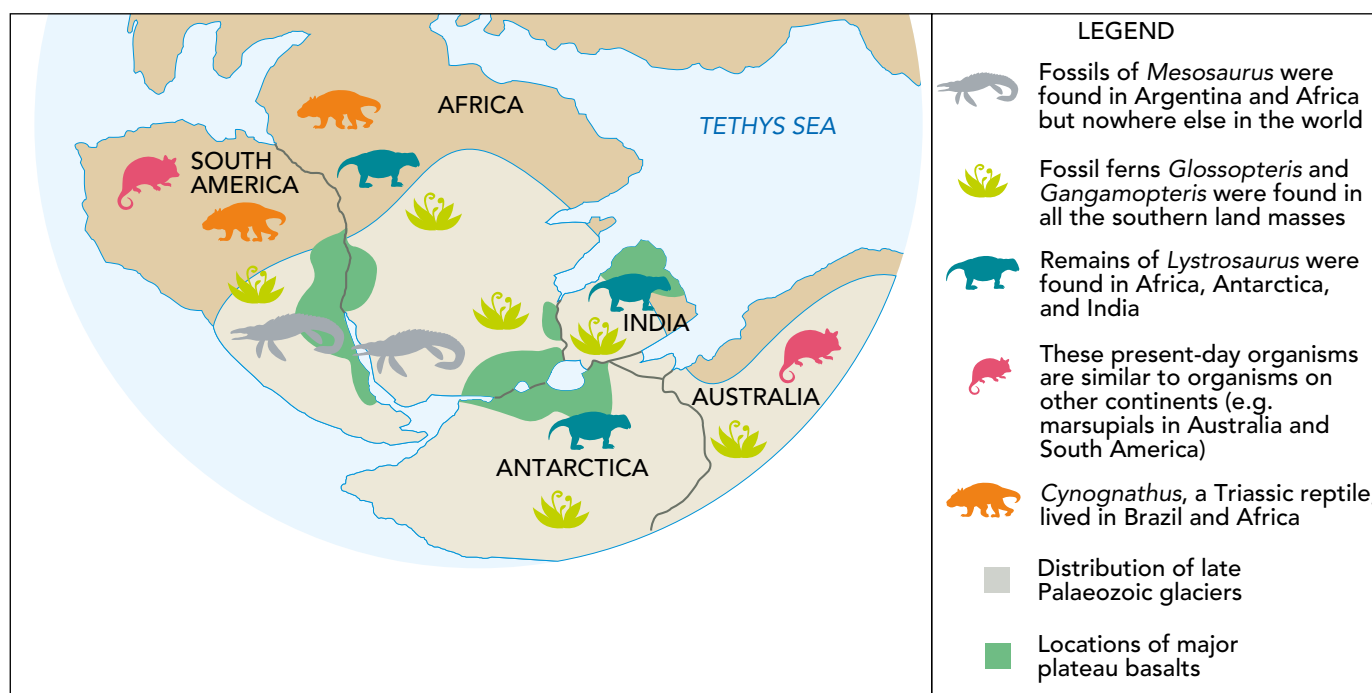


Figure 3 Evidence for the existence of the supercontinent Gondwana is provided by the similarity of fossils on different continents.

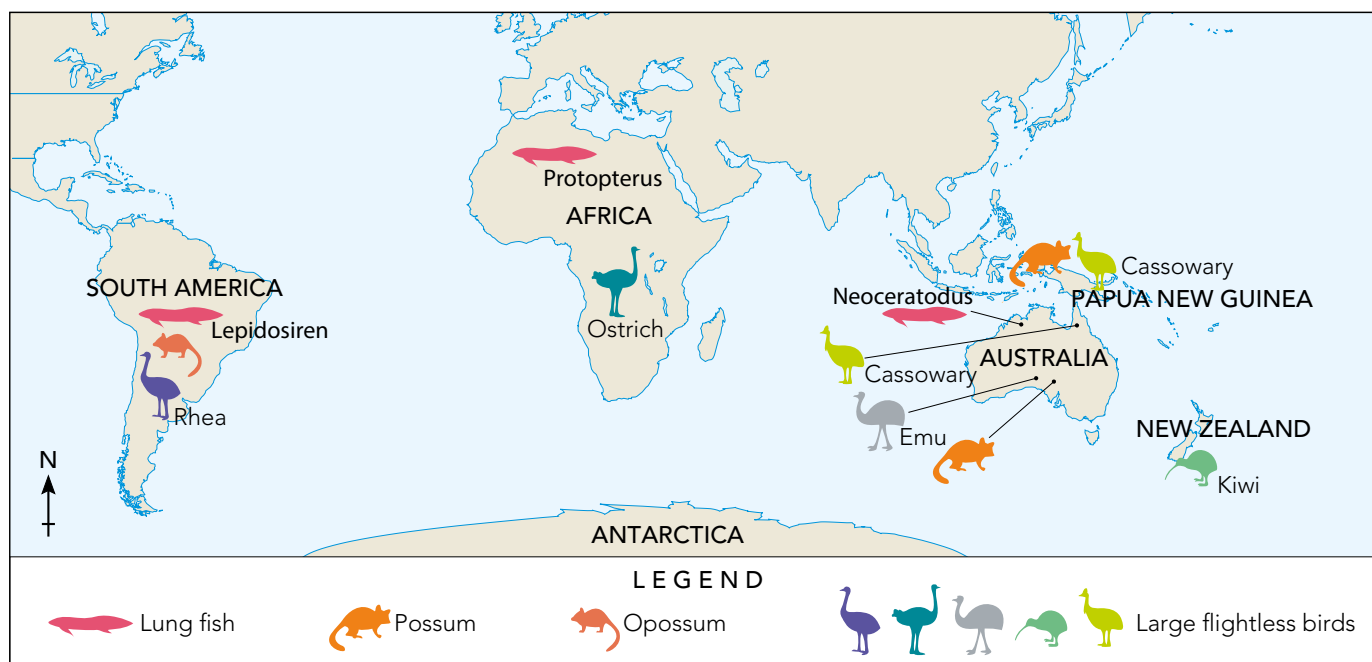


Figure 4 Similar lungfish are found in South America, Africa and Australia. Similar marsupials are found in South America and Australia.

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. It would



Figure 5 The rear legs on a snake (as shown by the arrow) are an example of a vestigial structure.

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 become '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.

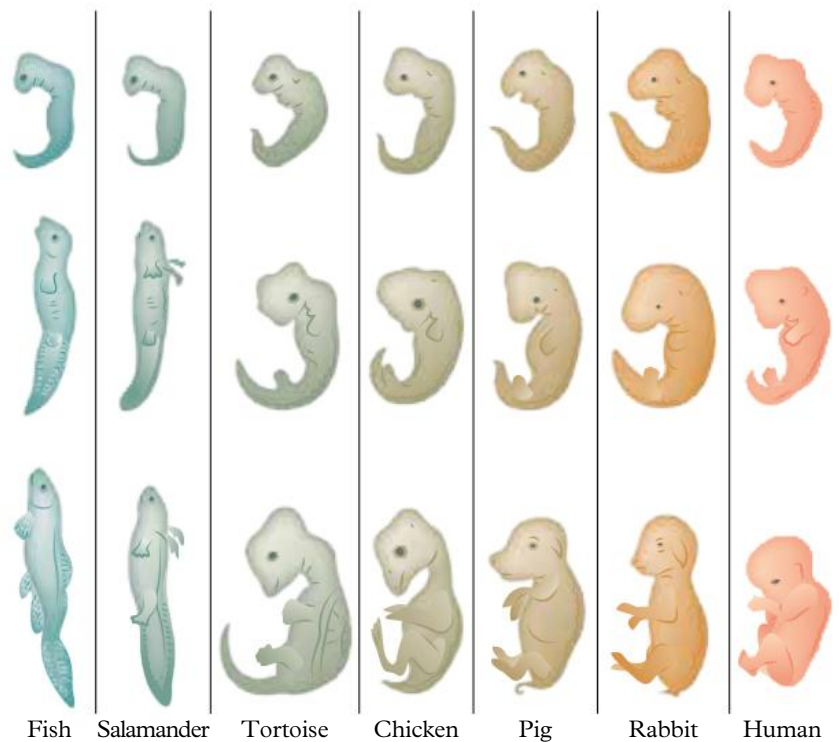


Figure 6 Common structures in the early stage of embryonic development of vertebrates indicate the existence of common genes.



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

Remember and understand

- 1 The frogs in Australia show their closest evolutionary relationships to frogs in Africa and South America. **Explain** how this is possible.

Apply and analyse

- 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.

Evaluate and create

- 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 to support her claim, describing two reasons that disagree with her claim, and deciding which reasons are most convincing).

3.6

DNA and proteins provide chemical evidence for evolution

In this topic, you will learn that:

- 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 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).

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.



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.

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 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. Currently, scientists use the differences in DNA sequences to compare the evolutionary relationship. This relationship is shown in a **phylogenetic tree** (Figure 3).

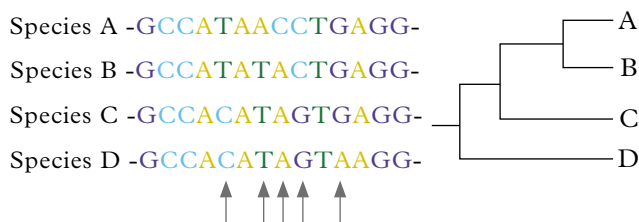


Figure 2 Comparing the DNA sequences allows scientists to determine the evolutionary relationship between different species. Species A is most closely related to B. Species D is the most distant relative of A. A phylogenetic tree for the four species is shown on the right.

Early DNA sequencing work on the genome of humans and great apes has shown that humans share a common ancestor with gorillas and chimpanzees. Comparisons of the DNA sequences of the β -haemoglobin gene has confirmed this.

phylogenetic tree
a branching tree-like diagram showing relationships between different taxonomic groups

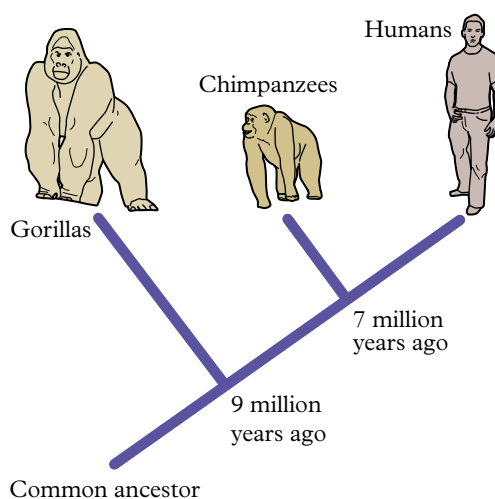


Figure 3 Gene sequencing has shown that humans, gorillas and chimpanzees all evolved from a common ancestor.

3.6 Check your learning

Remember and understand

- Identify** the smaller (bead-like) structures that make up proteins.
- Identify** the cause of gradual changes to the sequence of nucleotides in DNA.

Apply and analyse

- 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).
- 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).

- Use the phylogenetic tree in Figure 4 to **determine** which species is most closely related to species A.
- Explain** how DNA sequencing supports the concept of evolution from a common ancestor.

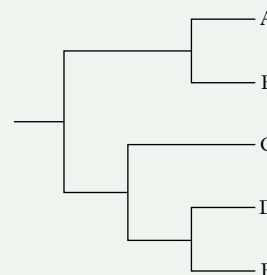


Figure 4 A phylogenetic tree

3.7

Humans artificially select traits

In this topic, you will learn that:

- 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 10 000 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



Figure 1 Some animals have become so dependent on humans that they struggle to survive in natural conditions. This wild sheep was found with wool 42 cm long. The fleece weighed over 40 kg when it was eventually shorn.

artificial selection when humans breed organisms that have desirable traits, increasing the likelihood of that trait occurring in the next generation

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.

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. Over many generations, the ‘wild’ traits were lost and the species was considered ‘domesticated’.

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



Figure 3 Another example of artificial selection, bubble-eye goldfish can have problems with buoyancy, which affects their ability to swim. Could these fish survive in the wild?



Figure 4 Selected for its hairless coat, the sphynx cat was recognised as a new breed in 2008. Would these animals survive in the wild?

of humans overusing antibiotics. *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.

horizontal transfer
the transfer of genetic material (usually containing antibiotic resistance) from a bacterium to another bacterium that is not its offspring

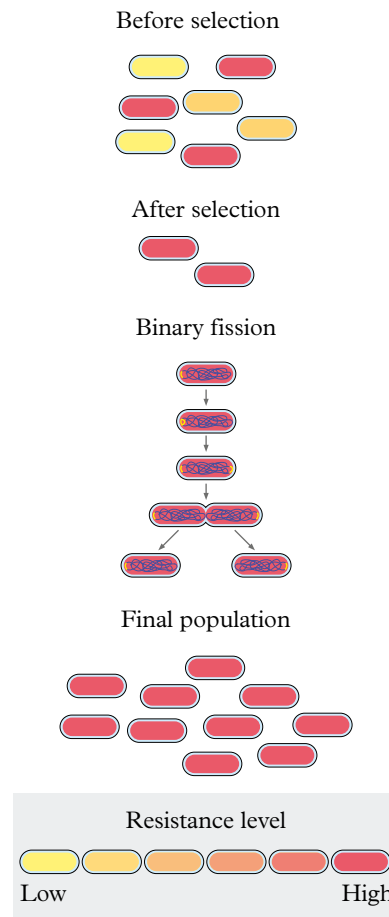


Figure 5 The frequent use of antibiotics allows for the selection of bacteria that are resistant to antibiotics. This increases the allelic frequency of resistance.

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

Remember and understand

- 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'.

Apply and analyse

- 4 **Compare** selective breeding and natural selection.

- 5 **Explain** how misusing antibiotics can contribute to the existence of MRSA.

Evaluate and create

- 6 A student claimed that artificial selection has interfered with nature. **Evaluate** their claim (by describing two reasons to support their claim, describing two reasons that disagree with their claim, and deciding which reasons are most convincing).

3.8 Natural selection affects the frequency of alleles

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.



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.

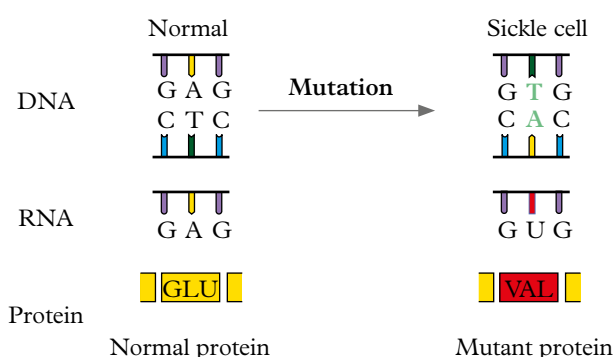


Figure 2 A mutation in the nucleotide sequence causes a change in the amino acid sequence at a DNA level.

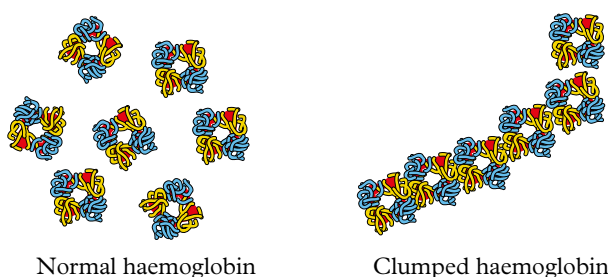


Figure 3 A change in the amino acid sequence causes the haemoglobin to clump together at the protein level.

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.

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.

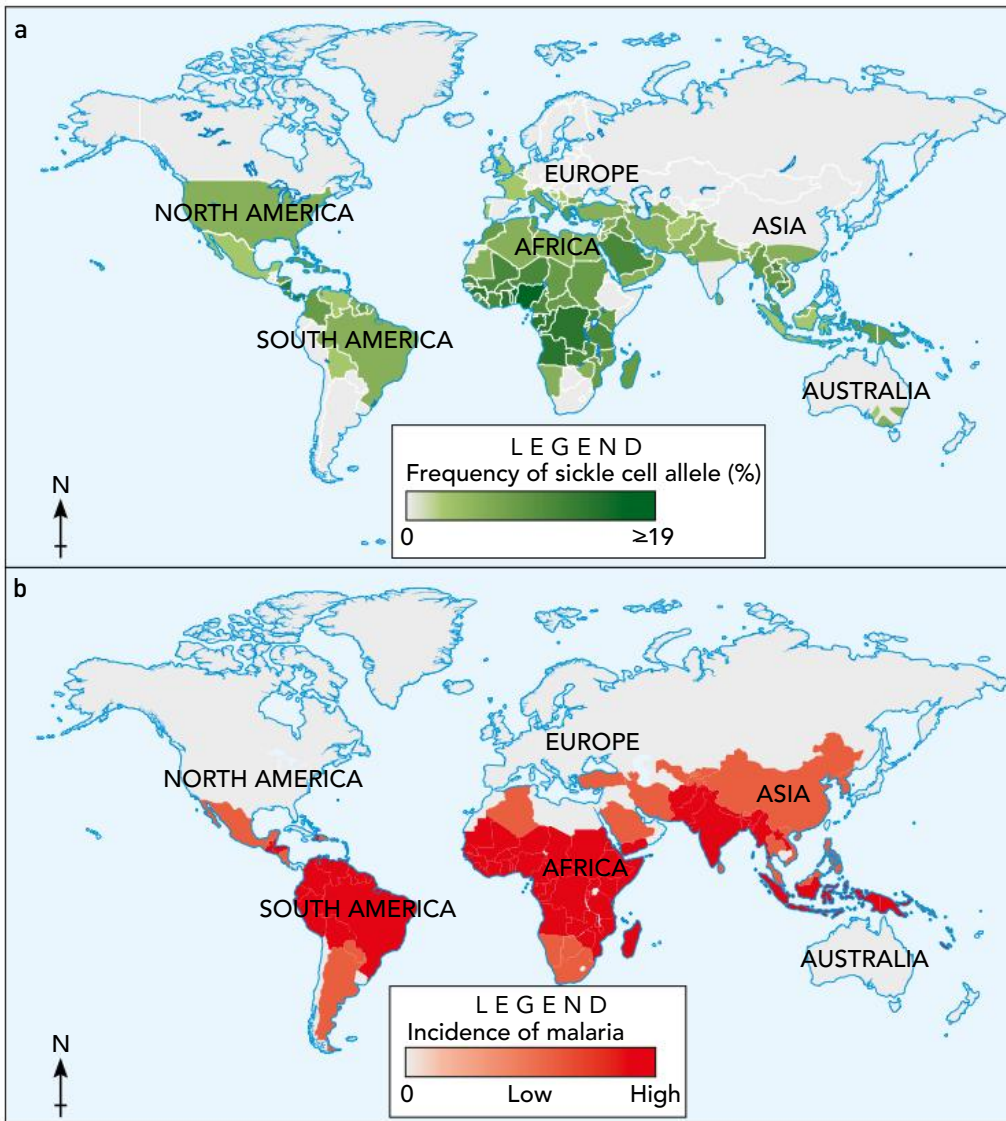


Figure 4 There is a strong correlation between **a** countries that have a high number of carriers for the sickle cell anaemia allele and **b** countries that have a high incidence of malaria.

3.8 Develop your abilities

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.

REVIEW 3

Multiple choice questions

- 1 **Identify** which evolutionary theory proposed that organisms inherited acquired characteristics.
A Darwinism
B Lamarckian theory
C Wallace's theory
D Natural selection
- 2 **Identify** 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 to be the oldest of the layers in Figure 1.
A layer 1
B layer 2
C layer 3
D layer 4

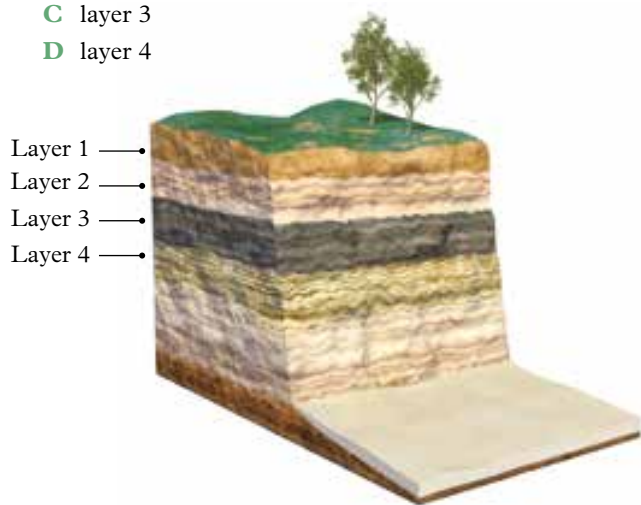


Figure 1 Layers of rock

Short answer questions

Remember and understand

- 4 **Contrast** a hypothesis and a theory.
- 5 **Define** the term 'natural selection', and **identify** the four essential factors for this process.
- 6 **Explain** the difference between incorrectly suggesting an organism has evolved as opposed to correctly suggesting that a population of organisms has evolved.
- 7 **Define** the term 'gene pool'.
- 8 **Identify** the professional title for a person who studies the fossil record and geological time periods.
- 9 *Archaeopteryx* had features of both birds and lizards. **Identify** the term that is applied to fossils that show the evolutionary progression between two very different forms.
- 10 **Describe** Gondwana.
- 11 The layering of sedimentary rocks is useful in relative dating. What is the basic principle of comparative dating?
- 12 **Contrast** a transitional fossil and a living fossil.
- 13 **Explain** precisely how fossils provide evidence for evolution.

Apply and analyse

- 14 Use examples to **illustrate** the two critical deductions that Darwin made – the struggle for existence and the survival of the fittest.
- 15 *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. **Explain** how this adaptive feature enabled *Callistemon* to exploit the current Australian environment.
- 16 **Compare** the terms 'allopatric speciation' and 'gene flow'.
- 17 **Explain** why a vestigial structure, once it has been reduced to a certain size, may not disappear altogether.

Evaluate

- 18 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.



Figure 2 The tortoises are unique to the individual Galapagos Islands.

- 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’, **explain** 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.

- 19** 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 **explain** whether mammals are likely to have originated on Gondwana.
- 20 Explain** how the study of DNA sequences helps in our understanding of evolution.
- 21 Compare** the terms ‘diversity’ and ‘evolution’.

Social and ethical thinking

- 22** Through selective breeding, humans are able to bring about speciation. **Discuss** the various scenarios in which this has occurred in the past and may occur now and in the future. **Describe** three examples of positive human intervention and three examples of detrimental intervention. **Justify** your decisions.
- 23** In 1869, Francis Galton (Charles Darwin’s cousin) studied the families of the most socially prominent people in English society and found that the children had similar characteristics to their successful parents. As a result, he suggested a program of eugenics where successful wealthy parents should be encouraged to have children, while poor and mentally deficient people should be sterilised. Select an ethical approach to **explain** why eugenics is considered unethical.

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.

» 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.

» 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.

» 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 tolerance of 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.

Reflect

The table below outlines a list of things you should be able to do by the end of Chapter 3 'Evolution'. Once you've completed the chapter, use the table to reflect on your ability to complete each task.

	I can do this.	I cannot do this yet.
Understand that scientific theories are based on well-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 56
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 60
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 62
Explain how the existence of fossils provides evidence to support the process 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 64
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 68
Understand 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 72
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 74
Explain how malaria is a selection pressure for the sickle cell anaemia allele. Outline 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 76

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Why is the periodic table important?

4.1

Science as a human endeavour:
Scientists refine models
and theories over time

4.2

The structure of an atom
determines its properties

4.3

Groups in the periodic table have
properties in common

4.4

Non-metals have properties in common

4.5

Metal cations and non-metal anions
combine to form ionic compounds

4.6

Non-metals combine to form
covalent compounds

4.7

Metals form unique bonds

4.8

Science as a human endeavour:
Nanotechnology involves the specific
arrangement of atoms

CHAPTER

4

THE PERIODIC TABLE

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?

4.1 Scientists refine models and theories over time

To develop the periodic table, scientists build on the work of previous generations. The discovery of new **elements** and the ability to recognise patterns and predict the existence of previously unknown elements all result from scientists analysing and refining models. The creation of the periodic table is often credited to Dmitri Mendeleev, who constructed a table with gaps for elements yet to be discovered. However, the ideas he used were first suggested decades before and refined centuries after his work began.

1789

Antoine Lavoisier, a French nobleman (Figure 3), made a detailed list of the substances that he believed to be elements. Assisted by his wife Marie-Anne, Lavoisier made a list that contained 33 elements grouped into metals and non-metals. Lavoisier's list also included some substances that we now know to be compounds.



Figure 3 Antoine Lavoisier and his wife, Marie-Anne

1829

In Germany, Johann Döbereiner was aware of 40 elements. He noted that some groups of three elements had similar properties and named these groups 'triads'. These groupings helped to identify patterns of behaviour, which helped with more accurate predictions about atomic structures.

2000 years ago

The ancient Greeks thought that everything was made of four 'elements' mixed together in different ratios (Figure 1). They named these elements fire, air, water and earth.

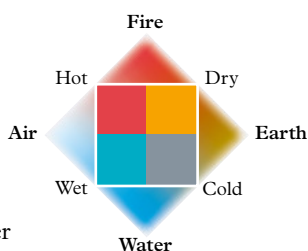


Figure 1 The four Greek 'elements'

2000 years ago

1600

1700

1800

1661

Irish-born chemist Robert Boyle (Figure 2) suggested that an element was a substance that cannot be broken down into a simpler substance in a chemical reaction.



Figure 2 Robert Boyle

1814

Swedish chemist Jacob Berzelius replaced the geometric patterns used as chemical symbols with letters that were an abbreviation of the element's name. Berzelius also used the weight of hydrogen to develop a system of atomic weights. Hydrogen is the lightest element, so it was given a value of 1. The remaining elements were given a whole number above 1.



Figure 4 Jacob Berzelius gave the elements abbreviated symbols such as He for helium.

1894

William Ramsay, a Scottish chemist, used the emerging technology of refrigeration to liquefy and separate the components of air. He successfully removed water, carbon dioxide, oxygen and nitrogen, but he found he had some unknown gas left behind. This was argon, the first in its group to be discovered. He later identified helium, neon, krypton and xenon. All these gases form the group of noble gases at the far right of the periodic table.

1864

English chemist John Newlands arranged the elements according to their atomic weights. He noticed that every eighth element had similar properties. This pattern was considered a recurring, or 'periodic', feature among the elements. Newlands compared the properties to music, with musical notes being grouped eight per octave. This comparison, called the law of octaves, was not accepted by other scientists.

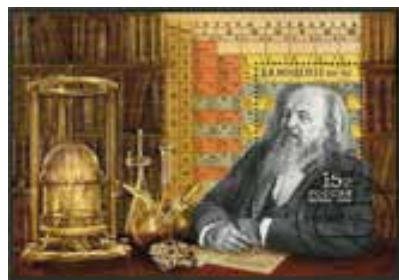


Figure 5 A stamp printed in Russia celebrating the achievements of Russian chemist Dmitri Mendeleev

1869

Dmitri Mendeleev constructed the first periodic table, leaving empty spaces for elements that were yet to be discovered. Building on the ideas of other scientists, Mendeleev identified 63 elements.

1900

1911

Marie Curie (Figure 6) was one of the many female scientists who identified and purified elements of the periodic table. Curie won two Nobel Prizes for her work on radiation.



Figure 6 Marie Curie developed the theory of radioactivity.



Figure 7 Henry Moseley's name is linked to significant advances in X-ray-related chemistry and physics, with many believing him worthy of a Nobel Prize.

1913

By the early 1900s, X-rays could be used to determine the atomic number of each element. Using this technology, Henry Moseley (Figure 7) refined the order of some of the elements in Mendeleev's periodic table and proposed a minor change to the periodic law: 'Elements have properties that recur or repeat according to their atomic number.'

1981

Gerd Binnig and Heinrich Rohrer invented the scanning tunnelling microscope. This microscope could see individual atoms.

1940

With the development of nuclear processes, elements heavier than uranium could be created. US scientist Glenn Seaborg, winner of the 1951 Nobel Prize in Chemistry, led a team of scientists who used a cyclotron to bombard uranium atoms with neutrons. This produced the very first atoms of neptunium and plutonium.



Figure 8 Atoms heavier than uranium are called the 'transuranium' or 'transuranic' elements. None of them occur naturally. The image shows a sample of neptunium.

element

a pure substance made up of only one type of atom (e.g. oxygen, carbon)

Today

Since the 1940s, similar nuclear processes have been used to synthesise the elements up to and including element 118. These elements are given temporary names until their discovery is confirmed. Element 118 had the temporary name ununoctium for 14 years before it was renamed oganesson in 2016.

Today

Mendeleev's periodic table

Dmitri Mendeleev is hailed as the creator of the modern periodic table. Building on the ideas of his contemporaries, Mendeleev, who lived in Russia, knew of 63 elements.

It is said that Mendeleev wrote the names and properties of each element on a small card, then arranged the cards in order of atomic weight. Mendeleev then noticed repeating patterns in the properties of the elements in front of him.

With this organisation complete, Mendeleev proposed the periodic law:

‘Elements have properties that recur or repeat according to their atomic weight.’

More importantly, Mendeleev’s organisation of cards identified ‘gaps’ that he attributed to elements that had yet to be discovered. Mendeleev predicted the properties of 21 unknown or undiscovered elements. When these elements were discovered, their properties were found to be very close to the properties that had been predicted by Mendeleev. This convinced many chemists of the accuracy and value of Mendeleev’s periodic table. Table 1 compares the properties of germanium with an element Mendeleev predicted called ekasilicon.

Mendeleev is often given sole credit for the development of the periodic table. This is because of the evidence he provided to support his table and because he assumed that there were missing elements; also, he accurately predicted the properties of these elements.

Table 1 Predicted properties of ekasilicon compared with the actual properties of germanium

Ekasilicon (symbol Es) as predicted in 1871	Germanium (symbol Ge) as discovered in 1886
Atomic mass: 72	Atomic mass: 72.6
Density: 5.50 g/mL	Density: 5.36 g/mL
Colour: grey metal	Colour: grey metal
Forms oxide EsO_2 ; density 4.70 g/mL, slightly basic	Forms oxide GeO_2 ; density 4.70 g/mL, slightly basic
Forms chloride EsCl_4 ; boiling point 100°C , density 1.90 g/mL	Forms chloride GeCl_4 ; boiling point 86°C , density 1.88 g/mL

4.1 Develop your abilities

Representing scientific ideas

When Mendeleev first published his version of the periodic table in 1869, he left many gaps in it for the elements that were yet to be discovered. As he could not determine the number of protons in an atom of each element, he arranged the atoms according to their atomic mass, how reactive they were (groups 1 and 17 are the most reactive), their ability to conduct electricity and other important properties.

- Evaluate** the effectiveness of two alternative versions of the periodic tables (shown in Figures 9 and 10) by:
 - > describing the information that can be obtained about hydrogen from the periodic table shown in Figure 9
 - > describing the information that can be obtained about hydrogen

from the periodic table shown in Figure 10. (HINT: Think about the shape of the diagram, and the size and location of hydrogen. Is it the same colour as other elements? What do you know about the elements around it?)

- > describing the information that can be obtained about hydrogen from the modern periodic table (see Figure 2 on page 87), which is based on Mendeleev’s periodic table
- > contrasting the periodic tables in Figures 9 and 10 with the modern periodic table
- > deciding which version of the periodic table is most appropriate to your chemical needs.

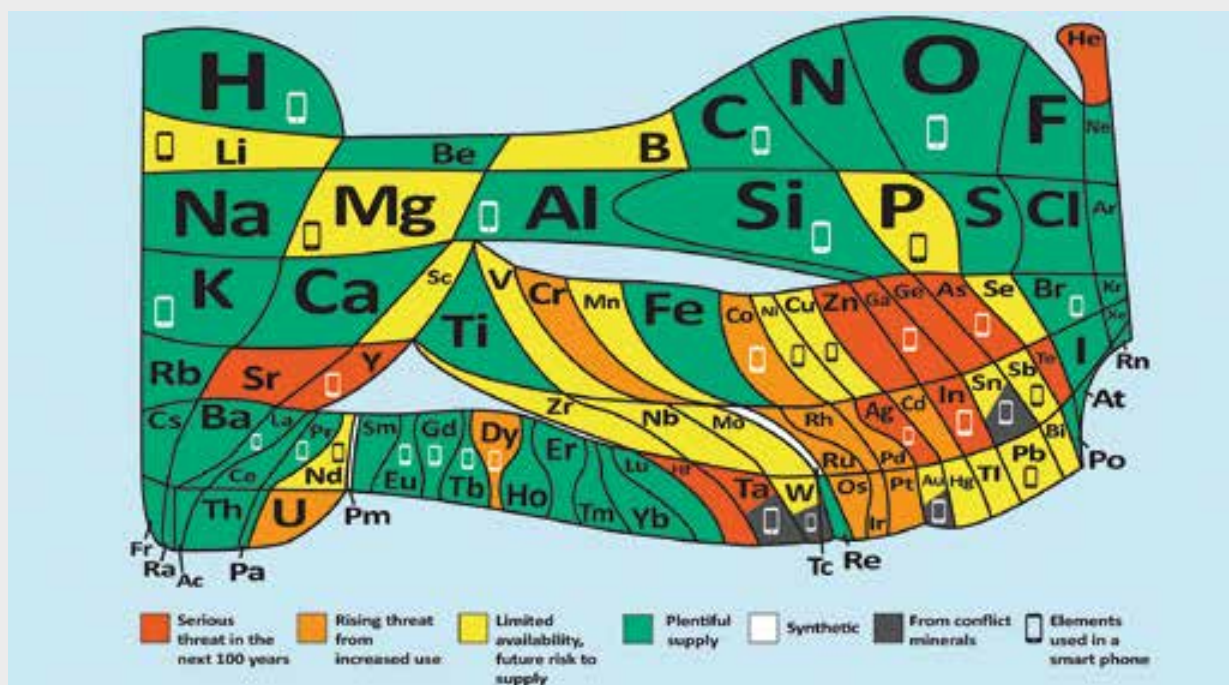


Figure 9 An alternative periodic table that identifies the amount of each element on Earth. European Chemical Society

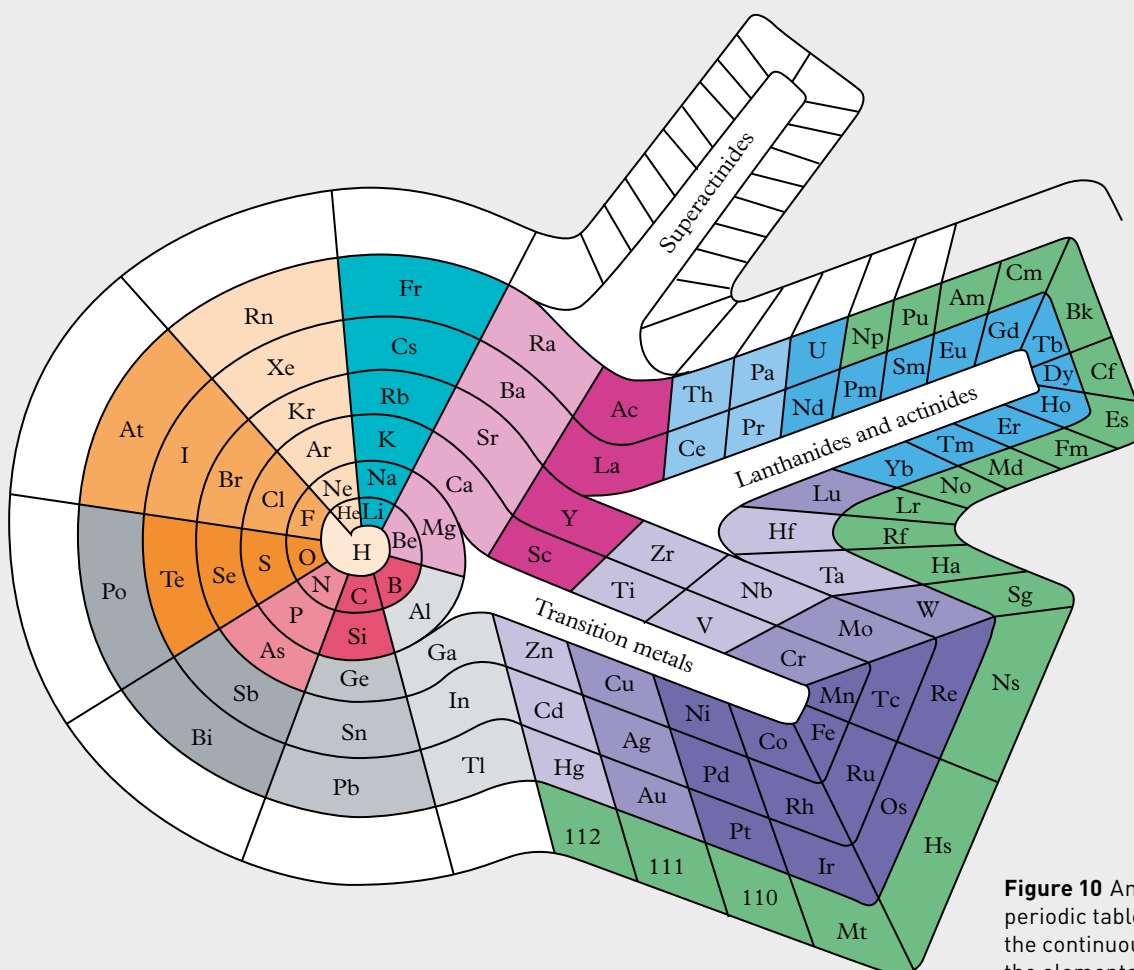


Figure 10 An alternative periodic table that identifies the continuous nature of the elements

4.2

The structure of an atom determines its properties

In this topic, you will learn that:

- the atomic number and name of an atom is determined by the number of protons it contains in its nucleus
- the mass number is the total number of protons (positive) and neutrons (neutral) in the nucleus
- 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 4.2
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

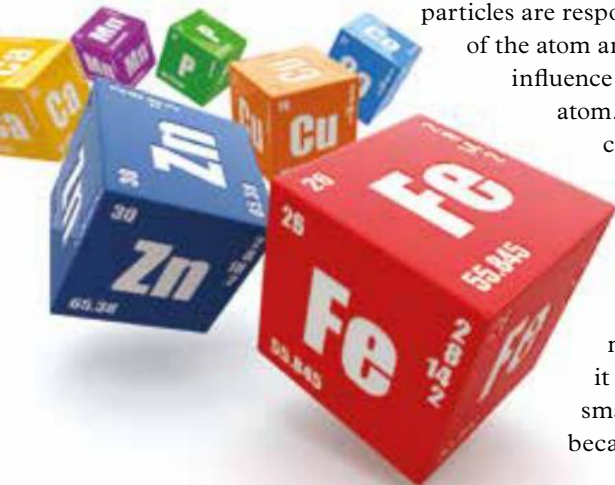
atomic number

the number of protons in an atom

Bohr model

a model of the atom in which electrons orbit the nucleus in a series of defined orbits known as shells

Figure 1 Elements from the periodic table



The periodic table

The periodic table organises elements (or types of atoms) in rows and columns (Figure 2). 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. These groups are similar to the triads described by Döbereiner.

The groups in the periodic table have been given numbers and sometimes names. For example, group 18 is named the ‘noble gases’. This makes communication easier, because the elements in each group 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 around

the nucleus, they affect the way the atoms bond with other atoms.

Electron configurations

The **Bohr model** of the atom can be used to consider how electrons are arranged in an atom. In this model, the electrons are arranged in shells around the nucleus. The electron shells are numbered from the nucleus outward, and the amount of space available limits the maximum number of electrons they can hold. Table 1 shows the maximum number of electrons that each shell can hold.

Table 1 The Bohr model of the atom

Shell number (from the nucleus outward) (<i>n</i>)	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.

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 $2 \times 3^2 = 18$.



Figure 3 Milk is a good source of calcium.

Worked example 4.2: 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 electronic 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.

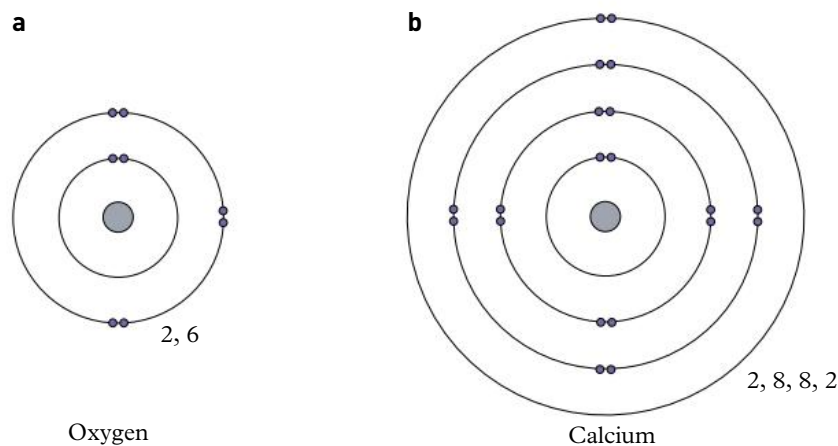


Figure 4 The electron configurations for oxygen and calcium are shown as simple shell diagrams.

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. The valence-shell electrons often interact with other atoms.

Emission spectra and electron shells

When atoms are heated in a flame, the electrons gain kinetic (heat) energy from the flame and become ‘excited’, jumping from their normal shell to a shell further out from

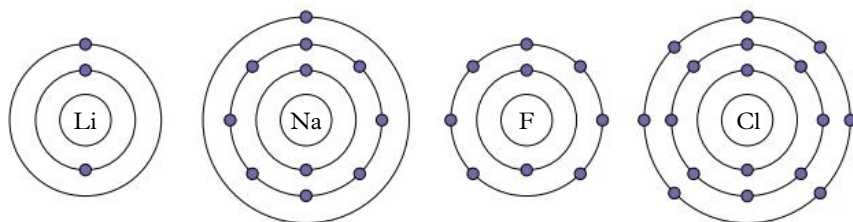


Figure 5 In group 1, the electronic configuration of lithium is 2, 1, whereas that of sodium is 2, 8, 1. The atoms of all other group 1 elements also have one electron in their outer valence shell of electrons. Elements in group 17 (e.g. fluorine and chlorine) have seven valence electrons.

the nucleus. From Year 9 you may remember that mass and energy cannot be created or destroyed, so when the electron moves back to its lower energy shell, the 'extra' energy is released in the form of light.

The energy gaps between electron shells vary from one atom to the next. For example, an electron dropping from shell 3 to shell 2 will release a different amount of energy to an electron dropping from shell 2 to shell 1. The

different amounts of light energy released can be seen as different frequencies or colours. Because each type of atom or element has a unique electron configuration, each element will release a unique emission spectrum of light colours. This generates a unique 'fingerprint' of different colour patterns. You might have seen the different-coloured flames when different elements were burned in an experiment in Year 9.

4.2 Check your learning

Remember and understand

- 1 **Describe** the valence shell of an atom.
- 2 **Contrast** (the difference between) a period and a group in the periodic table.
- 3 **Identify** the key feature of an atom that determines its atomic number. Use an example of two different elements to illustrate your answer.
- 4 For the Bohr model of the atom, **identify** the maximum number of electrons that the fourth electron shell can contain.

Apply and analyse

- 5 A potassium atom contains 19 protons.
 - a **Identify** the number of electrons that will be present in a potassium atom.

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. **Describe** how the electrons in a potassium atom could be moved into this shell.

- 6 Copy and complete Table 2.

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		

4.3

Groups in the periodic table have properties in common

In this topic, you will learn that:

- 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 valence 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

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)
- > hard
- > solid at room temperature (because they have a high melting and boiling point).

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 are unusual for metals because they have quite low melting

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

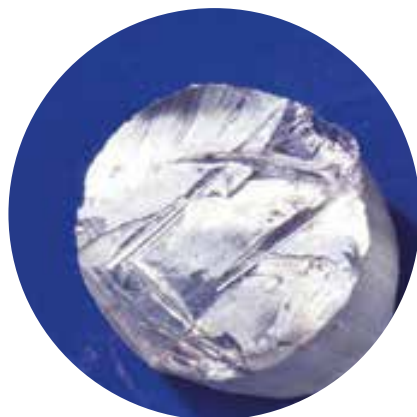


Figure 2 Freshly cut sodium, a group 1 metal



Figure 3 Potassium reacts spectacularly with water.

points and are soft and highly reactive. 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).



Figure 4 Magnesium, an alkaline earth metal, is very reactive when heated.

Transition metals

The **transition metals** are found in a large block of the periodic table that consists of the ten groups across the centre (groups 3–12). Some 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 .

Elements used in jewellery-making, such as platinum and gold, are transition metals.



Figure 5 Calcium is a soft grey metal; calcium carbonate is a white powder or stone.

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.

4.3 Check your learning

Remember and understand

- 1 **Identify** three properties common to metals.
- 2 **Calculate** the proportion of the periodic table that is composed of metals.
- 3 **Describe** the properties that are shared by all metallic elements.
- 4 **Identify** two properties shown by some transition metals that are not shown by group 1 or group 2 metals.

Apply and analyse

- 5 **Examine** the periodic table in Figure 2 (page 87).
 - 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.
- 6 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).

- 7 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.

Evaluate and create

- 8 **Propose** a way to represent the different groups of metals clearly and informatively, identifying the distinguishing properties of each group.

4.4

Non-metals have properties in common



Figure 1 Silicon and germanium are widely used in electronic devices because of their semiconductor properties – they conduct electricity in a very controlled way.

In this topic, you will learn that:

- 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

Metalloids are the small set of elements along the ‘staircase’ diagonal boundary between the metals and non-metals (Figure 2). 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. At room temperature, several non-metals are



Figure 3 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.

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

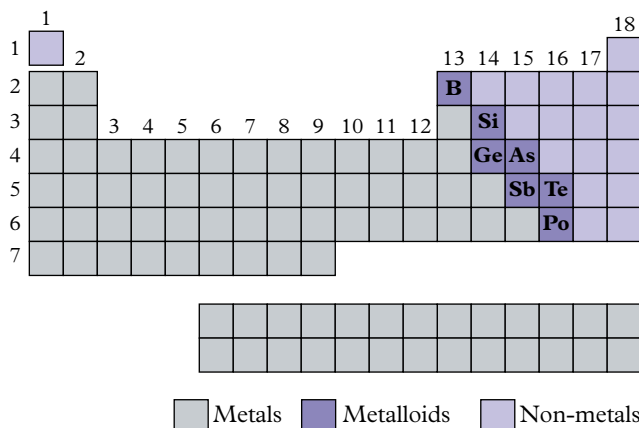


Figure 2 Regions of the periodic table

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 4).

As you go down the group, the melting points and boiling points of the halogens increase. At room temperature, fluorine and



Figure 4 Bleaches often contain halogens.

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. The noble gases are so called because they



Figure 5 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.

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 5).

noble gases
the stable gaseous elements in group 18 of the periodic table

4.4 Check your learning

Remember and understand

- 1 Explain** why non-metals are named according to what they are 'not' rather than what they have in common.
- 2 Define** the term 'semiconductor'.
- 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.
- 4 Identify** the dominant (most common) state of matter within the groups of non-metals.

- 5 Identify** the properties that metalloids share with metals.

Apply and analyse

- 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.

Evaluate and create

- 7 Explain** why the term 'metal-like' could be used to describe metalloid elements. **Create** a better name for this group of elements. **Explain** your answer.

4.5

Metal cations and non-metal anions combine to form ionic compounds

In this topic, you will learn that:

- metals form cations when they lose electrons to achieve a full, stable valence shell
- non-metals form anions when they gain electrons to achieve a full, stable valence shell
- polyatomic ions form when two or more atoms combine to form a charged ion
- positive cations are attracted to negative anions and form ionic compounds.

Forming ions

Electron shells are most stable when they have a full valence shell. All atoms can gain or lose valence electrons as required in an attempt to gain a full valence shell. In certain cases, electrons are shared between atoms to achieve a full valence shell.

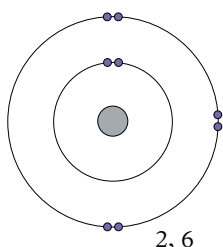


Figure 1 Oxygen tends to gain two electrons to fill its valence shell (from six to eight electrons). Overall, there will be two more negative charges than positive charges (from the protons in the nucleus), so the ion is written as O^{2-} .

The easiest way to achieve stability for atoms with only a few (1–3) valence electrons is to lose these electrons. For example, it is easier for an atom with two electrons in its outer shell to lose two electrons than to gain six electrons.

In contrast, if the valence shell is almost full (5–7 electrons), it is more likely that atom will gain an electron to fill the gap in the shell and become a stable atom with eight valence

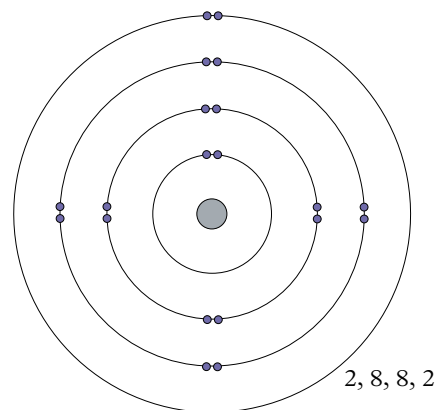


Figure 2 Calcium has two electrons in its valence shell, so it tends to lose them to achieve stability. The calcium ion formed is then written as Ca^{2+} to show that there are two extra protons compared with the number of electrons.

electrons. The number of positive protons does not change, even when the electrons move. Therefore, if an atom gains a negative electron, the overall charge of the atom becomes negative (more negative electrons than positive protons). If an atom loses electrons, then it becomes positively charged (more positive protons than negative electrons). In both these cases, the atom is then referred to as an **ion** – a charged atom. The charge number indicates how many electrons have been lost. A negative charge number indicates how many electrons have been gained. Worked example 4.5 shows how to calculate the charge of some atoms.

ion
an atom that is charged because it has an unequal number of electrons and protons

Worked example 4.5: 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. With more protons than electrons, the charge will be positive. Therefore, like all elements in group 1 the sodium ion has lost one electron and has 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. Like all elements in group 2, the oxygen ion has gained two extra electrons and has a charge of $2-$.



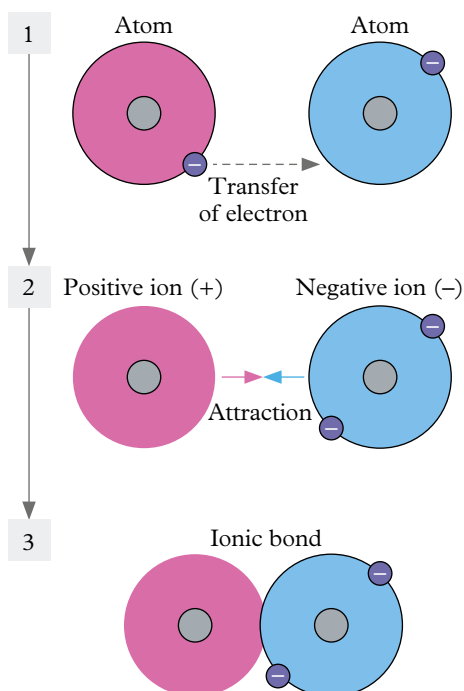
Figure 3 A plasma globe filled with a mixture of various noble gases

- c Atoms are always neutral. The neon atom is therefore neutral.

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 ions. Positively charged ions are called **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. Negatively charged ions are called **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**.



cation

a positively charged ion that results from an atom losing electrons

anion

a negatively charged ion formed when an atom gains electrons

ionic bond

a bond between a negatively charged anion and a positively charged cation

Figure 4 Ionic bonds form when a positive cation is attracted to a negative anion.

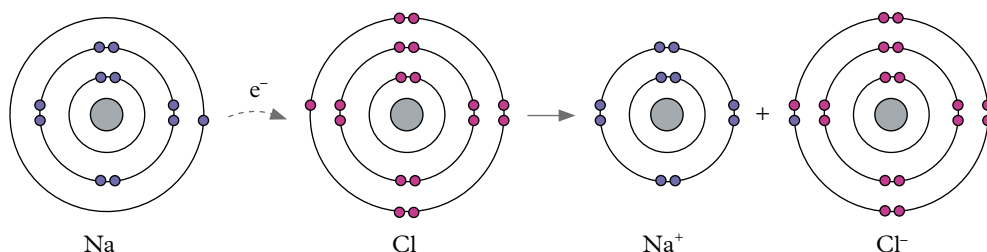


Figure 5 Sodium chloride is formed when sodium donates an electron to chlorine.

Properties of ionic compounds

ionic compound

a molecule made up of a negatively charged anion and a positively charged cation

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 6, 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.

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 .



Figure 7 Table salt is an example of an ionic compound.

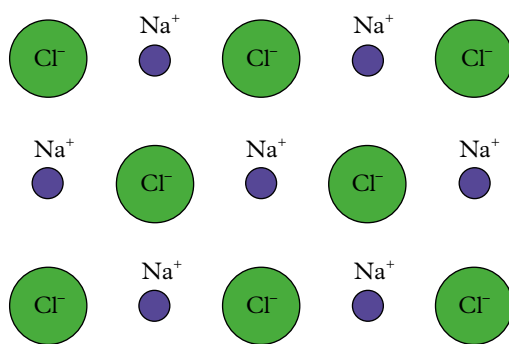


Figure 6 In an ionic compound, such as sodium chloride, the ions are arranged in alternating positions.

polyatomic ion

a charged ion that consists of two or more atoms bonded together

Polyatomic ions

A number of ions are made up of more than one atom. These are termed **polyatomic ions**. Figure 8 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 atoms (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 $1-$.

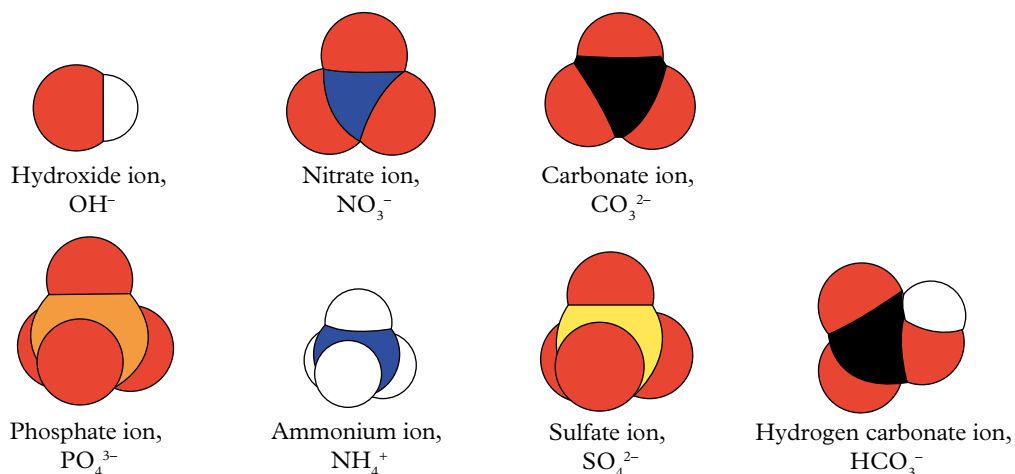


Figure 8 Some common polyatomic ions: the charge number indicates how many electrons have been lost. A negative charge number indicates how many electrons have been gained.

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 $(\text{NH}_4)_2\text{CO}_3$.

4.5 Check your learning

Remember and understand

- 1 **Define** the term ‘ionic compound’.
- 2 **Describe** what is meant by a ‘stable’ valence shell.
- 3 **Describe** why the group of an element can be used to quickly identify one or more of its properties.

Apply and analyse

- 4 Carefully **examine** the periodic table in Figure 2 (page 87).
 - 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.
- 5 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.
- 6 **Calculate** the ionic charges of the following:
 - a calcium cation
 - b chloride anion
 - c magnesium cation
 - d argon atom.
- 7 Use the information from Figure 8 and the text to **determine** the formula of the ionic compound that contains a phosphate ion and a potassium cation.
- 8 **Calculate** the maximum number of electrons that can be gained or lost by an 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).

4.6

Non-metals combine to form covalent compounds

In this topic, you will learn that:

- 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.



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.

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. For example, hydrogen can react with a reactive metal such as lithium. In this reaction, lithium loses an electron and donates it to the hydrogen, forming an ionic compound 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. A molecule has no

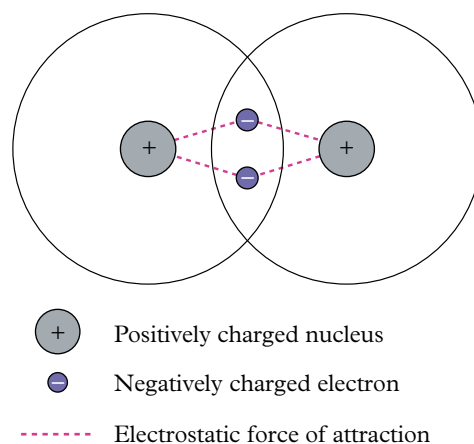


Figure 2 Some diagrams of molecules can show the electrons being shared between the atoms.

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.

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

Molecular compounds

Like elements, compounds also form molecules. 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.

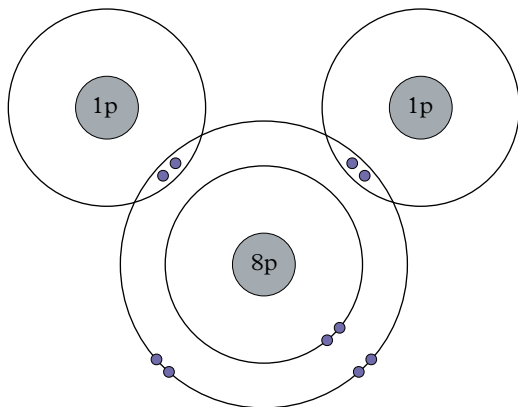


Figure 3 A shell diagram of a water molecule

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.



Figure 4 A 3D model is often used to show the arrangement of atoms in a molecule of water (H_2O).

molecular compound
a molecule that contains two or more different atoms bonded together

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 no strong 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.

4.6 Check your learning

Remember and understand

- 1 **Define** the term 'diatomic molecule'.
- 2 **Identify** the types of atoms (metals, non-metals) that form covalent bonds.
- 3 **Describe** a covalent bond.

Apply and analyse

- 4 **Explain** why molecular substances cannot conduct electricity.
- 5 In terms of the structure of the substance, **explain** why it is easier to turn liquid water into a gas than to break the covalent bonds between the hydrogen and oxygen atoms.
- 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 chloride molecules to the process of forming an oxygen molecule.
- 7 **Explain** why carbon dioxide has the formula CO_2 . (HINT: It has covalent bonding.)
- 8 **Compare** ionic bonding and covalent bonding.

4.7

Metals form unique bonds

In this topic, you will learn that:

- 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.

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 valence 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 valence-shell electrons in a metal as **delocalised electrons** because they are not 'stuck' to a particular atom. Note that only the valence-shell electrons in a metal are delocalised – all the other electrons orbit a particular atom. Metals are good electrical conductors because these delocalised valence-shell electrons are free to move through the structure of the metal.

delocalised electron
an electron in a molecule that can easily move between atoms

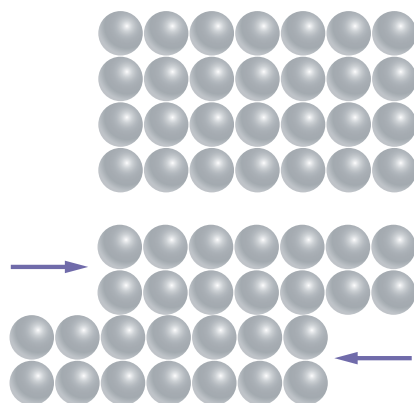


Figure 1 The arrangement of atoms in metals allows them to slide over each other when the metals are bent or hammered into shape.

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. In a molten liquid state, they continue to conduct electricity, but poorly compared to when solid. 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 ($\times 10^6 \text{ ohm}^{-1} \text{ cm}^{-1}$)
Aluminium	0.37
Silver	0.63
Carbon (graphite)	0.100
Copper	0.596
Gold	0.452
Iron	0.093
Lead	0.048
Magnesium	0.226
Sodium	0.210

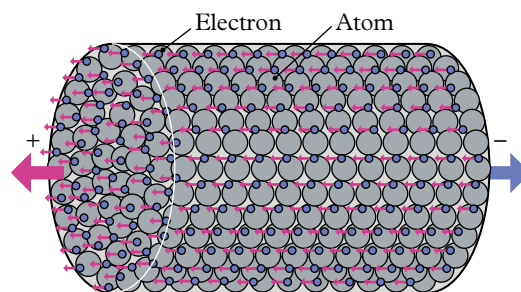


Figure 2 Delocalised electrons move about randomly in a metal, but they move towards the positive terminal of the power source when connected into a circuit.

Delocalised electrons are responsible for a pure metal being lustrous (shiny). The delocalised electrons in its surface reflect light extremely well (Figure 3).

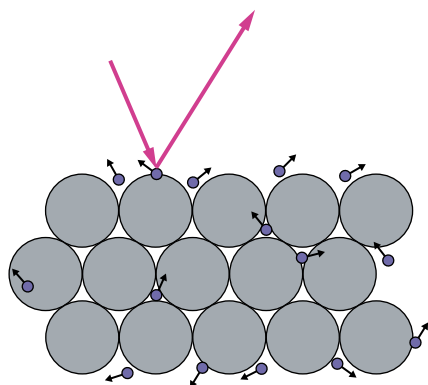


Figure 3 The delocalised electrons in the surface of a metal reflect light and cause it to be lustrous.

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.

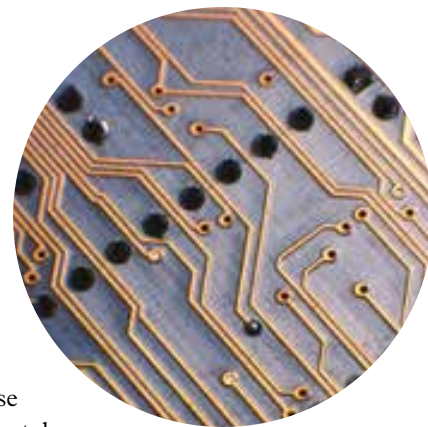


Figure 4 Gold bonding wire is used in integrated circuits.

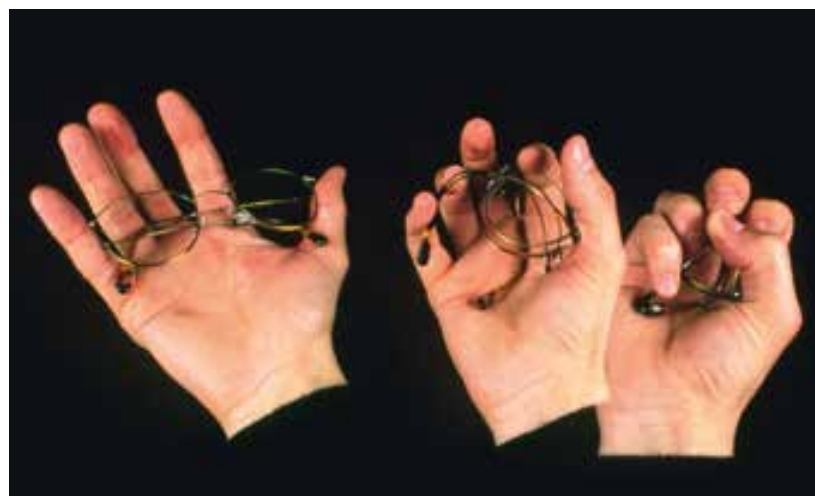


Figure 5 Memory wire is useful in eyeglass frames, allowing them to be bent out of shape without breaking.

4.7 Check your learning

Remember and understand

- Describe** the structure of a metal.
- Describe** what is meant by the phrase 'delocalised electrons'.
- Identify** the arrangement of atoms in a metal that enables each of the following properties.
 - malleability
 - conductivity
 - shiny appearance
- Define** an 'alloy'.

Apply and analyse

- Compare** the properties of an alloy with those of pure metal.

- Memory alloys have been used to repair broken bones. **Explain** why a memory alloy would be beneficial in this situation.

Evaluate and create

- 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).

4.8 Nanotechnology involves the specific arrangement of atoms

Atoms are approximately 0.3 nanometres (0.000 0003 mm) in diameter. Understanding the structure and properties of individual atoms allows scientists to control how these atoms are arranged.

nanotechnology
the manipulation
of individual atoms
to form structures

carbon nanotube
a very small tube of carbon
atoms, made synthetically

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 nitinol.

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.

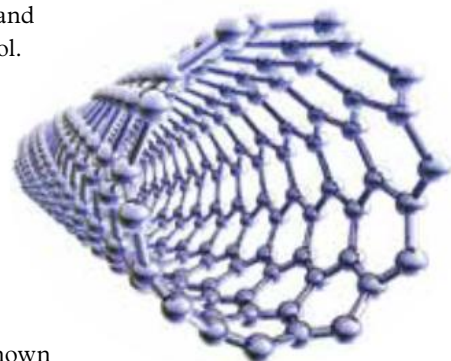


Figure 2 Nanotube technology is being investigated for a wide range of technological and medical uses.

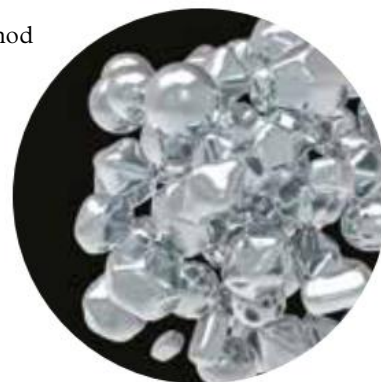


Figure 3 An illustration of zinc oxide nanoparticles

4.8 Develop your abilities

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** whether any experience in nanotechnology was needed to write the text. For example, are any technical terms used?

- 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.

REVIEW 4

Multiple choice questions

- 1 **Identify** the transition metal.
A caesium
B palladium
C fluorine
D radon
- 2 Rows of the periodic table are called:
A groups
B periods
C valences
D electron configurations.
- 3 Use the periodic table on page 87 to identify the correct statement about calcium.
A It is in period 2.
B It has an atomic number of 20 protons in its nucleus.
C Its electron configuration is 2, 8, 6, 2.
D It has six electron shells.

Short answer questions

Remember and understand

- 4 **Identify** the atomic number of the element known as Tennessine (Ts).
- 5 **Describe** the characteristic that determines the overall order of elements in the periodic table.
- 6 **Contrast** (the difference between) an atom and an element.
- 7 **Identify** 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
- 8 **Identify** the group number of the:
a alkaline earth elements
b halogens
c noble gases
d alkali metals.



Figure 1 Neon lights use neon, a noble gas.

- 9 **Define** the term 'valence shell'.
- 10 **Identify** the characteristics that elements in group 1 have in common.
- 11 **Describe** why transition metals are much more widely used than alkali metals.
- 12 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'.
- 13 **Describe** the key characteristic of metals that allows them to conduct electricity in the solid state.
- 14 **Explain** why elements in group 8 are more stable than elements in group 1.
- 15 When naming an ionic compound, **identify** which ion (anion or cation) is written first.
- 16 **Explain** each of the following.
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.

Apply and analyse

- 17 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.

- 18 **Consider** the following pairs of elements:
> chlorine and oxygen
> nitrogen and lithium
> fluorine and argon
> aluminium and potassium.
a **Identify** the pair(s) that will react to form an ionic compound.
b **Identify** the pair(s) that will react to form a molecular compound.
c **Identify** the pair(s) that will not react to form a compound.
In each case, **justify** your answer by contrasting the properties of the elements.

Evaluate

- 19 Scientists such as Berzelius and Mendeleev worked on their own to produce new ideas. Others, such as Seaborg, worked in a team. Now most scientists work in teams. **Describe** the advantages of working in a team.
- 20 Scientists deduce what it is like inside an atom from indirect evidence, similar to how astronomers determine the temperature and composition of stars. **Describe** 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. **Describe** a reason why the numbering system was changed.
- 23 A particle was found to contain 16 protons and 18 electrons.
- Identify** the element that makes up the particle. **Justify** your answer (by describing the key characteristic that you used to make your decision).
 - Identify** the charge of the particle. **Justify** your decision.
 - Identify** the symbol (including the charge) of the particle. **Justify** your answer.
- 24 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.

Social and ethical thinking

- 25 Lothar Meyer published a periodic table a few months after Mendeleev's periodic table.
- Explain** why Mendeleev receives the credit for this discovery.
 - In 1869 communication between scientists relied on letters that could take many months to travel to the scientific groups who published the findings. **Explain** how modern electronic communications create a fairer system than that of 1869 for awarding credit for scientific discoveries.

Critical and creative thinking

- 26 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.
- 27 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).

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.

» 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.

» 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 and how the use of these materials has improved the production method.

Reflect

The table below outlines a list of things you should be able to do by the end of Chapter 4 'The periodic table'. Once you've completed the chapter, use the table to reflect on your ability to complete each task.

	I can do this.	I cannot do this yet.
Track the development of atomic theory over time. Name the main developers who contributed to the periodic table and state what their major discoveries were.	☐	☐ Go back to Topic 4.1 'Science as a human endeavour: Scientists refine models and theories over time' Page 82
Understand the difference between periods and groups. Describe the importance of atomic number in determining the number of electrons. Describe the relationship between valence electrons and element properties.	☐	☐ Go back to Topic 4.2 'The structure of an atom determines its properties' Page 86
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 4.3 'Groups in the periodic table have properties in common' Page 90
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 4.4 'Non-metals have properties in common' Page 92
Explain ionic compounds using the terminology anion and cation. Explain the properties of ionic compounds. Draw the electron transfer between atoms and the resultant ions.	☐	☐ Go back to Topic 4.5 'Metal cations and non-metal anions combine to form ionic compounds' Page 94
Define what a covalent compound is and 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 4.6 'Non-metals combine to form covalent compounds' Page 98
Describe the structure of metallic bonding as a grid of cations in a sea of delocalised electrons. Compare metallic compounds to alloys and contrast the differences between them.	☐	☐ Go back to Topic 4.7 'Metals form unique bonds' Page 100
Define what nanotechnology is. Convert between length measurements of nanometres to more common units (e.g. cm). Provide examples of the uses of nanotechnology in society.	☐	☐ Go back to Topic 4.8 'Science as a human endeavour: Nanotechnology involves the specific arrangement of atoms' Page 102

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Why do some chemicals react?

5.1

Mass is conserved in a chemical reaction



5.2

Balanced chemical equations show the rearrangement of atoms

5.3

Synthesis and decomposition reactions can be represented by equations

5.4

Acid reactions depend on strength and concentration

5.5

The solubility rules predict the formation of precipitates



5.6

Combustion reactions between hydrocarbons and oxygen produce carbon dioxide, water and energy

5.7

Polymers are long chains of monomers

5.8

Temperature, concentration, surface area and stirring affect reaction rate

5.9

Catalysts increase the rate of a reaction

5.10

Science as a human endeavour: Green chemistry reduces the impact of chemicals on the environment

CHAPTER

5

CHEMICAL REACTIONS

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?

5.1

Mass is conserved in a chemical reaction

In this topic, you will learn that:

- in chemical equations, the starting chemicals (reactants) are shown on the left-hand side of the arrow
- in chemical reactions, the final chemicals (products) are shown on the right-hand side of the arrow
- the law of conservation of mass states that the total mass of the products is equal to the total mass of the reactants.

Representing chemical reactions

During a chemical reaction, one or more substances are transformed into different substances. The substances that are present at the start of a chemical reaction are called the **reactants**. The substances formed by the chemical reaction are called the **products**. We can write this by using a simple word equation.

Consider the reaction between the acid in vinegar and sodium bicarbonate. This reaction produces water, carbon dioxide gas and a substance called sodium acetate. It can be represented as:

acetic acid (in vinegar) + sodium bicarbonate
→ sodium acetate + carbon dioxide + water

The acetic acid and sodium bicarbonate are the starting chemicals (reactants) for this reaction. The products are the chemicals formed by the reaction. In this reaction they are sodium acetate, carbon dioxide and water.

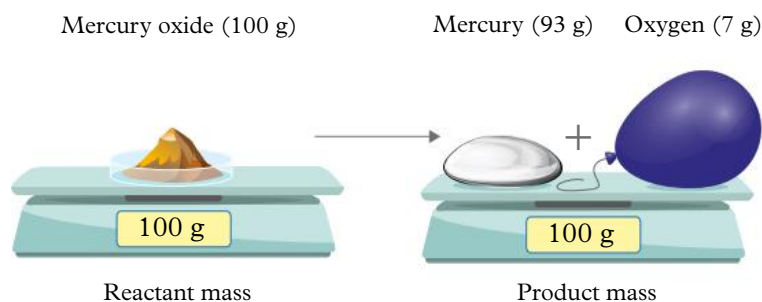


Figure 1 When mercury oxide (HgO) is heated, its atoms rearrange to form mercury liquid (Hg) and oxygen gas (O_2). The overall mass of the reactants and products is the same – no atoms are destroyed, and no new atoms are created.

The law of conservation of mass

If you do Experiment 5.1, you will find that when the products of a chemical reaction are not allowed to escape, the mass or quantity of elements present after the reaction is the same as the mass of the products at the start of the reaction. This is a very important observation. It shows that the total mass of the chemicals is not changed in a chemical reaction.

When a chemical reaction takes place, the chemicals interact, causing the atoms to break apart from each other before forming into new arrangements. However, no atoms are produced in the process and no atoms are destroyed. This is one of the most important laws in science: the law of conservation of mass.



Figure 2 Methane gas burning on a stove

Example of a chemical reaction

Methane gas (CH_4) is the main gas present in natural gas, which is used in the home for cooking and heating. When it burns, it combines with oxygen (O_2) in the air to form carbon dioxide (CO_2) and water (H_2O).

Figure 3 shows what happens to the atoms during this reaction. Different atoms are represented by different colours.

- 1 Count the number of each type of atom in the reactants (left-hand side of the arrow) and count the number of each type of atom in the products (right-hand side of the arrow). What do you notice?
- 2 Describe what has happened to the hydrogen atoms during the chemical reaction.
- 3 Describe what has happened to the oxygen atoms. Make sure you use the correct names of the chemicals in your description.

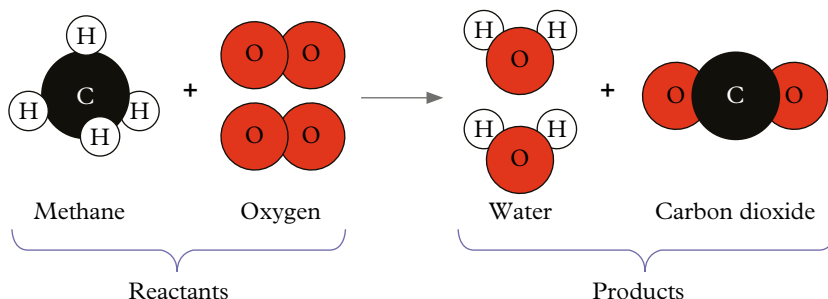


Figure 3 Atoms are rearranged during a chemical reaction.

Table 1 Representations of four chemicals

Chemical name	Formula/symbol	Diagram
Methane	CH_4	
Oxygen	O_2	
Water	H_2O	
Carbon dioxide	CO_2	

5.1 Check your learning

Remember and understand

- 1 **Define** the term 'mass'.
- 2 Use Table 1 to **identify**:
 - a an element composed of molecules
 - a compound composed of molecules.
- 3 If no mass is lost or gained in a chemical reaction, **describe** what this tells you about the individual atoms involved in the reaction.

Apply and analyse

- 4 **Explain** why the products have properties very different from those of the reactants, even though the total mass remains the same.
- 5 Early alchemists repeatedly tried to turn lead into gold. **Explain**, using the law of conservation of mass, why this would be impossible.

- 6 Write the word equation for the following reaction (by **identifying** the reactants and products).
Magnesium ribbon was burnt in the presence of oxygen to produce magnesium oxide.

Evaluate and create

- 7 **Evaluate** each of the following equations to determine whether they obey the law of conservation of mass (by comparing the number and types of atoms in the reactants to the number and types of atoms in the products, and deciding whether the atoms are conserved).
 - a $\text{C} + \text{O}_2 \rightarrow \text{CO}_2$
 - b $\text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O}$

5.2

Balanced chemical equations show the rearrangement of atoms

In this topic, you will learn that:

- chemical reactions can be described through observations, word equations or symbols
- the law of conservation of mass is used to write a balanced chemical equation
- a balanced chemical equation has equal numbers of each type of atom on both sides of the equation.



Figure 1 Sodium metal reacts violently with water, undergoing a chemical change.

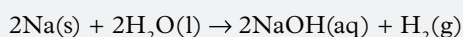
Describing chemical reactions

Perhaps you have seen sodium metal reacting with water at school or on the internet. There are different ways to describe this reaction.

- > *Describing observed changes:* The sodium metal dissolves in the water; heat is produced; fizzing is caused by the production of hydrogen gas. If there is enough heat, the hydrogen gas catches fire above the sodium metal.
- > *Using a word equation:* The reactants are sodium and water. These interact to form the products, sodium hydroxide and hydrogen gas. A word equation summarises the changes:

sodium + water →
sodium hydroxide + hydrogen

- > *Using a chemical equation:* This includes the formulas of all the substances involved and the ratio in which they react:



Each representation tells us something different about the changes occurring in the chemical reaction.

Table 1 States and their symbols

State	Symbol
Gas	(g)
Liquid	(l)
Solid	(s)
Aqueous (dissolved in water)	(aq)

Reacting hydrogen and oxygen

When hydrogen gas burns in oxygen, large amounts of heat energy are produced. If this reaction happens in uncontrolled conditions, it is very dangerous. However, when used safely in a carefully controlled way, hydrogen can be an excellent renewable fuel that doesn't emit carbon dioxide. Car manufacturers are already developing hydrogen-fuelled cars. An advantage of using hydrogen as a fuel is that the only substance emitted in the exhaust is water vapour – there are no carbon dioxide emissions. Also, unlike fully electric cars, hydrogen cars don't need enormous, heavy batteries.

When hydrogen combusts with oxygen in the air, the oxygen atoms and hydrogen atoms split up from each other and join to form molecules of water (H₂O). The atoms have not been created or destroyed. You can show what is happening by using a diagram or a chemical equation.

Balancing chemical equations can require a systematic approach where each atom is counted on both sides of the equation. Changing the number of one group of molecules (by changing the larger coefficients and not the subscripts) may affect a number of other atoms. It is important to continue to check and change the coefficients until all atoms are accounted for and balanced on both sides of the equation. Worked example 5.2 illustrates how to write a balanced chemical equation.



Figure 2 The reaction of hydrogen with oxygen caused the Hindenburg explosion.

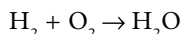
Worked example 5.2: Writing balanced chemical equations

Write the chemical equation for the following reaction: Hydrogen combines with oxygen to produce water.

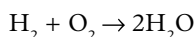
Solution

The equation can be written by using the following steps.

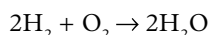
- 1 Write out the word equation for the reaction: hydrogen + oxygen → water
- 2 Write a simplified chemical equation using the formulas of each molecule involved. Identify the number of atoms in each molecule. If more than one, write the number as a subscript (a small number at the bottom right side of the symbol). For example, water is H_2O (two hydrogen atoms with a single oxygen atom), and hydrogen and oxygen each exist as a pair of atoms.



- 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 2.
- 4 Compare the number of each type of atom in the reactants with the number in the product. In this case, there are four atoms in the reactants and three atoms in the product. 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 another water molecule to the product – shown by adding a number (called a coefficient) to the formula. This balances the number of oxygen atoms but also doubles the number of hydrogen atoms (Table 3).



The unbalanced hydrogen atoms can be balanced by doubling the number of hydrogen molecules (Table 4).



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 (Table 1).

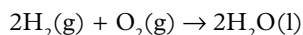


Table 2 Number of each type of atom in the reactants and products

	Reactants	→	Products	
Type of atom:	H	0	H	0
Number of atoms:	2	2	2	1

Table 3 The number of oxygen atoms is balanced

	Reactants	→	Products	
Type of atom:	H	0	H	0
Number of atoms:	2	2	4	2

Table 4 Check the equation is balanced

	Reactants	→	Products	
Type of atom:	H	0	H	0
Number of atoms:	4	2	4	2

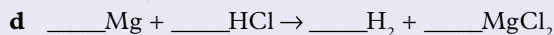
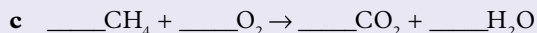
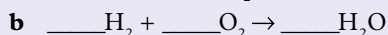
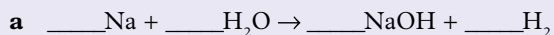
5.2 Check your learning**Remember and understand**

- 1 **Identify** a way of describing a chemical reaction that explains what is happening to the atoms. **Justify** your answer (by identifying each way of describing a chemical reaction and describing the information provided by each approach).
- 2 **Identify** which representation of a chemical reaction tells us most about the chemicals. **Justify** your answer.

Apply and analyse

- 3 **Identify** what the '(s)', '(l)', '(g)' and '(aq)' symbols represent in the chemical equation for the reaction of sodium metal with water.
- 4 **Explain** why chemical reactions that are not 'balanced' are always incorrect.

- 5 Balance the following equations by adding numbers as required:

**Evaluate and create**

- 6 Imagine one of your classmates missed this class and asked for your help to understand how to balance a chemical equation. **Describe** how you would explain it to them. **Create** a set of instructions using any medium you think would be most useful (e.g. a written list, an illustrated poster, a presentation etc.).

5.3

Synthesis and decomposition reactions can be represented by equations

In this topic, you will learn that:

- synthesis reactions combine multiple reactants to form a new compound
- decomposition reactions break down a reactant into multiple products.

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.

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.

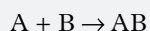
Similarly, the chemical reactions that are used to make compounds can also be classified. Classifying reactions into different types helps us predict what products will be produced. Reactions can be classified as synthesis, decomposition, combustion or hydrolysis (reaction with water) reactions, among others.

Synthesis reactions

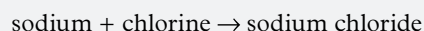
synthesis

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:



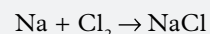
This equation is a general equation and it helps you determine what will be produced in a synthesis reaction. In synthesis reactions, the two reactants combine to form a new product. For example:



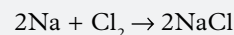
Writing chemical equations

Once you have predicted the product that will be formed and written the word equation, you can write the chemical equation.

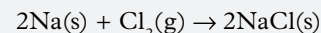
- 1 Write the chemical formula for each of the molecules. Are they ionic compounds or covalent compounds? Use subscript numbers to indicate the number of each type of atom in the molecule:



- 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:



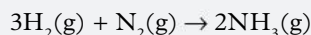
- 3 Determine whether the reactants and products are solids (s), liquids (l), gases (g) or aqueous solutions (a soluble solution mixed with water) (aq):



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:

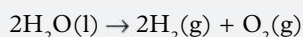


Nitrogen is not a very reactive element so the reactants must be heated under very high pressure to make the reaction happen.

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:



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:



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

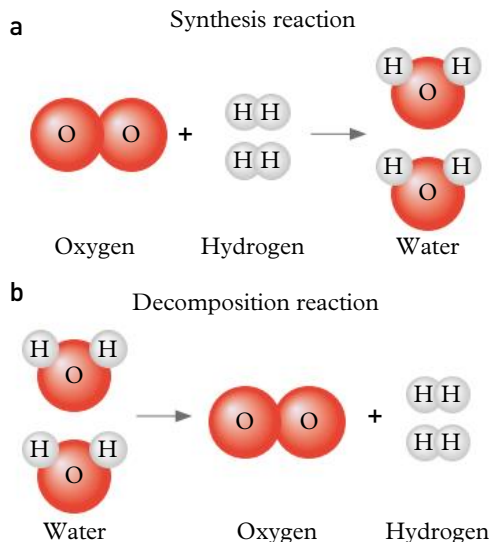
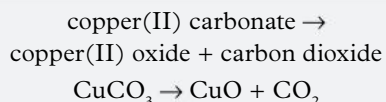


Figure 1 a Synthesis reactions combine the reactants to make a more complex product. **b** Decomposition reactions break the chemical bonds in the reactants to form simpler substances.

decomposition

a reaction that involves the breakdown of a compound into simpler substances

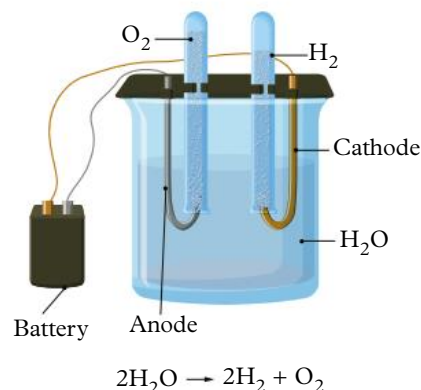
building materials, such as mortar. Calcium oxide is produced by the thermal decomposition of calcium carbonate (CaCO_3):



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.

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.



5.3 Check your learning

Remember and understand

- Describe** the law of conservation of mass.
- Explain** why decomposition reactions always produce more than one product.
- Explain** why synthesis reactions are sometimes called combination reactions.

Apply and analyse

- Contrast** the reaction used to produce ammonia and the reaction used to produce calcium oxide, in terms of the types of chemical reactions.

- Explain** why energy is required in:

- decomposition reactions
- direct synthesis reactions.

- Predict** the products of the following synthesis reactions, and write a balanced chemical equation for each one.

- calcium and oxygen
- hydrogen and chlorine

5.4

Acid reactions depend on strength and concentration

In this topic, you will learn that:

- acids have a pH less than 7, and bases have a pH greater than 7
- 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.

Acids

Acids are a group of chemicals with similar properties. 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.

neutralisation

a reaction in which an acid and a base combine to produce a metal salt and water



Figure 2 Zinc metal reacting with acid

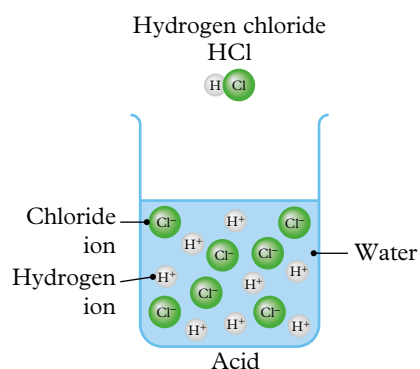


Figure 1 When acids dissolve in water, they form ions.

Bases

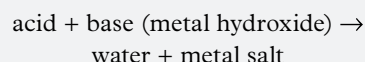
A base is defined as a substance that gains a hydrogen ion. All bases have a bitter taste, turn litmus paper blue, feel slippery and have a pH of greater than 7. Bases that dissolve in water are called alkalis. Like acids, some bases

are more reactive than others. Some, such as caustic soda (NaOH), can burn the skin.

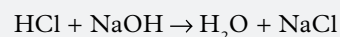
Neutralisation reactions

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:

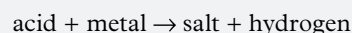


For example:

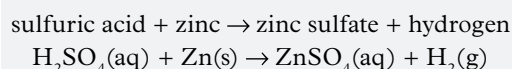


Acid and metal reactions

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:



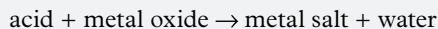
For example:



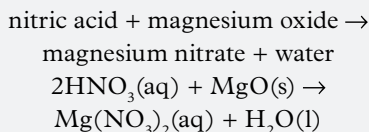
Note: Only the more reactive metals will form a metal salt and hydrogen when reacting with acids. Copper, silver and gold are less reactive metals.

Acids and metal oxides

An acid and a metal oxide react to form a metal salt and water:

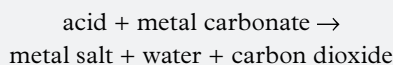


For example:

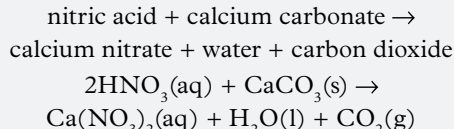


Acids and metal carbonates

An acid and a metal carbonate react to form a metal salt, water and carbon dioxide:



For example, acid rain can affect the calcium carbonate that makes up marble.



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

5.4 Check your learning

Remember and understand

- Identify** what must be reacted with an acid to produce:
 - hydrogen gas
 - carbon dioxide.
- Identify** the name of the reaction of an acid with a base. **Explain** why it is given this name.

Apply and analyse

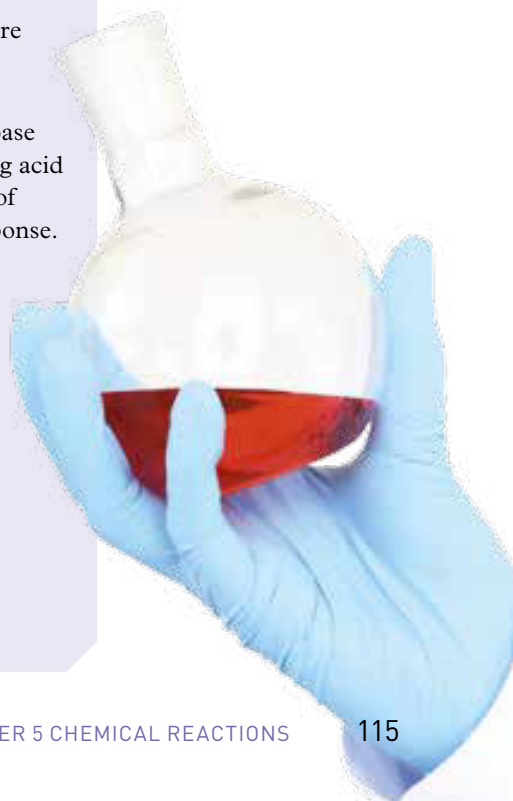
- Write chemical equations for:
 - dilute nitric acid (HNO_3) reacting with magnesium metal
 - dilute ethanoic acid (CH_3COOH) reacting with solid potassium carbonate (K_2CO_3)
 - dilute hydrochloric acid (HCl) reacting with calcium hydroxide ($\text{Ca}(\text{OH})_2$) solution.

- Explain** why it is unsuitable to store acids in metal containers.
- 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.
- Contrast** the terms ‘concentrated’ and ‘strong’. **Explain** whether a solution can be both concentrated and strong.

Evaluate and create

- Create** a diagram of acid and base molecules before and after a neutralisation reaction.

Figure 3 When working with chemicals, it is important to wear safety gloves.



5.5

The solubility rules predict the formation of precipitates

In this topic, you will learn that:

- 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.

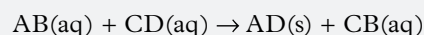
precipitate

a solid, insoluble compound formed in a precipitation reaction

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:



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.

double displacement reaction

when two reactants exchange ions to form new products during a chemical reaction

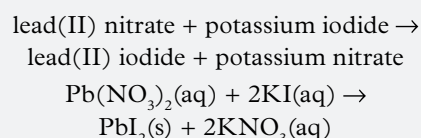
precipitation reaction

a reaction used to produce solid products from solutions of ionic substances

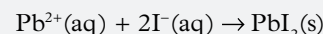
spectator ion

an ion that does not take part in a chemical reaction

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:



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:



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.

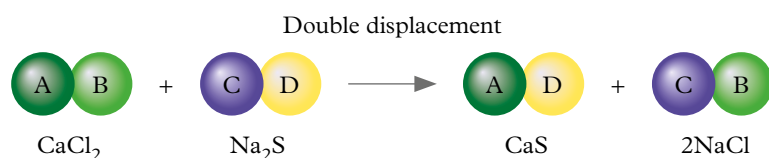


Figure 1 A double displacement reaction involves chemical compounds exchanging ions to form new compounds.

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 , $CaSO_4$

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 $\text{Cu}(\text{OH})_2$ 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 $\text{Cu}(\text{OH})_2$ 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:

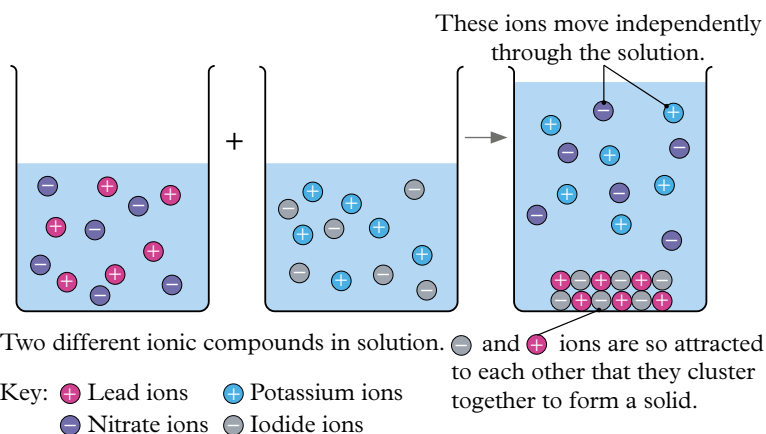
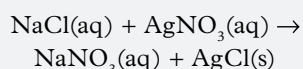


Figure 2 At the particle level, when a solution of lead(II) nitrate ($\text{Pb}(\text{NO}_3)_2$) is added to potassium iodide (KI), the ion partners are swapped.



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.

5.5 Check your learning

Remember and understand

- 1 Draw a diagram to show which particles are present in a beaker containing a sodium chloride solution.
- 2 **Identify** the symbol that is used to show the state of an insoluble compound.

Apply and analyse

- 3 Use the solubility rules to **determine** 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

- 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 write balanced chemical equations for each reaction.
 - a zinc nitrate + potassium hydroxide $\rightarrow$
 - b calcium nitrate + sodium carbonate $\rightarrow$



Figure 4 Yellow lead(II) iodide forming in a precipitation reaction

5.6

Combustion reactions between hydrocarbons and oxygen produce carbon dioxide, water and energy

In this topic, you will learn that:

- 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

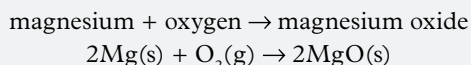
When molecules react with oxygen, it is called oxidation.

When metals react with oxygen, a basic metal oxide is formed:



As the metal has formed a compound, this is also classified as a corrosion reaction. The metal oxide produced is an ionic compound.

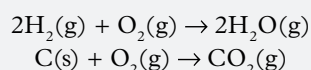
In the case of very reactive metals, this oxidation is highly exothermic (it releases energy) and rapid. For example:



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:

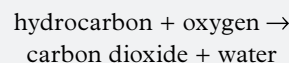


Both of these reactions are highly exothermic. The first reaction can cause explosions. (This is the reaction that causes the 'pop' in the pop test for hydrogen.) Carbon is the principle constituent of coal. Both reactions produce a flame and so are classified as reactions.

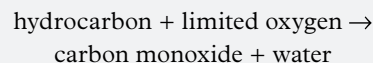
Combustion reactions require oxygen and a fuel. A fuel is a substance that will undergo a chemical reaction in which a large amount of useful energy is produced at a fast but controllable rate. According to this definition, fuels are the substances we use to produce heat and/or electricity, and to run engines and motors.

Combustion of hydrocarbons

The most common fuels we use for combustion are compounds of carbon and hydrogen (known as **hydrocarbons**). When pure hydrocarbons burn in unlimited oxygen, carbon dioxide and water are produced:



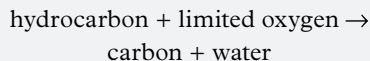
When there is less oxygen available, carbon monoxide forms:



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:



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}), diesel is a mixture with the average formula $\text{C}_{12}\text{H}_{23}$, natural gas is mainly CH_4 , and liquefied petroleum gas (LPG) is propane (C_3H_8).

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

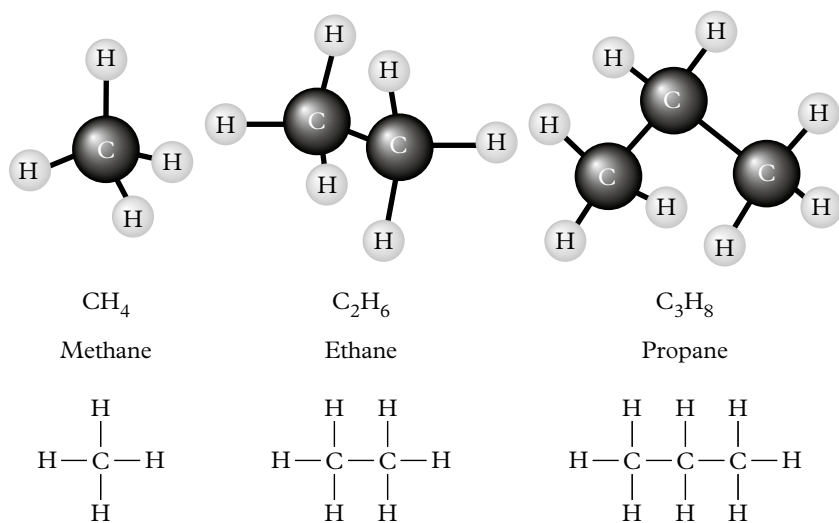


Figure 3 Hydrocarbons are compounds containing only carbon and hydrogen molecules.

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.

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.

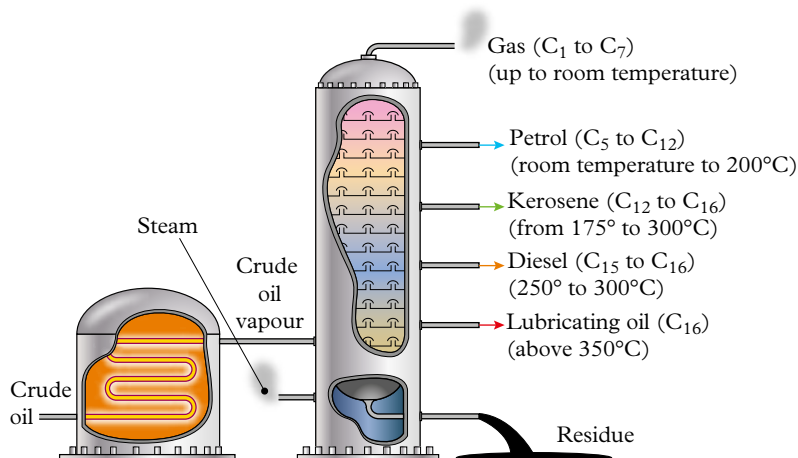


Figure 4 As the crude oil is slowly heated, vapour (gas) forms. As the vapour rises, it cools. When the vapour reaches the height where the temperature is equal to the fraction's boiling point, it condenses into a liquid.

5.6 Check your learning

Remember and understand

- Define** the term 'oxidation reaction'.
- Explain** why carbon fuels are so important to our society.
- Explain** why the amount of oxygen available can affect the products formed in the combustion process.
- Identify** which group of elements do not react with oxygen.
- Explain** why it is important to burn hydrocarbons in a well-ventilated area.

Apply and analyse

- Identify** an example of a substance that might be considered a fuel by a:
 - firefighter
 - chemist.
- Write a balanced equation for the combustion of each of the following hydrocarbons in excess oxygen.
 - petrol
 - LPG
 - natural gas
 - diesel
- Identify** which fuel in question 7 requires the most oxygen to burn cleanly.

5.7

Polymers are long chains of monomers

In this topic, you will learn that:

- polymerisation is the process of forming a long-chain polymer from smaller monomer molecules.

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

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.

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.



Figure 1 The basic structure of a linear polymer. The small circles represent small groups of atoms.

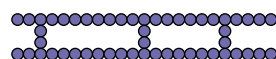


Figure 2 The basic structure of an elastomer

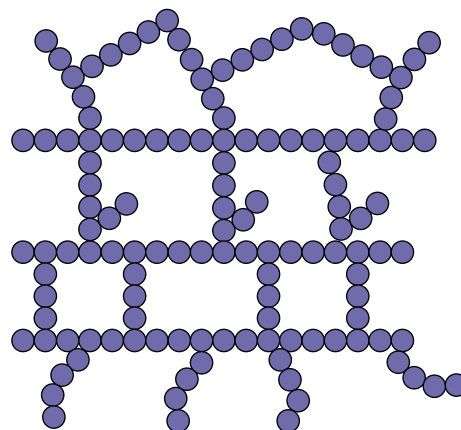


Figure 3 A cross-linked polymer

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.

Most 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

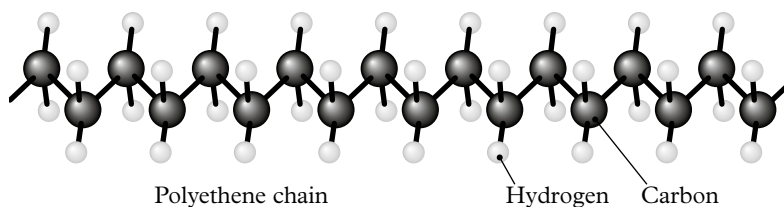
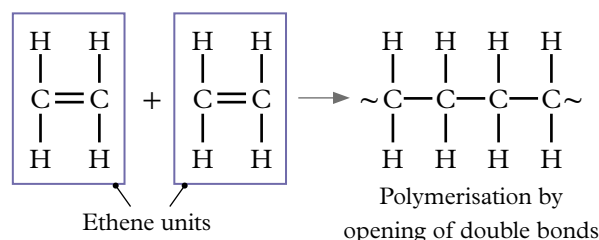


Figure 5 The formation of polyethene from ethene molecules

5.7 Check your learning

Remember and understand

- 1 **Identify** the monomer unit of polyethene.
- 2 Use the structure of elastomers to **explain** their properties.

Apply and analyse

- 3 **Contrast** a linear polymer and a cross-linked polymer.
- 4 For each of the following applications, **state** 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

- 5 **Identify** the plastic you would expect to be a thermosetting polymer: a linear polymer or a cross-linked polymer. **Justify** your response.

Evaluate and create

- 6 **Discuss** the decision to use thermoplastic paint for painting markings on roads, instead of other types of paint.

polymerisation

the process of joining smaller units (monomers) to form a long-chain molecule (polymer)

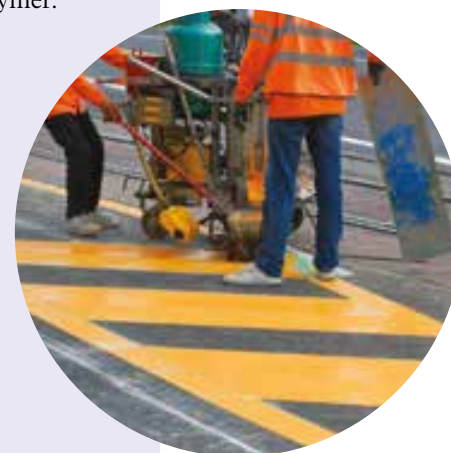


Figure 6 Thermoplastic paint is used to mark roads.

5.8

Temperature, concentration, surface area and stirring affect reaction rate

In this topic, you will learn that:

- 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 temperature, concentration or surface area, or by stirring the reactants.

reaction rate
how fast or slow a reaction proceeds

Why reaction rates are important

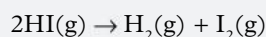
A **reaction rate** is how fast a reaction proceeds. It is important to realise that this does not mean more products are formed in the reaction. This can be illustrated by a 100 m race. A runner can run fast or slow; the only difference is how quickly the runner finishes the 100 m. A fast reaction has 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:



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.

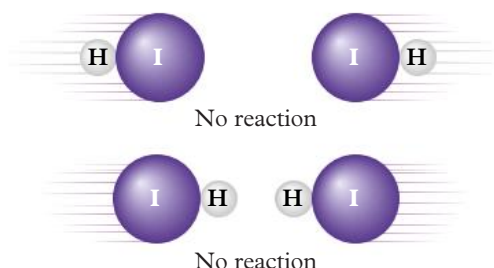
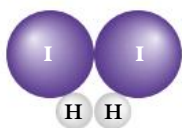


Figure 1 If collisions between HI molecules are unsuccessful, the HI molecules do not react with each other.

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.



H_2I_2 is an intermediate complex.

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 large-sized bits of material. The surface area is not the size of the pieces but the total area exposed to possible collisions (Figure 5).

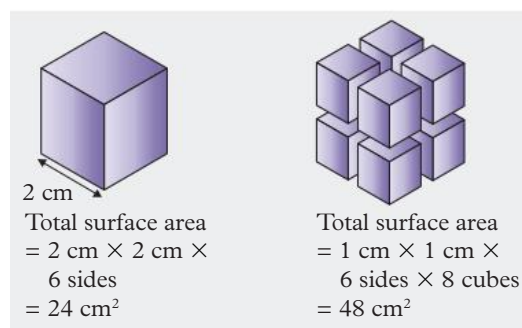


Figure 5 The total surface area of many small particles is larger than that of a single large particle of the same volume.

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.

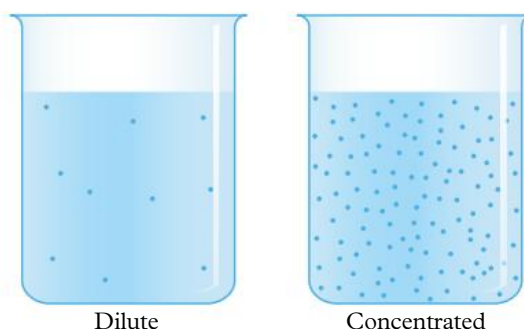


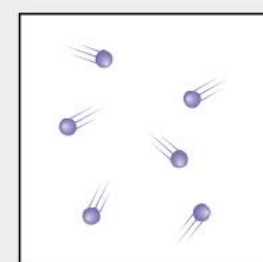
Figure 6 A concentrated solution contains more dissolved particles than a dilute solution.

Increase the temperature

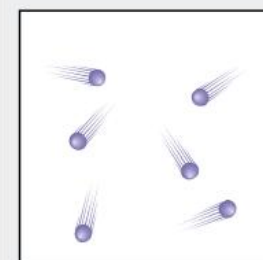
Particles in a hot substance have more kinetic energy than particles in a cold substance. This means that the particles in a hot substance vibrate faster than the particles in a cold substance (Figure 7).

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.



Cold substance (particles have low kinetic energy)



Hot substance (particles have high kinetic energy)



Step aside. I have more kinetic energy than you.

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.

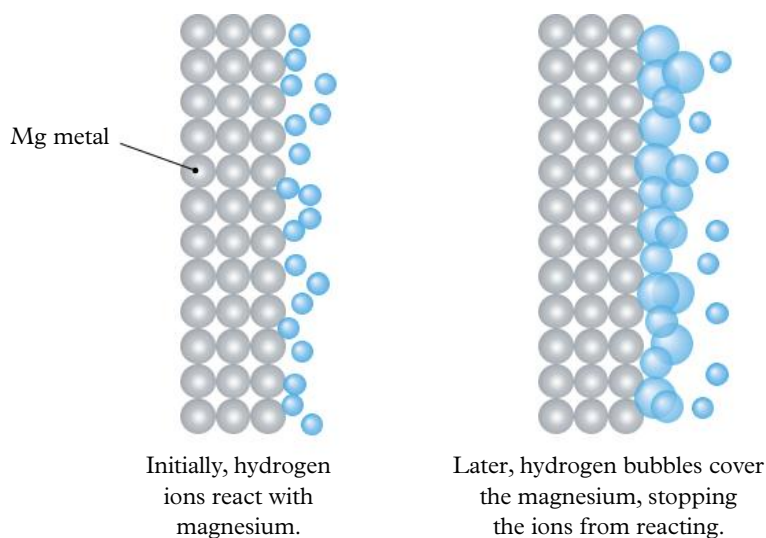


Figure 8 Sometimes the presence of the product can slow down a chemical reaction.

Case study 5.8: Detoxifying cycad plants

Aboriginal 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.

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 Aboriginal 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 Australian Aboriginal 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.

Figure 9 Cycad seeds must be detoxified before they can be safely consumed.



5.8 Check your learning

Remember and understand

- 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 the reactants are heated.

Apply and analyse

- 6 **Consider** Case study 5.8: Detoxifying cycad plants.
 - 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.
- 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.

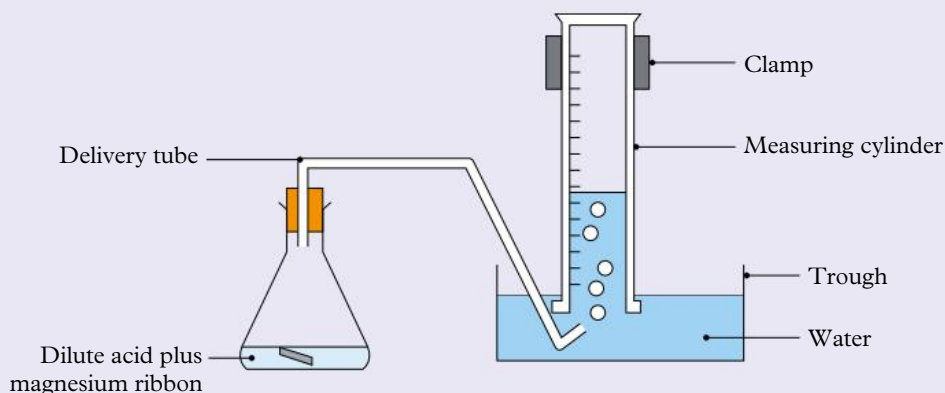


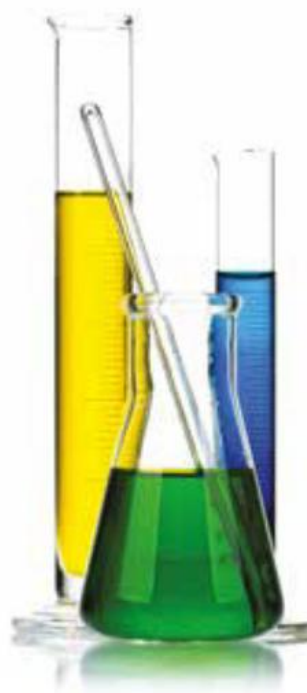
Figure 10 The scientist's experimental set-up

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.

Figure 11 Stirring the reactants increases the rate of a chemical reaction.



5.9

Catalysts increase the rate of a reaction

In this topic, you will learn that:

- 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 1). As the exhaust gases pass through the converter, they react on the surface of the metals to form harmless gases. The metals adsorb (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 $\text{CO}_2\text{(g)}$ and $\text{N}_2\text{(g)}$. Catalysts are usually metals such as platinum, palladium and rhodium.

catalyst

a substance that increases the rate of a chemical reaction without undergoing any permanent chemical change

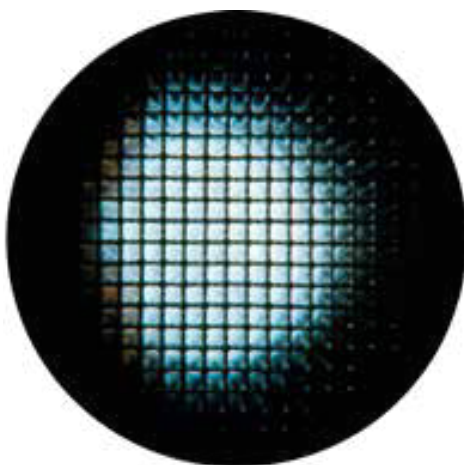
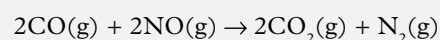


Figure 1 Catalysts are often used in the form of a grid to maximise the surface area.

The overall reaction that occurs in the catalytic converter in a car's exhaust pipe is:



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 Catalytic converters are used to reduce harmful pollution from exhaust gases.

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, $\text{O}_3\text{(g)}$, 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 many more skin cancers and eye problems.

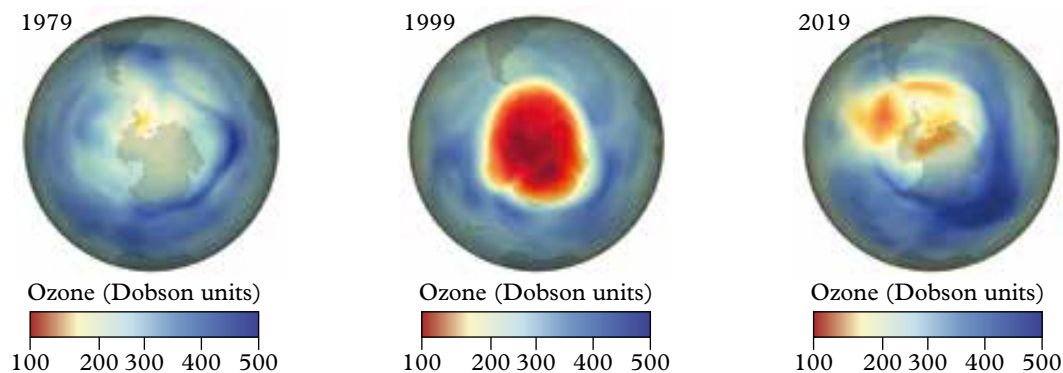


Figure 3 Ozone levels reduce over the southern hemisphere every year. The darker colours show the growth of the 'hole' in the ozone layer between 1979 and 1999, and its decrease after CFCs were banned.

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 4), 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.

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 and so will only catalyse certain reactions.



Figure 4 Chlorofluorocarbons (CFCs) were used to pressurise the gas in aerosol cans before it was proved that CFCs damage the ozone layer.

5.9 Check your learning

Remember and understand

- 1 Define** the term 'catalyst'.
- 2 Describe** two ways in which catalysts can work.
- 3 Describe** a catalytic converter. **Explain** why they are used.

Apply and analyse

- 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.
- 6 Identify** which part of the CFC molecule destroys ozone. **Describe** how this atom becomes detached.

5.10 Green chemistry reduces the impact of chemicals on the environment

Being 'green' means doing something positive for the environment. Chemical scientists with special knowledge in ecology, biochemistry, zoology and botany study the environment and how it responds to changes. These scientists monitor the environment to detect changes caused by natural events, as well as by human actions.

biodegradable

describes an object or a substance that can be broken down by bacteria, fungi or other living organisms

Low-impact chemicals

Some chemicals have a negative impact on the environment and living things. When these substances are identified, scientists act to reduce their use and prevent them from entering the environment. Some substances are banned altogether.

New chemical products and processes are described as 'green' if they have less impact on the environment than the product or process they replace. The study and development of new substances that have a low impact on the environment is called 'green chemistry'.

Green chemistry is sometimes called 'sustainable chemistry' because it aims to reduce the negative impact of chemicals on the environment.

Some examples of the development of 'green' alternatives are described below.

PESTICIDES AND HERBICIDES

Pesticides and herbicides have been used to kill organisms that eat our food crops and the plants that compete with these crops for sunlight and nutrients. In the past, some of these products killed many different types of organisms, not just the target pest. Most were non-degradable (did not break down) and

remained in the environment long after they were no longer needed. These substances are now banned and have been replaced with **biodegradable** poisons. In many cases, chemical poisons have been replaced with new farming practices, such as crop rotation and planting pest-resistant crop varieties.

HEAVY METALS

Heavy metals include lead, mercury and cadmium. Heavy metals had many uses, especially in dyes, and were used in chemical processes as catalysts. But these metals accumulated in the bodies of living things, including people.

The most dramatic example is that of Minamata disease, caused when people in Minamata, Japan, in 1956, were poisoned by mercury after eating seafood contaminated by a chemical company. The use of these metals in situations where they could enter the environment has been largely stopped. They have been replaced by different catalysts and even different production processes.

SOLVENT-BASED PAINTS

Acrylic paints have replaced solvent-based enamel paints and lacquers. The solvents used in enamel paints, such as turpentine, were hydrocarbons and they evaporated as the paint dried. If these hydrocarbon solvents entered waterways, they were toxic to aquatic life, and the fumes from the paint caused 'painter's disease' in people who inhaled them.

These solvent-based paints have been replaced with acrylic paints, which are water-based and set by polymerisation of the paint, not by evaporation of a solvent.



Figure 1 Acrylic paints have replaced solvent-based paints.



Figure 2 There are many ways in which you can reduce your impact on the environment.

How science can help

You can help protect the environment and the planet by adopting the slogans ‘Reduce, Reuse, Recycle’ and ‘Act Local, Think Global’ to reduce your footprint on the environment. Below are some practical steps you might take.

- » Install solar panels on the roof of your home if possible, and ask your school to do the same.
- » Reduce food waste by composting grass clippings and food scraps and using this compost to grow your own herbs and vegetables.
- » Reduce your consumption of red meat and dairy products to help reduce greenhouse gas emissions.
- » Recycle any waste that can be recycled, and request recycling bins at your work or school.
- » Reduce your usage of things that consume a lot of energy, such as air travel and cryptocurrencies.
- » Walk, use public transport or ride a bike instead of using the car where possible.
- » Use any single-use items, such as a plastic bag or a bottle of water, many times where hygienically possible ... and then recycle it!

5.10 Develop your abilities

Personal and environmental safety

Before new agricultural or veterinary chemicals that contain a new active ingredient can be produced or imported into Australia, they must first be approved for use by the Australian Pesticides and Veterinary Medicines Authority (APVMA) to make sure that they satisfy the safety, trade, efficacy and labelling criteria. The information that needs to be provided may be the results of scientific experiments or a comparison to an existing chemical that is already in use.

- 1 A chemical manufacturer would like to import a herbicide (substance that kills plants) that has the active ingredient diquat dibromide monohydrate. As a scientist working for the APVMA, you are responsible for preparing recommendations for or against the importation of new products. Write a recommendation that provides evidence to support your decision by:
 - > using a Safety Data Sheet (SDS) for this product (which can be found by searching the internet) to describe the chemical’s toxicity to:
 - > humans
 - > animals
 - > the environment
 - > describing how this active ingredient is currently used in Australian agriculture
 - > describing how and why this chemical is used or not used in the European Union
 - > outlining your decision for or against the importation of the new product.

REVIEW 5

Multiple choice questions

- Identify** the correct product for this synthesis reaction:
 $2\text{Mg} + \text{O}_2 \rightarrow$
A 2MgO
B MgO_2
C MgO
D $2\text{Mg}_2\text{O}_4$
- 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
- 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

Short answer questions

Remember and understand

- Describe** the differences between decomposition reactions and direct synthesis reactions.
- Identify** the types of products that are formed when acids react with metals, carbonates or bases.
- Describe** two different types of reactions that produce carbon dioxide.
- In terms of particles, **identify** what is required for a chemical reaction to take place.
- Identify** four factors that will affect the rate of a chemical reaction.
- Describe** two ways that the rate of chemical reactions can be measured.

Apply and analyse

- 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.
- 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.

- Sodium metal was reacted with purified bauxite (Al_2O_3) to produce aluminium and sodium oxide (Na_2O).

- Identify** the type of reaction that occurred.
- Construct** a chemical equation for the process, ensuring that the law of conservation of mass is applied to the equation.

- 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 1.

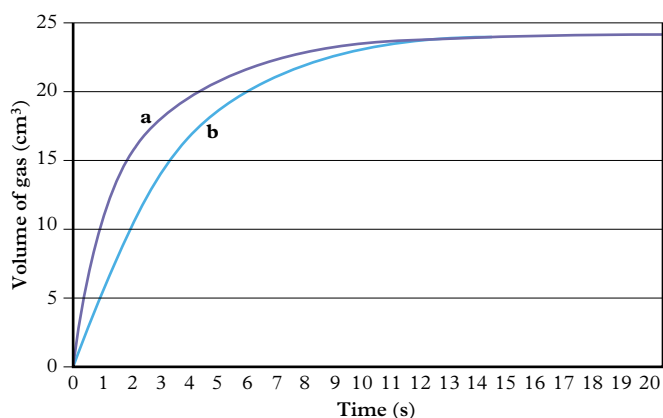


Figure 1 Trial results

- Use the information provided to **construct** a title for the graph.
 - Identify** which line (a or b) represents the trial at 20°C and which represents the trial at 30°C .
 - Use the information provided in the graph to **describe** the relationship between temperature and the rate of reaction.
 - Use the collision model to **provide** an explanation for the relationship identified in part c.
 - 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).
 - Write a balanced equation to **summarise** the chemical reaction taking place. (HINT: The information you need to start is in the question.)
- Describe** two examples of catalysts used in the production of chemical products.
 - In many industrial environments, the presence of a fine dust is regarded as an explosion hazard. **Explain** why coal dust is more likely to explode than chunks of coal.
 - Describe** two examples of green chemistry that you could apply at home.

Evaluate

- 17 **Explain** how the particle model of matter helps us understand the rate of reactions.
- 18 The reaction $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{SO}_3(\text{g})$ 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: $2\text{SO}_2(\text{g}) + 2\text{NO}_2(\text{g}) \rightarrow 2\text{SO}_3(\text{g}) + 2\text{NO}(\text{g})$
- Step 2: $2\text{NO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}_2(\text{g})$

Explain why the nitrogen dioxide is regarded as a catalyst. Give two reasons.

Social and ethical thinking

- 19 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. If you had been part of the debate in the 1920s, **describe** two arguments that you would make against the use of tetraethyl lead.

Critical and creative thinking

- 20 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 **explain** why most catalysts are used in the form of a powder or fine mesh.
- 21 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** whether 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

- 22 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, in what form they occur naturally, and what chemical processes are used to extract the pure metals.

» Minamata disease

Minamata disease is caused by 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)

» Ozone and CFCs

Although governments limited the use of CFCs to reduce the damage to the ozone layer, it took time for many countries to recognise the risks and act on the advice from scientists. Investigate how evidence for ozone depletion was discovered and how countries responded to the evidence. Discuss the implications for possible future action (or inaction) of governments based on scientific advice.

Reflect

The table below outlines a list of things you should be able to do by the end of Chapter 5 'Chemical reactions'. Once you've completed the chapter, use the table to reflect on your ability to complete each task.

	I can do this.	I cannot do this yet.
Explain that in chemical equations the starting chemicals are shown on the left-hand side of the arrow. Explain that the law of conservation of mass states that the total mass of the reactants is equal to the mass of the products.	☐	☐ Go back to Topic 5.1 'Mass is conserved in a chemical reaction' Page 108
Describe a chemical reaction. Write, balance and assign states to chemical reactions.	☐	☐ Go back to Topic 5.2 'Balanced chemical equations show the rearrangement of atoms' Page 110
Recognise the difference between a synthesis reaction and a decomposition reaction. Write, balance and assign states to simple synthesis and decomposition reactions.	☐	☐ Go back to Topic 5.3 'Synthesis and decomposition reactions can be represented by equations' Page 112
Determine the difference between an acid and a base, including key features and properties. Write, balance and assign states to neutralisation reactions.	☐	☐ Go back to Topic 5.4 'Acid reactions depend on strength and concentration' Page 114
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 5.5 'The solubility rules predict the formation of precipitates' Page 116
Define the terms 'oxidation', 'combustion' and 'hydrocarbon'. Write, balance and assign states to oxidation reactions with metals and non-metals. Explain the effect of limiting the amount of oxygen in hydrocarbon combustion reactions.	☐	☐ Go back to Topic 5.6 'Combustion reactions between hydrocarbons and oxygen produce carbon dioxide, water and energy' Page 118
Define the terms 'monomer', 'polymer', 'cross-linked', 'thermosetting' and 'thermoplastic'. Determine whether polymers are thermoplastic or thermosetting based on their properties and determine where this knowledge may be useful around the home/real world.	☐	☐ Go back to Topic 5.7 'Polymers are long chains of monomers' Page 120
Define the term 'collision theory' and identify how this relates to the rate of a chemical reaction. Explain how to increase the rate of a chemical reaction using collision theory for surface area, concentration, temperature and stirring.	☐	☐ Go back to Topic 5.8 'Temperature, concentration, surface area and stirring affect reaction rate' Page 122
Define what a catalyst is and how it can increase the rate of a chemical reaction. Explain the two types of catalysts and give examples.	☐	☐ Go back to Topic 5.9 'Catalysts increase the rate of a reaction' Page 126
Define what green chemistry is and why it is beneficial to the environment or society. Determine how people as citizens can utilise the principles of green chemistry to reduce their carbon footprint.	☐	☐ Go back to Topic 5.10 'Science as a human endeavour: Green chemistry reduces the impact of chemicals on the environment' Page 128

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What can we do about climate change?



6.1 The Earth's spheres are balanced

6.2 The water cycle is a global cycle

6.3 Matter cycles through the Earth's spheres



6.4 Human activity affects the carbon cycle

6.5 Evidence supports the enhanced greenhouse effect

6.6 Climate change has widespread effects



6.7 Science as a human endeavour: Humans can impact climate change

CHAPTER

6

GLOBAL SYSTEMS

What if?

Increased sea levels

What you need:

Map of local coastal areas with height above sea level marked or highest astronomical tide marked, map showing local food-growing regions

What to do:

Compare the two maps. What do you notice about the areas that are at risk of current high tides?

What if?

- » What if the high-tide line was to increase by 1 m? (Would your home be at risk?)
- » What if the high-tide line was to increase by 5 m? (Would food-growing regions be at risk?)

6.1

The Earth's spheres are balanced

In this topic, you will learn that:

- the Earth is made up of the lithosphere (solid crust), atmosphere (air), hydrosphere (water) and biosphere (living organisms)
- interaction between the Earth's spheres maintains global temperatures and climate.



Interactive 6.1A
Atmosphere



Interactive 6.1B
Classifying components of the Earth

lithosphere

the outermost layer of Earth, consisting of the upper mantle and crust

tectonic plate

a large layer of solid rock that covers part of the surface of the Earth; movement of tectonic plates can cause earthquakes

atmosphere

the layer of gases surrounding the Earth

The solid crust of the Earth (lithosphere) interacts with the atmosphere (air) and hydrosphere (solid, liquid and gaseous water) to influence temperature and therefore the climate in mountains and deserts, as well as the ocean currents. In return, these three spheres affect all the living organisms in the biosphere. A balance must be maintained to ensure the survival of all life on this planet.

The lithosphere

The outermost rocky layer of the Earth is the **lithosphere**. It is made up of the upper mantle and the crust (Figure 1). Although the crust and upper mantle are approximately 80 km thick, at the scale of the Earth they actually form a very thin layer.

The rocky crust of the Earth is made from magma (molten rock), which cools very slowly and at different times all over the surface of the

Earth. The heat from the magma escapes into the air and water surrounding it. The cooled crust settles as uneven giant plates of rock that are mismatched and butt up against their neighbours, covering the entire Earth. The giant pieces are called **tectonic plates**. These plates float on the semi-liquid magma at the top of the mantle. The heat in the mantle creates currents that slowly stir through the molten rock, moving the tectonic plates as well. The tectonic plates move about 2–10 cm per year – a similar rate to the growth of your fingernails.

The lithosphere is the slowest of Earth's systems to change. Small changes can take thousands, even millions, of years.

The atmosphere

The **atmosphere** is a layer of gases that we commonly call air (Figure 2). The atmosphere is relatively thin compared to the size of the Earth: if the Earth were the size of a party balloon, the atmosphere would only be as thick as the rubber skin of the balloon.

The Earth is the only planet in our solar system that has an atmosphere that sustains life. It helps keep us warm, controls our weather, protects us from the dangers from space and carries sounds.

The most important gas for humans and other animals is oxygen (O_2), which makes up 21 per cent of the atmosphere. Oxygen in the Earth's atmosphere allows organisms to respire. Other gases in the atmosphere include ozone (O_3), which offers protection from the Sun's UV radiation; carbon dioxide (CO_2), water (H_2O) and other greenhouse gases, which trap heat to keep us warm; and nitrogen (N_2), which makes up 78 per cent of the atmosphere.

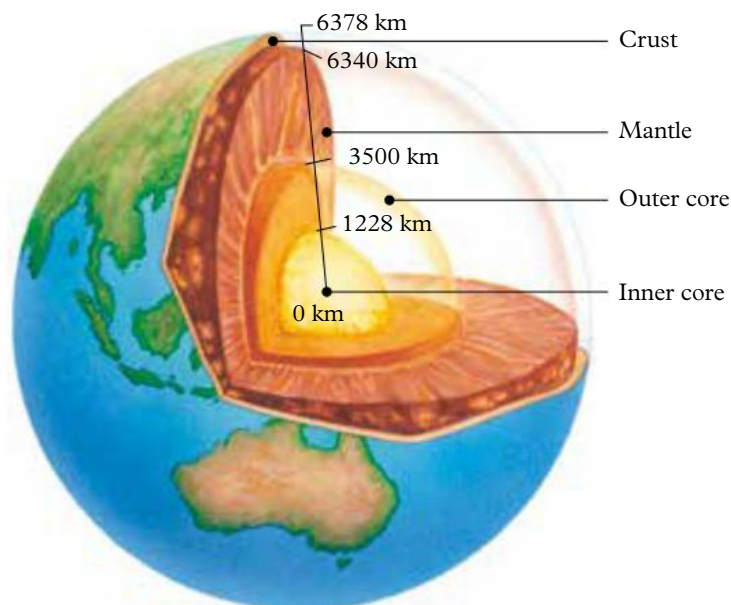


Figure 1 The Earth is made up of layers.

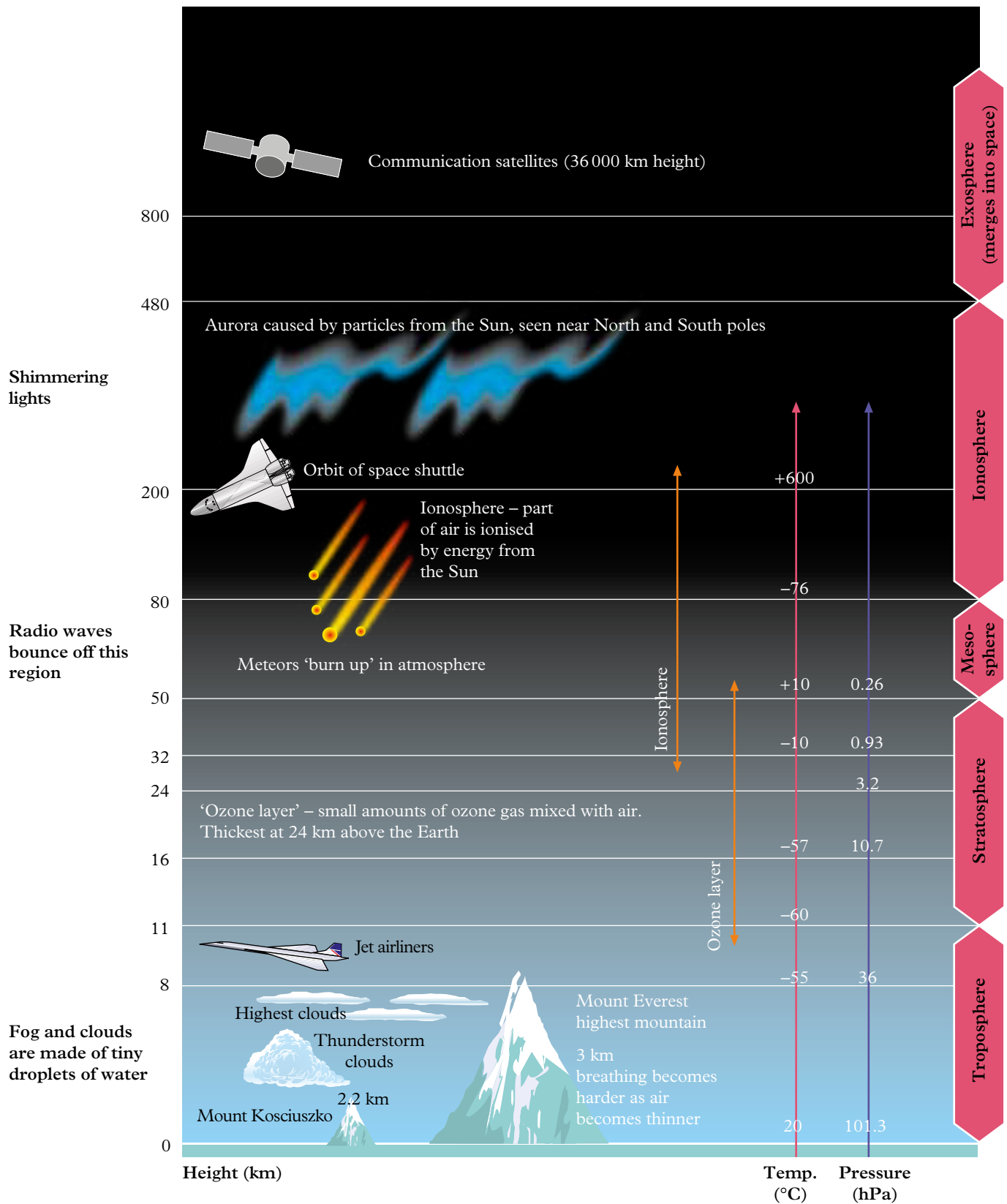


Figure 2 Each layer of the Earth's atmosphere has different characteristics.

hydrosphere

all the solid, liquid and gaseous waters on Earth that support life

cryosphere

the frozen water in the hydrosphere

biosphere

a layer around the Earth's surface that supports life; consists of the atmosphere, hydrosphere and lithosphere

biodiversity

the variety of life; the different plants, animals and micro-organisms and the ecosystems they live in

Layers in the atmosphere

The atmosphere is more dense at ground level and thins out as you go higher above the Earth's surface: 99 per cent of all the air in the atmosphere is found within 80 km of the Earth's surface. There is not really a top to the atmosphere – the air just thins out, with decreasing pressure, until you reach the relative emptiness of space. These changing conditions are identified as several atmospheric layers.

The hydrosphere

The **hydrosphere** is made up of all the Earth's water – oceans and lakes but also the water in glaciers, the soil and even in the air (Figure 3). The hydrosphere covers approximately 70 per cent of the Earth's surface, making the Earth the 'blue planet' when viewed from space. The huge amount of water, in all its various forms, is also home to many types of plants and animals. The hydrosphere interacts with and is influenced by each of the other spheres. The heat from the lithosphere warms the atmosphere and hydrosphere, allowing the production of water in three different states: liquid, vapour and solid (glaciers and ice).

The hydrosphere influences climate

The part of the hydrosphere that is made up of frozen water is called the **cryosphere**. The cryosphere is very important in regulating

the climate on the Earth and the amount of nutrients in the ocean. When the ice melts, it produces very dense cold water that sinks to the bottom of the ocean disturbing the nutrients on the ocean floor. As the icy water is carried away by the current, it slowly warms and lifts the nutrients to the surface, where it starts the ocean's food chain. As the current travels north, the atmosphere heats the water, causing it to evaporate and affect the climate.

The biosphere

The **biosphere** is made up of all the living things on the Earth, including plants, animals and bacteria. Within this sphere, there is an enormous degree of organisation and an amazing variety of different types of organisms (**biodiversity**; *bio* = life, *diversity* = variety). Each organism is interdependent with others; the survival of each species is dependent on other species. The biosphere needs to maintain a careful balance.

The Earth is the only planet in our solar system that can support a biosphere. Although life could exist in all spheres on the Earth, most living things can only survive in a fairly narrow range of conditions – from deep under the ocean to high in the mountains.



Figure 3 All the Earth's water makes up the hydrosphere.

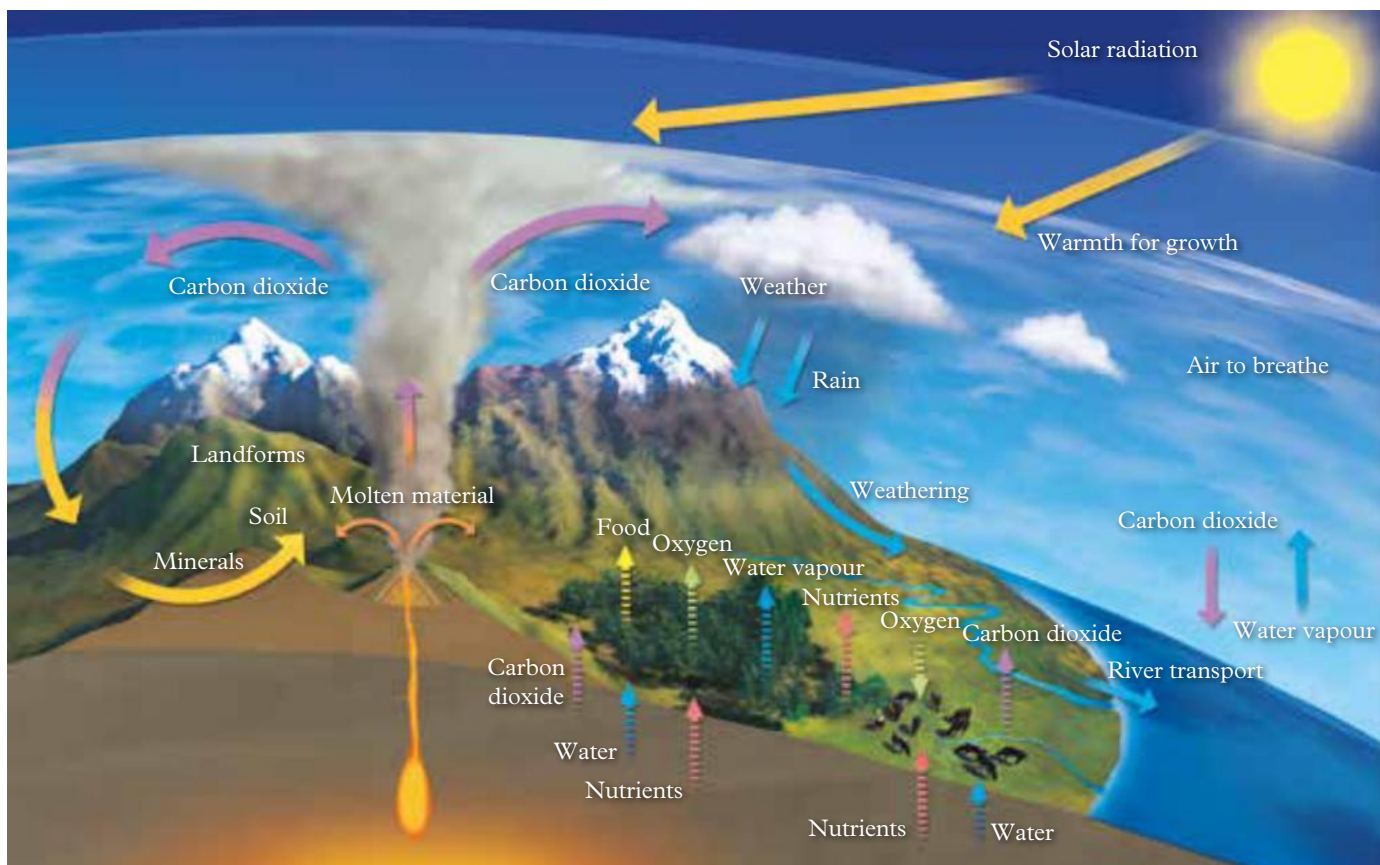


Figure 4 The inputs and outputs of the Earth's living and non-living systems.



Figure 5 Volcanoes are part of the lithosphere.

6.1 Check your learning

Remember and understand

- 1 **Describe** the different elements that make up the lithosphere.
- 2 **Define** the term 'biosphere'.
- 3 **Describe** what happens to the amount of air as you go higher into the atmosphere.

Apply and analyse

- 4 **Identify** the layer of the atmosphere in which we live.
- 5 **Compare** the hydrosphere and the cryosphere.
- 6 **Explain** how the hydrosphere interacts with the other spheres.

Evaluate and create

- 7 Draw a Venn diagram with four interlocking circles, one for each of the spheres studied. **Label** each sphere and include all the features they share.

6.2

The water cycle is a global cycle

In this topic, you will learn that:

- water continually cycles through the hydrosphere
- weather is a day-to-day measure of temperature, air pressure and rain
- climate is a long-term measure of the weather conditions over time.

The hydrosphere includes all the water on the Earth, including the water in the air, trapped in ice and underground. It includes solid ice, liquid ocean and lakes, and the water vapour in the air.

Water cycle

Water is an essential part of life and is important for many metabolic processes in your body. It is continuously cycled through the hydrosphere, moving through the atmosphere and biosphere in the process. However, this does not mean that there is a never-ending

supply of water. This is because the water cycle (Figure 1) is a global cycle. This means that water is not equally available in all ecosystems. For example, water that evaporates from the desert may later fall as rain on a forest thousands of kilometres away. For this reason, an ecosystem may have too little water (drought) or too much water (floods) for the organisms within it to continue to survive. This is why it is important to monitor and analyse the patterns of rainfall across the globe to make predictions about **weather** elsewhere.

weather

a snapshot of what the air and conditions are like in any one place on Earth at any one time

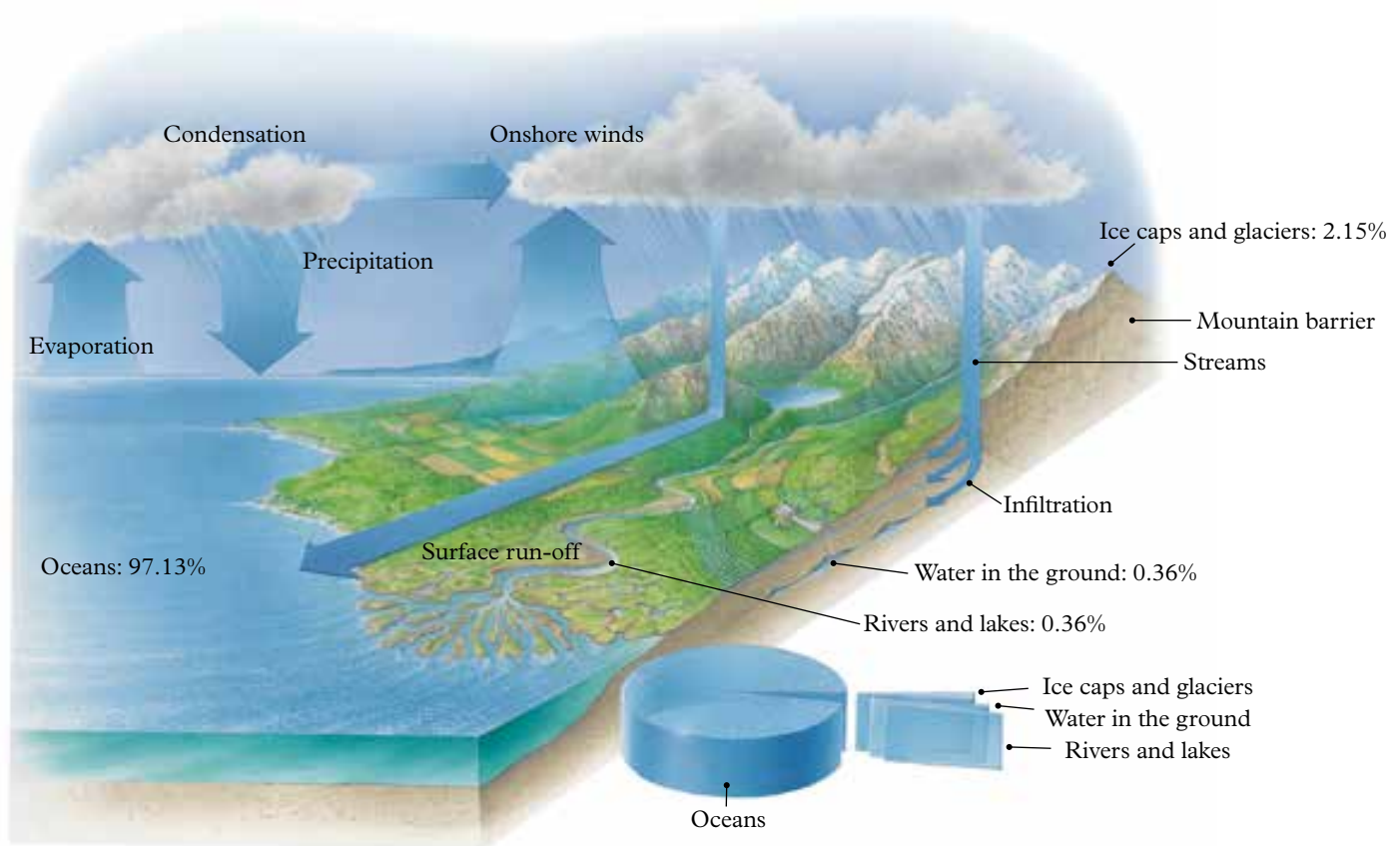


Figure 1 The distribution of water on the Earth and the water cycle

Clouds and rain

Water vapour is the source of all **clouds** and **precipitation** and is therefore the most important gas in the atmosphere when it comes to understanding atmospheric processes. Water vapour is evaporated water – water as a gas.

Water vapour that has evaporated from forests, oceans and rivers rises, lowering the air pressure in the area. This is especially noticeable in the Amazon rainforest, where the transpiration of water from the trees generates enormous amounts of water vapour. When the water vapour reaches the cooler parts of the atmosphere, its kinetic energy decreases, allowing droplets of liquid water to condense – condensation. The drops of water then form into clouds, which may be carried onto land by winds. If they reach a mountain barrier or another colder air mass, the clouds will rise and cool further. The colder air can no longer hold the condensed droplets and they fall as precipitation – rain, hail or snow. The precipitation eventually moves back to the world's lakes and oceans through rivers and streams (collection) and the process begins again. In this way, forests can supply much of the water vapour that contributes to both the weather and the climate.

Weather and climate systems

Weather reports tell you the temperature, rainfall and other factors. It is a snapshot of day- to-day changes. **Climate** is more 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, governments to decide whether to invest in certain technologies, or even households to decide whether they'll need to install an air conditioner.



Figure 2 The evaporation of water from the rainforest affects the climate.



Figure 3 Flooding may follow torrential rain during a cyclone.

water vapour

water in the gaseous state

cloud

a visible mass of condensed water in the atmosphere

precipitation

in meteorology: the process in which water vapour in the upper atmosphere becomes liquid water in the form of rain, snow or sleet and falls to the ground

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

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

Weather

Regions near the equator are warmer than regions near the poles. Near the equator, the Sun is directly overhead in the middle of the day. Because of this, the energy from the Sun is concentrated, so these regions are heated intensely. Near the poles, the Sun is lower in the sky, shadows are longer and energy from the Sun becomes more spread out. This is because the Earth's surface is curved, so the Sun's rays come in at an angle.

As the air heats up, the particles in the air spread out and become less dense. As a result, the less dense warmer air rises above the more dense cold air. This means the warm air near the equator rises into the atmosphere and colder air near the poles moves towards the equator to fill the space left by the warm air (Figure 4). The movement of air is better known as **wind**. 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 can cause winds to deviate from the path you might expect them to take. 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.

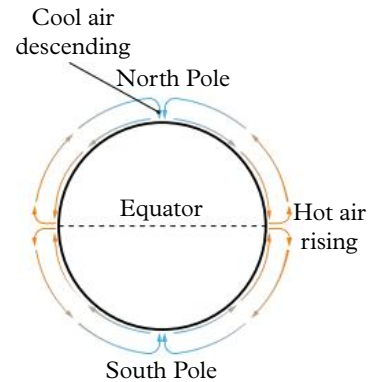


Figure 4 Movement of air at the equator and at the poles can result in the circular movements of air called cyclones.

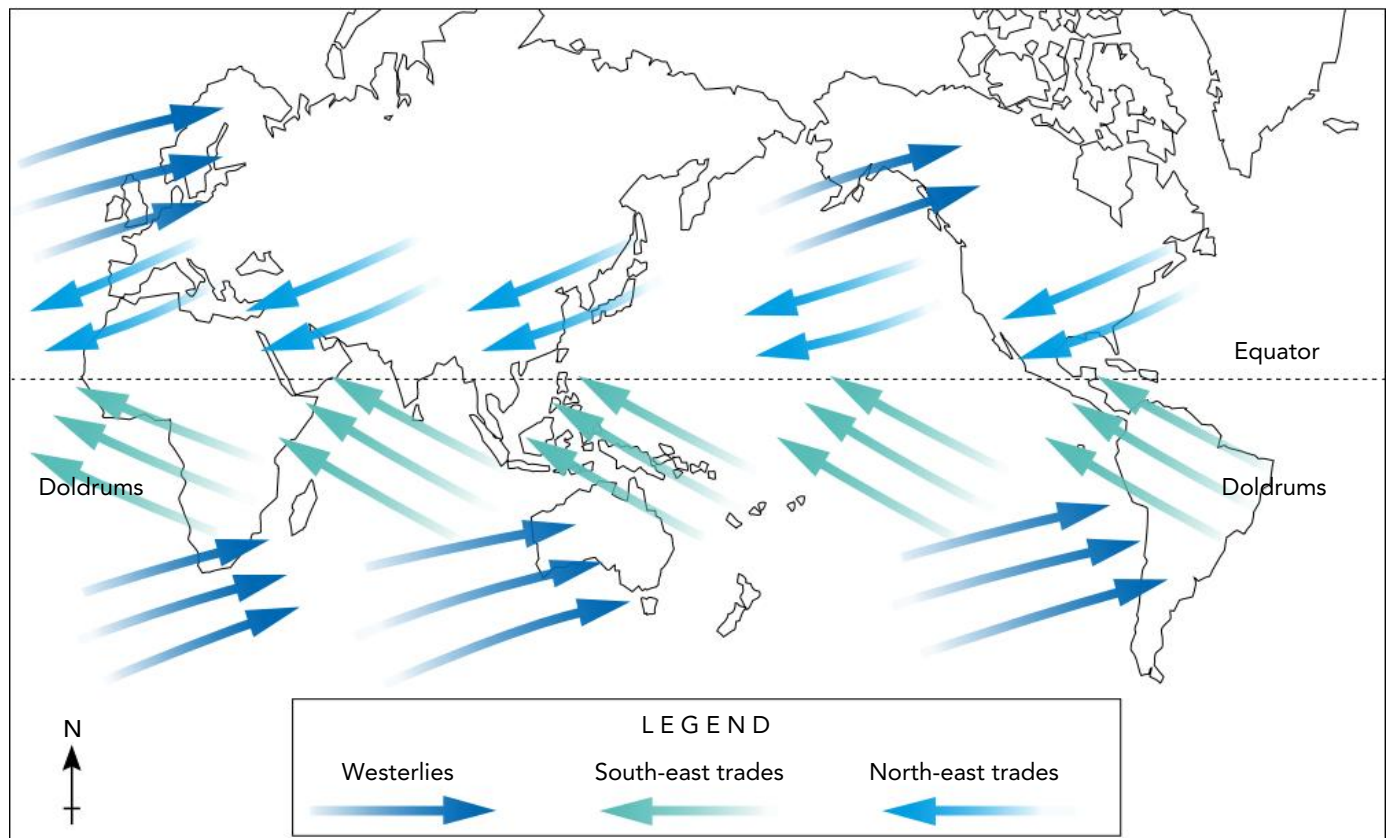


Figure 5 Wind patterns over the Earth. The Doldrums are areas of low pressure where winds tend to be very calm.

On a weather map, air pressure differences 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 also shown on a weather map (Figure 6b). Low-pressure areas are frequently associated with clouds and precipitation, whereas high-pressure systems bring clear blue skies.

isobar

a line drawn on a weather map that joins places of equal air pressure

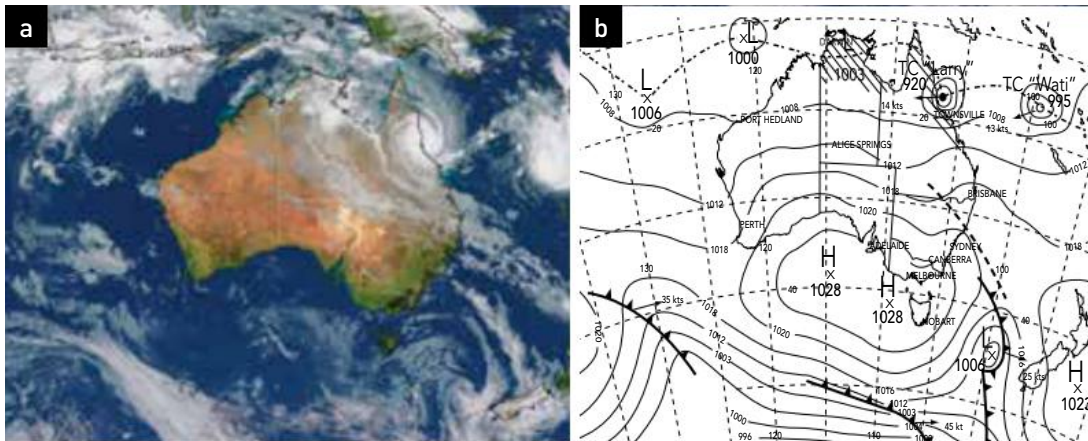


Figure 6 **a** A satellite image and **b** weather map showing tropical Cyclone Larry as it crosses the Australian coast at Innisfail, just south of Cairns, in 2006.

6.2 Check your learning

Remember and understand

- 1 **Compare** weather and climate.
- 2 **Define** the term 'air pressure'.
- 3 **Explain** what happens to the pressure of the air when it is heated.

Apply and analyse

- 4 **Describe** the relationship between winds and rising air.
- 5 **Describe** the conditions that must occur for water vapour in clouds to fall as precipitation.

- 6 **Identify** and **describe** four weather features shown on the weather map in Figure 7.

Evaluate and create

- 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. Prepare a 2 minute video in which you are a meteorologist on the news who explains why the cyclone is forming.

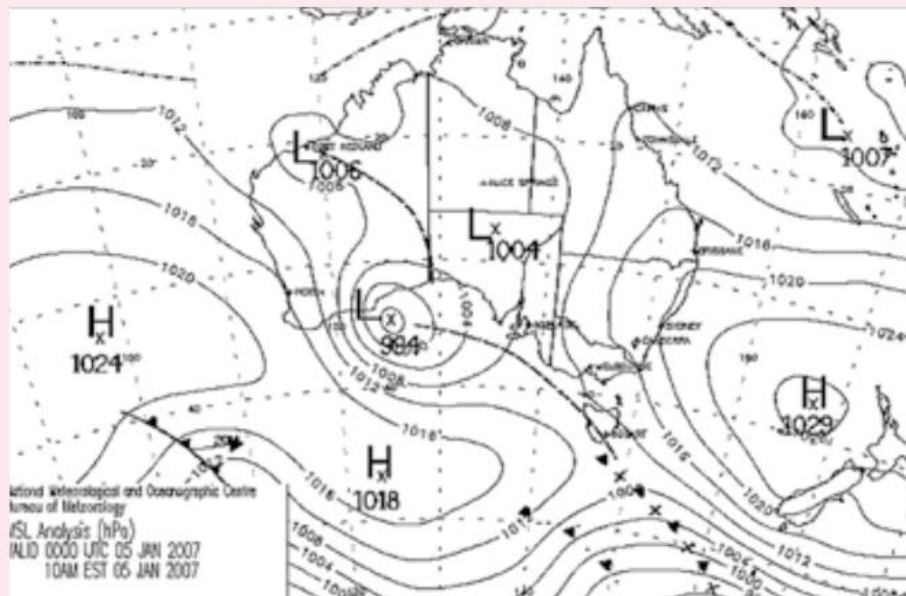


Figure 7 A weather map of Australia during the wet season

6.3

Matter cycles through the Earth's spheres

In this topic, you will learn that:

- oxygen cycles through the atmosphere, lithosphere and biosphere
- the cycle of nitrogen through the lithosphere and atmosphere is essential to life in the biosphere
- weathering of the lithosphere and the decay of organisms in the biosphere allows the cycling of phosphorus.

The cycling of all nutrients through the Earth's spheres is essential to sustaining life. If every time we inhaled oxygen it was lost to the atmosphere for good, plants would die without the oxygen atoms in carbon dioxide, animals would starve, and the biosphere would collapse. We know this is not the case – plants are able to absorb carbon dioxide from the atmosphere and produce more oxygen.

Cycling oxygen

Oxygen is an essential ingredient in cellular respiration, the process by which most organisms obtain energy for life. The Earth has a fixed supply of 'useful' oxygen, even though

it can be found everywhere. There are three reservoirs of oxygen:

- 1 the atmosphere (0.49 per cent)
- 2 the Earth's crust (lithosphere) and the oceans (99.5 per cent; Figure 1)
- 3 living organisms – the biosphere (0.01 per cent).

In the atmosphere, oxygen exists as the molecules O_2 and O_3 (ozone) and in compounds such as water (H_2O) and carbon dioxide (CO_2). Oxygen can dissolve in the oceans, where it is available for uptake by marine organisms.

The oxygen cycle is influenced heavily by processes in the biosphere and atmosphere (Figure 2). In the biosphere, photosynthesis



Figure 1 Almost all the oxygen on Earth is locked in the compounds that make up the lithosphere.

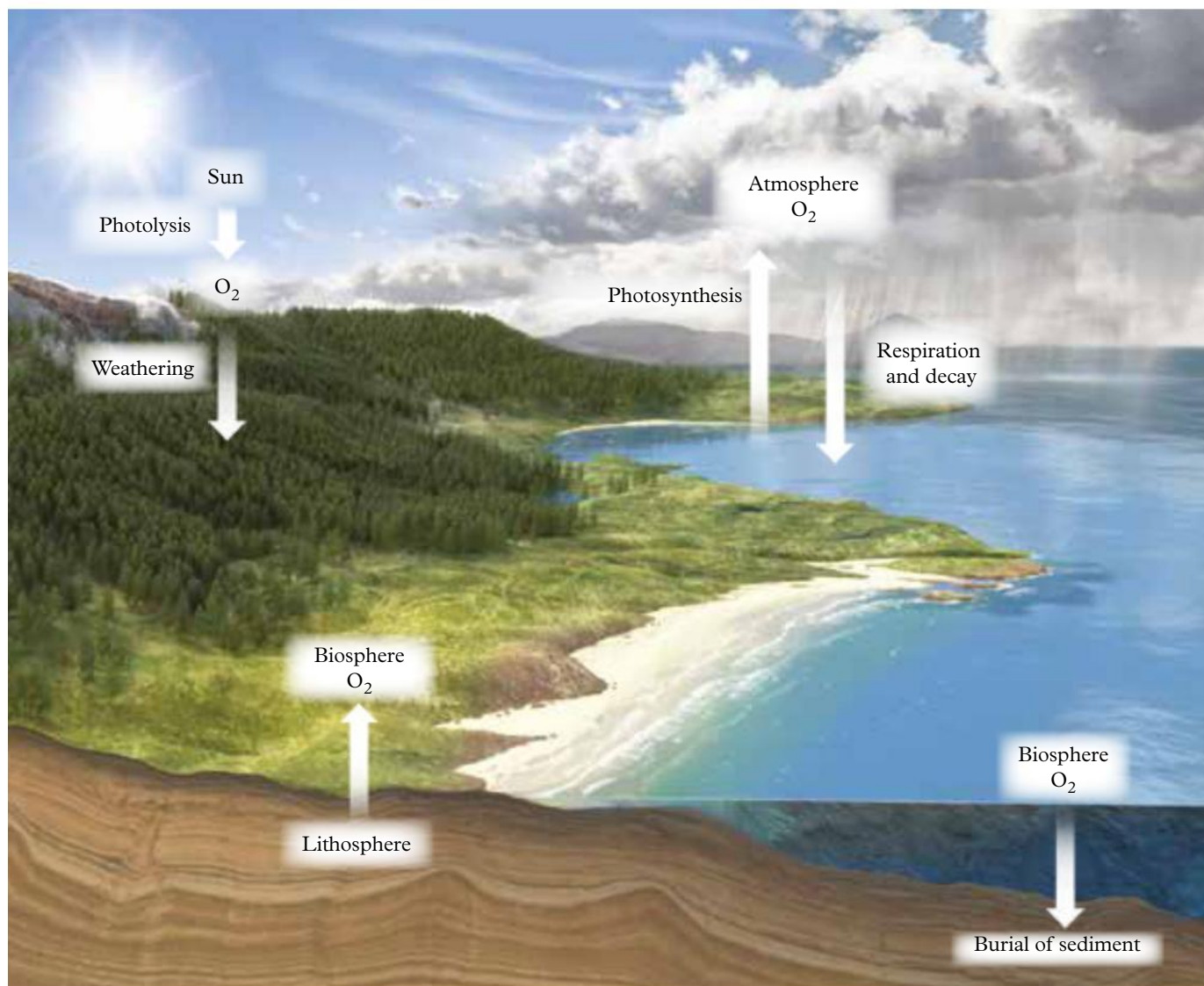
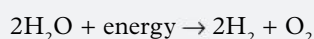


Figure 2 The oxygen cycle

releases oxygen and cellular respiration absorbs oxygen. In the atmosphere, oxygen is formed by UV light converting water to oxygen and hydrogen in a process known as **photolysis**:



Oxygen is removed from the atmosphere through the process of cellular respiration, and it is returned by the decay of organisms and the weathering of exposed rocks.

Cycling nitrogen

Nitrogen is necessary for the synthesis (construction) of proteins and nucleic acids, which are vital genetic building blocks for all organisms. Although nitrogen makes up 78 per cent of the gases in the atmosphere

(making it the most abundant gas), it is not in a form that can be used by living organisms. Bacteria play an important role in changing nitrogen into usable forms – nitrate, nitrite and ammonium ions – and returning it to the atmosphere.

Nitrogen-fixing bacteria are able to 'fix' or convert nitrogen (N₂) from the atmosphere into nitrate (NO₃⁻) ions, nitrite (NO₂⁻) ions and ammonium (NH₄⁺) ions. Nitrogen-fixing bacteria often live in the root nodules of legumes – plants such as peas and beans (Figure 3). The nitrogen compounds produced by the bacteria are used by the plant to synthesise proteins. In return, the plant provides protection and other essential elements to the bacteria. Other **denitrifying bacteria** living in the soil are able to return

photolysis

the breakdown of a chemical substance by light; an example is the breakdown of water into oxygen and hydrogen

nitrogen-fixing bacteria

bacteria that convert nitrogen from the atmosphere into various nitrogen compounds

denitrifying bacteria

bacteria that return nitrogen to the atmosphere

nitrogen back to the atmosphere to start the cycle again (Figure 4).

Many human activities affect the cycle of nitrogen in the atmosphere and lithosphere. These include fossil fuel emissions and run-off from fertilisers.

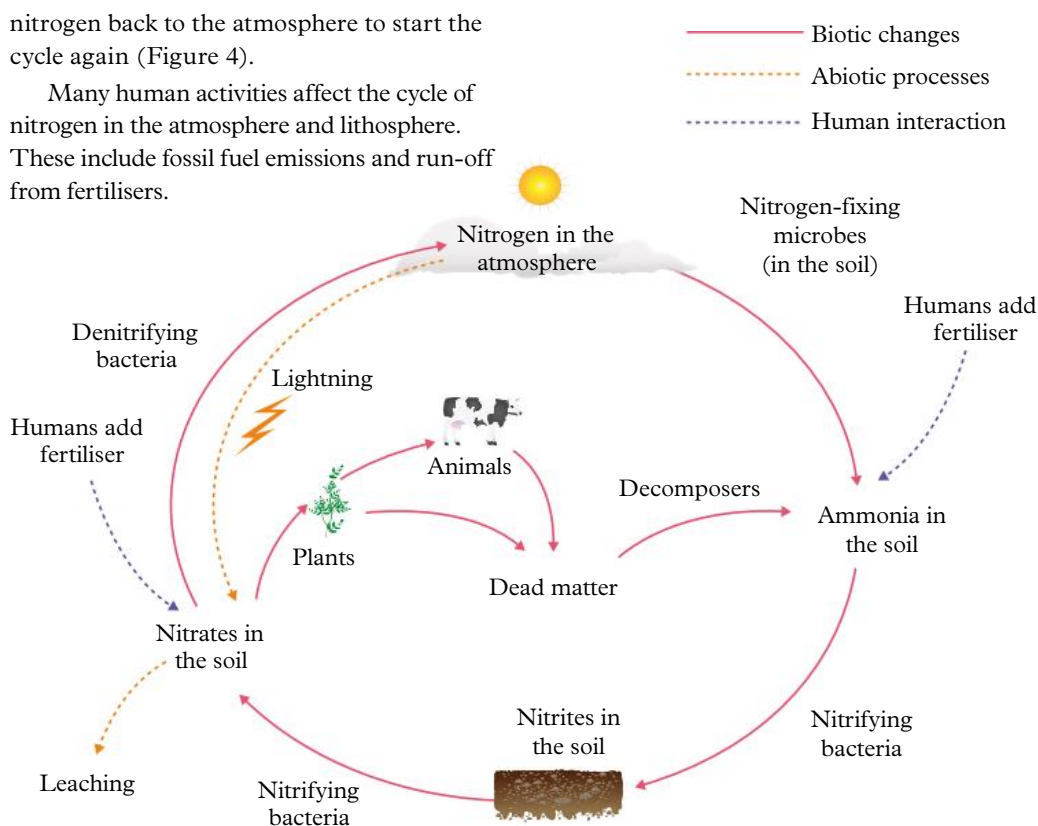


Figure 4 The nitrogen cycle

Figure 3 Legumes, such as peas and beans, have nitrogen-fixing bacteria living in the nodules on their roots. Consequently, farmers will often plant legumes between crops to maintain nitrogen levels in the soil.



Cycling phosphorus

Phosphorus is an essential component of the energy molecule ATP (adenosine triphosphate), as well as the DNA and RNA molecules (with sugar-phosphate backbones). Without phosphorus, an organism cannot use available energy-containing molecules.

The phosphorus cycle is the slowest of the biogeochemical cycles (Figure 5). Unlike photosynthesis and respiration, for example, weathering and decay are lengthy processes.

Most of the phosphorus available to living organisms comes from sedimentary rocks and soils. Unlike the other biogeochemical cycles, the phosphorus cycle does not have a gaseous phase. Phosphorus is not a common element, and its availability is often the limiting factor for plant growth.

Farmers will often apply phosphate fertilisers to agricultural land or plant legumes between crops.

In the phosphorus cycle:

- > rain weathers rocks, releasing phosphate ions into the soil
- > plants absorb phosphate ions via their roots, bringing phosphorus into the food chain
- > phosphorus absorbed by organisms returns to the soil through urine, faeces and the decomposition of the organism
- > phosphorus is locked in sediments and rocks for millions of years before being released by weathering and erosion; this completes the cycle.

Phosphorus is mined for use as a fertiliser. Run-off from agricultural land can lead to excessive levels of phosphorus in waterways. Because phosphorus encourages plant growth, excess levels lead to the increased growth of plankton, algae and bacteria, which consume oxygen. In addition to blocking sunlight from bottom-dwelling organisms, this results in

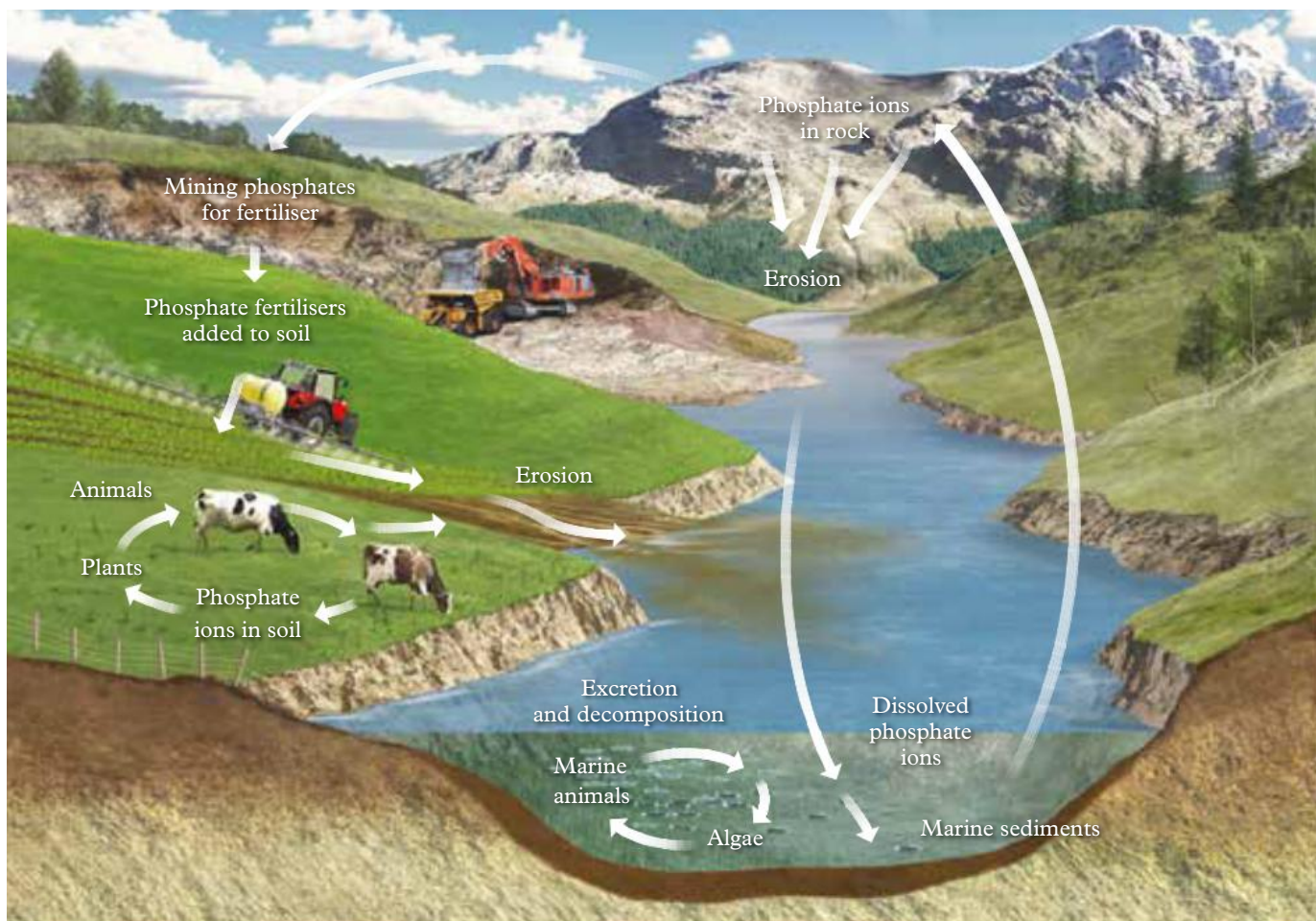


Figure 5 The phosphorus cycle

an increase in oxygen consumption within this environment, suffocating fish and other aquatic animals. This process is known as

eutrophication. To reduce this problem, phosphorus is no longer included in most detergents.

eutrophication
a process whereby excessive levels of phosphorus in waterways result in excess growth of algae and bacteria, which consume oxygen, suffocating fish and other aquatic animals

6.3 Check your learning

Remember and understand

- 1 **Identify** the three reservoirs of oxygen.
- 2 **Identify** three important molecules in your body that contain phosphorus.

Apply and analyse

- 3 **Explain** why plants might struggle to grow in nitrogen-poor soils.
- 4 **Explain** why the cycling of nutrients is referred to as a 'biogeochemical cycle'

(by defining the terms 'bio', 'geo', 'chemical' and 'cycle', and using an example to illustrate your answer).

Evaluate and create

- 5 Draw a concept map that shows the contribution of micro-organisms to the cycling of nutrients in an ecosystem.

6.4

Human activity affects the carbon cycle

In this topic, you will learn that:

- carbon cycles through all the Earth's spheres
- carbon trapped in the lithosphere cycles very slowly, whereas carbon in the biosphere and atmosphere cycles much faster
- carbon can be stored in carbon sinks such as fossil fuels and the ocean; human activity can cause the carbon sinks to release carbon into the atmosphere as carbon dioxide.



Video 6.4
The carbon cycle

Cycling carbon

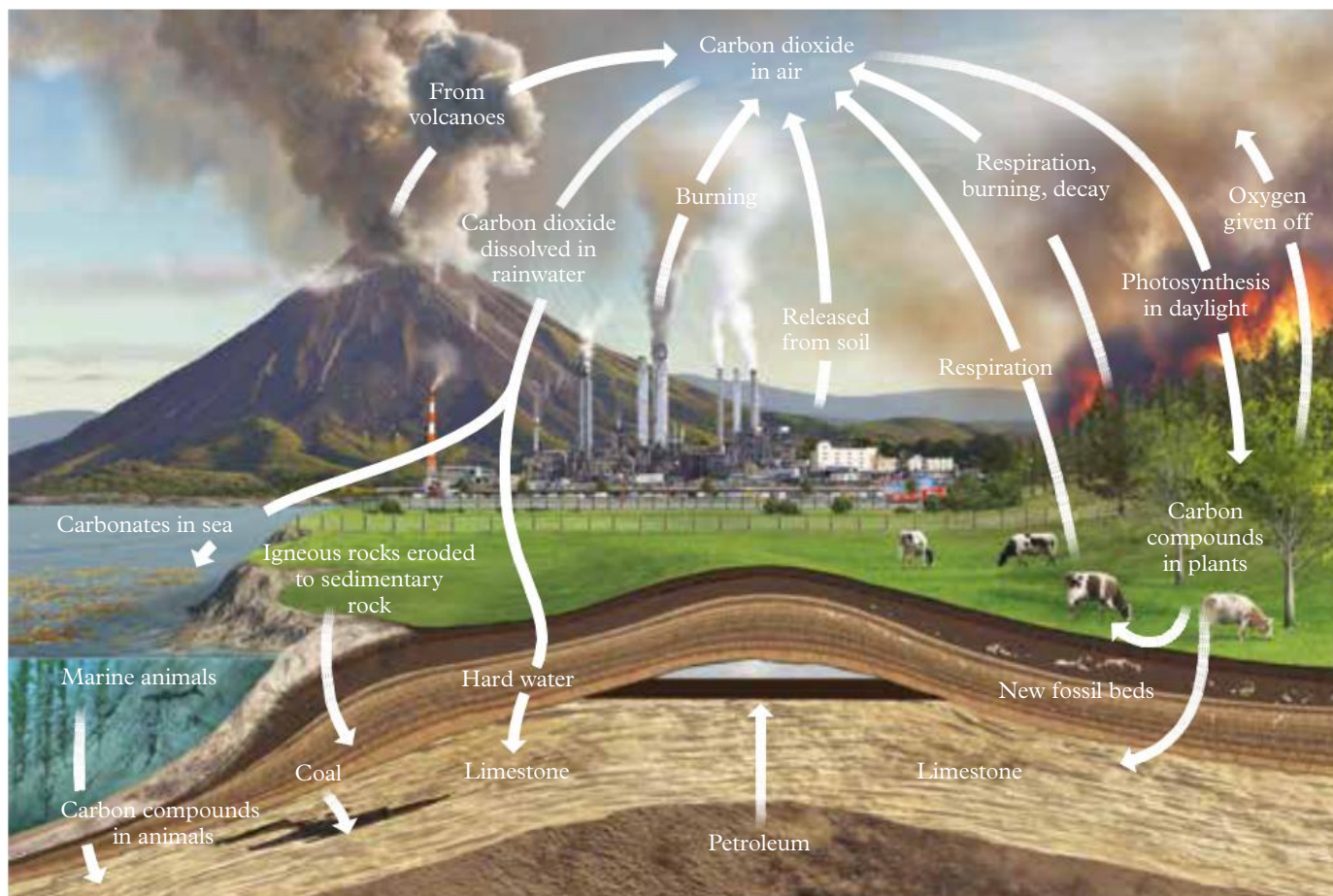
Carbon is the fourth most abundant element on Earth and is the basic component of all living organisms. It is the basis of carbohydrates, proteins and lipids. Carbon can cycle through the land, oceans and atmosphere over both the short and long term (Figure 1).

- > The geological carbon cycle is a long-term cycle that occurs over hundreds to millions

of years and has resulted in the bulk of carbon being locked in rocks or in sediments as fossil fuels.

- > The biological/physical carbon cycle is a short-term cycle that occurs over days, weeks, months and years, and it involves the cycling of carbon through photosynthesis and cellular respiration.

Figure 1 The carbon cycle



Humans tap into the geological carbon cycle by extracting oil, natural gas and coal (all of which are hydrocarbons) for use in cars and energy production. Large-scale extraction and the use of these fossil fuels has resulted in increased levels of carbon dioxide in the atmosphere. Coupled with an increase in deforestation, this increase in carbon dioxide has led to an enhanced greenhouse effect, altering temperature and rainfall patterns significantly.

Fire plays an important role in transferring carbon dioxide from the land to the atmosphere (Figure 2). Fires consume biomass and organic matter, producing carbon dioxide as well as methane, carbon monoxide and smoke (solid carbon particles).

Carbon is stored over the long term in the trunks and branches of trees. It is also temporarily stored in the bodies of other organisms, such as herbivores and carnivores. When these organisms die, carbon is returned to the atmosphere as carbon dioxide by decomposers.

Carbon sinks

A carbon sink is any feature of the environment that absorbs and/or stores carbon, keeping it from the atmosphere. Forests take in carbon dioxide, so they are a very significant carbon sink. However, the ability of forests to absorb carbon has been reduced as a result of the large-scale clearing of forests throughout the world.

The ocean is another important carbon sink. It absorbs atmospheric carbon dioxide, consequently becoming more acidic. Carbon is also stored in:

- > decomposed organic matter, such as coal, natural gas, petroleum and shale oil

- > rocks, such as limestone, marble, dolomite, chalk and other carbonates
- > organic matter in the soil
- > dissolved carbon dioxide in the oceans and other waters
- > the shells of marine organisms and some terrestrial organisms.

Human impact

Ecosystems depend on the biogeochemical cycling of water, carbon dioxide and other nutrients. Human activities have affected these cycles in many ways. For example:

- > We have reduced the total mass of fished species by as much as 90 per cent in much of the world.
- > Freshwater ecosystems have been altered through the building of dams for irrigation and hydroelectric power production, resulting in changed river flows.
- > Agriculture and farming have converted more than half the world's many grasslands for human use.

Human activity has diverted or prevented 20–30 per cent of the flow of geobiochemical molecules that are fixed by natural ecosystems (e.g. carbon fixation). This is due to:

- > maintaining crops (15 per cent)
- > establishing urban areas (1.8 per cent)
- > grazing livestock (2.3 per cent)
- > habitat degradation (e.g. desertification) (4 per cent).



Figure 2 Bushfires are an important part of the carbon cycle, releasing carbon back into the atmosphere.

6.4 Check your learning

Remember and understand

- 1 **Define** the term 'carbon sink'. Give two examples of carbon sinks.
- 2 **Explain** how you are part of the carbon cycle.

Apply and analyse

- 3 **Contrast** the geological carbon cycle and the biological/physical carbon cycle.
- 4 **Describe** two ways human activity affects the carbon cycle.

- 5 **Compare** the speed at which carbon is released into the atmosphere through the biosphere and burning. **Describe** how this compares with carbon being released from the hydrosphere.

Evaluate and create

- 6 **Create** a poster that explains the carbon cycle to a Year 7 student. **Consider** the scientific language that you will need to explain the cycle to the student.

6.5

Evidence supports the enhanced greenhouse effect

In this topic, you will learn that:

- the Earth is surrounded by an atmosphere of natural greenhouse gases that reflect radiation from the Sun and retain the warmth from the Earth
- evidence for enhanced global warming can be found in the melting of sea ice and permafrost and increasing sea levels.

enhanced greenhouse effect

an increase in carbon dioxide and other heat-capturing gases in the atmosphere, resulting in increased warming of the Earth

natural greenhouse effect

the natural warming of the Earth due to water vapour and other gases being present in small amounts in the atmosphere and affecting the Earth's radiation balance

The Earth's climate has changed many times throughout history. These changes can take many thousands of years to slowly warm or cool the Earth and change the climate. A climate change event is occurring now: from dusty farms experiencing drought in the outback to families fleeing their homes in the worst flooding we have ever seen. This climate change is due to the **enhanced greenhouse effect** and is different to previous changes. It started during the Industrial Age (1850) and has increased the Earth's average temperature by 0.95°C since 1900. This short time period does not allow time for living organisms (including humans) to adapt and evolve.

surface. Heat gradually leaves the Earth's surface and is radiated back into space. Some heat is trapped by the gases in the atmosphere. These gases act like a giant greenhouse of warm air, keeping the Earth warm. If heat was not trapped, the temperature would drop to -100°C each night and rise to 80°C in the day. The gases that contribute to the greenhouse effect include carbon dioxide, water vapour, methane, nitrous oxide and ozone.

Since the Industrial Revolution of the eighteenth and nineteenth centuries, the level of greenhouse gases has been increasing, causing an enhanced greenhouse effect.

The greenhouse effect

The **natural greenhouse effect** is critical for maintaining life on Earth. Solar energy passes through the atmosphere and warms the Earth's

Increased levels of greenhouse gases

The concentration of carbon dioxide in the air has changed significantly, by approximately 34 per cent, since 1750. The bulk of that increase has happened since 1959. The concentration of methane in the atmosphere has also risen dramatically over the past century, more than doubling.

The main greenhouse gas is carbon dioxide. It is formed by the burning of fossil fuels, such as coal, petrol, oil and gas. We all use energy for heating, lighting, transport, industry and communications. Burning carbon-based fossil fuels releases energy (usually as heat) and produces carbon in the form of carbon dioxide and sometimes carbon monoxide or solid particulate carbon.

Forests consume carbon dioxide in the process of photosynthesis. Massive deforestation for farming and urban land has prevented carbon dioxide being removed from

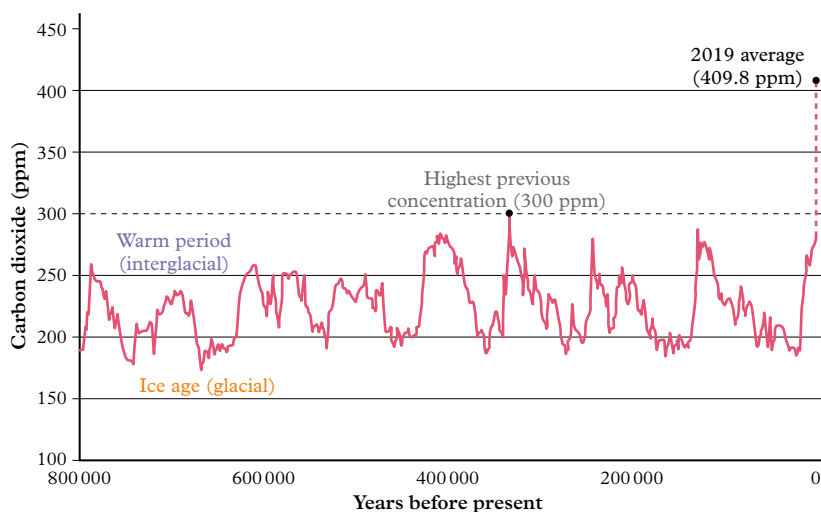


Figure 1 Carbon dioxide levels in the atmosphere have increased significantly since 1750. NOAA Climate.gov, Data: NCEI

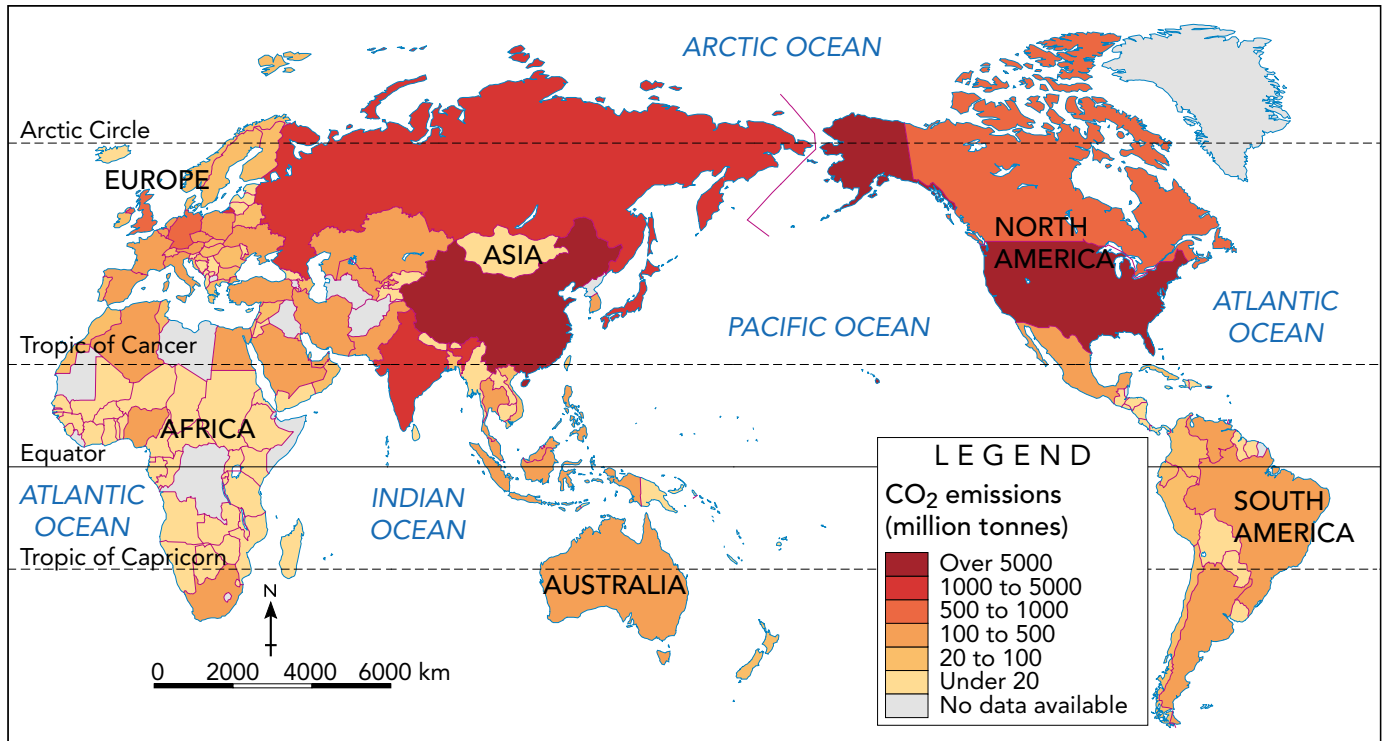


Figure 2 Global CO₂ emissions by area

the air, contributing to the increase in carbon dioxide levels. This increase in CO₂ production and decrease in absorption has resulted in an overall increase in the amount of carbon dioxide present in the atmosphere (Figure 1). Figure 2 shows which parts of the world emit the highest amounts of carbon dioxide.

Natural sources of methane gas in the Earth's atmosphere include the decay of organic materials in wetlands, termites, emissions from the oceans and the melting of methane hydrates, which are frozen forms of methane found in the ocean floor. Human activity also produces methane through energy production, increased emissions from livestock (e.g. cattle), landfill, biomass burning and waste treatment. The increase in these greenhouse gases has resulted in more heat being trapped in the atmosphere (Figure 4). Figure 5 shows how global temperatures have changed since 1900.

Melting sea ice

The ocean is very important in the regulation of global temperatures. It is a carbon sink, absorbing carbon, but it also absorbs up to 90 per cent of the solar radiation that hits the ocean. As it warms, ocean water is less able to

absorb solar radiation. The warmer water also causes sea ice to melt.

Sea ice is vast, shiny and bright white; it acts as a big mirror that reflects the Sun's radiation back out to space, once again keeping the Earth cooler (Figure 3). When this ice melts, more heat is absorbed by the water, increasing its temperature. The warmer water heats the atmosphere above it, driving a cycle that increases global temperature even further.



Figure 3 Arctic sea ice reflects heat from the Earth.

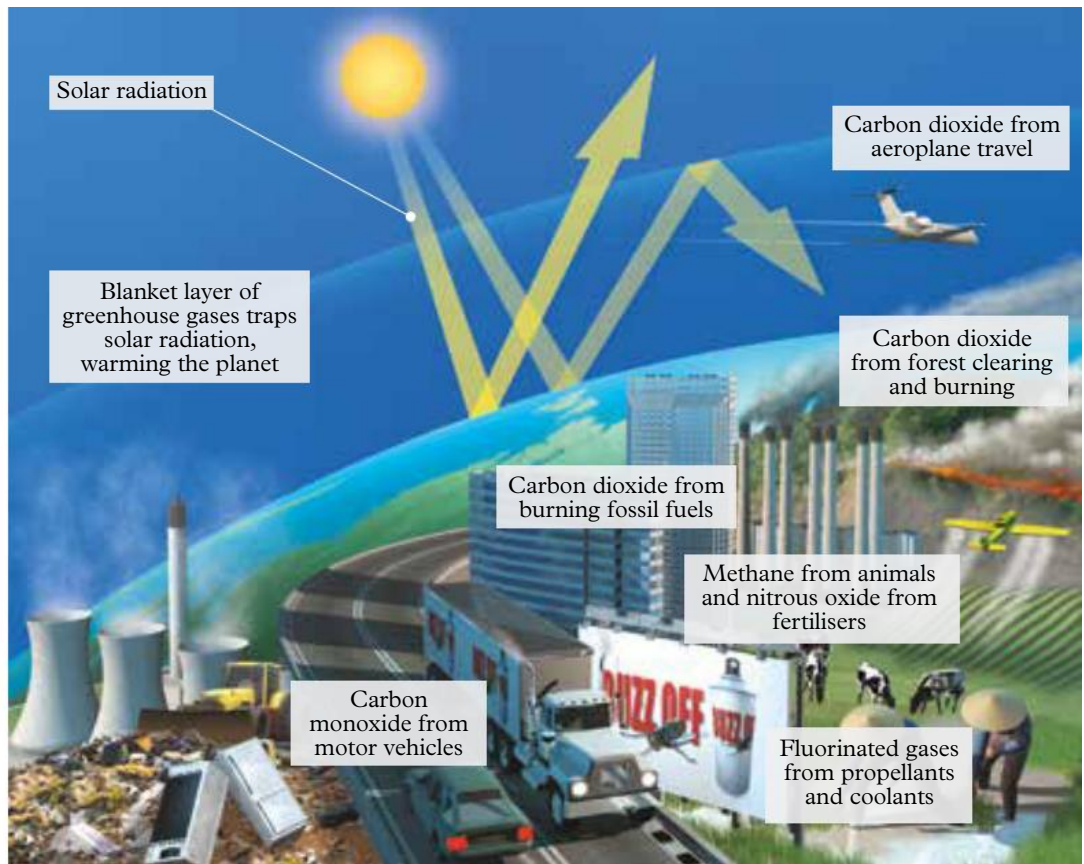


Figure 4 Factors contributing to human-induced climate change

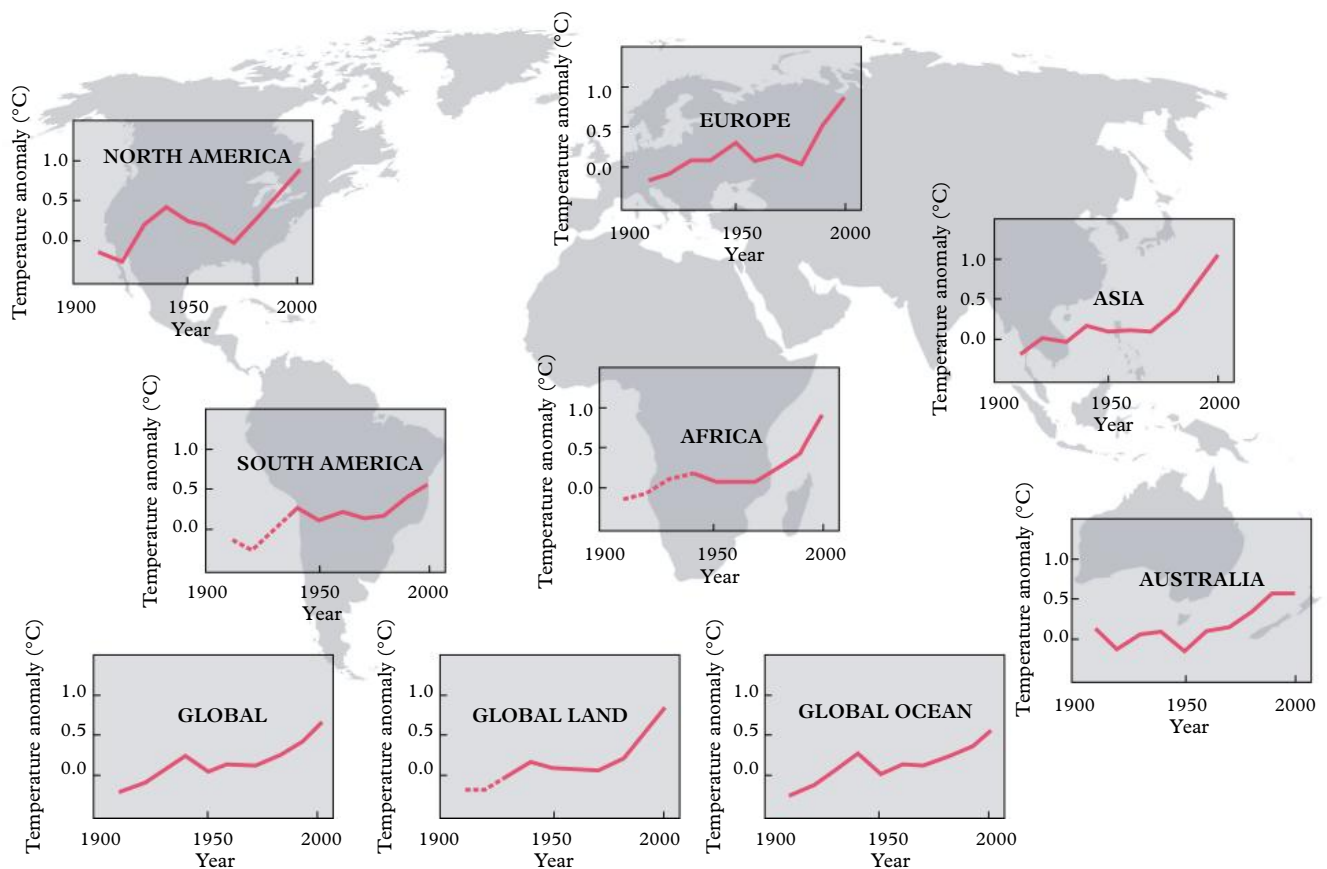


Figure 5 Global changes in temperature since 1900

Melting permafrost

Permafrost is permanently frozen ground that stores carbon from plant material frozen during the last Ice Age. Scientists have been measuring the temperature of the permafrost in Siberia for over 150 years and they have noticed an upwards trend. This means the ice is getting close to melting temperature (0°C) (Figure 6). Scientists believe that as much as two-thirds of the Earth's permafrost could disappear by 2200.

If the Earth's permafrost does melt, it will release thousands of years' worth of carbon into the atmosphere. This would equate to roughly as much as half of all fossil fuel emissions to date from when the world became industrialised.

Rising sea levels

The gravitational pull of the Moon (and Sun), together with the rotation of the Earth, mean there is a high tide approximately every 11 hours. Over many centuries, average water levels have varied. An Ice Age traps water in glaciers and sea ice, exposing land bridges for animals to migrate. These changes are very slow, taking thousands of years to affect sea levels. Over the last 100 years, there has been a dramatic change in sea levels as a result of enhanced greenhouse effect melting ice at the polar ice caps (Figure 7).

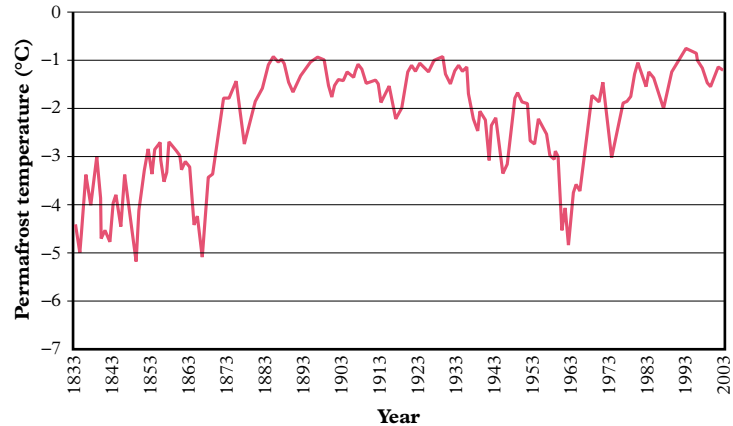


Figure 6 Historical measurements of Siberian permafrost temperatures at 5 m depth suggest that the permafrost is becoming warmer.

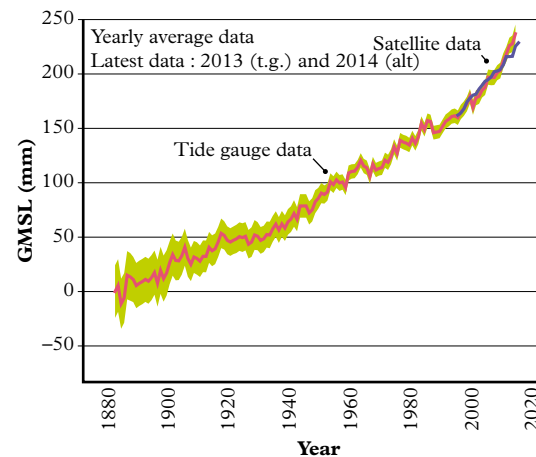


Figure 7 The CSIRO measured the Global Mean Sea Level (GMSL) from coastal tidal gauges and satellite data from 1880 to 2014. The overall trend indicates a consistent rise in sea levels.

6.5 Check your learning

Remember and understand

- Identify** the two most significant carbon-containing greenhouse gases.
- Explain** why the natural greenhouse effect is actually good for life on Earth.
- Identify** how much the temperature on Earth has risen over the past century.
- Define** the term 'permafrost', and **explain** why it will add to greenhouse gas emissions if it melts.

Apply and analyse

- Explain** why climate scientists compare trends over many decades rather than data for one or two years.

- Climate-change deniers suggest that the increase in sea levels is part of a normal cycle. **Compare** the timescale of previous global warming events to current climate change caused by the enhanced greenhouse effect.

Evaluate and create

- Examine** the data shown in this topic. Use the data to support your opinion of the validity of global warming caused by the enhanced greenhouse effect.

6.6

Climate change has widespread effects

In this topic, you will learn that:

- enhanced climate change will increase the number of extreme weather events
- rapid changes in climate may result in a loss of biodiversity.

The Earth's global systems are in a delicate balance. The small changes in the average global temperature can have different effects depending on the location. An average change of 0.95°C globally has meant a change of 3°C in the Antarctic in the last 50 years. This is impacting the speed and amount of ice melt, which affects the currents and the flow of nutrients in the ocean. The change is also happening so fast that many organisms will not have time to evolve.

Extreme weather events

The number of extreme weather events around the world is increasing. Warmer oceans will result in increased water vapour in the atmosphere. Rapidly rising hot air causes stronger winds. Scientists predict 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 category 4 or 5 has risen by 15 per cent over the past 20 years. We can also expect to see an increase in the loss of human lives as a result.

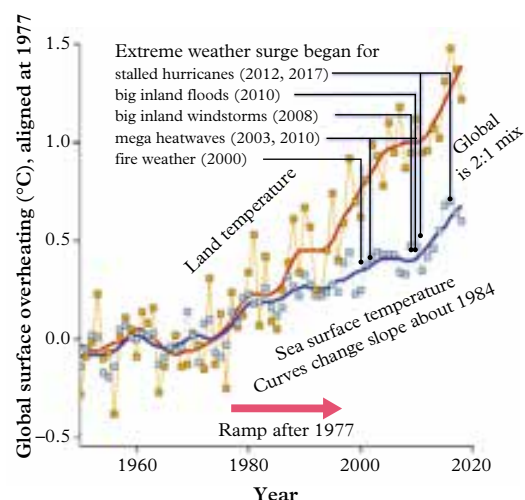


Figure 2 Heatwaves are lasting longer than they did 50 years ago. NASA GISTEMP V4 Foundation.org



Figure 1 The aftermath of a cyclone; the number of severe cyclones is increasing.

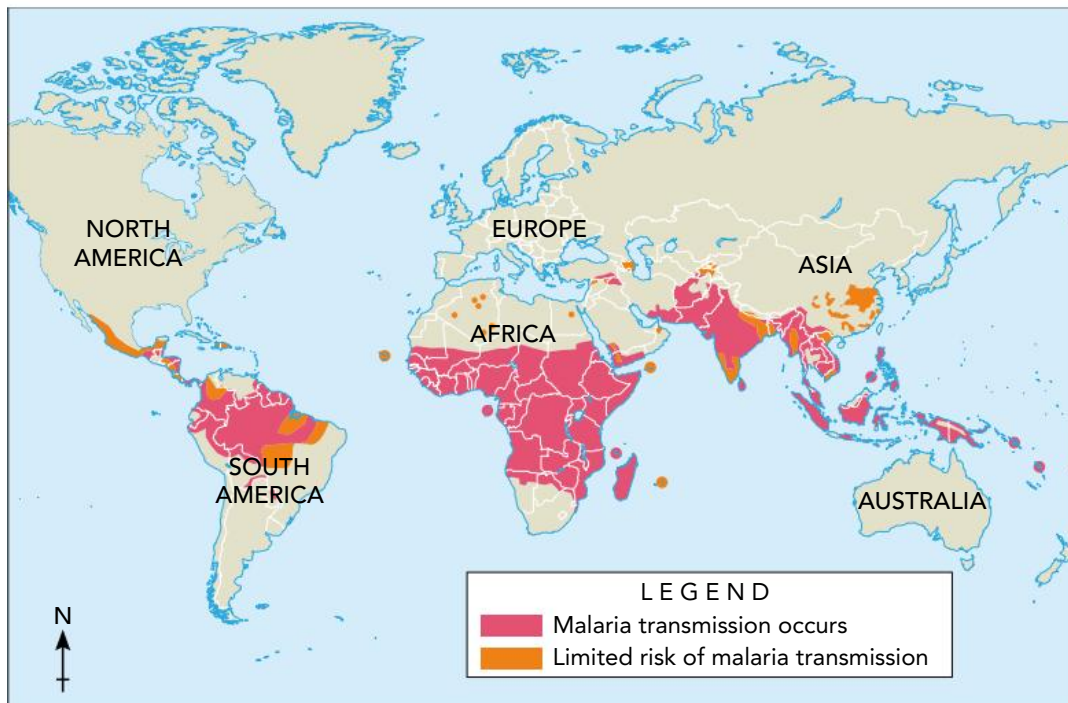


Figure 3 Countries or areas at risk of transmission of malaria, 2010

Health and disease

Higher temperatures in summer have increased heat-related deaths. Even though the temperature has risen by less than 1°C, the heatwaves are lasting longer, causing people to become more dehydrated, and resulting in heart strain and disrupted sleep. 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 3). 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, and contributing to increased deaths.

Loss of biodiversity

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 (Figure 5). 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. 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 observed.

Australian native plants and animals are well adapted to year-to-year climate fluctuations, such as floods and droughts, but often they can only survive within a narrow range of temperatures. This means that many species and ecosystems could be highly vulnerable



Figure 4 Cities cause a lot of pollution, which affects the global climate.

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 with a 1°C increase in temperature. 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.

Deep ocean currents and climate control

Within the oceans are large deep ocean currents that act like conveyor belts to churn heat through various parts of the world and regulate temperature (Figure 6).

Ocean currents have the important job of moving warm water from equatorial regions towards the poles; the water then cools and this colder water travels from the poles back to the warmer areas of the Earth. These large ‘conveyor belts’ of water are driven by differences in temperature and salinity. Colder water is dense and heavy, and it moves towards the ocean floor; warmer water is less dense and moves up towards the surface, completing the up-and-down movement, like a conveyor belt. 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. Therefore, the remaining water is more concentrated in salt and sinks 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 climate changes. 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 over 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 small changes in the temperature of the Antarctic region will result in large changes in the climate of all parts of Australia.



Figure 5 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.

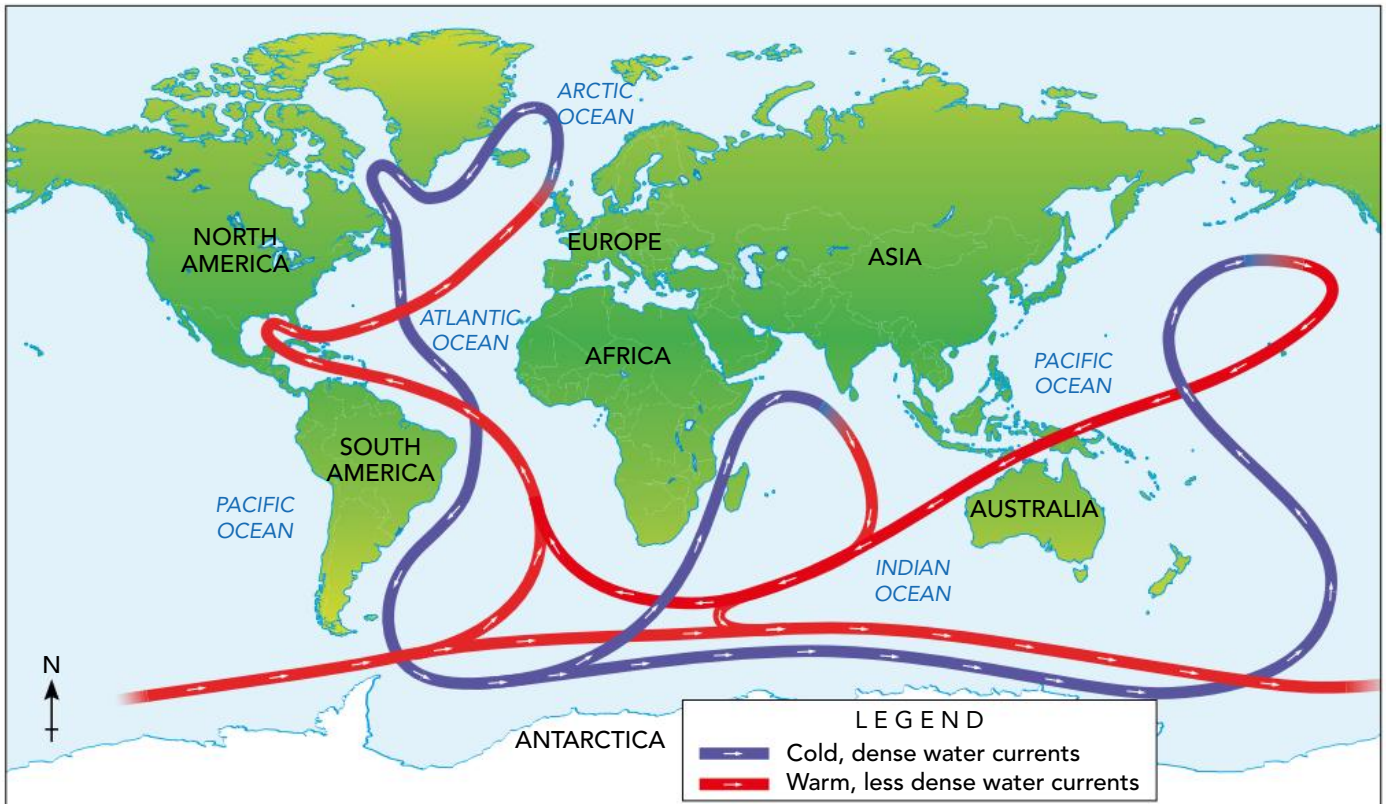


Figure 6 The path of the ocean 'conveyor belt', in which differences in temperature and salinity drive the movement of large currents of water.



Figure 7 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.

6.6 Check your learning

Remember and understand

- 1 **Define** the term 'extreme weather event'.
- 2 **Explain** why an increase in the number of cases of malaria is expected as a result of enhanced global warming.
- 3 **Explain** how the loss of one species can affect other species.

Apply and analyse

- 4 **Explain** why ocean currents are responsible, in part, for global temperature.

- 5 **Explain** how the temperature of the Pacific Ocean can affect Australia's climate.

Evaluate and create

- 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 whether the statement is correct).

6.7 Humans can impact climate change

The idea of climate change (previously called global warming) was first raised by the scientific community in 1977. As a result, scientists around the world began to coordinate their research in the World Climate Research Program. By 1983, the enhanced greenhouse effect was becoming a political issue. Currently, global warming is seen as a worldwide problem and this has influenced the focus of scientific research.

carbon tax

a tax levied on the carbon content of fuels used by businesses or homes

carbon trading scheme

the process of allocating a set limit of carbon credits to businesses, which can then trade the credits

Kyoto Protocol

In 1997, an international treaty called the Kyoto Protocol was signed by many of the countries that are part of the United Nations. This document stated that global warming exists and that it is a result of carbon dioxide emissions arising from human activity.

The countries that signed the protocol agreed to start working to reduce carbon

emissions by 2005. Australia ratified the agreement in 2007. This required the Australian Government to limit its average annual greenhouse gas emissions during 2008–2012 to 108 per cent of its emissions in 1990. In 2012, the Protocol was amended to allow countries to extend the commitment to 2020, to allow time to create a new comprehensive climate treaty that would require all countries to reduce their emissions of greenhouse gases.

Paris Agreement

In 2015, a legally binding agreement was signed by all nations (rich, poor, developed and developing) to greatly reduce the amount of greenhouse gases that they produced. It has a system of monitoring and reporting the targets set by individual countries every five years. Australia has currently agreed to reduce its greenhouse gas emissions to 26–28 per cent below 2005 levels by 2030.

Reducing carbon emissions

Many governments are encouraging industries in their countries to reduce carbon emissions. Some governments are charging a fee for each tonne of carbon a business emits. This is often called a **carbon tax**. Other governments have instigated a **carbon trading scheme** where each business is allowed to release a predetermined amount of carbon emissions.

If a company needs to release more carbon dioxide or methane as part of their production process, then they must buy an allocation from another company. This also allows other industries to actively extract carbon dioxide from the atmosphere in order to sell 'carbon credits'. One carbon credit is often equivalent to one tonne of carbon dioxide.



Figure 1 The use of renewable energy, such as wind power, is one way to reduce carbon emissions.

Geosequestration

The capture and storage of carbon dioxide underground is called geosequestration. This process, often employed by oil companies, involves capturing carbon dioxide from power station chimneys, separating it and compressing it into a liquid. The liquid is then pumped into depleted oil or gas wells and sealed with a solid plug of thick clay.

Carbon farming

Plants remove carbon dioxide from the air as part of photosynthesis. This carbon dioxide is converted into sugars and proteins that are then used by the plant to grow. Therefore, the greenhouse gas becomes part of the plant's structure. The carbon is considered to be locked in the plant for as long as it lives. For some trees this can be hundreds of years. Carbon farming is the process of growing plants that are not harvested for firewood, building or any other purpose (Figure 2).

Reducing methane production

Methane, another greenhouse gas, is often produced as a result of grass fermenting in a cow's stomach. Our increasing global population has meant a need for more food (including meat). This has resulted in more cattle being farmed and, therefore, more methane being released into the atmosphere. Microbiologists at the University of Queensland are studying ways to modify the

bacteria present in the stomachs of cows so that they do not produce as much methane. The model they use is the bacteria found in the foregut of kangaroos. This particular species of bacteria produces mainly acetic acid as a waste product. This acetic acid is then digested further by the kangaroo. It is hoped that the way these bacteria digest grasses can be mimicked by the bacteria in a cow, thereby reducing the emission of the greenhouse gas.

Small changes, big differences

There are many ways each person can reduce their climate impacts. These include:

- » using public transport or car pooling
- » switching off electrical appliances
- » using renewable energy such as solar panels
- » buying local produce, which prevents fossil fuels being used to transport food long distances
- » reducing, reusing and recycling items to prevent them going into landfill and generating methane.

Our ability to make these changes is affected by social factors. A country with a low socioeconomic population will consider increasing wealth to be more important than future environmental concerns. The challenge is to support these countries in considering larger global issues as well as local issues.



Figure 2 Carbon farming removes carbon from the atmosphere and locks it away for hundreds of years.

6.7 Develop your abilities

Scientific communication

Presenting data to an audience can take many forms. An increasingly common way to present important information is an infographic. Infographics are visual ways to present data so that the viewer can easily see the patterns. This can be through the use of graphs, pictures and important figures.

- 1 Select some of the key information you have learnt about climate change and plan an infographic for your peers.
 - a **Decide** on the 1–2 key ideas that you want to present in your infographic. This should be reflected in the pictures and data that you use on the infographic.
 - b **Identify** data (graphs or tables) in this chapter that support the key ideas.
 - c **Identify** how you can present this data in a simple and effective manner. Use pictures of different sizes to represent different values (Figure 3).

- d Write the key ideas in a short phrase or sentence so that they are obvious to the viewer.



Figure 3 Data such as increasing storm strength or biodiversity can be represented in different ways.

REVIEW 6

Multiple choice questions

- 1 Select the best definition for the lithosphere.
A the outermost rocky layer of the Earth including the mantle and crust
B the layer of gases that surrounds Earth and other planets
C the intersection between the atmosphere, hydrosphere and biosphere
D the collection of all the Earth's water
- 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 Which of the following would not reduce carbon emissions?
A charging a carbon tax
B using public transport
C using solar energy
D using fire instead of electricity

Short answer questions

Remember and understand

- 4 **Identify** the layer of the Earth where the tectonic plates are found.
- 5 **Identify** three gases that are found in our atmosphere and **explain** why they are important to life on the Earth.
- 6 **Describe** a drought and **identify** which sphere is responsible.
- 7 **Explain** how the lithosphere contributes heat to the atmosphere.
- 8 **Identify** the largest reservoir of oxygen on Earth.
- 9 **Explain** why the cold water from melted sea ice sinks to the bottom of the ocean.
- 10 **Describe** three ways that increased industrialisation, particularly since the nineteenth century, has affected ecosystems.
- 11 **Describe** the most significant way in which humans have affected ecosystems.
- 12 **Describe** two predicted outcomes of rapid climate change.
- 13 **Contrast** the greenhouse effect and the enhanced greenhouse effect.

Apply and analyse

- 14 The hydrosphere can have a huge effect on the other spheres. Australia is prone to devastating droughts when there is not enough water available for the needs of its people or wildlife.
a **Describe** how drought affects the biosphere.
b **Describe** how drought affects the atmosphere.
- 15 **Contrast** water and water vapour. (HINT: Can both be found in the atmosphere?)
- 16 **Explain** why it is warmer near the equator than elsewhere on the Earth.
- 17 The northern bettong is a very small, endangered nocturnal marsupial (Figure 1). It is an omnivore that eats small invertebrates, herbs, grasses and a species of fungus that makes up approximately 45 per cent of its diet. Northern bettongs were once widely distributed throughout Queensland. However, there are now only three populations left along the western edges of the wet tropics of north Queensland.

Investigate the northern bettong on the internet.

Describe the human activities that are contributing to the northern bettong being listed as endangered.



Figure 1 The northern bettong is an endangered species.

- 18 The glaciers on Mount Kilimanjaro in Tanzania are disappearing eight times faster than 20 years ago due to climate change. **Explain** how cloud cover can affect the atmospheric temperature and the melting of glaciers.
- 19 **Describe** how ocean currents affect the climate.

Evaluate

- 20 The biosphere includes parts of the atmosphere, lithosphere and hydrosphere. **Identify** two elements of the biosphere you may find in each of these three spheres.
- 21 **Compare** water currents and air currents.

22 Identify what 'H' and 'L' represent on a weather map. **Describe** how they are formed and the type of weather they represent.

23 The human population was fairly stable until about 1 CE. Then it started to grow, and its growth accelerated until it almost reached an exponential rate. In the past century, the human population has almost quadrupled. **Describe** the likely effects of the population increase on world ecosystems.

24 Evaluate the effects of melting permafrost on climate change (by defining 'permafrost', describing the effects of melting permafrost on Earth's spheres, and deciding whether these effects will contribute to climate change).



Figure 2 Melting permafrost can impact Earth's spheres.

Social and ethical thinking

25 Over 80 per cent of the Earth's energy resources are non-renewable and declining. In the twentieth century, most energy use was concentrated in a few nations that make up only a small proportion of the Earth's population. The seven largest economies at the beginning of the twenty-first century (with 10 per cent of the global population) used approximately 45 per cent of the total primary energy supply. Yet, approximately 2 billion people on Earth do not have access to electricity. In a group, **discuss** the ethical fairness of this distribution.

Critical and creative thinking

- 26** Draw a diagram that identifies the way phosphorus cycles through the biosphere and lithosphere.
- 27** Construct a chart or table that describes environmental carbon sinks and carbon producers.
- 28** Draw a mind map showing the potential connections and dependencies between the four spheres of the Earth and their components. **Identify** as many links as possible.

29 Imagine you had to reduce your energy impact on the environment. Look at all the appliances and gadgets in your home. **Identify** 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 you could live without.

30 The Earth's climate and weather are the result of global interactions between systems and cycles. **Evaluate** how this supports the argument that logging in any country affects everyone else on the planet (by describing how trees contribute to the atmosphere, hydrosphere and biosphere, describing how the sphere in one country affects other countries, and describing how the spheres affect weather and climate).

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.

» Responding to climate change

The Paris Agreement is an agreement between countries that aims to reduce greenhouse gas emissions in the atmosphere to 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 whether Australia will be able to meet its commitment. Describe how you could contribute to this target.

» Peak oil

Our society runs on fossil fuels. Investigate the concept of peak oil and what implications it will have for our lives in the not-too-distant future.

» Climate change: Global warming or Ice Age?

Like the Earth, the Sun demonstrates cycles of behaviour. One such pattern that has been identified is a period during which sunspots are absent. The next predicted period of sunspot absence is around 2020 and could last 14 years. The lack of sunspots could result in a global temperature decrease for the Earth. Investigate the potential impact of this solar cycle on the Earth's climate.

Reflect

The table below outlines a list of things you should be able to do by the end of Chapter 6 'Global systems'. Once you've completed the chapter, use the table to reflect on your ability to complete each task.

	I can do this.	I cannot do this yet.
Identify the differences between the lithosphere, atmosphere, hydrosphere and biosphere. Explain how each sphere interacts with the others.	☐	☐ Go back to Topic 6.1 'The Earth's spheres are balanced' Page 134
Explain how water cycles through three states of matter based on the temperature of the globe. Explain how various weather patterns are created by the cycling of air around the globe based on global temperatures. Describe the Coriolis effect.	☐	☐ Go back to Topic 6.2 'The water cycle is a global cycle' Page 138
Explain how matter moves through the oxygen, nitrogen and phosphorus cycles.	☐	☐ Go back to Topic 6.3 'Matter cycles through the Earth's spheres' Page 142
Explain how matter moves through the carbon cycle and identify the key participants. Apply the carbon cycle to explain a carbon sink. Identify and describe the impact that humans have on the carbon cycle.	☐	☐ Go back to Topic 6.4 'Human activity affects the carbon cycle' Page 146
Explain the trend in increased temperature over time. Explain why greenhouse gas concentrations in the atmosphere are rising.	☐	☐ Go back to Topic 6.5 'Evidence supports the enhanced greenhouse effect' Page 148
Describe the effects that small increases in global temperature have on extreme weather events, health and disease, loss of biodiversity, and deep ocean currents and climate control.	☐	☐ Go back to Topic 6.6 'Climate change has widespread effects' Page 152
Recognise the importance of the Kyoto protocol. Explain how greenhouse gas emissions can be reduced by humans.	☐	☐ Go back to Topic 6.7 'Science as a human endeavour: Humans can impact climate change' Page 156

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What is the Big Bang?

7.1

Science as a human endeavour:
The universe was studied
by early Australians

7.2

The Earth is in the Milky Way

7.3

Stars have a life cycle

7.4

The galaxies are moving apart

7.5

Evidence supports
the Big Bang theory

7.6

Science as a human endeavour:
Technology aids cosmological
research

CHAPTER

7

THE UNIVERSE

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?)

7.1

The universe was studied by early Australians

While many people consider the ancient Greeks (400 BCE) to be the first astronomers, there is increasing recognition of early astronomers among the Aboriginal and Torres Strait Islander 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. Aboriginal and Torres Strait Islander peoples had many practical uses for what they observed in the night sky. It was their calendar and also an integral part of their culture and spirituality.

Aboriginal and Torres Strait Islander peoples' calendar

Constellations are groups of stars that form a picture in the night sky. To many groups among the Aboriginal and Torres Strait Islander peoples, the appearance of certain constellations at sunrise or sunset and how they tracked across the sky provided information on animal activity about when and what to hunt.

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 Aboriginal and Torres Strait Islander peoples' stories about the emu in the sky. However, to the people living on Wiradjuri country (central New South Wales) it is part of their calendar. When the emu, known as Gugurmin in Wiradjuri language, appears on the eastern horizon at sunset, then 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 who live 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 Aboriginal and Torres Strait Islander peoples living in the Gulf of Carpentaria,



Figure 1 The emu-shaped dark patch in the Milky Way tells Aboriginal and Torres Strait Islander peoples when it is time to hunt.

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 their seasonal calendar.

Farming by the stars

Aboriginal and Torres Strait Islander peoples also plan their farming by the stars. The 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. Although they use Tagai to tell the direction when navigating, they also use this constellation to identify the best time to start planting their 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 their seasonal calendar.

Stories in the stars

Aboriginal and Torres Strait Islander peoples are diverse and live in all parts of Australia. Each tribal or national group has its own language and stories of the stars. Many of the stories are used to pass on information or explain laws and traditions.

The constellation of stars called Orion by Europeans has different stories told about it by the different peoples. The Yolngu people of the Northern Territory call this constellation Djulpan. They tell 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

were forbidden to eat any king-fish. The brothers caught king-fish after king-fish but had to throw them all back. Eventually one of the brothers became so hungry he ate the king-fish. The Sun-woman (Walu) saw him kill the king-fish and in anger, created a water spout that lifted the brothers up into the sky.

To the Napaljarri-warnu Jukurrpa peoples 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 acted as a warning for the two groups to respect their differences.

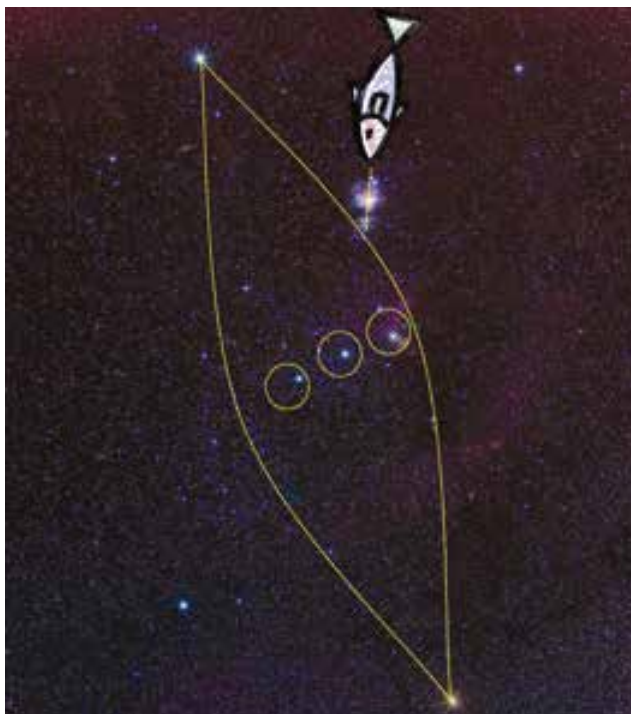


Figure 2 Different stories are used by Aboriginal and Torres Strait Islander peoples to explain the same constellation. The Yolngu people call the Orion constellation Djulpan.

7.1 Develop your abilities

Early scientists

For thousands of years, the Aboriginal and Torres Strait Islander peoples have observed and recorded the recurring patterns of star movement in the sky. Developing these stories required 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 Aboriginal and Torres Strait Islander peoples 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
 - > recording and processing
 - > analysing and evaluating
 - > communicating

7.2

The Earth is in the Milky Way

In this topic, you will learn that:

- 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.

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), 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 km 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 distance that light travels in 1 year

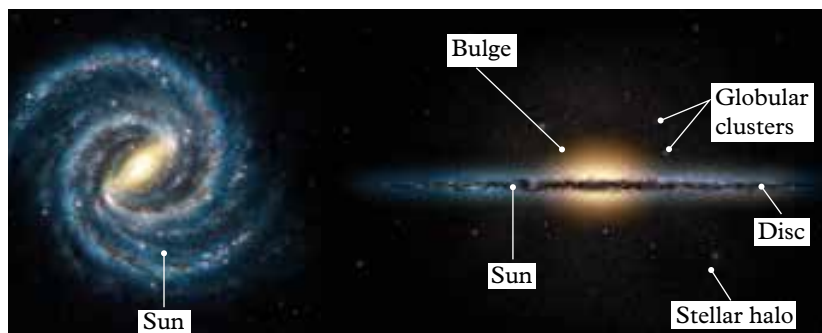


Figure 1 Left: The Earth is located in the spiral galaxy called the Milky Way. Right: When viewed from the side, the galaxy is a disc shape that can be viewed across the night sky on Earth.

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 1 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.

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.

nuclear fusion

a reaction in which two lighter atomic nuclei fuse to form a heavier nucleus, releasing energy

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

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 $9\,500\,000\,000\,000 = 9.5 \times 10^{12}$ km/light-year

Distance to Large Magellanic Cloud = $(9.5 \times 10^{12}) \times$ light-years of Large Magellanic Cloud
 $= (9.5 \times 10^{12}) \times (1.8 \times 10^5)$ km
 $= 9.5 \times 1.8 \times 10^{(12+5)}$ km
 $= 17.1 \times 10^{17}$ km

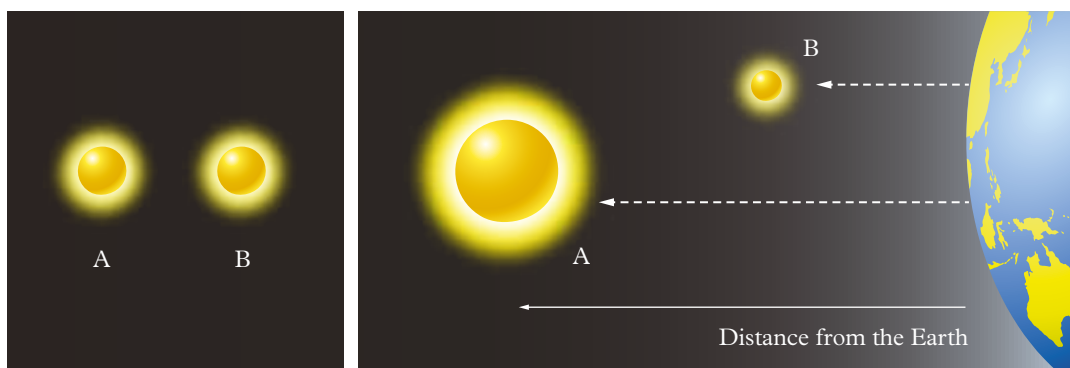


Figure 2 Although both stars A and B have the same apparent magnitude, A is more luminous and has a higher absolute magnitude than B.

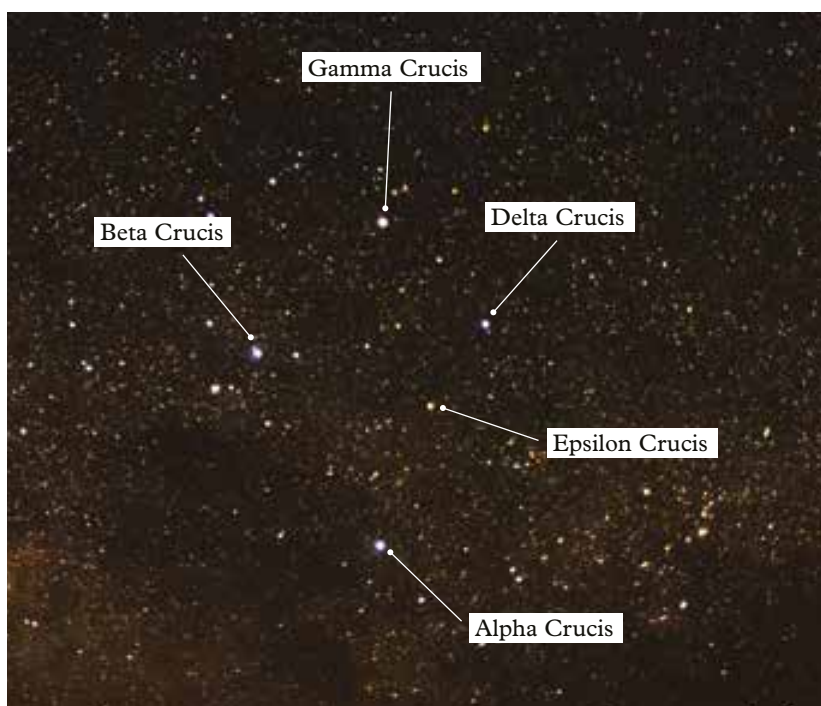


Figure 3 The Southern Cross constellation

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

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.

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.

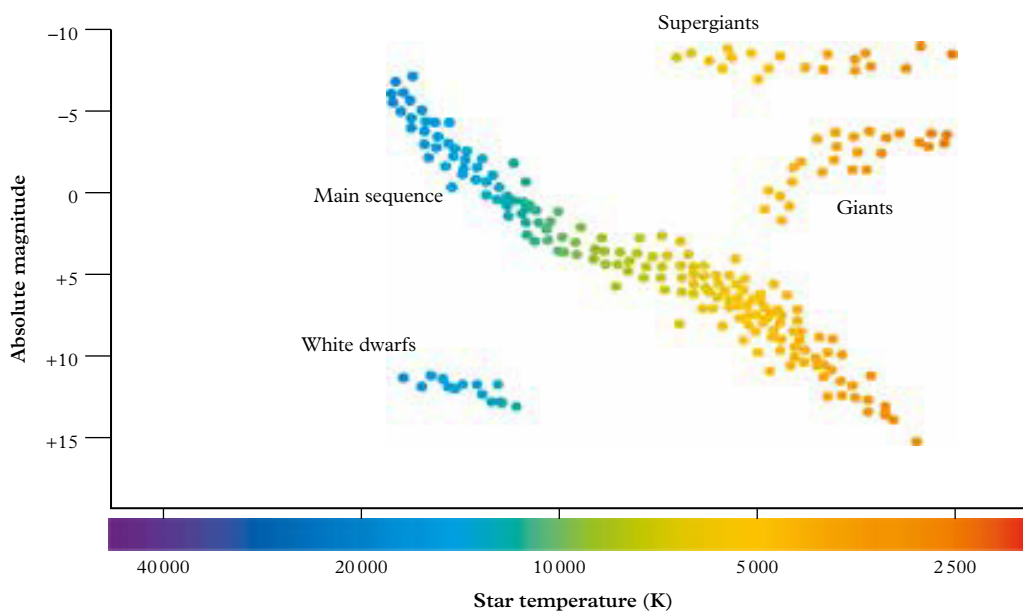


Figure 4 A Hertzsprung–Russell diagram

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 (i.e. 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 (e.g. in January and then six months later in July), its position relative to other stars may appear to be different (Figure 5).

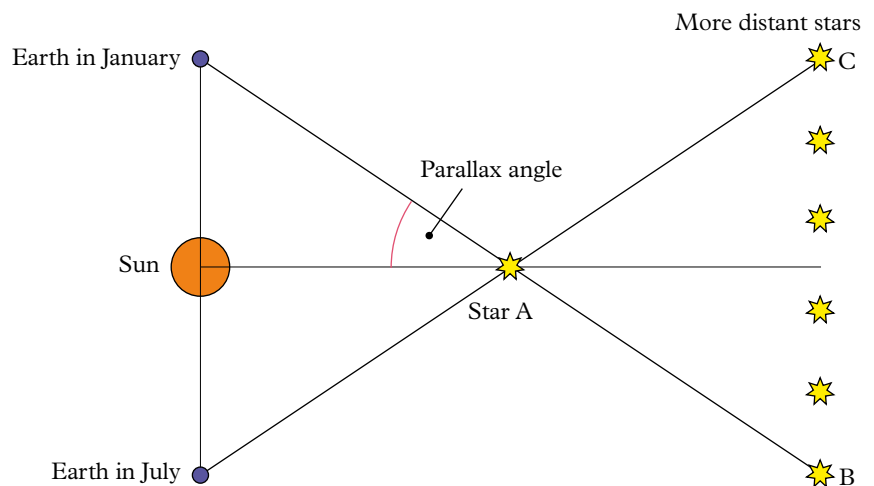


Figure 5 Measuring the distance to stars using stellar parallax. In January, star A, a close star, is in line with a more distant star, star B, but in July it is in line with star C. By measuring the parallax angle and knowing the radius of the Earth’s orbit, the distance to star A can be calculated.



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

Remember and understand

- Define** the following terms.
 - star
 - galaxy
 - light-year
- Identify** the name of the galaxy that contains our solar system.
- Describe** a main sequence star.
- Define** the term ‘parallax’.
- Draw the Southern Cross constellation and **describe** what you know about the different stars in the constellation.

- Compare** absolute magnitude scale and apparent magnitude scale.

Apply and analyse

- Calculate** the distance (in km) to Beta Centuri at 525 light-years away from the Earth.
- Explain** why the Milky Way galaxy appears so large in the night sky compared with other galaxies.
- If a star that was 20 light-years away exploded right now, **calculate** when we would see it exploding.

7.3

Stars have a life cycle

In this topic, you will learn that:

- 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 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.



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

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. 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 1 This image of Kn 61, a newly 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.

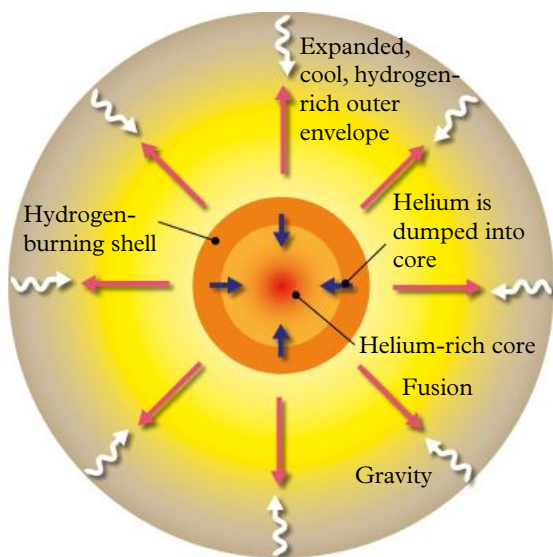


Figure 2 How a red giant star forms

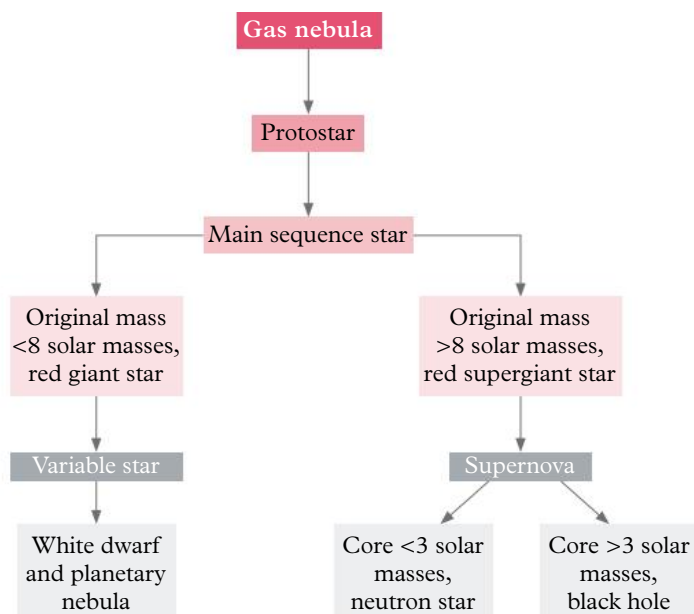


Figure 3 The life cycle of a star

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

Remember and understand

- 1 **Identify** the event between gas atoms that marks the birth of a star.
- 2 **Describe** a red giant star.
- 3 **Define** the term 'nebula'.
- 4 **Explain** the forces involved in hydrostatic equilibrium.
- 5 **Identify** what is left after a supernova.
- 6 **Compare** a white dwarf and a black dwarf.

Apply and analyse

- 7 Draw a flow chart to show the life cycle of a star the size of our Sun.
- 8 Our Sun is 1 solar mass. **Explain** 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. Draw a flow chart to show the life cycle of a blue star.

7.4

The galaxies are moving apart

In this topic, you will learn that:

- 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.

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 spectroscopy; 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

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. 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.



Figure 2 Edwin Hubble made his observations from the Hooker Telescope – an older, less powerful telescope than the Hubble Telescope shown here, which was named in his honour.

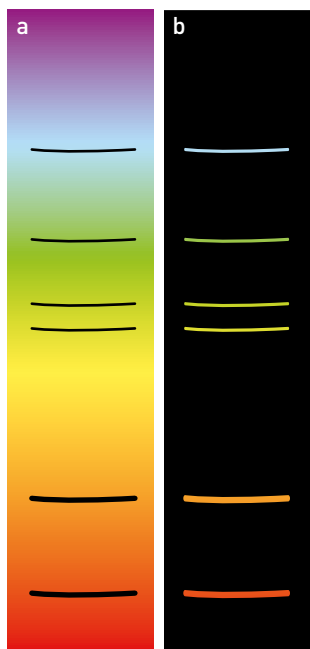


Figure 1 a Absorption spectrum and b emission spectrum of helium

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 3).

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 4). 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 (US)-born Australian Brian Schmidt. Their research determined the expansion of the universe is accelerating. As a result, Brian Schmidt was awarded a Nobel Prize in 2011.

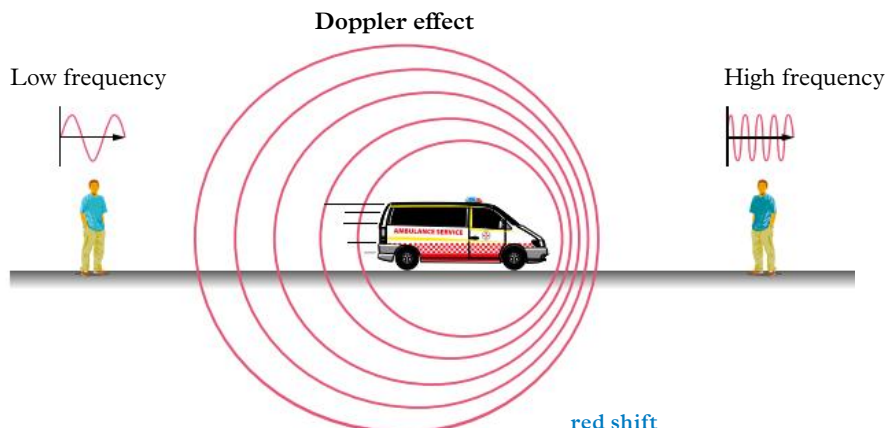


Figure 3 The Doppler effect

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

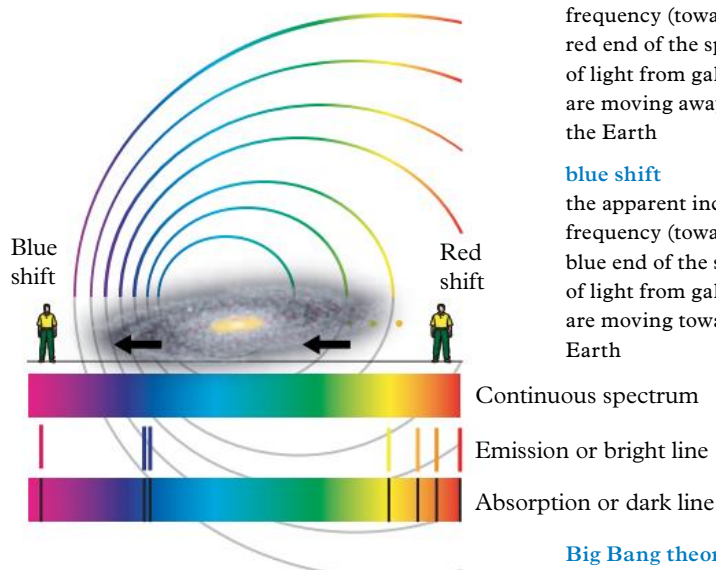


Figure 4 Red shift and blue shift

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

Remember and understand

- Describe** how you would identify an absorption spectrum.
- Explain** the Doppler effect.

Apply and analyse

- Identify** whether a racing car that has a higher pitch than normal (higher frequency) is travelling towards or away from you.
- Compare** the emission spectra and absorption spectra for helium.
- Explain** why red-shifted light shows that a galaxy is moving away from the Earth.
- Figure 5 shows the spectra observed from three stars. Star A is at a fixed distance from the Earth, whereas stars B and C are moving.

- Explain** what the dark lines on each spectrum represent.
- Explain** which star, B or C, is moving towards the Earth.

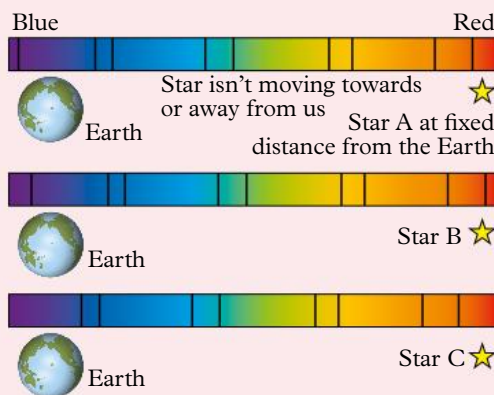


Figure 5 The spectra observed from three stars: A, B and C

7.5

Evidence supports the Big Bang theory

In this topic, you will learn that:

- 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

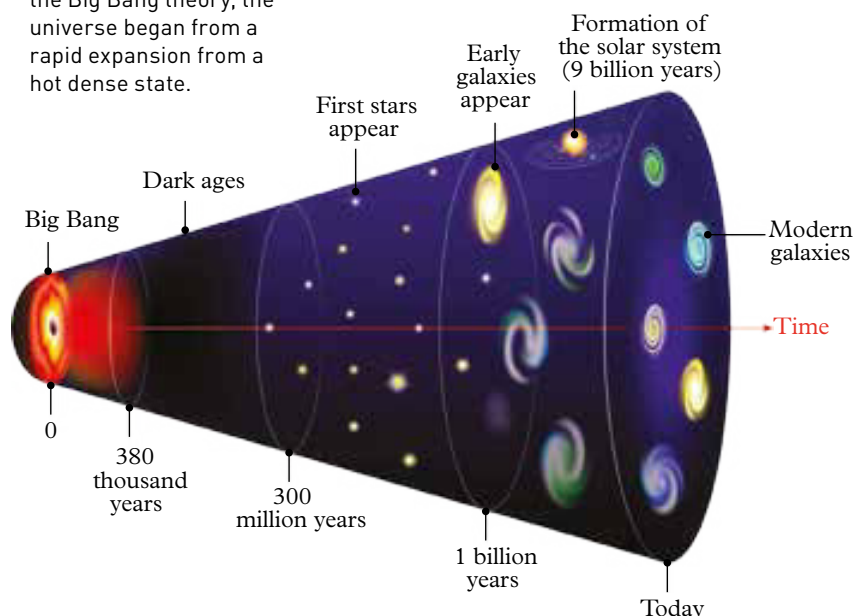
were moving. The speeds were enormous. In fact, it is not the galaxies themselves that are moving away; rather, space is expanding and taking the galaxies with it (Figure 1).

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.

Figure 1 According to the Big Bang theory, the universe began from a rapid expansion from a hot dense state.



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.



Figure 2 Arno Penzias (left) and Robert Wilson (right) in front of their horn antenna, with which they discovered cosmic microwave background radiation.

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

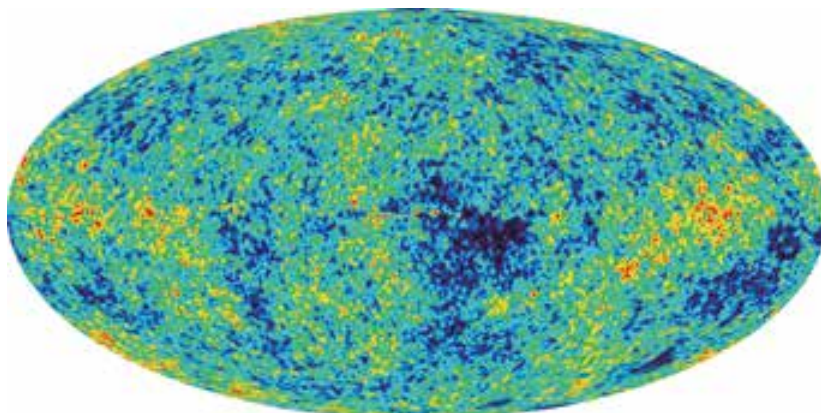


Figure 3 Fluctuations in the cosmic microwave background radiation are shown as temperature fluctuations over the sky. These fluctuations correlate with the formation of nearby matter.

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.

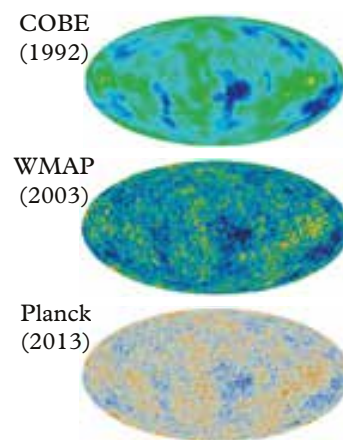


Figure 4 Images from the COBE (Cosmic Background Explorer), WMAP (Wilkinson Microwave Anisotropy Probe) and Planck satellites

7.5 Check your learning

Remember and understand

- 1 **Explain** why the Big Bang was not a bang at all.
- 2 **Describe** the events that occurred during the Big Bang.

Apply and analyse

- 3 **Define** the term 'cosmic microwave background radiation', and **explain** why its existence is important.
- 4 Cosmic microwave background radiation has been called 'ancient whispers'. **Explain** why this name is appropriate.

- 5 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.
- 6 **Describe** other evidence that supports the Big Bang theory.

7.6 Technology aids cosmological research

Australian Square Kilometre Array telescope takes shape in WA outback

BY GIAN DE POLONI

13 October 2014

A project to build one of the world's most powerful radio astronomy telescopes is taking shape in Western Australia's outback.

The \$160 million Australian Square Kilometre Array Pathfinder (ASKAP) is being built in a radio quiet area of WA's Murchison region, about a four-hour drive from the port city of Geraldton.

The project has seen the installation of 36 huge antenna dishes on Boolardy

Station, which will eventually work together to survey large areas of sky to help scientists understand how galaxies have formed and evolved.

CSIRO scientist Lisa Harvey-Smith said although only six of the dishes were active, the images that had been taken so far were remarkable.

'The latest picture we've taken has almost 2000 galaxies in it, which is incredible,' she said.

'It's kind of a wide field image of the sky.

'Once we've got 36 telescopes, we'll be able to do a huge survey of the entire night's sky and see millions of new galaxies, black holes and things in the very distant universe that no one's ever seen before.'

She said the question of what exactly the telescope will be able to see in distant space was a complete mystery.

'The discovery potential of this telescope is quite amazing,' she said.

'Even now, we've been able to look at galaxies that are actually older than our Earth – which is a pretty incredible thing – and look into the distant universe to search for galaxies that were actually around billions of years ago and may not exist anymore.'

Dr Harvey-Smith said the giant dishes were picking up radio waves being emitted from objects in space.

'Our eyes can't see radio waves, so the data that we get is just boring ones

and zeros, but we actually use clever computer algorithms and a super computer that's based in Perth to make the images into real optical type images that we can see,' she said.

Telescope will view area 200 times size of moon

Project director Antony Schinckel said images produced so far were stunning.

'The thing about ASKAP is it's a completely new type of telescope – it's never been built before – so a lot of this very early work is simply understanding exactly how to use it,' he said.

'Many of our staff said "look, it's not worth trying to do much with just the six dishes because we won't be able to see much", but they've been completely shown to be wrong.

'Trying to predict ahead to what we're going to see with 36 at the full capability is really hard but we'll be able to very quickly map really big areas of the sky and by really big, I mean in a single snapshot we'll be able to see an area around about 200 times the size of the full moon.

'There are still huge holes in our knowledge of how our universe evolved, where galaxies come from, how planets form and we expect ASKAP will be able to really help us answer a lot of that.'

Dr Schinckel estimated it would cost about \$10 million a year to keep the project going.

'We've had good support from the Government over the last few years and

Figure 1 Three ASKAP telescopes are trained towards the sky east of Geraldton. (Alex Cherney)



we believe the Government does see the positive impacts of these sorts of projects,' he said.

'There's the pure science side, there's the very tight international collaboration aspect, there's the technology spin off, there's training of engineers and scientists who may or may not stay on in astronomy but may go on to work in other fields.'

ASKAP is viewed as a precursor to the future \$1.9 billion Square Kilometre Array, which will be built in both the Murchison and South Africa in 2018, with input in design and funding coming from 11 countries.

The SKA is expected to be the largest and most capable radio telescope.

Murchison ideal location for project

Dr Harvey-Smith said the isolation of the Murchison region made it the perfect place for the project.

'If you could imagine trying to listen for a mouse under your floorboards hearing tiny scratching noises, you don't want to be playing the radio very loudly in the background,' she said.

'It's the same type of thing with the radio telescopes.

'We're looking for tiny, tiny signals incredibly weak from galaxies billions of light years away.

'They're so weak we have to amplify them millions of times with specialist electronic equipment.'

Dr Schinckel said the communications infrastructure in place to support the telescope was unfathomable.

'The raw data rate we get from the telescopes is about 100 terabytes per second,' he said.

'To put that in context, that's about the entire traffic of the internet all around the world in one second.



Figure 2 This wide shot image taken from the ASKAP telescope over 12 hours shows distant galaxies. (CSIRO)

'Luckily the super computers we have on site can very quickly reduce the data back to a more manageable volume of around about 10 gigabytes per second.

'The sheer volume of that and the speed of which that raw data comes in is truly astounding.'

Dr Harvey-Smith said she could control the telescope from the comfort of her lounge room.

'As one of the research scientists, I can access the telescope from Sydney – from my house, on my laptop,' she said.

'We just send signals through the internet and tell the telescope what to do.

'It's pretty amazing that we can have a giant international scientific facility with very few people actually out there on the site.'

It is hoped the entire network of dishes will be fully operational by March 2016.

7.6 Develop your abilities

Communicating science ideas

The Australian Square Kilometre Array is still being completed in different stages. Each stage will add new stations with new antennas. The final structure will comprise 512 stations arranged around a large core with three spiral arms spread over 65 km. Each station will have 256 individual antennas.

1 **Investigate** the current structure that is available for research. 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 the 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 ASKAP.

REVIEW 7

Multiple choice questions

1 **Identify** the shape of the galaxy in Figure 1.

- A oblong
- B elliptical
- C regular
- D cubic



Figure 1 The Andromeda galaxy

2 Nebulae are clouds made of:

- 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.

Short answer questions

Remember and understand

- 4 **Describe** why scientists Penzias and Wilson won the Nobel Prize.
- 5 **Identify** the following statements as true or false.
 - 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.
- 6 **Explain** why light-years are used instead of kilometres as a unit of distance in space.
- 7 **Contrast** astronomy and astrology.

8 **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

- 9 **Explain** why it is difficult to judge the distance of a star by measuring only its brightness.
 - 10 **Explain** how the night sky enables us to look back in time.
 - 11 List the following in order of size from largest to smallest: neutron star, the Sun, white dwarf, red giant.
 - 12 **Compare** a white dwarf and a red giant.
 - 13 **Explain** why the ASKAP is an important tool for astronomers.
- ### Apply and analyse
- 14 **Describe** the Doppler effect.
 - 15 **Explain** the link between Hubble's observations and the Doppler effect.
 - 16 **Explain** why you cannot see stars (apart from the Sun) during the day.
 - 17 **Contrast** the emission spectra and absorption spectra of an element.
 - 18 **Compare** red shift and blue shift.
 - 19 Draw a diagram to **explain** why different stars are visible from different places on the Earth's surface.
 - 20 **Describe** the evidence that supports the Big Bang theory.

Evaluate

- 21 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).
- 22 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.

23 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

24 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.

25 Explain why we do not use light-years for measuring distances within our solar system.

26 Many ancient cultures, including Aboriginal and Torres Strait Islander peoples, had beliefs about the origin of constellations based on observations. These observations would be used for cultural and farming practices. **Investigate** Aboriginal and Torres Strait Islander peoples' beliefs about constellations and how these have been used. **Evaluate** 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 2). 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 has improved our understanding of celestial bodies. Use ethical reasoning to **compare** the cost of this mission and how the money could have been spent on Earth.



Figure 2 The Dawn space probe is on an interplanetary cruise.

28 Watch the movie *Interstellar* and **investigate** how the discovery of gravitation waves would help us understand the nature of dark energy, which is causing the universe's expansion to accelerate. Have a class discussion about this.

Critical and creative thinking

29 Create a poster showing the fate of the Sun as it expands from its current size into a red giant and then as it contracts into a white dwarf. **Label** each stage and find photos from the internet to illustrate the process.

30 View a space movie. **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.

» Ion propulsion

The engines on some spacecraft use a unique, hyper-efficient system called ion propulsion. Define the term 'ion'. Evaluate whether 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.

» Australian observatories

The Parkes Radio Telescope is a well-known Australian telescope. Find out a brief history of this telescope and how it is used. The movie *The Dish* might be helpful in your research.

» Dark matter

Scientists think there is extra matter in the universe that is invisible. This is called dark matter. Compare ordinary matter and dark matter. Describe the evidence that scientists have for 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 until 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.

» 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.

Reflect

The table below outlines a list of things you should be able to do by the end of Chapter 7 'The universe'. Once you've completed the chapter, use the table to reflect on your ability to complete each task.

	I can do this.	I cannot do this yet.
Demonstrate an understanding of the significance of astronomy to the cultures, spirituality and calendars of Aboriginal and Torres Strait Islander 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 early Australians' Page 162
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 164
Relate the formation of stars and galaxies to the force of gravity. 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 168
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. Relate the amount of red shift of a galaxy to its speed and distance from Earth.	☐	☐ Go back to Topic 7.4 'The galaxies are moving apart' Page 170
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 172
Explain what the Australian Square Kilometre Array Pathfinder and the Square Kilometre Array are. Identify some possible benefits of the Square Kilometre Array to furthering our understanding of the cosmos.	☐	☐ Go back to Topic 7.6 'Science as a human endeavour: Technology aids cosmological research' Page 174

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How do we describe movement?

8.1

Displacement is change in position with direction

8.2

Velocity is speed with direction

8.3

Acceleration is change in velocity over time

8.4

An object in motion remains in motion until a net unbalanced force acts on it

8.5

Net force equals mass $\times$ acceleration

8.6

Each action has an equal and opposite reaction

8.7

Momentum is conserved in a collision

CHAPTER

8

MOTION

What if?

Speeding cars

What you need:

Stopwatches, trundle wheel



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.

What to do:

- 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

In this topic, you will learn that:

- 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.



Figure 1 Displacement indicates the direction of motion.

Distance and displacement

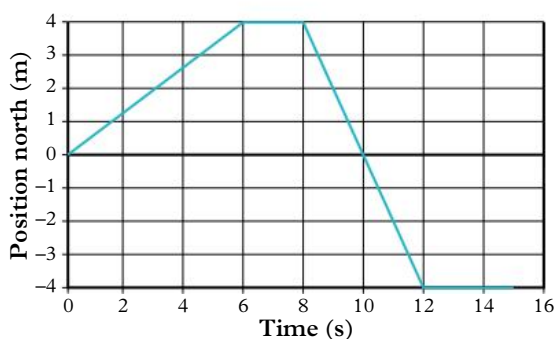
During a normal day, you may cover a considerable distance – on the way to school, on the way home and around school from classroom to classroom. However, at the end of the day you will most likely end up in exactly the same place as where you started – your bed! So, you could say that you haven't really 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.

magnitude
the size or extent of something

Figure 2 This position–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.



Position–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 position–time graph (also called a displacement–time graph). A position–time graph is a picture of the motion of an object. Position–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 position is always on the y -axis (Figure 2). 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 3 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.

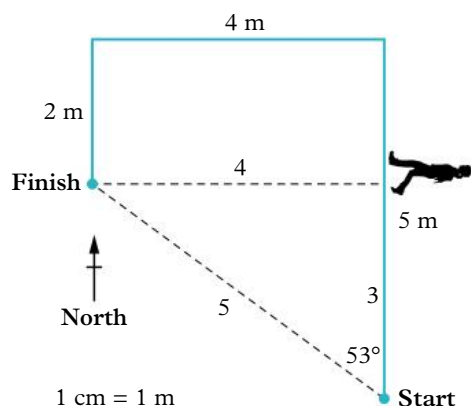


Figure 3 This person walks a total of 11 m. The displacement can be calculated by drawing a right-angle triangle and using Pythagoras' theorem. The final position of the person is 5 m north 53° west or 5 m on a bearing of 307° .

Worked example 8.1A: Calculating distance and displacement over time

The position–time graph shown in Figure 2 shows the movements of a person over 15 seconds.

- Calculate the distance they travelled.
- Calculate the displacement of the person.

Solution

- 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.
- 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.

- Calculate the distance travelled by the person.
- Calculate the displacement of the person from their starting point.

Solution

- The total distance travelled by the person can be calculated by adding all the distances together.
 $5 + 4 + 2 = 11$ m
- The displacement of the person must include the distance from their starting point and the direction (Figure 3).

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.

$$\cos \theta = \frac{\text{adjacent length}}{\text{hypotenuse length}}$$

$$\cos \theta = \frac{3}{5}$$

$$\theta = 53^\circ$$

The displacement of the person is 5 m, north 53 degrees west (an angle of 53 degrees in the west direction of the north/upwards line).

8.1 Check your learning

Remember and understand

- Describe** a motion that has zero displacement.
- Compare** displacement and distance.

Apply and analyse

- An object moves 14 m north and then 14 m south.
Calculate the distance that it has covered. **Calculate** its displacement.
- Compare** a vector quantity and a scalar quantity.
- 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.
- 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, draw this movement as a position–time graph.

- Consider** the graph in Figure 4.

- Describe** the motion shown.
- Calculate** the distance covered in the graph.
- Calculate** the displacement shown.

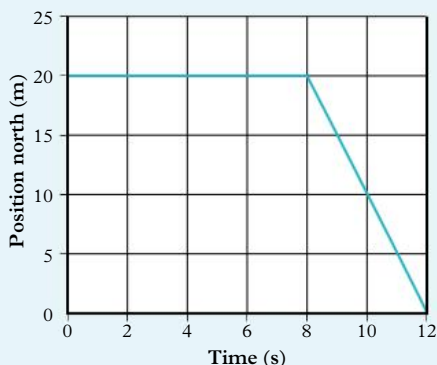


Figure 4
A position–time graph

8.2

Velocity is speed with direction

In this topic, you will learn that:

- 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.

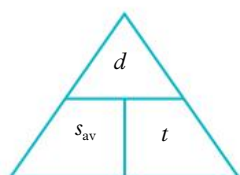
Average speed

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 position–time graph (Figure 3).



$$\begin{aligned} s_{\text{av}} &= \frac{d}{t} \\ t &= \frac{d}{s_{\text{av}}} \\ d &= s_{\text{av}} \times t \end{aligned}$$

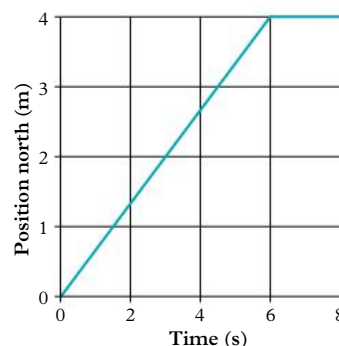


Figure 3 The speed of the object in this position–time graph can be calculated by determining the gradient of the graph.

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.

$$\begin{aligned} \text{Distance travelled } (d) &= s_{\text{av}} \times t \\ &= 5 \text{ m/s} \times 1.5 \text{ s} \\ &= 7.5 \text{ m} \end{aligned}$$

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.

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.

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 (see Figure 4).

$$\text{Average velocity } (v_{av}) = \frac{\text{displacement}}{\text{time}}$$

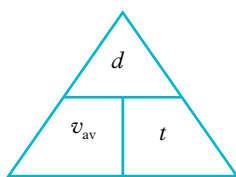


Figure 4 The average velocity triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

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 position–time graph, but the nature of the gradient indicates the direction. For example, if the gradient is a straight line and positive on a position–time graph, the velocity is constant or unchanging in the positive direction. If the gradient on a position–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

It is useful to represent an object's speed graphically. This is called a speed–time graph. In these graphs, speed is plotted on the y-axis and time on the x-axis. If the graph is sloping upwards then the velocity is increasing (becoming faster) in the north direction. If the gradient is negative (sloping downwards) towards the x-axis, then the velocity will be decreasing (slowing down) until it reaches 0 m/s. If the graph shows the object moving 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.

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.

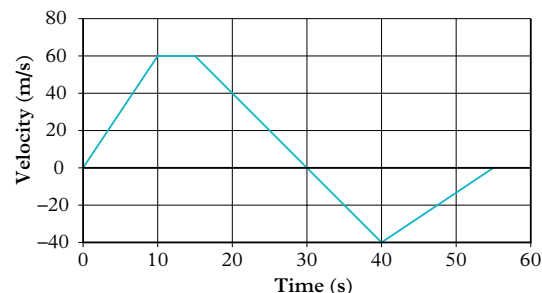


Figure 5 This velocity–time graph shows an object with changing velocity.

- 0–10 seconds (triangle): The object increased speed or accelerated.

$$\text{Area (0–10 s)} = \frac{1}{2} \times \text{base} \times \text{height} = 0.5 \times 10 \times 60 = 300 \text{ m}$$

- 10–15 seconds (rectangle): The object kept the same speed.

$$\text{Area (10–15 s)} = \text{base} \times \text{height} = 5 \times 60 = 300 \text{ m}$$

- 15–30 seconds (triangle): The object slowed down to a stop.

$$\text{Area (15–30 s)} = \frac{1}{2} \times \text{base} \times \text{height} = 0.5 \times 15 \times 60 = 450 \text{ m}$$

$$\text{Total displacement in the positive (north) direction} = 300 + 300 + 450 = 1050 \text{ m}$$

- 30–40 seconds (triangle): The object increased speed in the negative (south) direction.

$$\text{Area (30–40 s)} = \frac{1}{2} \times \text{base} \times \text{height} = 0.5 \times 10 \times -40 = -200 \text{ m}$$

- 40–55 seconds (triangle): The object decreased speed in the negative (south) direction.

$$\text{Area (40–55 s)} = \frac{1}{2} \times \text{base} \times \text{height} = 0.5 \times 15 \times -40 = -300 \text{ m}$$

$$\text{Total displacement in the negative (south) direction} = 200 + 300 = 500 \text{ m}$$

$$\text{Therefore, total displacement} = 1050 \text{ m north} - 500 \text{ m south} = 550 \text{ m north.}$$

8.2 Check your learning

Remember and understand

- 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).
- Use the average velocity triangle to **calculate** the three different formulas.
- Describe** what the area under a velocity–time graph indicates.

Apply and analyse

- Calculate** the value of 80 km/h in metres per second.

Evaluate and create

- 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.

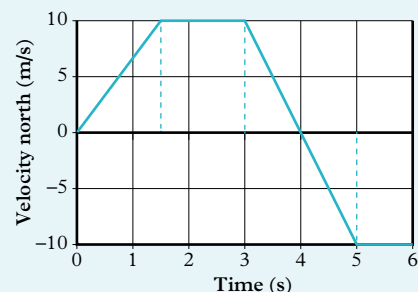


Figure 6 A velocity–time graph

8.3

Acceleration is change in velocity over time

In this topic, you will learn that:

- 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.



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, $g = 9.8$ or 10 m/s^2

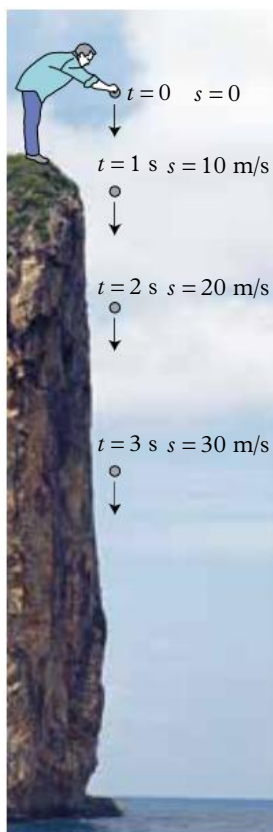


Figure 1 Each second, the speed of the falling rock increases by almost 10 m/s , ignoring air resistance. This means the acceleration is 10 m/s^2 downwards.

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.

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 almost 10 m/s due to gravity (actually, it is 9.8 m/s , which is very close to 10). We say it has accelerated at a rate of 10 m per second in 1 second or at 10 m per second per second (written as 10 m/s/s or 10 m/s^2 or 10 m s^{-2}).

After another second at the same rate, the rock would reach a velocity of almost 20 m/s .

After 3 seconds, it would reach a velocity of almost 30 m/s . Of course, this analysis ignores the effects of air resistance, which would prevent the rock from reaching a velocity of 30 m/s after 3 seconds.

The acceleration value of 10 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.

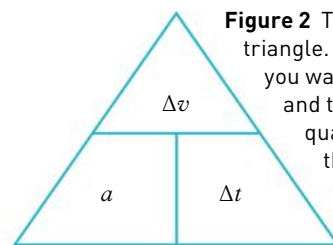


Figure 2 The acceleration triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

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.

Worked example 8.3A: Describing velocity and acceleration

Describe the velocity and acceleration of the object in the first 3 seconds of Figure 6.

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 6.

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.

$$\begin{aligned}\text{Acceleration} &= \frac{\text{change in velocity}}{\text{change in time}} \\ &= \frac{\text{final velocity} - \text{starting velocity}}{\text{final time} - \text{starting time}} \\ &= \frac{0 - 4 \text{ m/s}}{4 - 3 \text{ s}} \\ &= \frac{-4 \text{ m/s}}{1 \text{ s}} \\ &= -4 \text{ m/s}^2\end{aligned}$$

Since the velocity is positive, the negative number indicates the object has decelerated.

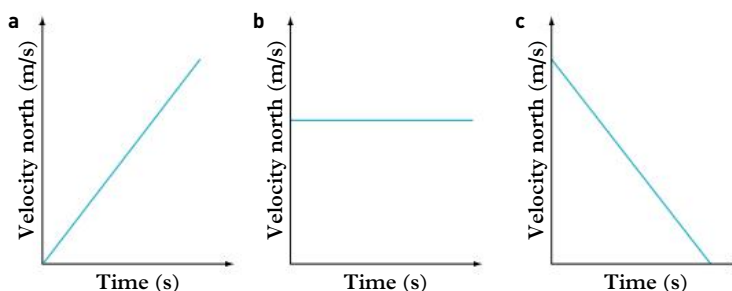


Figure 3 Velocity–time graphs (for an object moving in the positive direction) showing **a** constant positive acceleration (i.e. speeding up), **b** zero acceleration (i.e. constant speed) and **c** negative acceleration (i.e. slowing down or decelerating)

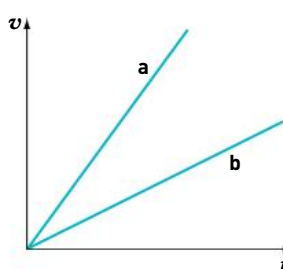


Figure 4 Velocity–time graphs showing **a** steep gradient, indicating high acceleration, and **b** gentle gradient, indicating lower acceleration



Figure 5 Acceleration is the change in velocity over time.

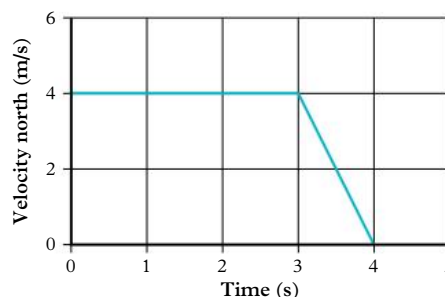


Figure 6 Acceleration can be determined by the gradient of a velocity–time graph.

8.3 Check your learning

Remember and understand

- 1 Use the acceleration triangle to **calculate** the three different formulas.
- 2 **Explain** what is meant by the term ‘deceleration’.
- 3 **Calculate** the acceleration of an object if its velocity is constant.

Apply and analyse

- 4 **Describe** the motion of an object with the speed–time graph shown in Figure 7.
- 5 An object starts from rest and accelerates at a rate of 4 m/s^2 . **Calculate** its velocity after each second for 5 seconds.
- 6 **Compare** accelerating and decelerating objects.

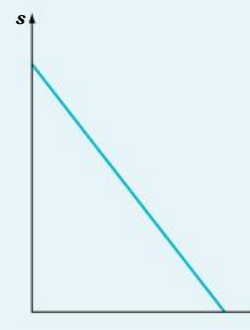


Figure 7 A speed–time graph

8.4

An object in motion remains in motion until a net unbalanced force acts on it

In this topic, you will learn that:

- 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 fell 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

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.



outlined his laws of motion and his law of universal gravitation.

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.

The law of inertia

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.

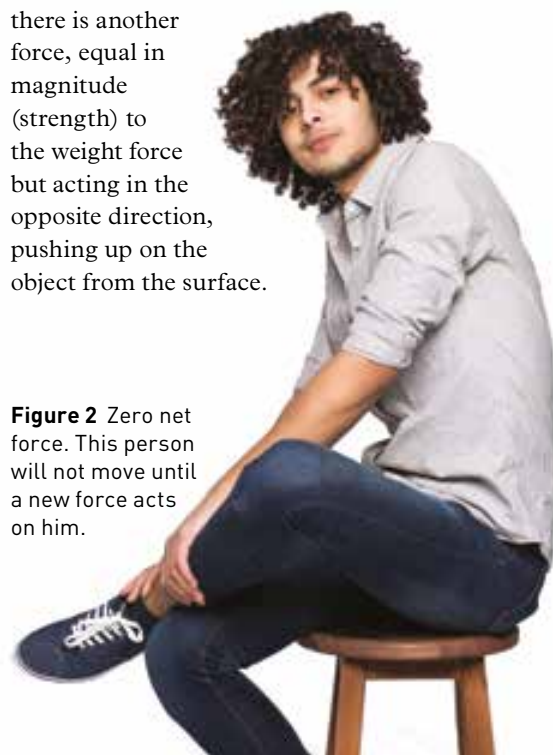




Figure 3 Inertia is responsible for vehicles tilting as they turn. Without friction from tyres gripping the road, turning would be nearly impossible.

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.'

How Newton's first law applies if the object is already moving

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

Remember and understand

- 1 **Define** the term 'net force'.
- 2 **Describe** what happens to a stationary object with zero net force acting on it.
- 3 **Describe** what happens to a moving object with zero net force acting on it.
- 4 **Define** the term 'inertia'.

Apply and analyse

- 5 **Describe** an example of 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.

Evaluate and create

- 8 **Create** a poster for Year 7 students that explains why you should wear a seatbelt in a car.

8.5

Net force equals mass $\times$ acceleration

In this topic, you will learn that:

- 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: $F_{\text{net}} = ma$.'



Interactive 8.5
Force definitions

Figure 1 Pedalling provides the thrust force when riding a bike.



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 2 Braking provides a drag force.

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 speed.

We can express this relationship in a simple equation:

Net force = mass $\times$ acceleration

$$F_{\text{net}} = m \times a$$

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.

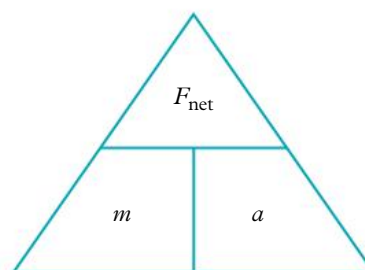


Figure 3 The net force equation can be written as a triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

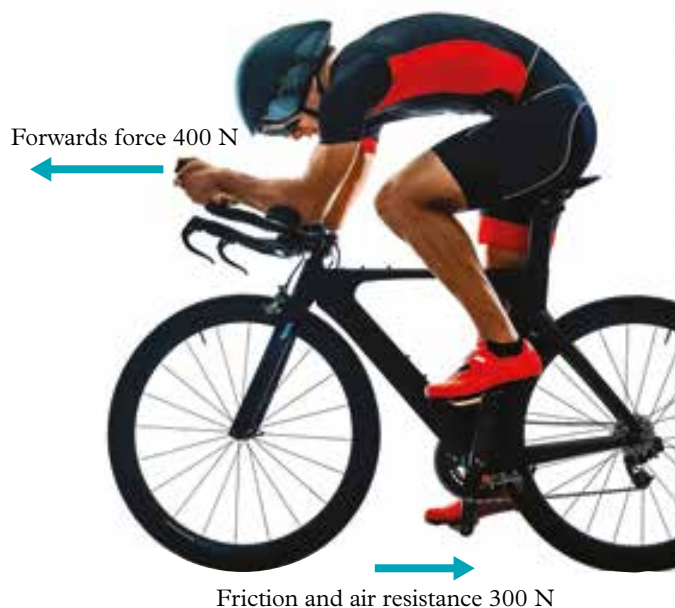


Figure 4 Various forces act on a cyclist.

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 ($100 \text{ kg} \times 1.6 \text{ m/s}^2$) on the Moon and 1000 N ($100 \text{ kg} \times 10 \text{ m/s}^2$) 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.

$$\text{Weight} = \text{mass} \times \text{gravitational acceleration}$$

$$W = m \times g$$

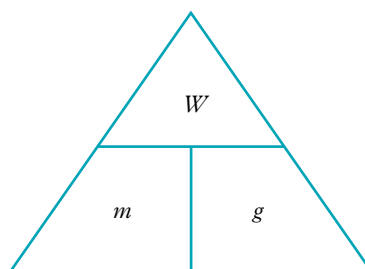


Figure 5 Weight is the force of gravity acting on an object’s mass. Weight (force) = mass $\times$ acceleration due to gravity.



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.

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) = $+400 \text{ N}$

Reverse forces (drag + friction) = -300 N

Net force = $400 - 300 = 100 \text{ N}$ forwards

$$\begin{aligned} \text{Acceleration} &= \frac{\text{net force}}{\text{mass}} \\ &= \frac{100 \text{ N forwards}}{90 \text{ kg}} \\ &= 1.11 \text{ m/s}^2 \end{aligned}$$

The cyclist would increase his speed by 1 m/s every second.

8.5 Check your learning

Remember and understand

- Define** the term ‘weight force’.
- Describe** what happens to a moving object if it is acted on by a net force in the same direction as its motion.
- Describe** what happens to a moving object if it is acted on by a net force in the opposite direction to its motion.

Apply and analyse

- Compare** the acceleration of a bus full of passengers to that of an empty bus, if the same net force was used.

- Explain** why a bike slows down on a level road when the rider stops pedalling.
- A net force causes a mass of 10 kg to accelerate at 2 m/s^2 . **Calculate** the magnitude of the net force.

Evaluate and create

- Create** a poster that explains why trucks need a greater stopping distance than cars.

8.6

Each action has an equal and opposite reaction

In this topic, you will learn that:

- 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.

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.

reaction force

the force acting in the opposite direction to an initial force

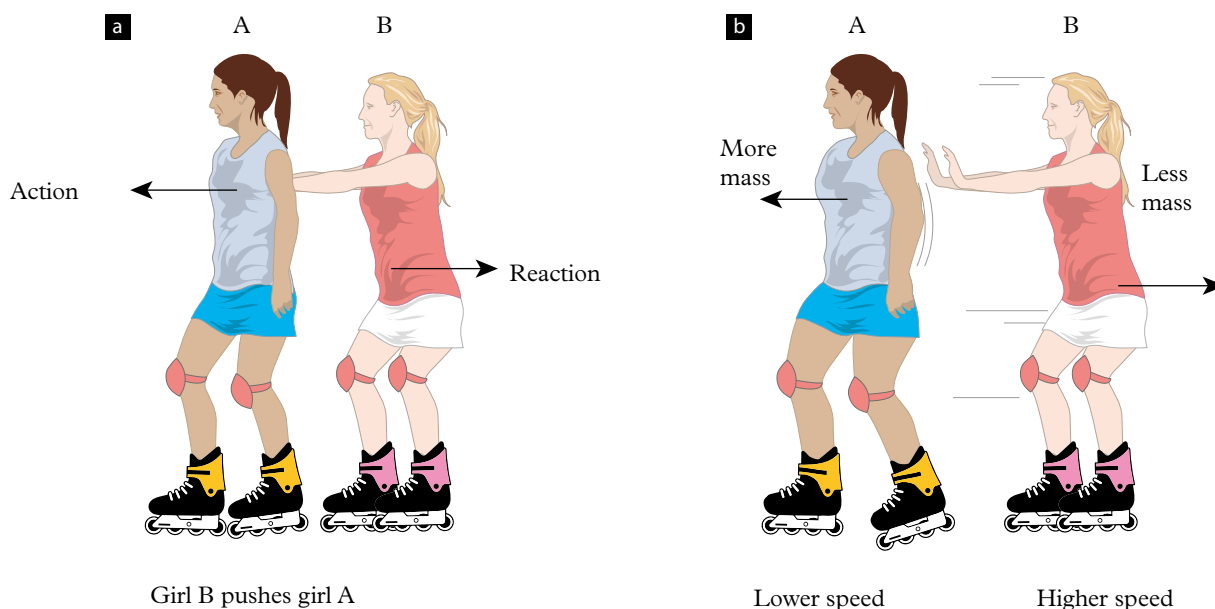


Figure 1 **a** Girls A and B have equal mass. Girl B pushes girl A (action), and girl A pushes girl B backwards (reaction). Girl A moves forwards and Girl B moves backwards. **b** Girl A has more mass than girl B. Both the action and reaction forces are identical and opposite in direction. As Girl A has more mass, her speed will be less than that of girl B.

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 ($F_{\text{net}} = ma$) 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

Remember and understand

- Describe** Newton's third law in your own words.
- Identify** the action and reaction forces of leaning against a wall.

Apply and analyse

- A person pushes forwards on an object with a force of 30 N. **Calculate** the reaction force that acts on the person.
- A boy of weight 500 N sits on a chair. **Describe** the direction and magnitude of the reaction force that acts on the boy.
- 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.

- Identify** the action–reaction pair when a sprinter uses a set of starting blocks for the start of a sprint race.
- Identify** the action–reaction pair when a softball player hits a home run.

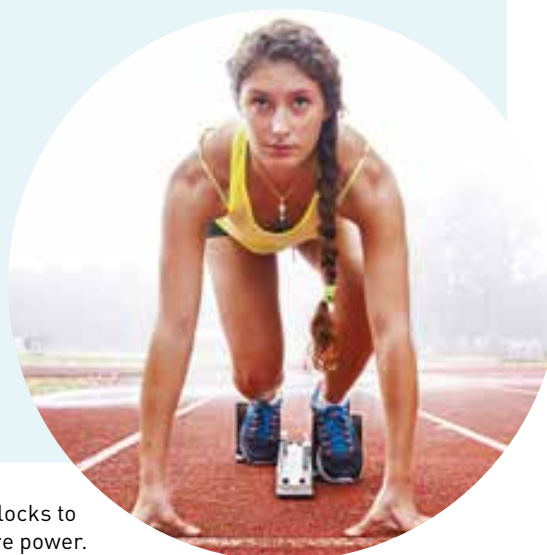


Figure 3 Sprinters use starting blocks to help them start the race with more power.

8.7

Momentum is conserved in a collision

In this topic, you will learn that:

- 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.

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:

$$\text{Momentum} = \text{mass} \times \text{velocity}$$

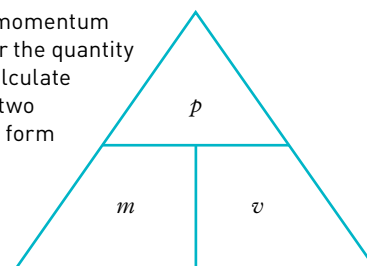
$$p = m \times v$$

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.

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

Worked example 8.7A: Calculating initial momentum

Figure 3 represents a relatively safe head-on collision between two dodgem cars.

- Calculate the initial momentum of each car.
- Calculate the total initial momentum of the two cars.

Solution

- Velocity (green car) = 0.8 m/s; mass (green car) = 701 kg

Initial momentum (green car):

$$\begin{aligned} p(\text{green car}) &= m \times v \\ &= 701 \times 0.8 \\ &= 561 \text{ kg m/s} \end{aligned}$$

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):

$$\begin{aligned} p(\text{purple car}) &= m \times v \\ &= 660 \times -0.7 \\ &= -462 \text{ kg m/s} \end{aligned}$$

- The total initial momentum of the two cars = $561 - 462 = 99 \text{ kg m/s}$.
The positive number tells us that the total momentum is to the right 99 kg m/s.

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**Remember and understand**

- Identify** the units of momentum.
- Describe** the law of conservation of momentum.

Apply and analyse

- Use the momentum triangle to **calculate** the three different formulas.
- Explain** why it is harder to stop a cricket ball than a tennis ball travelling at the same velocity.
- Explain** why it is harder to stop a fast-moving tennis ball than a slow-moving tennis ball.
- Calculate** the momentum of a 600 kg golf cart that is travelling at 0.8 m/s.

Evaluate and create

- Use your understanding of momentum to **evaluate** which would cause the greatest damage: colliding with a truck or colliding with a car.

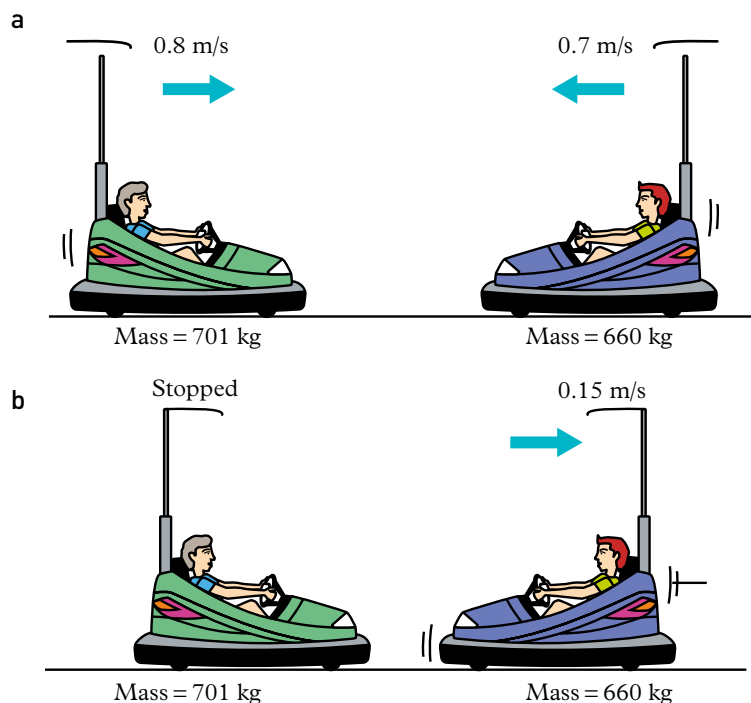


Figure 3 **a** Before the collision **b** After the collision

Figure 4 The rapid change in momentum as a result of a car crash can be seen in the crushed panels of this car.



REVIEW 8

Multiple choice questions

- 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.
 - Newton's first law
 - Newton's second law
 - Newton's third law
 - law of inertia
- Charlie walked 1 km to the supermarket from her house, then 3 km to the florist and 3 km back home again.
Calculate Charlie's total displacement.
 - 7 km
 - 0 km
 - 21 km
 - 14 km
- Identify** the formula that is used to calculate average speed.
 - average speed = $\frac{\text{total time taken}}{\text{total distance travelled}}$
 - average speed = $\frac{\text{total displacement}}{\text{total time taken}}$
 - average speed = $\frac{\text{total acceleration}}{\text{total displacement}}$
 - average speed = $\frac{\text{total distance travelled}}{\text{total time taken}}$

Short answer questions

Remember and understand

- 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

- Describe** an object's speed if it travels with zero acceleration.
- Describe** an object's speed if it travels with constant deceleration.
- Identify** the following statements as true or false. Rewrite the incorrect statements so that they are true.
 - A force will only change an object's speed.
 - A force is always needed to keep an object in motion.

- The quantity of weight is measured in kilograms.
- A force has magnitude and direction, making it a vector.

- Identify** each of the following quantities as scalar or vector.
 - force
 - speed
 - distance
 - displacement
 - velocity
 - acceleration
 - momentum
- Identify** the quantity that can be determined by the gradient of a displacement–time graph.
- Identify** the quantity that can be determined by the area under a velocity–time graph.
- Renee catches a softball.
 - Describe** the action.
 - Describe** the reaction.
- Compare** velocity and speed.
- Object A has more mass than object B. **Compare** the acceleration of the two objects if they are pushed with the same force.

Apply and analyse

- A student measured the velocity of an object that was dropped off the side of a cliff. They displayed the data in Table 2.

Table 2 The velocity of the object over time

Time (s)	Velocity (m/s)
0	0
10	1
20	2
30	3
40	4
50	5

- Draw a velocity–time graph to show the motion of the object.
 - Calculate** the acceleration of the object using the gradient of the graph.
- A person walked 3 km east, then 4 km north and then 9 km east again (Figure 1).

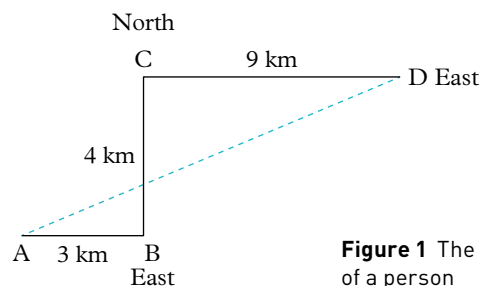


Figure 1 The displacement of a person

- a **Calculate** the total distance travelled.
- b **Calculate** their final displacement (by calculating the total distance east and total distance north, drawing a right-angle triangle with these values and using Pythagoras' theorem).

- 16 A professional bike rider measured their velocity over time (Figure 2).

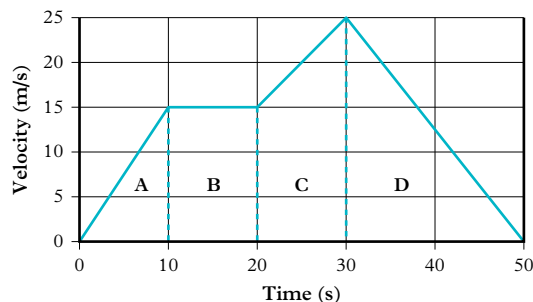


Figure 2 The velocity–time graph of a bike rider

- 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.
- 17 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 down 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.
- 18 Figure 3 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.

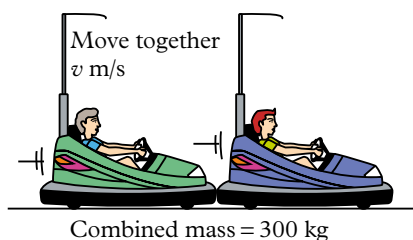


Figure 3 A collision between two dodgem cars

- 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.

Evaluate

- 19 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'.
- 20 **Calculate** the mass of an object that would accelerate at 3.5 m/s^2 under the influence of a net force of 70 N.
- 21 **Calculate** the acceleration of a 500 g object under the influence of a net force of 500 N.

Social and ethical thinking

- 22 **Identify** the safety features of the car shown in Figure 4. **Identify** the safety features that could be added to this car. Adding extra safety features adds to the cost of the car. **Describe** how the socioeconomic status of a person can determine the safety of the car they drive.

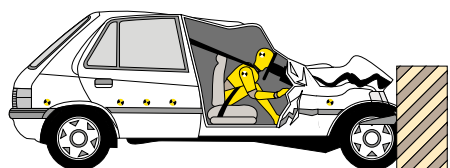


Figure 4 A crash-test car

Critical and creative thinking

- 23 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.
- 24 Motion is the result of forces acting in different directions. **Describe** the forces you believe to be acting when an object is stationary.

Research

- 25 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.

» g-forces

Aircraft pilots flying military jets and those in the Red Bull Air Race commonly experience *g*-forces. A ride at Luna Park is called ‘*g*-force’. Describe a situation when pilots experience *g*-forces. Explain what the human tolerance of *g*-forces is and the effect they have on the body. Describe other examples of theme park rides or situations where people experience *g*-forces.

» Car safety features

Modern cars may be equipped with electronic stability control (ESC), anti-lock braking systems (ABS), electronic brake distribution (EBD), RVC tachometers, traction control systems (TCS) and park assist. Find out about each of these and other car safety features under development. Explain how they contribute to the safety of passengers.

Reflect

The table below outlines a list of things you should be able to do by the end of Chapter 8 ‘Motion’. Once you’ve completed the chapter, use the table to reflect on your ability to complete each task.

	I can do this.	I cannot do this yet.
Explain the difference between distance and displacement using appropriate examples. Plot and interpret position/displacement–time graphs for linear motion.	☐	☐ Go back to Topic 8.1 ‘Displacement is change in position with direction’ Page 180
Explain the difference between speed and velocity using appropriate examples. Determine the speed/velocity of an object from the gradient of a position/displacement–time graph.	☐	☐ Go back to Topic 8.2 ‘Velocity is speed with direction’ Page 182
Manipulate the formula, $a = \frac{v-u}{\Delta t}$, appropriately to determine the unknown variable: initial velocity, final velocity, acceleration or time.	☐	☐ Go back to Topic 8.3 ‘Acceleration is change in velocity over time’ Page 184
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 186
State Newton’s second law of motion and explain this law using appropriate examples. Manipulate the formula, $F_{\text{net}} = ma$, appropriately to determine the unknown variable: net force, mass or acceleration.	☐	☐ Go back to Topic 8.5 ‘Net force equals mass $\times$ acceleration’ Page 188
State Newton’s third law of motion and explain this law using appropriate examples of action–reaction pairs.	☐	☐ Go back to Topic 8.6 ‘Each action has an equal and opposite reaction’ Page 190
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 192

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How can we control energy?

CHAPTER

9

ENERGY

9.1

Work occurs when an object is moved or rearranged. Energy can be calculated



9.2

Energy is always conserved



9.3

Thermodynamic systems that are connected reach thermal equilibrium



9.4

Conduction transfers kinetic energy between particles. Convection causes the particles to move

9.5

Thermodynamics can be described by laws



What if?

Toy car

What you need:

Ramp, toy car, small weights

What to do:

- 1 Set up the ramp so that one end is 20 cm above the ground.
- 2 Place the toy car at the top of the ramp and release it without pushing.
- 3 Measure how far the car rolls beyond the bottom of the ramp.

What if?

- » What if the ramp was lifted higher?
- » What if weight was added to the toy car?

9.1

Work occurs when an object is moved or rearranged. Energy can be calculated

In this topic, you will learn that:

- work is a measure of how much energy has been transferred into moving or rearranging an object
- kinetic energy (movement energy) is calculated using an object's speed and mass
- gravitational potential energy (stored gravitational energy) is calculated using the height and mass of an object
- elastic potential energy is the energy stored in an object because of its deformation.

work

when an object is moved by a force

kinetic energy

the energy possessed by moving objects

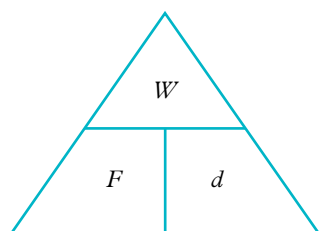


Figure 1 The work triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

Work

In a car crash, the crumple zones of a car are designed to absorb energy by crumpling. In scientific terms, we say that **work** is done. Work is a measure of how much energy has been transferred whenever things are moved or rearranged by a force. The larger the force acting, the greater the work done. The longer the distance over which the force acts, the greater the work done. This means the amount of work done depends on the size of the force and the distance (see Figure 1):

$$\text{Work} = \text{force applied} \times \text{distance moved}$$

$$W = F \times d$$

Work and energy are scalar quantities, so no direction is needed. If you apply a force to an object and it doesn't move, no work is done.

When a force is applied to an object and it moves, the object gains (kinetic) energy. Therefore, work is a measure of how much energy has been transferred from one object to another.

If the force is measured in newtons (N) and the distance is measured in metres (m), the work done is in units called joules (J). For example, when 1 N of force is used to move an object 1 m, the amount of work done is 1 J.

Kinetic energy

Motion is needed for cars to crash. The energy of motion is called **kinetic energy** (KE). The larger the mass of an object, the greater its kinetic energy. Also, the faster an object is travelling, the greater its kinetic energy.

Kinetic energy depends on the speed of the object, squared:

$$\text{Kinetic energy} = \frac{1}{2} \times \text{mass} \times \text{speed squared}$$

$$\text{KE} = \frac{1}{2} \times m \times v^2$$

where mass is in kilograms (kg), speed is in metres per second (m/s) and KE is in joules (J).

When a car driver presses on the brake pedal, all the kinetic energy of the car is dissipated (released) by the brakes as heat. In a car crash, the kinetic energy is dissipated much more quickly as the car crumples and deforms.

Worked example 9.1A shows how to calculate the kinetic energy of a moving car.

Worked example 9.1A: Calculating kinetic energy

Calculate the kinetic energy of a 500 kg car that is travelling at 30 km/h.

Solution

All values must be in the correct units.

$$m = 500 \text{ kg}$$

$$v = 30 \text{ km/h} = 30 \times \frac{1000 \text{ m}}{3600 \text{ s}} = 8.33 \text{ m/s}$$

$$\begin{aligned} \text{Kinetic energy (car)} &= \frac{1}{2} \times m \times v^2 \\ &= \frac{1}{2} \times 500 \times 8.33^2 \\ &= 17\,347 \text{ J} \end{aligned}$$

Gravitational potential energy

If we lift an object to a height, we use energy that is transferred to the object as **gravitational potential energy** (GPE). The larger the mass and the height, the more energy we use and the more gravitational potential energy the object gains:

$$\begin{aligned}\text{Gravitational potential energy} &= \text{mass} \times \text{gravity} \times \text{height} \\ \text{GPE} &= m \times g \times h\end{aligned}$$

where mass is in kilograms (kg), height is in metres (m) and GPE is in joules (J). Gravity has its normal value of 9.8 or 10 m/s².

Worked example 9.1B shows how to calculate gravitational potential energy.

Worked example 9.1B: Calculating gravitational potential energy

Calculate the amount of gravitational potential energy a 500 kg car has if it is lifted 150 cm above the ground.

Solution

All values must be in the correct units.

$$m = 500 \text{ kg}$$

$$h = 150 \text{ cm} = 1.5 \text{ m}$$

$$g = 10 \text{ m/s}^2$$

Gravitational potential energy (car)

$$= m \times g \times h$$

$$= 500 \times 10 \times 1.5$$

$$= 7500 \text{ J}$$

Elastic potential energy

Bouncing a ball is a collision between the ball and the ground (Figure 2). It involves gravitational potential energy, kinetic energy and **elastic potential energy** (EPE), plus usually a small amount of sound and heat energy. EPE is a form of energy that is stored in elastic materials that are deformed or temporarily bent out of shape. As the ball hits the ground, it compresses or deforms, transforming some of the kinetic energy to heat or thermal energy. The remainder of the kinetic energy is stored as elastic energy in the deformed ball. This energy transforms back to kinetic energy when the ball expands again and is

propelled upwards into the air. A flat ball cannot transform this energy, so it doesn't bounce.

$$\text{Elastic potential energy} = \frac{1}{2} \times \text{spring constant} \times \text{extension (or compression) squared}$$

$$\text{EPE} = \frac{1}{2} \times k \times x^2$$

where k is the spring constant (a measure of how 'stiff' the object is) in newtons per metre (N/m), x is the extension (or compression) in metres (m) and EPE is in joules (J).

Worked example 9.1C shows how to calculate the elastic potential energy of a ball.

Worked example 9.1C: Calculating elastic potential energy

Calculate the elastic potential energy that is stored in the rubber of a tennis ball that is compressed 5 cm. The ball has a spring constant of 440 N/m. Assume that no thermal energy is produced.

Solution

All values must be in the correct units.

$$k = 440 \text{ N/m}$$

$$x = 5 \text{ cm} = 0.05 \text{ m}$$

$$\begin{aligned}\text{Elastic potential energy (tennis ball)} &= \frac{1}{2} \times k \times x^2 \\ &= \frac{1}{2} \times 440 \times 0.05^2 \\ &= 0.55 \text{ J}\end{aligned}$$

gravitational potential energy

the energy possessed by an object raised to a height in a gravitational field

elastic potential energy

the energy possessed by stretched or compressed objects



Figure 2 When the ball hits the ground, the ball becomes deformed, transforming the kinetic energy into elastic potential energy.

9.1 Check your learning

Remember and understand

- 1 **Define** the scientific term 'work'.
- 2 Use the work triangle to **calculate** the three different formulas.

Apply and analyse

- 3 **Calculate** the amount of work done if a force of 200 N moves an object 6 m.
- 4 **Calculate** the amount of work done if a force of 400 N is applied to a heavy object and it doesn't move.
- 5 **Describe** how the kinetic energy of an object is affected if its mass decreases and the other values remain constant.
- 6 **Describe** how the gravitational potential energy of an object is affected if its height increases and the other values remain constant.
- 7 The 450 kg car stopped at the top of the hill, which was 100 m tall. **Calculate** the gravitational potential energy of the car.

9.2

Energy is always conserved

In this topic, you will learn that:

- the law of conservation of energy states that energy cannot be created or destroyed
- waste energy in the form of heat and sound energy can be formed in the transfer or transformation of energy
- the efficiency of the energy transformation can be calculated.

law of conservation of energy

a scientific law stating that the total energy in a system is always constant and cannot be created or destroyed

Whenever energy is converted from one form into other forms, the total energy of the system remains constant because extra energy cannot be created, nor can energy be destroyed. This is called the **law of conservation of energy**.

This is most obvious when you jump on a trampoline (Figure 1). When you are high above the trampoline, you have gravitational potential energy. As you start to move down, you gain velocity and therefore kinetic energy. The closer to the trampoline you get, the less gravitational potential energy and the more kinetic energy you have. As soon as you start stretching the trampoline, your kinetic energy and gravitational potential energy are being transformed into elastic potential energy in the trampoline. Eventually you will stop moving and the trampoline will be completely stretched. All the kinetic energy has been transformed into elastic potential energy. Eventually the elastic potential energy is transformed back into kinetic energy and

gravitational potential energy, and you will start moving up into the air again.

Theoretically, the total amount of energy from your jump is constant. In reality, there may be a small amount of heat energy produced as you fall due to air resistance. This 'loss' of energy is not really a loss, just a transfer of energy into a non-usable form. The efficiency of energy transfer or transformation can be calculated by comparing how high above the trampoline you started and the height you reach on the rebound.

$$\text{Energy efficiency} = \frac{\text{amount of usable final energy}}{\text{amount of initial energy}} \times 100$$

Any difference in height is a result of heat or sound energy.

Worked example 9.2 shows how to calculate the energy efficiency of a bounced tennis ball.

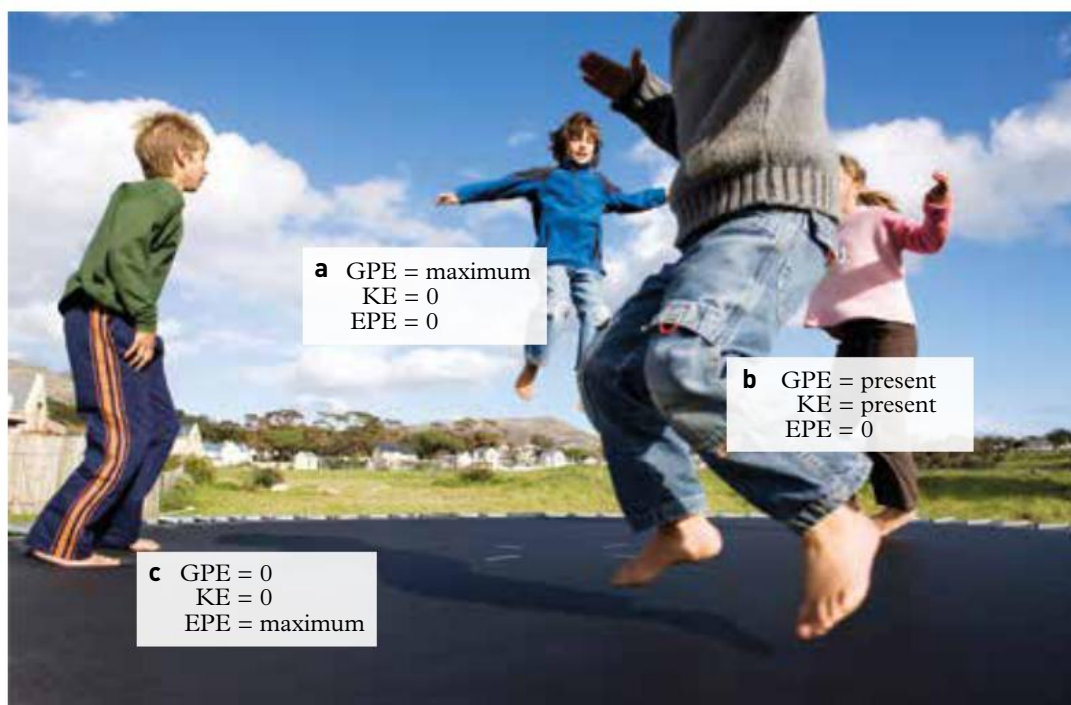


Figure 1 Although the individual energy quantities vary between the highest point **a**, through position **b** to the lowest position **c**, the total energy of the 'system' remains constant.

Worked example 9.2: Calculating energy efficiency

Calculate the energy efficiency of a tennis ball that was dropped from 100 cm above the ground, and rebounded to 85 cm above the ground.

Solution

Amount of usable
final energy = gravitational potential energy of rebounded ball
 $= m \times g \times 85 \text{ cm}$

Amount of initial
energy = gravitational potential energy of starting ball
 $= m \times g \times 100 \text{ cm}$

Energy efficiency = $\frac{\text{amount of usable final energy}}{\text{amount of initial energy}} \times 100$
 $= \frac{m \times g \times 85}{m \times g \times 100} \times 100$

The m and g can be cancelled out as they are on the top and bottom of the fraction.

Energy efficiency = $\frac{85}{100} \times 100 = 85\%$



Figure 2 The elastic potential energy in muscles can be transformed into kinetic energy.

pendulum

a mass that is attached by a string to a pivot point

Pendulums

A **pendulum** is a mass that is attached by a string to a pivot point. When the mass is drawn upwards, it gains gravitational potential energy. When the mass is let go, the force of gravity pulls it down to its original position, converting the gravitational potential energy to kinetic energy. The momentum built up by the moving mass causes the mass to then swing in the opposite direction. This means all the kinetic energy is converted back into gravitational potential energy. Pendulums (such as a swing in a playground; Figure 3) are a good example of how energy efficiency can be measured.

Some kinetic energy is always lost as waste energy when it is transformed to heat (and sometimes sound). This is evident when the pendulum does not quite reach the height at which it started.



Figure 3 A swing will not reach its original height because it 'loses' energy as heat and sound energy.

9.2 Check your learning

Remember and understand

- 1 Explain** the law of conservation of energy using an example of your own.
- 2 Define** (using an example) the term 'waste energy'.

Apply and analyse

- 3 Evaluate** the claim that energy is lost when a ball bounces (by describing the law of conservation of energy, defining the term 'lost', explaining the term 'waste energy', and deciding whether the claim is correct).
- 4 Describe** the conservation of energy that occurs when you use a slinky.
- 5 Calculate** the energy efficiency of a person jumping on a trampoline if they drop from a height of 2 m and rebound to a height of 1.5 m.
- 6** The following statements are incorrect. Rewrite them to make them correct.
 - a** The energy efficiency of all systems is always 100 per cent.
 - b** The law of conservation of energy doesn't always apply.
 - c** Pendulums always return to their original height.
 - d** A roller coaster rolling down a ramp will stop at the bottom of the ramp.

9.3

Thermodynamic systems that are connected reach thermal equilibrium

In this topic, you will learn that:

- a thermodynamic system is a quantity of matter that has a boundary around it
- the energy generated by the motion of particles is called thermal energy
- temperature is a measure of the average thermal energy of all the particles in a thermodynamic system
- thermal energy is transferred from hotter thermodynamic systems to cooler thermodynamic systems until thermal equilibrium is reached.

thermodynamics

the science of how heat and temperature are related to energy and the properties of matter

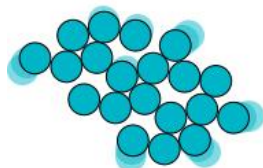


Figure 1 The particles in air are free to move about.

thermodynamic system

a quantity of matter that has a boundary around it

Thermodynamics

Thermodynamics is the study of how heat, or thermal energy, can be transferred between objects, or transformed into other forms of energy. Because energy cannot be created or destroyed, when a hot object cools down, the thermal energy is transferred from the molecules in the hot object to the surrounding air particles. Alternatively, the energy can be transformed into another form of energy.

Thermodynamic systems

If you put a hot brick into a bucket of cold water, the water will gradually heat up, and the brick will gradually cool down. This is because the thermal energy is transferred from the brick to the water. The brick and the bucket of water can be described as a thermodynamic system.

A **thermodynamic system** is a system that connects or interacts with other systems. It is defined as a quantity of matter that has a boundary around it. When two thermodynamic systems are connected, an exchange of thermal energy may occur.

Thermal energy is the total energy of all the moving or vibrating particles in an object. Substances such as bricks, water and air are made of particles. The particles in solid objects such as the brick cannot move around very much. Instead, they vibrate against and transfer thermal energy to each other. The particles in solids have very little kinetic energy because of their lack of freedom of movement. The particles in water have more kinetic energy

than those in the brick. These molecules can move more freely around each other, while remaining in contact. The molecules in air have the most kinetic energy. They are free to move in any direction, resulting in many collisions (Figure 1).

The particles in a thermodynamic system move around at different speeds, depending on their temperature. When a system is hot, its molecules move faster than when it is cold (Figure 2). Because the molecules are moving faster, they collide with more energy and push each other further apart to occupy more space, or increase the pressure if the gas is contained in a fixed volume. We say the gas expands – the particles don't get bigger, but the space between the particles increases.

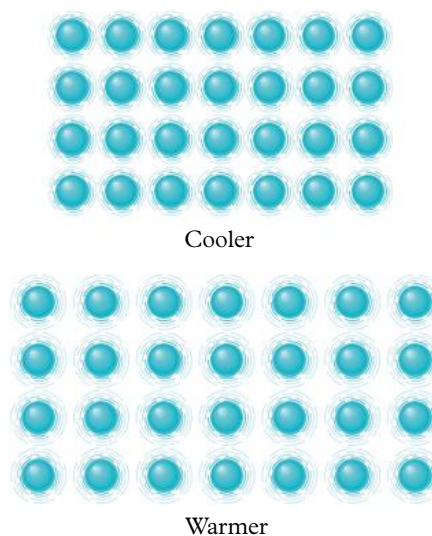


Figure 2 Particles in a thermodynamic system vibrate faster when they are heated.

Insulation

If a thermodynamic system is perfectly insulated from its surroundings, it is described as a **closed system**. Because energy cannot be created or destroyed, the thermal energy, and therefore temperature, of the system will not change – the vibration of the atoms or the movement of the molecules will never stop. However, every hot object eventually transfers some of its thermal energy to its surroundings and cools until both systems reach the same temperature. The only way to avoid this is to constantly transfer more thermal energy from somewhere else to replace the ‘lost’ thermal energy.

Thermal equilibrium

Thermal energy is different from the temperature of an object. **Temperature** is the average kinetic energy of the particles moving in the system, whereas **thermal energy** is the total energy of all the moving particles.

When two objects or systems are at different temperatures, there is a temperature gradient. The thermal energy of the hot object will be transferred down the temperature gradient to the cooler object. Examples include a hot brick in a bucket of cold water (Figure 3) or you sitting in a warm bath. The thermal energy of the bath water will be transferred to you and is also lost to the air around you. You become warmer, and the bath water becomes cooler. Eventually, you and the bath water will reach the same temperature, and the transfer of energy will stop.

When the thermal energy of an object is the same as that of its surroundings, **thermal equilibrium** has been achieved.

When you use a thermometer to measure temperature, such as that of the air in the room, the thermometer is actually measuring its own temperature. When the thermometer is in thermal equilibrium with the air around it, the temperature that it measures is the temperature of the surrounding air. To get an accurate measurement, you have to allow time for the thermometer to reach thermal equilibrium with the object being measured. You are waiting for the transfer of thermal energy from the hotter object – either the thermometer or the object it is measuring.

closed system

a system with a boundary that does not exchange energy with its surroundings

temperature

the average kinetic energy of the particles moving in a system

thermal energy

the scientific term for heat energy

thermal equilibrium

when the thermal energy of an object is equivalent to that of its surroundings



Figure 3 A hot brick will pass on thermal energy to the water until the brick and the water reach thermal equilibrium.

9.3 Check your learning

Remember and understand

- Describe** what happens to molecules when they are heated.
- Describe** what happens to a hot cup of tea as it reaches thermal equilibrium.

Apply and analyse

- Identify** which has the higher temperature: a cup of water at 70°C or a bucket of water at 70°C . **Justify** your answer (by defining temperature, describing the temperature of both objects and explaining why you made your decision).

- Describe** something you can do at home that uses objects at different temperatures and creates thermal equilibrium.
- Some ice at 0°C is added to a bucket of water at 20°C . The resulting combination reaches an equilibrium temperature of 19°C . **Explain** why it didn't reach 10°C .

Evaluate and create

- Explain** how you could use your knowledge of thermal equilibrium to test the effectiveness of an insulated container, such as a thermos, in keeping food warm.

9.4

Conduction transfers kinetic energy between particles. Convection causes the particles to move

In this topic, you will learn that:

- thermal energy moves spontaneously from a hotter thermodynamic system to a cooler thermodynamic system
- heat transfer can occur when one system passes its kinetic energy on to another (conduction) or when the hot, highly kinetic particles themselves move (convection).

conduction

the transfer of thermal energy by direct contact with no movement of material

thermal conductor

a material that allows thermal energy to flow through

thermal insulator

a material that prevents or slows down the transfer of thermal energy

Heating by conduction

Heat transfer by **conduction** is the transfer of thermal energy from matter that is warmer to matter that is cooler. This happens spontaneously when two thermodynamic systems make direct contact with each other and reach thermal equilibrium.

Consider what happens when you heat a saucepan of water on a gas burner.

- 1 When the gas burns, thermal energy is released.
- 2 The hot molecules in the gas flame move quickly and occasionally bump into atoms of the relatively cold metal of the saucepan.
- 3 Kinetic energy passes to the slowly vibrating atoms in the saucepan so that they vibrate faster.

- 4 The quickly vibrating atoms in the saucepan bump into other nearby metal atoms, transferring thermal energy to them. This heats the saucepan.
- 5 When the saucepan heats up, energy is transferred to the water inside it.

Although the thermal energy moves through the metal of the saucepan and into the water, the atoms in the metal do not change their positions – metal atoms do not move into the water.

Conductors and insulators

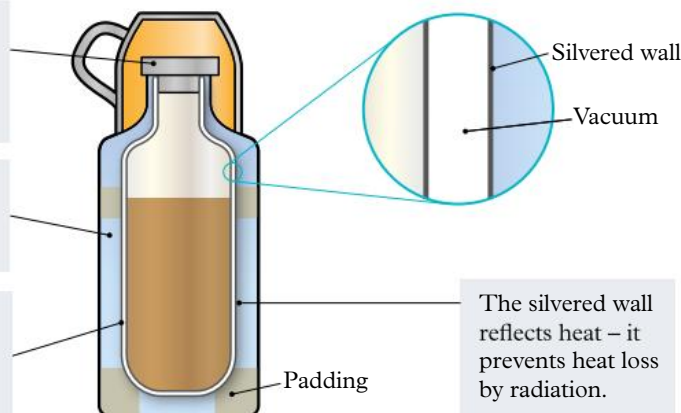
A **thermal conductor** is any material that allows thermal energy to flow easily through it. All metals are conductors, although some are better conductors than others. **Thermal insulators** are materials that slow down the

Figure 1 Vacuum flasks are designed to keep hot substances hot and cold substances cold. To do this they must prevent the contents from losing or gaining heat – conduction and convection must be minimised. Careful choice of materials and clever design make this possible.

The plastic stopper is an insulator – it prevents heat loss or gain through convection and conduction.

The glass walls are insulators – they prevent heat loss or gain through conduction.

The vacuum between the walls is an insulator – it prevents heat loss or gain through conduction and convection.



transfer of thermal energy because the molecules don't allow the energy to flow very easily. Insulators such as socks, jumpers and blankets keep us warm in cold weather. They make it difficult for our body heat to escape, insulating us against the cold. Insulation in the roof and walls of a house prevents heat gain and loss during summer and winter. So insulation can hold thermal energy in or keep it out.

Heating by convection

In liquid and gas thermodynamic systems, thermal energy moves by **convection**. Tiny currents, called **convection currents**, carry the thermal energy. A convection current is a movement within a liquid or gas.

When you heat a saucepan of water on a gas flame, the following occurs.

- 1 Thermal energy transfers by conduction from the hot saucepan to the water molecules that are touching the metal.
- 2 The water molecules in contact with the metal at the bottom of the pan, closer to the flame, gain kinetic energy and move faster than the molecules in the water above. Because they are moving faster, they take up more space. They are less dense.
- 3 As a result, the heated (less dense) water molecules near the bottom of the saucepan begin to rise, leaving room for the cooler (more dense) water molecules to take their place.

- 4 The heated water molecules take thermal energy with them as they move.

We heat liquids from below because most of the energy transfer in liquids (and gases) takes place by convection. This process happens in the air. The Sun heats the ground and the warmed ground then heats the air next to it by conduction. The warmed air, being less dense than the cooler air above, rises, taking the thermal energy with it. This distributes the energy through a much deeper layer of air than could occur just by conduction from the ground. This process of convection in the air is what drives the weather on Earth.



Figure 2 Convection currents are created in a saucepan of water when it is heated. The heated water molecules (shown in red) rise, while the cooler ones (shown in blue) sink.

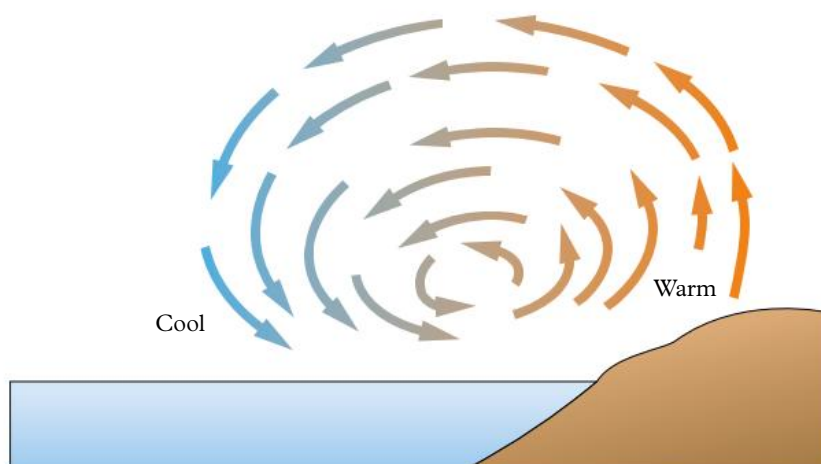


Figure 3 The circulation of air in a sea breeze

9.4 Check your learning

Remember and understand

- 1 Think of a situation where you can see expansion due to heating of a solid, liquid or gas. **Explain** what the molecules or atoms are doing to cause the expansion.
- 2 **Identify** two examples of situations where thermal energy is transferred by:
 - a conduction
 - b convection.
- 3 **Identify** one example of where good thermal insulators and conductors are needed in everyday life. **Describe** the materials that are used in each situation.
- 4 **Explain** why scientists refer to thermal energy transfer as heating, even though in every case something is being cooled.

Apply and analyse

- 5 Some modern saucepans have a copper bottom, steel sides, a plastic handle and a glass lid. **Explain** why each of these materials are used for a particular part of each saucepan.

Evaluate and create

- 6 **Create** an advertisement for a piece of clothing that displays the thermal properties of the materials used in its construction.
- 7 You are going on a camping trip and you want to take some hot tea with you. You have a flask, a plastic bottle and a ceramic mug. Your friend tells you to take the tea in a plastic bottle, because it will keep the tea warmer for longer. **Evaluate** this claim.

convection

the transfer of thermal energy by the movement of molecules in air or liquid from one place to another

convection current

the current or flow of air or liquid that results from the transfer of thermal energy through convection

9.5

Thermodynamics can be described by laws

In this topic, you will learn that:

- the total amount of energy in a system is the sum of its kinetic energy, gravitational potential energy and internal energy
- internal energy is the energy of and between the particles in the thermodynamic system
- the first law of thermodynamics describes how the internal energy of a system can increase if heat is added and decrease if work is done by the system
- as energy is transformed from one form to another, the thermal energy formed increases the amount of entropy in a system; this is the second law of thermodynamics.



Figure 1 The total amount of energy in a light bulb is the sum of its kinetic energy, gravitational potential energy and internal energy.



Figure 2 This sealed thermos acts like a closed thermodynamic system, conserving the internal energy.

Total energy of a system

The total energy of an object, or thermodynamic system, can be calculated by adding together the kinetic energy of the system, the gravitational potential energy of the system and the internal energy of the system. Consider the energy of a light bulb (Figure 1). A light bulb hanging from the ceiling has gravitational potential energy. If a breeze is blowing in the room, the light bulb may swing slightly. This adds kinetic energy to the light bulb. There is also the energy inside the light bulb – the light bulb’s internal energy.

Internal energy

The internal energy of a system can be calculated by adding together the kinetic energy of the molecules (their thermal energy) and the energy that attracts the atoms to each other in the molecule (their bonds). Because energy cannot be created or destroyed, the internal energy of any system will remain the same until energy is transferred in or out. An example of this is a sealed thermos flask that contains hot water. Because heat cannot be transferred into or out of the system, the internal energy will be conserved. This is known as a closed system, with no energy being transferred in or out.

Closed (or isolated) systems do not usually exist in the real world. Because thermal energy is always transferred from a hot object to a cold object, most thermodynamic systems transfer some heat to their surroundings. You would see this if you left the thermos sitting on a table for



Figure 3 In an open thermodynamic system, energy can be transferred to the surroundings. The internal energy of this saucepan of boiling water needs to be replaced because energy is lost with the escaping steam.

24 hours. Eventually, thermal energy will be transferred from the hot water to the thermos, and from the thermos to the atmosphere. As a result, the hot water will lose internal energy and cool down.

Heat engines

Another example of how internal energy can change is found in the operation of heat engines. Heat engines convert thermal energy into mechanical movement.

A steam engine is an example of a heat engine. A steam engine heats water to produce steam. The steam exerts a force on a piston, causing it to move. In a steam train, the piston

is used to move the wheels (Figure 4). The internal energy of the water remains constant until thermal energy is added. This increases the kinetic energy of the water molecules so that they can leave the liquid state and move as a gas. The internal energy of a gas is higher than that of a liquid. This higher internal energy results in the steam pushing against the piston, transferring some of the energy into movement (kinetic energy). As the piston pushes, the crank and connecting rod turn the steam train's wheels and the train moves.

Remember that work is a measure of how much energy has been transferred into moving or rearranging an object. As energy cannot be created or destroyed, the internal energy of the steam will decrease as a result of the piston's movement.

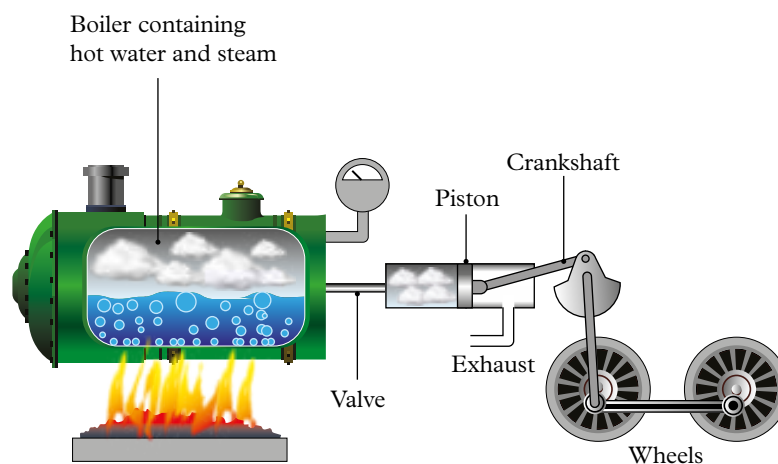


Figure 4 The internal energy of a steam engine decreases as the work of steam pushing the pistons is done. This energy is replaced by burning fuel.

First law of thermodynamics

You have just seen two ways in which the amount of internal energy of a thermodynamic system can change. Internal energy can be increased by the addition of heat, and decreased by doing work. This is the **first law of thermodynamics**.

Second law of thermodynamics

Every time energy is transformed, thermal energy is generated. In most cases, the thermal energy is transferred to the surrounding air

molecules, increasing their random movement. The energy in the randomly moving air particles cannot be transferred, transformed or reused in any way. This means the amount of useful energy decreases and the amount of disorganised random movement (**entropy**) increases. The **second law of thermodynamics** describes this relationship. Over time, energy is transformed from one form to another, causing thermal energy to be produced and increasing the amount of entropy.

first law of thermodynamics

a rule stating that the internal energy of a thermodynamic system can change, increasing when heat is added and decreasing when work is done

entropy

the amount of energy in a closed system that is no longer available to be transformed

second law of thermodynamics

a scientific rule stating that, over time, energy is transformed from one form to another, causing thermal energy to be produced and increasing the amount of entropy

9.5 Check your learning

Remember and understand

- 1 **Define** the term 'thermodynamics'.
- 2 **Describe** the first law of thermodynamics. **Provide** an example to support your description.
- 3 **Describe** the second law of thermodynamics. **Provide** an example to support your description.
- 4 **Define** the term 'entropy'.

Apply and analyse

- 5 If the total energy of a thermodynamic system is 45 joules, and 6 joules of work is done by the system, **calculate** the final total energy of the system.
- 6 For many centuries, scientists and inventors worked to design a perpetual motion machine that would keep moving forever without any additional energy. Use the laws of thermodynamics to **explain** why this is not possible.

REVIEW 9

Multiple choice questions

- The fact that energy cannot be created or destroyed but can be transformed or converted is explained by:
 - gravitational potential energy
 - kinetic energy
 - the law of conservation of energy
 - the law of conservation of mass.
- The formula used to calculate gravitational potential energy is:
 - $\frac{1}{2} \times m \times v^2$
 - $\frac{1}{2} \times m \times g \times h$
 - $\frac{1}{2} \times k \times x^2$
 - $m \times g \times h$.
- The formula used to calculate kinetic energy is:
 - $\frac{1}{2} \times m \times v^2$
 - $\frac{1}{2} \times m \times g \times h$
 - $\frac{1}{2} \times k \times x^2$
 - $m \times g \times h$.

Short answer questions

Remember and understand

- Write the general equations used to determine:
 - work done on an object
 - kinetic energy of an object
 - gravitational potential energy of an object
 - elastic potential energy.
- Contrast** thermal energy and temperature.
- Define** the following terms.
 - thermodynamic system
 - thermal insulator
 - thermal equilibrium
 - temperature gradient
- Compare** conduction and convection.
- Consider what happens when a block of ice melts.



Figure 1 Melting ice

- Describe** what is happening to the molecules as the ice melts. Draw a diagram to **illustrate** your answer.
 - Explain** where the energy to melt the ice comes from. **Explain** how the energy is transferred to the molecules of ice.
- Use the formula for kinetic energy to show that, if speed is doubled, the energy of a car crash will be four times as high.
 - Identify** the following statement as true or false.
If two thermodynamic systems are in equilibrium with a third system, then they are in thermal equilibrium with each other.
 - Use an example to **explain** the term 'entropy'.

Apply and analyse

- If a force of 30 N is used to move an object 0.2 m, **calculate** the work that was done.
- Use Figure 2 to answer the following questions.

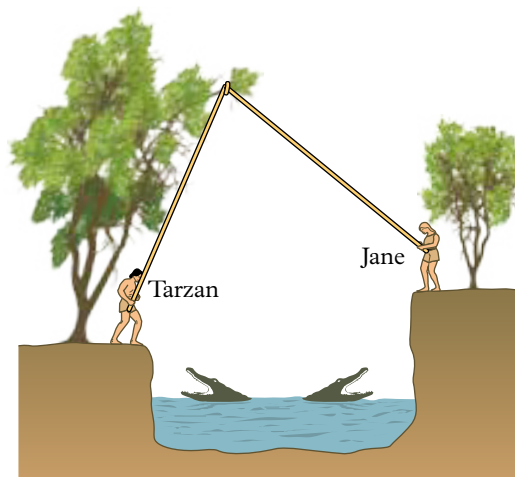


Figure 2 Tarzan and Jane, and crocodiles

- Explain** whether Tarzan could use a vine to swing to Jane. **Justify** your answer (by describing the gravitational potential energy of Tarzan, explaining how the law of conservation of energy explains the energy transformation to kinetic energy, and deciding whether this will provide enough energy for Tarzan to reach Jane). (Assume that Jane does not lose any of her energy.)
- Explain** whether Jane could use a vine to swing to Tarzan. **Justify** your answer.
- Evaluate** who (Tarzan or Jane) would have the greatest gravitational potential energy.
- If Jane has a mass of 60 kg and her height above the ground is 3 m, **determine** her gravitational potential energy.

- e If Jane uses the vine to swing down to Tarzan, use the law of conservation of energy to **determine** her kinetic energy when the vine is vertical.
 - f **Calculate** Jane's velocity at this point.
- 14 Zelda wanted to bungee jump off a 50 m high bridge.
- a If Zelda has a mass of 75 kg, **calculate** her gravitational potential energy.
 - b As she jumps, the elastic bungee cord stretches. Use the conservation of energy law to **determine** the elastic potential energy of the bungee cord when Zelda is at the lowest point of her jump. (Assume no energy is transferred to the surrounding.)
 - c If the spring constant of the bungee cord is 15 N/m, **calculate** the distance the bungee cord stretched.
 - d **Explain** the assumption that is made regarding air resistance in this question.
- 15 **Describe** how the elastic potential energy of an object is affected if its stiffness increases and the other values remain constant.
- 16 A 450 kg car was driven at 60 km/h up a hill. **Calculate** the kinetic energy of the car.
- 17 A student claimed that their vacuum flask containing hot coffee was a closed thermodynamic system and therefore the coffee would never cool down. **Evaluate** their claim (by defining 'closed thermodynamic system', comparing the vacuum flask to this definition and deciding whether the claim is correct).
- 18 A silver teaspoon is placed in a cup filled with hot tea. After some time, the exposed end of the spoon becomes hot, even with no direct contact with the liquid. **Explain**, using the correct terminology, how this occurred.

Evaluate

- 19 **Describe**, in terms of kinetic energy of particles, why:
- a convection can only occur in liquids and gases, not solids
 - b when energy transfers by convection or conduction, the substance through which the energy transfers also gets heated
 - c good thermodynamic insulators are usually solids
 - d energy can transfer between objects only from the warmer thermodynamic system to the cooler thermodynamic system
 - e neither convection nor conduction is a way of transferring energy through a vacuum.

- 20 In some countries, double-glazed windows are used for heat insulation. They consist of two sheets of glass with a thin gap between them. **Explain** how this makes them better insulators than other glass windows with a single pane of glass.
- 21 **Evaluate** each of the following statements (by identifying the form(s) of energy that is used, describing how the rules of energy described in this chapter apply, and deciding whether the statement is correct).
- a A scooter gains energy as it rolls down a hill.
 - b An insulated container will stop hot tea from cooling down.
 - c Ice blocks transfer the cold to the water in a glass.

Social and ethical thinking

- 22 Insulating a house requires the homeowner to spend money; however, it reduces the cost of energy to heat or cool the house. Many people do not own their own house and therefore rely on their landlord to spend money to reduce the tenant's energy bills. Use the two ethical approaches (consequentialism ethics and deontological ethics) to **describe** the ethics of the decision that the landlord needs to make.
- 23 A group of students wanted to go bungee jumping on a school camp. All of the parents gave permission for their children to participate. One student decided at the last minute that they did not want to jump because they were worried that the jump was too high and that would affect how fast they would be going at the end of the rope. Use the terms 'gravitational potential energy' and 'kinetic energy' to **explain** their concern. Use the deontological ethical approach to **describe** why you should respect their decision.

Critical and creative thinking

- 24 Design a poster with a picture that describes the first or second law of thermodynamics.
- 25 Design a poster that shows the physics of bungee jumping.
- 26 An advertisement for a solar panel claims: 'It is the most effective solar panel compared to others on the market because it creates more electrical energy from the Sun'. Critically **evaluate** this claim (by identifying who made the claim, describing how this claim might benefit them, explaining how the statement could be correct, then explaining how the statement could be incorrect, and deciding whether you could trust the claim).

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.

» Perpetual motion machine

Investigate attempts by scientists to design a perpetual motion machine. Describe three machines that were claimed by the inventor to be perpetual motion machines. Use the laws of thermodynamics to explain why one of these machines could not remain in motion indefinitely.

» Bungy jumping

Investigate the sport of bungy jumping. Identify who originally developed the sport. Describe where they jumped to provide evidence that it was safe. Describe the factors that need to be taken into account before a person is allowed to jump. Use conservation of energy and elastic potential energy to describe the physics of a bungy jump.

» Newton's cradle

Investigate and describe a Newton's cradle. Use the law of conservation of energy to describe its motion. Explain why the movement eventually slows.

Reflect

The table below outlines a list of things you should be able to do by the end of Chapter 9 'Energy'. Once you've completed the chapter, use the table to reflect on your ability to complete each task.

	I can do this.	I cannot do this yet.
Explain work, kinetic energy, gravitational potential energy and elastic potential energy using appropriate examples. Manipulate the formulas for work, kinetic energy, gravitational potential energy and elastic potential energy appropriately to determine the relevant unknown variable.	☐	☐ Go back to Topic 9.1 'Work occurs when an object is moved or rearranged. Energy can be calculated' Page 198
Explain the law of conservation of energy using appropriate examples. Explain the principle of energy efficiency and apply the formula: $\text{Energy efficiency} = \frac{\text{amount of usable final energy}}{\text{amount of initial energy}} \times 100$	☐	☐ Go back to Topic 9.2 'Energy is always conserved' Page 200
Describe how thermodynamic equilibrium is achieved in terms of heat transfer, temperature changes and the motion and kinetic energy of particles within the substances involved.	☐	☐ Go back to Topic 9.3 'Thermodynamic systems that are connected reach thermal equilibrium' Page 202
Explain how heat energy is transferred by conduction and convection in terms of the motion of particles.	☐	☐ Go back to Topic 9.4 'Conduction transfers kinetic energy between particles. Convection causes the particles to move' Page 204
Explain the first law of thermodynamics in terms of changes in internal energy and work done. Explain how the second law of thermodynamics states that no energy transformation is 100 per cent efficient, resulting in an increase in entropy.	☐	☐ Go back to Topic 9.5 'Thermodynamics can be described by laws' Page 206

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How does your brain learn and remember?

CHAPTER

10

LEARNING AND MEMORY

10.1

The brain is responsible for learning and memory



10.2

Animals have innate behaviours to survive



10.3

Animals can learn behaviour from their environment



10.4

Information must be effectively encoded and stored for it to be recalled



10.5

Memory and learning can be improved



10.6

Science as a human endeavour: Neuroimaging makes memory and learning visible

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?

10.1 The brain is responsible for learning and memory

In this topic, you will learn that:

- 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, your brain would not be able to produce an image when you hear the name of a colour.

Our senses, including what we see, hear, taste, touch or smell, help our brains to understand our surroundings. Information that can be detected by our senses is called **stimuli**.

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

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 each of their functions.

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.

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

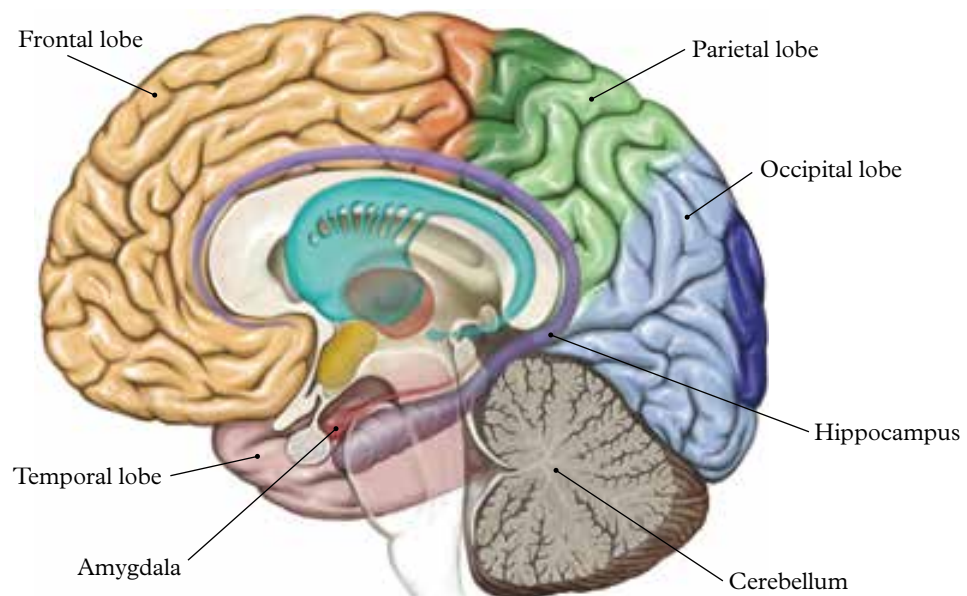


Figure 1 Parts of the brain involved in memory

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. 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.

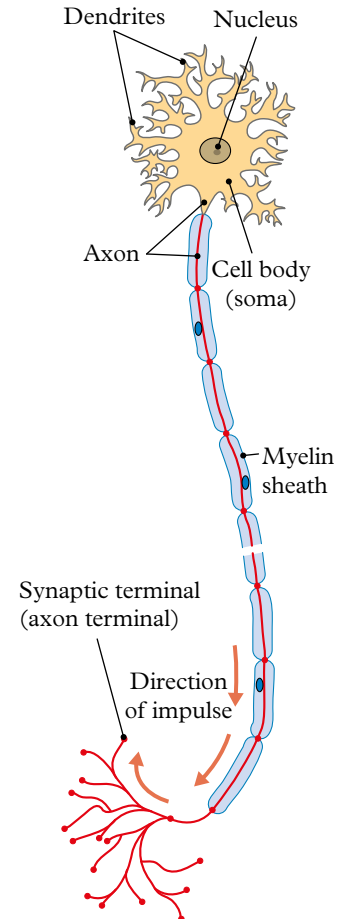


Figure 2 A neuron receives messages via the dendrites, and sends messages via the axon terminal.

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

10.1 Check your learning

Remember and understand

- 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 and analyse

- 5 Use an example of a memory you have, to **describe** the role of the hippocampus and amygdala in creating memories.

Evaluate and create

- 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.

10.2 Animals have innate behaviours to survive

In this topic, you will learn that:

- 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. 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. 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. 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.

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.

10.2 Check your learning

Remember and understand

- 1 **Identify** whether pre-programmed behaviour is a result of nature or the environment. **Explain.**
- 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.

Apply and analyse

- 4 **Explain** why a male bowerbird's nest-building behaviour is a species-specific behaviour.
- 5 **Compare** (the similarities and differences between) imprinting and species-specific behaviours.

- 6 **Identify** 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.

Evaluate and create

- 7 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.

10.3 Animals can learn behaviour from their environment

In this topic, you will learn that:

- 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

punishment

a negative result or consequence of a behaviour

classical conditioning

a learned behaviour that is linked to a previously neutral stimulus



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.

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.

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**.

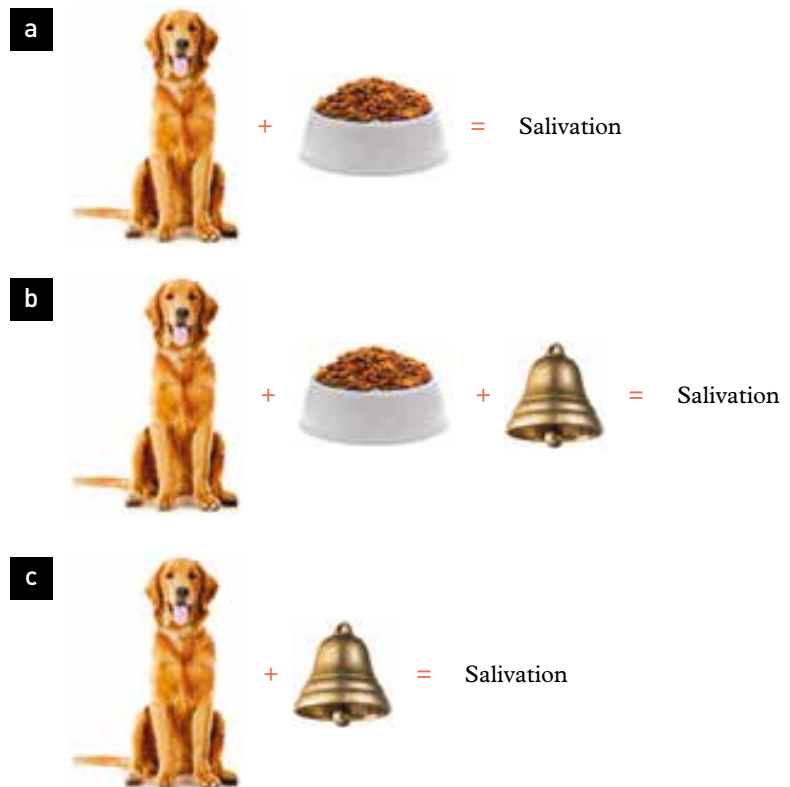


Figure 3 **a** Before classical conditioning, the dog salivates when it sees its food. **b** During conditioning, the dog pairs the sound of a bell with food and salivates. **c** The dog salivates when it hears the bell because it has associated the bell with food.

10.3 Check your learning

Remember and understand

- 1 **Define** the term 'learning'.
- 2 **Describe** how learning occurs through operant conditioning.
- 3 Use an example to **describe** observational learning.

Apply and analyse

- 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.

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

10.4 Information must be effectively encoded and stored for it to be recalled

In this topic, you will learn that:

- 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.

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', which includes sensory memory,

short-term memory and long-term memory. Table 1 compares the three types of memory.

Sensory memory

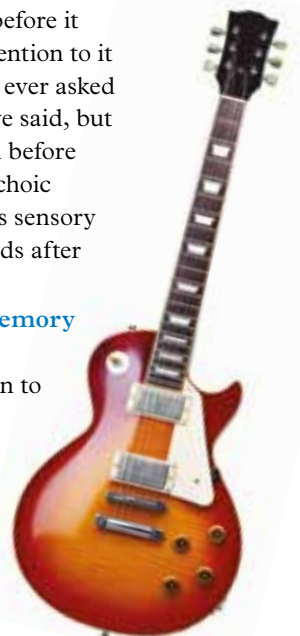
Our senses have the ability to briefly store memories. But not all **sensory memory** is transferred to short-term memory. It is only the stimuli that we pay attention to that are encoded and transferred to short-term memory.

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 – 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.



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

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. 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.

Table 1 compares the three types of memory.

Table 1 Comparison of duration and capacity for different memory types

Lobe	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

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

10.4 Check your learning

Remember and understand

- 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.

Apply and 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.



Figure 2 We may associate a kookaburra with birds, Australia, morning or a sports team based on the organisation of semantic networks.

10.5 Memory and learning can be improved

In this topic, you will learn that:

- 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.

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.

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.

10.5 Check your learning

Remember and understand

- 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.

Apply and analyse

- 4 **Compare** chunking and maintenance rehearsal.
- 5 **Compare** an acronym and an acrostic.

- 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.'

Evaluate and create

- 7 **Create** your own acrostic for recalling the five different mnemonic strategies for improving long-term memory as listed in Table 1.

Figure 2 When trying to remember something, the more unusual the image you conjure up is, the more it can help!



10.6 Neuroimaging makes memory and learning visible

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.

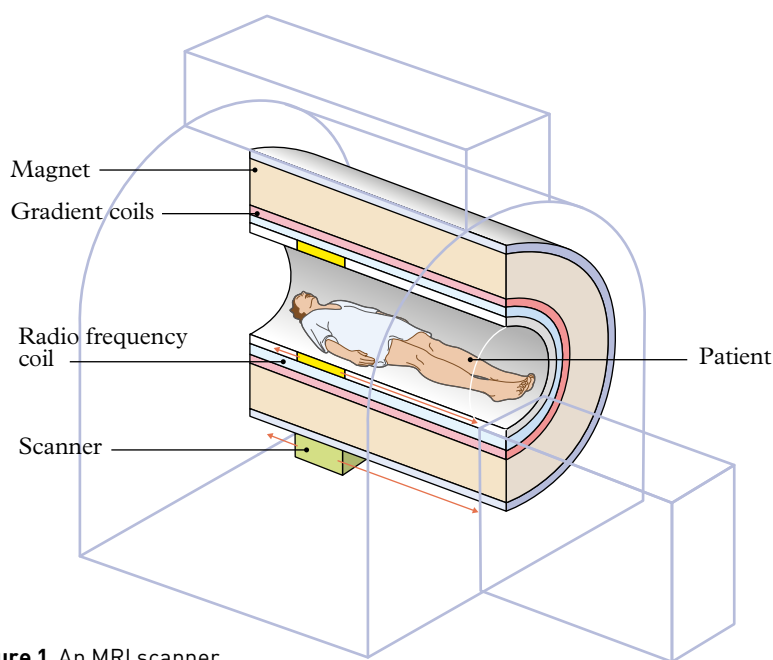


Figure 1 An MRI scanner

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 the brain

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. It also allows scientists to identify memory-related structures, such as the hippocampus,

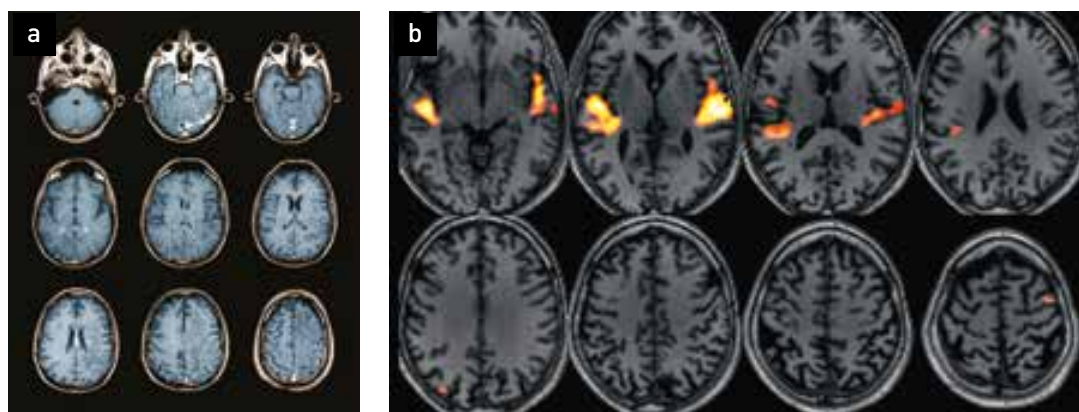


Figure 2 **a** MRI scans show 3D images of the brain. **b** fMRI scans show the activity patterns of the brain.

amygdala, cerebellum and cerebral cortex. 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. 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.

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.

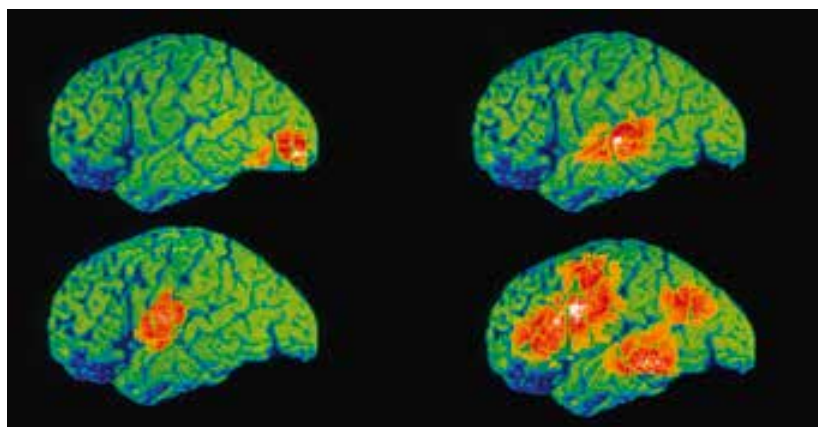


Figure 3 PET scans show brain activity in particular areas.

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 areas of 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

10.6 Develop your abilities

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.

Multiple choice questions

- 1 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 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 Use of consequences such as rewards and punishment are a feature of which type of learning?
 - A species-specific behaviours
 - B classical conditioning
 - C operant conditioning
 - D innate learning

Short answer questions

Remember and understand

- 4 **Define** the term ‘neural pathway’. **Explain** why it is important in learning.
- 5 Complete Table 1.

Table 1 Lobes of the brain and their key roles

Lobe	Key role
Frontal lobe	
Occipital lobe	
Temporal lobe	
Parietal lobe	

- 6 **Describe** the role of genetics in pre-programmed behaviours.
- 7 **Contrast** imprinting and species-specific behaviour.
- 8 **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.

- 9 **Describe** how encoding, storage and retrieval each contribute to the processing of memories.
- 10 **Name** the three types of memory.
- 11 **Describe** the role of short-term memory.
- 12 **Describe** the role of long-term memory.
- 13 **Describe** an example of a mnemonic strategy. **Identify** the type of memory it can enhance.
- 14 **Explain** how mnemonic strategies can improve:
 - a short-term memory
 - b long-term memory.
- 15 **Describe** the strategy known as ‘maintenance rehearsal’, and **explain** how it can improve our recall of key words stored in short-term memory.

Apply and analyse

- 16 **Explain** how the hippocampus and cerebral cortex work together when creating memories.
- 17 Katia is learning gymnastics. **Identify** the area of her brain that will store the memory of the actions for her gymnastic routines.
- 18 Oliver 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.
- 19 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.
- 20 **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.
- 21 **Explain** why shor-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.
- 22 Give your own example of an animal behaviour that would be described as:
 - a species-specific behaviour
 - b maturation.

- 23 **Explain** how positive reinforcement is different to punishment.
- 24 Complete Table 2 by reflecting upon 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			

- 25 **Identify** which type of learning (positive reinforcement or punishment) matches the following scenarios. **Justify** your answer for each response.
- 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.
 - A child fell out of a tree and broke her arm, so now she chooses not to climb trees.
- 26 **Identify** 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.
- 27 **Identify** one similarity and one difference between:
- positive reinforcement and punishment
 - operant conditioning and classical conditioning
 - operant conditioning and observational learning.
- 28 **Explain** why a light stimulus must be encoded in order for our brain to understand what we have seen.
- 29 **Compare** the capacity and the duration of echoic and iconic sensory memories.
- 30 Which type of memory would we be using if we were adding up the prices of three items at the supermarket?
- 31 **Compare** (by identifying a similarity and a difference between) maintenance rehearsal and elaborative rehearsal.
- 32 **Identify** a similarity and a difference between chunking and chaining.

Evaluate

- 33 **Discuss** the roles of both nature and nurture in enabling animals to survive and thrive in their environment.
- 34 **Identify** 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.

- 35 **Discuss** how learning is different from a pre-programmed behaviour. How might both influences on behaviour be an advantage to the survival of an animal species?
- 36 **Create** a poster with a mind map or diagram explaining how sensory memory, short-term memory and long-term memory interact.
- 37 **Create** a story using the strategy of chaining to recall the following 10 words 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 words in order.



Figure 1 Can you remember the words, like koala, in order?

Social and ethical thinking

- 38 Imagine you were offered the opportunity to take a smart pill that would improve your memory. **Identify** 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. **Describe** the ethical issues that could possibly arise as a result of taking such a pill.

Critical and creative thinking

- 39 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. **Explain** why this assumption could not be true.
- 40 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. **Explain** why it is important to repeat fMRI scans several times before drawing a conclusion about the activity of the brain.

Research

- 41 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?

» 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.

» 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, and strategies for healthy eating and sleep habits as part of a regular routine.

Reflect

The table below outlines a list of things you should be able to do by the end of Chapter 10 'Learning and memory'. Once you've completed the chapter, use the table to reflect on your ability to complete each task.

	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 10.1 'The brain is responsible for learning and memory' Page 212
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 10.2 'Animals have innate behaviours to survive' Page 214
Explain that learning is a demonstrated change in behaviour as a result of experience. Describe the process of operant conditioning and classical conditioning.	☐	☐ Go back to Topic 10.3 'Animals can learn behaviour from their environment' Page 216
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 10.4 'Information must be effectively encoded and stored for it to be recalled' Page 218
Explain how mnemonics can improve short-term memory capacity and long-term memory stores.	☐	☐ Go back to Topic 10.5 'Memory and learning can be improved' Page 220
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 10.6 'Science as a human endeavour: Neuroimaging makes memory and learning visible' Page 222

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CHAPTER

11

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 ($\frac{1}{2}$ cup) dried peas soaked overnight in 2 cups of water, or frozen peas (thaw first)
- > 200 mL (1 cup) water
- > 6 g (1 tsp) table salt
- > 20 mL dishwashing liquid
- > 1 g ($\frac{1}{4}$ tsp) 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 glass vials
- > 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 glass vial. There should be enough of this mix for eight test tubes or vials, which can be shared in the class.
- 2 Dribble 15 mL of ice-cold ethanol down the side of the test tube or vial – there should be equal amounts of filtrate and ethanol in the test tube or vial.

- 3 Leave the test tube or vial 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.

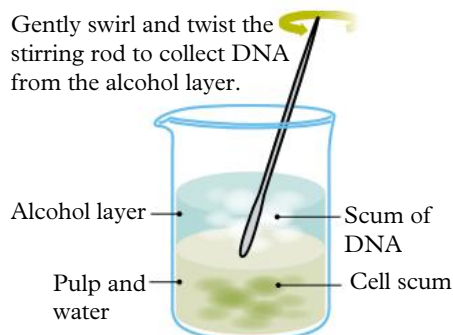


Figure 1 Procedure for collecting DNA from the alcohol layer

- 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 $\times 10$ 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 similarities and differences between) the DNA of the dried 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 dried 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).

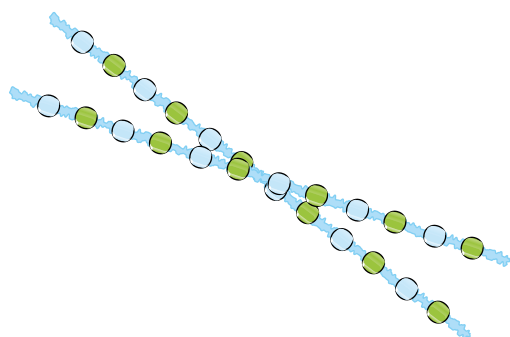


Figure 1 Representation of the sugar-phosphate backbone of DNA molecules

- 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).

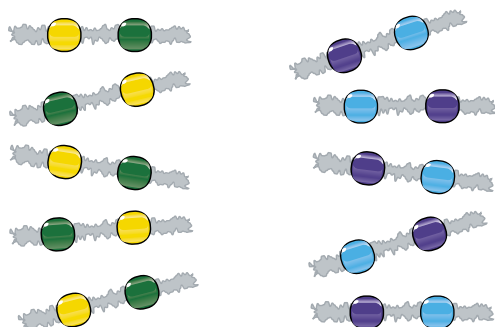


Figure 2 Representation of paired nitrogen bases A-T and G-C

- 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).

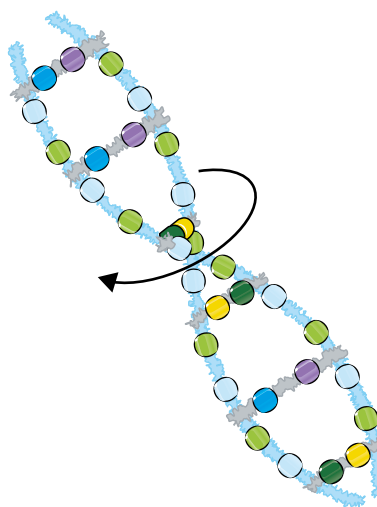


Figure 3 Representation of the DNA double helix structure

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

- Write the complementary sequence of DNA for this part of the gene.
- 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.)
- 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.
- Describe how the protein strand would change if the twelfth nucleotide in the DNA template strand (guanine) was changed to a thymine.

Discussion

- Compare the genetic code of DNA (ATGC) with a chromosome.
- Contrast (the differences between) DNA and RNA.
- 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).

Base triplet			Acid		
First base	Second base	Third base			
U	C	U	UUU	Phe	
		C	UUC		
	A	U	UUA	Leu	
C	C	U	UUG		
		C			
	A	U	CUU	Leu	
A	C	U	CUC		
		C	CUA		
	A	U	CUG		
G	C	U	AUU	Ile	
		C	AUC		
	A	U	AUA		
G	C	U	AUG	Met/Start	
		C			
	A	U	GUU	Val	
G	C	U	GUC		
		C	GUA		
	A	U	GUG		
U	C	U	UCU	Ser	
		C	UCC		
	A	U	UCA		
C	C	U	UCG		
		C			
	A	U	CCU	Pro	
A	C	U	CCC		
		C	CCA		
	A	U	CCG		
G	C	U	CAU	His	
		C	CAC		
	A	U	CAA	Gln	
U	C	U	CAG		
		C			
	A	U	AAU	Asn	
C	C	U	AAC		
		C	AAA	Lys	
	A	U	AAG		
G	C	U	GAU	Asp	
		C	GAC		
	A	U	GAA	Glu	
U	C	U	GAG		
		C			
	A	U	GGU	Gly	
C	C	U	GGC		
		C	GGA		
	A	U	GGG		
A	C	U	UGU	Cys	
		C	UGC		
	A	U	UGA	Stop	
G	C	U	UAA	Stop	
		C	UAG	Stop	
	A	U	UGG	Trp	

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

- View a slide under the microscope at the greatest magnification possible.
- 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).

- 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.

Discussion

- Explain why DNA can be difficult to see under the microscope during interphase.
- Describe an advantage of DNA being tightly wound around a protein during mitosis.
- Describe the possible consequences for a cell if errors occur during the process of DNA replication that occurs during interphase.
- 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
- > Felt-tipped pens
- > Sticky tape
- > 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 bivalent 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/bivalent 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.

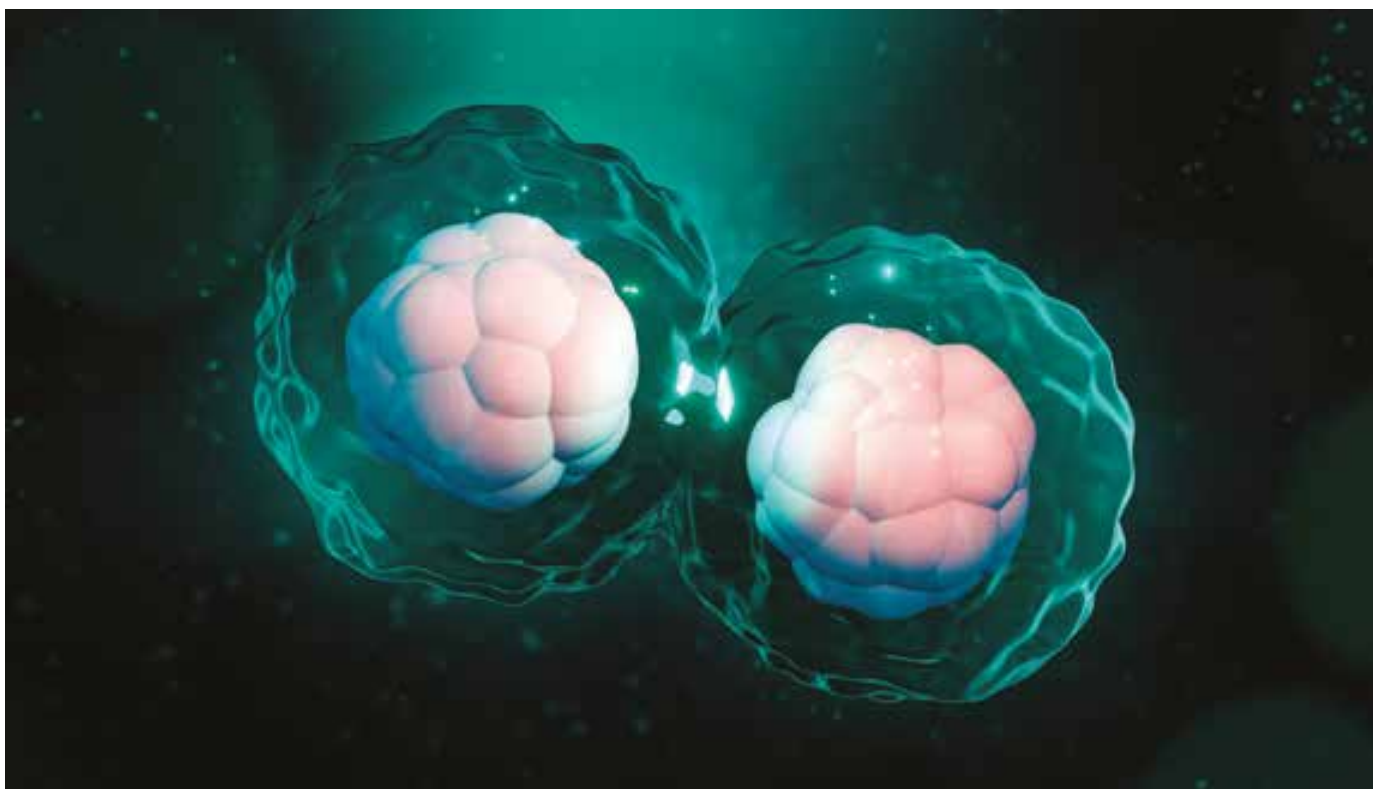


Figure 1 Can you identify this stage of meiosis?

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
- > Pink and white large 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.

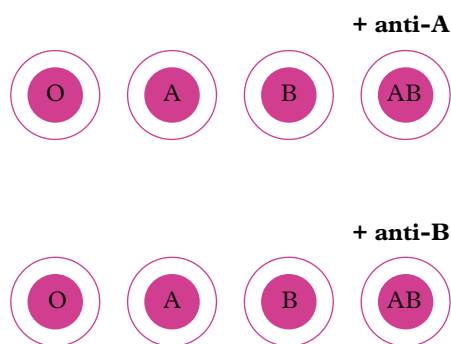


Figure 1 Where to place blood samples on the spotting tile

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 type AB blood, 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.

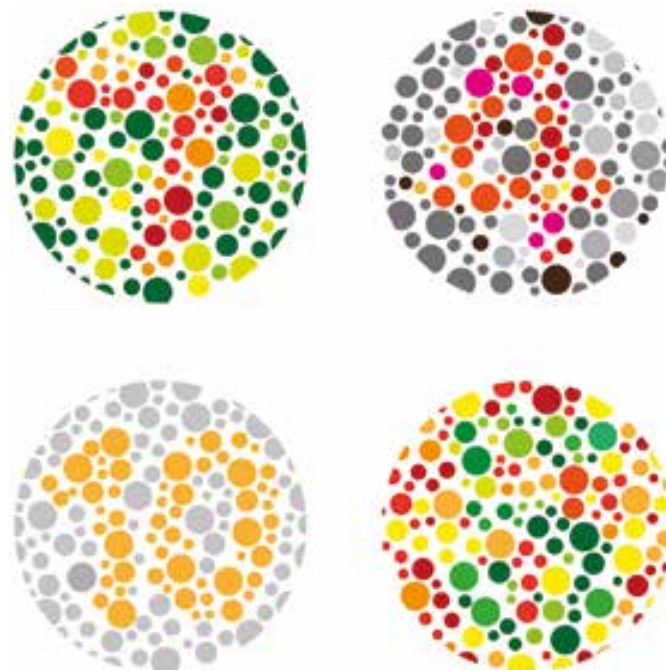


Figure 1 The Ishihara colour test uses coloured dots to identify whether a person is colour blind. The dots in each of these pictures are arranged to represent a number.

2.11 Identifying mutations

SKILLS LAB

Aim

To identify how a mutation in a DNA sequence can cause a disease.

- 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
 - 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).
 - Describe the outcome of mutation 1 on protein synthesis. You may wish to consult the codon table in Figure 1.
 - Describe the outcome of mutation 2 on protein synthesis.
- 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

- Identify the type of mutation.
- Describe the amino acid change that would occur in the PrPc protein.
- Distinguish between natural and induced mutation.

Discussion

- Compare the definitions for mutation and mutagen.
- Identify three types of mutagens.
- 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).

		Second base				
		U	C	A	G	
First base	U	UUU Phe UUC	UCU Ser UCC UCA UCG	UAU Tyr UAC UAA Stop UAG Stop	UGU Cys UGC UGA Stop UGG Trp	U C A G
	C	CUU Leu CUC CUA CUG	CCU Pro CCC CCA CCG	CAU His CAC CAA Gln CAG	CGU Arg CGC CGA CGG	U C A G
	A	AUU Ile AUC AUA AUG Met/Start	ACU Thr ACC ACA ACG	AAU Asn AAC AAA Lys AAG	AGU Ser AGC AGA Arg AGG	U C A G
	G	GUU Val GUC GUA GUG	GCU Ala GCC GCA GCG	GAU Asp GAC GAA Glu GAG	GGU Gly GGC GGA GGG	U C A 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 amount 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 absolute 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
 - Hippo
AGTCCCCAAAGCAAAGGAGACTATCCTT
CCTAAGCATAAAGAAATGCCCTTCTCTAA
ATC
 - Giraffe
AGTCTCCAAATGAAAGGAGACTATGGCT
CCTAAGCACAAAGAAATGCCCTTCCCTAA
ATA
 - Rhino
AGTCCTCCAACTAAGGAGACCATCTTTC
CTAAGCTCAAAGTTATGCCCTCCCTTAA
ATC
 - Pig
AGATTCCAAAGCTAAGGAGACCATTGTT
CCCAAGCGTAAAGGAATGCCCTTCCCTAA
ATC
 - Cow
AGTCCCCAAATGAAAGGAGACTATGGTT
CCTAAGCACAAAGGAATGCCCTTCCCTAA
ATA

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.

Table 1 Comparison of molecular differences in DNA sequences between animals

Hippo				
Cow				
Giraffe				
Rhino				
	Pig	Hippo	Cow	Giraffe

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.

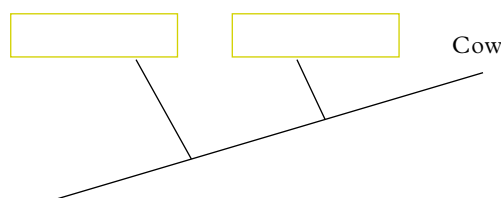


Figure 1 Phylogenetic tree

- 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 or 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.

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

- 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

- Identify which two traits are most important for your new breed to inherit.
- Using Table 2, choose which dogs you need to breed to achieve your desired traits.
- 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.
- 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.

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

- 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

- Explain why all three puppies were not identical.
- 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).
- If you were to breed the dogs for another generation, identify the puppies you would select to be the parents. Justify your answer.
- 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).
- 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.

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.

4.3 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.

4.4 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 below. (Chlorine has been completed in step 5 as an example.)
- 2 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 potassium atom and a fluorine atom meet
 - 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.



Figure 1 Use highlighters to categorise the different elements of the periodic table.

4.5A 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 Experiment 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 end of the electrode 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.

4.5B 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

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-}

on the ion. 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.

4.6 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 ₂ O				
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.

4.7 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.

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.



Figure 1 Use the newspaper to weigh the sand.

5.1 Comparing mass before and after a chemical reaction

EXPERIMENT

Aim

To determine whether mass is conserved in a chemical reaction.

Materials

- > Sodium bicarbonate
- > Vinegar
- > Balloon
- > Balance
- > Measuring cylinder
- > 2 conical flasks
- > Watch glass
- > Spatula
- > Powder funnel
- > Bench mat

Method

Part A

- 1 Copy the results table for Part A (Table 1) to record your results.
- 2 Weigh 2.0 g of sodium bicarbonate onto a watch glass.
- 3 Add 20 mL of vinegar to a flask.
- 4 Ensure the balance is reading zero. Weigh the vinegar and flask. Record this mass (M_1).
- 5 Predict whether the mass of the flask and vinegar after the reaction with the sodium bicarbonate will be more, the same or less than the initial mass.
- 6 Add 2.0 g of sodium bicarbonate (M_2) to the flask containing the vinegar and swirl until the bubbling stops.
- 7 Weigh the flask after the reaction has stopped. Record the final mass (M_3).



Figure 1 When adding reagents, be careful not to spill any contents.

Part B

- 1 Copy the results table for Part B (Table 2) to record your results.
- 2 Weigh 2.0 g of sodium bicarbonate onto a watch glass.
- 3 Add 20 mL of vinegar to a flask.
- 4 Ensure the balance is reading zero. Weigh the vinegar, flask and a balloon. Record this mass (M_1).
- 5 Predict whether the mass of the flask, vinegar and balloon after the reaction with the sodium bicarbonate will be more, the same or less than the initial mass.

- 6 Add 2.0 g of sodium bicarbonate (M_2) to the balloon and carefully stretch the opening of the balloon over the neck of the flask so that the sodium bicarbonate does not spill.
- 7 Hold the end of the balloon directly over the top of the flask so that the sodium bicarbonate spills into the vinegar (keeping the contents sealed).
- 8 Weigh the flask, with the balloon still attached, after the reaction has stopped. Record the final mass (M_3).



Figure 2 The balloon prevents the gas from escaping the flask.

Results

Copy and complete Tables 1 and 2.

Table 1 Results for Part A

Mass of flask and vinegar (M_1)	Mass of sodium bicarbonate (M_2)	Total mass before reaction ($M_1 + M_2$)	Mass after reaction (M_3)

Table 2 Results for Part B

Mass of flask, vinegar and balloon (M_1)	Mass of sodium bicarbonate (M_2)	Total mass before reaction ($M_1 + M_2$)	Mass after reaction (M_3)

Discussion

- 1 Compare the initial and final masses for each part of the experiment.
- 2 Compare the results with your predictions.
- 3 Identify the gas that was produced.
- 4 Describe the purpose of sealing the flask with the balloon.
- 5 Describe the purpose of the control for this experiment.
- 6 Identify a possible random error and systematic error for this experiment. Describe how these errors could be minimised.

Conclusion

Compare the results of this reaction with the law of conservation of mass.

5.2 Modelling chemical equations

CHALLENGE

Aim

To use the law of conservation of mass to balance a chemical equation.

What you need

- > 5 paper bags
- > Model atom kit (or laminated squares labelled oxygen (O) atom, carbon (C) atom and hydrogen (H) atom)
- > Felt-tipped pen

Part A

What to do

- 1 Each paper bag represents a molecule. Create a molecule of oxygen (O_2) by placing two oxygen 'atoms' in a paper bag. Write ' O_2 ' on the bag.
- 2 Use two paper bags and four model hydrogen atoms to create two molecules of hydrogen (H_2). You have now created the reactants in the chemical reaction:
 $2H_2 + O_2 \rightarrow 2H_2O$
- 3 Label the two remaining paper bags ' H_2O '. Take the model atoms out of the reactant bags and place them in the product H_2O bags. Are there enough atoms to fill the H_2O bags?

Discussion

- 1 Explain why there needed to be more molecules/bags of hydrogen than oxygen.
- 2 Describe what would happen if one more molecule of oxygen was added to the reaction.
- 3 Compare this model reaction with the law of conservation of mass.

Part B

What to do

- 1 Use new bags and the model atoms to create two molecules of methane (CH_4).
- 2 Identify the number of oxygen molecules (O_2) that you would need to turn these methane molecules into carbon dioxide (CO_2) and water (H_2O). Use the bags and model atoms to check your prediction.

Discussion

- 1 Identify the number of oxygen molecules you needed to balance this equation.
- 2 Identify the number of carbon dioxide and water molecules you were able to create with two methane molecules.
- 3 Write the word equation for this reaction.
- 4 Write the balanced chemical equation for this reaction.



Figure 1 There's more to this paper bag than meets the eye.

5.3A 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	> Rubber stopper
> Dilute hydrochloric acid (1 M)	> Wooden splint
> 2 test tubes and test-tube rack	> 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.

5.3B 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	> Bunsen burner
> Pyrex (high-strength) test tube	> Matches
> Test-tube rack	> Spatula
> Test-tube holder	> Gloves and safety glasses

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.

Background

Copper sulfate (CuSO_4) is an ionic substance containing copper(II) (Cu^{2+}) ions and sulfate (SO_4^{2-}) ions.



CAUTION! Wear safety glasses throughout this experiment. Do not let the carbon rods touch when they are in the beaker. Ensure that no liquid comes into contact with the power supply at any time.

Aim

To use electricity to produce copper metal from copper(II) sulfate.

Materials

- > Copper(II) sulfate
- > 100 mL beaker
- > Stirring rod
- > Spatula
- > 2–12 V DC power supply
- > 12 V globe and globe holder
- > Wires with alligator clips
- > 2 carbon rods

Method

- 1 Add one spatula of the copper(II) sulfate to the beaker and half fill it with water.
- 2 Stir until the crystals are all dissolved.
- 3 Set the power supply to a maximum of 6 V and connect the circuit as shown in Figure 1.



Figure 1 Experiment set-up

- 4 Touch the carbon rods together to check the circuit works and then place the carbon rods in the beaker with a 1 cm gap between them.
- 5 Hold the rods in place for 30 seconds and observe any changes that occur.
- 6 Turn off the power supply.

Results

Record your observations in an appropriate format.

Discussion

- 1 Describe the evidence that copper was formed in the reaction.
- 2 Use the structure of the copper sulfate to describe the:
 - > role of the water in the process
 - > role of the electric circuit
 - > reason that the copper was only found on one of the carbon electrodes.
- 3 Evaluate if a usable amount of copper could be produced this way (by describing the amount of energy used and the amount of copper produced in the time, and deciding if it would make an effective business model). If not, describe the changes that would need to be made to the set-up to produce more copper.
- 4 Identify if this is a synthesis or decomposition reaction. Justify your answer (by comparing the definition with the reaction that occurred).
- 5 Identify if this experiment is a case study, a model/simulation, quantitative analysis or a controlled experiment. Justify your decision (by comparing the definition with the method).

Conclusion

Describe what you know about decomposition reactions.

5.4 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. $\text{pH} = 7$).
- 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.

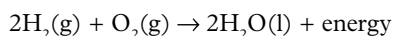
Results

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:



- 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.

5.5 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 ($\text{Ca}(\text{NO}_3)_2$), copper(II) nitrate ($\text{Cu}(\text{NO}_3)_2$), magnesium nitrate ($\text{Mg}(\text{NO}_3)_2$), 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
$\text{Ca}(\text{NO}_3)_2$				
$\text{Cu}(\text{NO}_3)_2$				
$\text{Mg}(\text{NO}_3)_2$				
AgNO_3				
CuSO_4				

- 2 Make a second 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.

Results

- 1 Using your other copy of the results table, describe any precipitate that forms.
- 2 Use Table 1 (page 116) 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. 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.

5.6 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	> Heatproof mat
> 9 V battery	> Balance
> Crucible	> 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.

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.

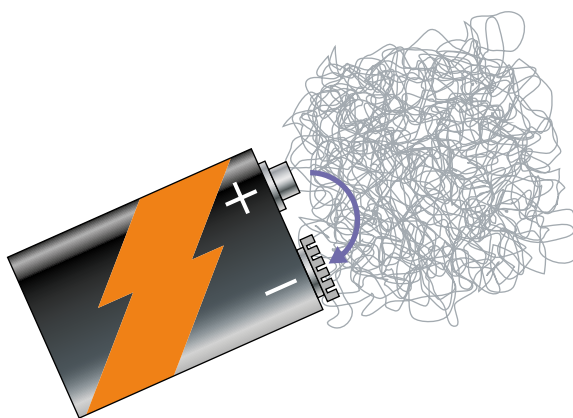


Figure 1 Experiment set-up

5.7 Polymerisation of casein

EXPERIMENT

Background

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	> Bench mat
> 5 mL vinegar	> Spatula
(CH ₃ COOH)	> Filter paper
> Bunsen burner	> Funnel
> Matches	> 250 mL beaker
> Tripod	> Conical flask
> Thermometer	> Heatproof gloves
> Gauze mat	> 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 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.

5.8 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

- 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.
- 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.
- 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

- Write a balanced chemical equation for the chemical reaction.
- Describe the relationship between your independent variable and dependent variable as shown by your graph.
- Compare your hypothesis with the results you obtained.
- 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.
- 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)									

5.9 Using a catalyst

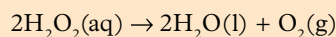
EXPERIMENT



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. The reaction used in this experiment is the decomposition of hydrogen peroxide:



Materials

- > 3 per cent hydrogen peroxide (H_2O_2) solution (10 mL)
- > Manganese dioxide (MnO_2) powder
- > Test tubes and test-tube stand
- > 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 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.

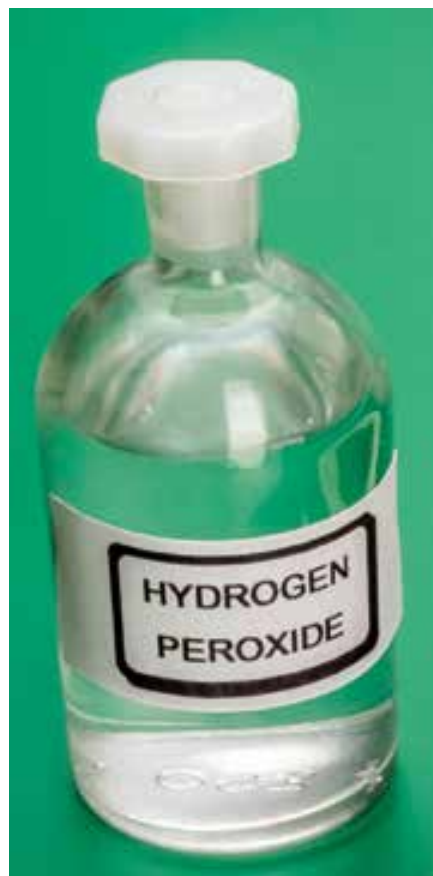


Figure 1 Hydrogen peroxide is used as a disinfectant and bleach.

Conclusion

Describe how a catalyst affects the rate of a reaction.

6.1 Using computer simulations

CHALLENGE

Aim

Use a computer to simulate the temperature at the deepest point of Earth's mantle, 2800 km below the 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 in a table.

6.2A Making a simple barometer

CHALLENGE

Aim

To make a simple barometer.

What you need

- > Straw
- > Glass jar
- > Balloon
- > Rubber band
- > 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 (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.
- 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 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.

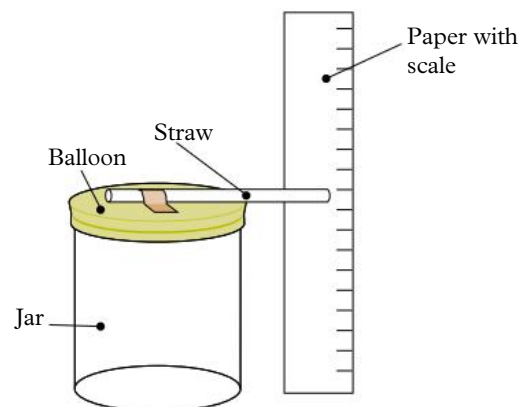


Figure 1 Experiment set-up

6.2B Make your own clouds

EXPERIMENT

Aim

To simulate the process of condensation.

Materials

- > Ice cubes
- > Gauze mat
- > Water
- > Evaporating dish
- > Heatproof mat
- > Matches
- > Tripod
- > Bunsen burner
- > 250 mL beaker
- > Safety glasses

Method

- 1 Set up the apparatus as shown in Figure 1 (except for the evaporating dish and ice).
- 2 Heat the water in the beaker until it boils.
- 3 Turn the gas off and place an ice-filled evaporating dish on top of the beaker.
- 4 Carefully observe what happens.

Results

Record your observations in an appropriate format.

Discussion

- 1 Describe the action that produced water vapour.
- 2 Describe what happened to the water vapour as it neared the ice cubes.
- 3 Identify which of the Earth's spheres contains water vapour.
- 4 Explain why the condensation of water is important to the biosphere.

Conclusion

Describe what you know about the importance of water condensation in the Earth's spheres.

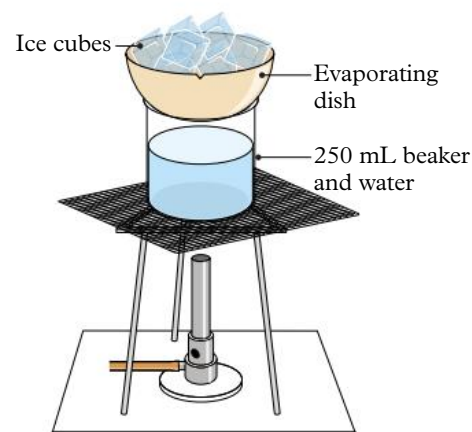


Figure 1 Experiment set-up

6.3 Testing phosphorus

EXPERIMENT

Aim

To determine whether phosphorus is present in a variety of detergents.

Materials

- > Variety of detergents
- > Phosphorus (or phosphate) testing kit
- > Test tubes and test-tube rack
- > Measuring cylinder
- > Deionised/distilled water

Method

- 1 Add 9 mL of deionised/distilled water to a test tube.
- 2 Add 1 mL of detergent to the test tube.
- 3 Follow the instructions of the phosphorus (or phosphate) testing kit to determine whether there is phosphorus present in the detergent.
- 4 Repeat steps 1–3 with the remaining detergents.

Results

Record your observations in an appropriate table.

Discussion

- 1 Identify the detergents that contained phosphorus/phosphate.
- 2 DNA and ATP (a high-energy molecule) contain phosphorus/phosphate. Describe what would happen to an organism that could not obtain enough phosphorus/phosphate.
- 3 Define the term ‘eutrophication’ to explain why the levels of phosphorus or phosphate in soil need to be controlled.
- 4 Check the labels on the detergents in your home. Identify the phosphorus-containing detergents that are used in your household.
- 5 Evaluate the reliability of the testing kit (by identifying other variables that may affect the outcome of the test, describing how these variables are or are not controlled, and explaining whether the test procedure is repeatable and reproducible).

Conclusion

Describe what you know about the phosphorus cycle.



Figure 1 This experiment requires test tubes.

6.4 Modelling a carbon sink

CHALLENGE

Aim

To model a carbon sink.

This activity may be demonstrated by your teacher.



CAUTION! Dry ice is frozen carbon dioxide (-79°C). Do not touch the dry ice with your fingers or metal objects. Use wooden or plastic tongs. Do not seal dry ice in any container as the gas expands rapidly.

What you need

- > Dry ice
- > 100 mL water
- > Universal indicator and pH colour chart
- > 250 mL beaker
- > Piece of netting
- > Watch glass that covers the top of the beaker
- > Sticky tape
- > Wooden or plastic tongs

What to do

- 1 Place the water in the beaker.
- 2 Add 5 drops of universal indicator to the water.
- 3 Place the netting over the top of the beaker and push down the centre slightly. This will provide a pouch to suspend the dry ice above the water. Use sticky tape to hold the netting in place.
- 4 Place a piece of dry ice in the netting and position the watch glass over the top of the beaker.
- 5 Observe any colour changes in the water.

Discussion

- 1 Describe what happened to the solid dry ice when it was sitting in the netting.
- 2 Describe any changes you noticed in the water and universal indicator.
- 3 Identify the final pH of the water.
- 4 Provide an explanation for the changes you noticed.
- 5 Define the term 'carbon sink'.
- 6 Describe how you could use this demonstration to explain the consequences of increased carbon dioxide levels in the atmosphere.

6.5A What factors affect a greenhouse?

EXPERIMENT



CAUTION! Soil may contain bacteria that is harmful. Wear a mask when handling soil. Avoid breathing Perlite dust and wear gloves.

Aim

To determine which surfaces of the Earth absorb energy and radiate it as heat and so are likely to contribute most to the warming of the atmosphere.

Materials

- > 3 cups of dark soil
- > 3 cups of white sand or perlite
- > White paint and brush
- > Water
- > 6 identical clear, empty 600 mL soft-drink bottles with labels removed
- > 6 one-hole rubber stoppers with thermometers inserted that fit securely into the bottle top, or data-logging equipment with long steel temperature probes secured in place with Blu-Tack
- > Sunlight or portable reflector lamp with 150 W floodlight bulb
- > Funnel
- > Stopwatch
- > Marker pen
- > Stand to support the lamp set-up (retort stand and clamps)

Method

- 1 Work as a group and label the bottles A, B, C, D, E and F. Paint the upper one-third of bottles B, D and F white to represent cloud cover. Allow paint to dry.
- 2 Use a funnel to fill the base of bottles A and B with dark soil, bottles C and D with white sand or perlite, and bottles E and F with room-temperature water. Ensure that you use the same depth (5–7 cm) in each bottle.
- 3 Put the thermometers inserted in the rubber stoppers into the bottle tops. Ensure that the bulbs are just above the top of the base (dirt, water, perlite or sand). If the bulbs are below the base, they may record the heat absorbed directly by the soil or water, which will affect your data. You want to measure the temperature of the air (the atmospheric temperature). If using a data-logger temperature probe, secure and seal into the top of the bottle with Blu-Tack.

- 4 Record the initial baseline atmospheric temperature of each bottle in a table.
- 5 If it is a sunny day, take your bottles outside. Alternatively, set up the 150 W light source on a stand facing down. Place the bottles underneath the light source approximately 15 cm away from the lamp. It is important that all bottles receive equal light. Depending on your light source, you may be only able to do two bottles at a time. If this is the case, ensure the two bottles have the same base; for example, dirt.
- 6 In an appropriate table, record the temperatures of each bottle every 2 minutes for at least 20 minutes. Calculate the mean temperature for each type of bottle base and record it in the table.

Results

Predict which bottle will reach the highest temperature and justify your prediction.

Draw a graph of time (in minutes) against the mean bottle temperature to record your observations.

Discussion

- 1 Use the graph to compare the rate of increasing temperature for the different bottles.
- 2 Identify which bottled environment:
 - a produced the lowest temperature
 - b would lead to the least heating of the atmosphere.
- 3 Explain the temperature difference between the dark soil and the white sand/perlite.
- 4 Explain the temperature difference between the water and the white perlite.
- 5 Explain how this experiment demonstrates the effect of the oceans and dark and light surfaces on air temperature.
- 6 If the deserts are increasing and ice is melting, exposing dark soil, describe the expected effects this will have on atmospheric temperature.
- 7 Explain why each base type (dirt, water, perlite or sand) was duplicated in this experiment.

Conclusion

Summarise your key findings from this experiment.

6.5B 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.

6.6 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 of salt and water.
- 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.

7.1A Using a star chart

SKILLS LAB

Aim

To use a star chart to identify the position of a star or constellation.

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.

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

Aim

To determine the role of Penny Sackett and Brian Schmidt in astronomy.

Background

Two prominent astronomers currently practising in Australia are Penny Sackett and Brian Schmidt (Figure 1).



Figure 1 Brian Schmidt and Penny Sackett

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.

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	> Sticky tape
> Retort stand (about 76 cm in height)	> Needle or pin
> Clamp	> 2 × A4 sheets of paper
> Coat hanger	> 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 pin hole 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 the red shift and blue shift that are seen with starlight.

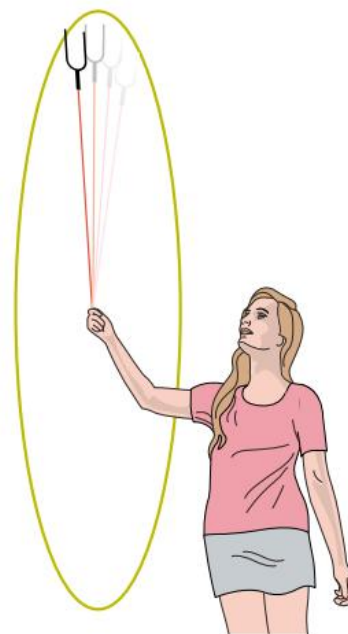


Figure 1 Using the Doppler effect apparatus

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).

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 position–time graph.

Working in pairs, act out the position–time graph in Figure 1.

What you need

- > Clear space (maybe outside)
- > Tape measure
- > Stopwatch
- > Masking tape
- > Marker pen

What to do

- 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.

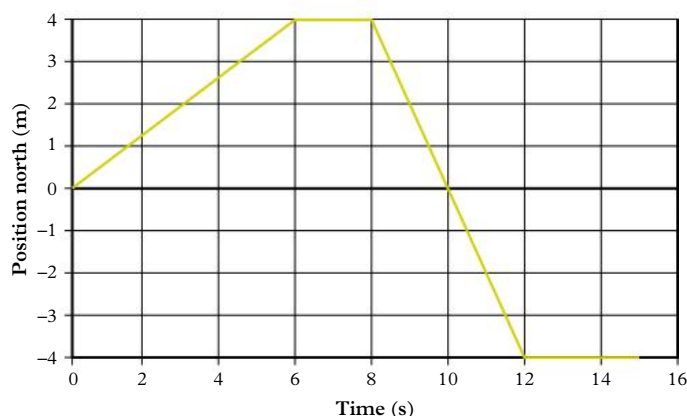


Figure 1 A position–time graph

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 position–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	> 2 electrical wires
> Scissors	> Glue
> 2–12 V DC power supply	> Ticker tape
> Graph paper	> 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 $\div$ 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 position–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 Design another experiment you could perform with the motion sensor.
- 4 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).

Conclusion

Describe the information that can be gained from graphs created by a motion sensor.

8.3 Measuring acceleration by timing or using a motion sensor

CHALLENGE

Aim

To measure the acceleration of a falling object.



CAUTION! Never drop objects from high places without looking below to make sure the area is clear.

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 reasoning (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

Aim

To use Newton's laws to identify an object full of liquid.



CAUTION! Some students may be allergic to eggs. Do not eat or drink in the laboratory.

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?

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 contents of a fresh egg will change their movement when the egg is stopped.
- 4 Describe how the contents of a boiled egg will change their 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)
- > Graph paper
- > Masking tape
- > 2 rubber bands
- > 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).

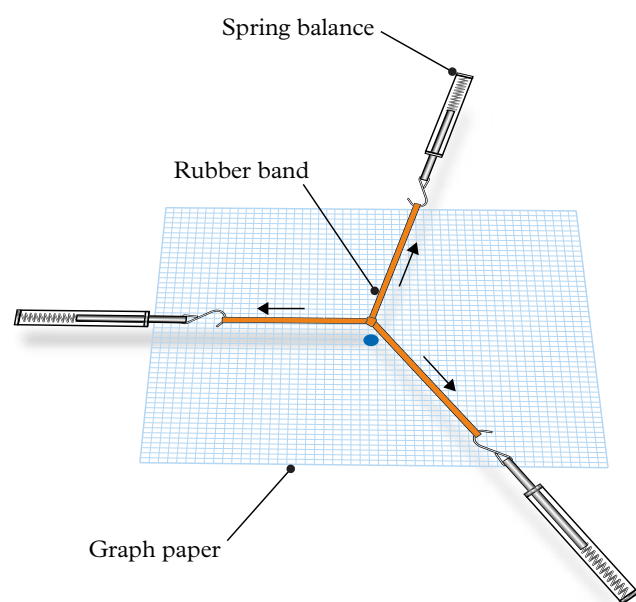


Figure 1 Experiment set-up

- 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 $1\text{ cm} = 1\text{ N}$) 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	> Motion sensor or stopwatch
> String	> Tape measure or ticker timer
> Mass hanger and brass 50 g masses	> 2–12 V power supply
> Several 1 kg masses	> Ticker tape
> Desk-mountable pulley wheel with clamp	> 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 $(2 \times \text{the distance travelled} \div \text{time squared})$.
 - 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	> Sticky tape
> Drinking straw	> 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.

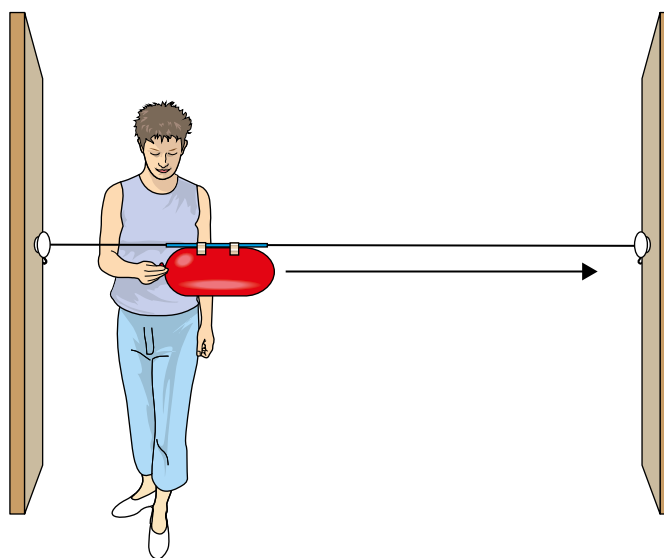


Figure 1 Experiment set-up

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 at the same time. 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 following result headings in 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.

9.1 What if a rubber band was stretched further?

EXPERIMENT



CAUTION! Wear safety glasses at all times to prevent eye injuries.

Aim

To determine the relationship between the elastic potential energy and the kinetic energy of a rubber band.

Materials

- > Metre ruler
- > Rubber bands
- > Tape measure
- > Chalk
- > Spring balance

Method

- 1 Use the chalk to place a mark on the ground. This is the starting point for your rubber band.
- 2 Hook one edge of the rubber band on the end of the ruler. Pull the rubber band back to the 10 cm mark on the ruler and let it go.
- 3 Measure the distance the rubber band moved.
- 4 Repeat steps 2 and 3 another three times (remembering that the angle and height need to be consistent with the first attempt). Average the distance the rubber band moved.
- 5 Use the spring balance to determine the amount of force (N) needed to stretch the rubber band 10 cm.

Inquiry

What if the rubber band was stretched further?

- > 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

- 1 Draw a graph of the distance the rubber band was stretched against the distance the rubber band moved.
- 2 If $F = kx$ where F is the force needed to stretch the rubber band 10 cm (as measured by the spring balance) and x is 0.1 m, then what is k , the elastic constant for your rubber band?
- 3 Use the elastic constant you measured in step 2 to determine the amount of energy in the rubber band when you stretched it 10 cm. Remember to convert the centimetres into metres.

Discussion

- 1 Describe the relationship between the distance the rubber band was stretched and the distance the rubber band moved.
- 2 Identify where the initial energy came from to stretch the rubber band.
- 3 Identify the type of energy in the rubber band.
- 4 Calculate the amount of work that was done when the rubber band was first stretched. ($W = Fd$)
- 5 If all the elastic potential energy was transformed to kinetic energy, calculate the amount of kinetic energy the rubber band had when it left the ruler.
- 6 Calculate the velocity of the rubber band when it left the ruler. ($KE = \frac{1}{2}mv^2$)

Conclusion

Describe what you know about the energy in an rubber band.

9.2 Conservation in action

CHALLENGE

Aim

To investigate the movement of a pendulum.

Background

Analysis of a simple pendulum shows that it follows a similar pattern to dropping a mass.

What you need

- > Simple pendulum made from a mass on the end of a length of string
- > Retort stand
- > Balance
- > Tape measure

What to do

- 1 Hang the simple pendulum from the retort stand (Figure 1).
- 2 Lift up the mass and release it. As it swings, its GPE is converted into KE and back into GPE. The process continues until the pendulum finally comes to rest.
- 3 Measure how much GPE the pendulum mass had at the start before it was released by measuring its mass and starting height above the bench and using the GPE formula.
- 4 Allow the pendulum to complete 10 full swings (the release point is swing 0) and stop it at the end of its tenth swing. Hold the weight at the finishing height.
- 5 Measure the finishing height of the pendulum.

Discussion

- 1 Draw a picture of the pendulum at its highest point. Calculate its gravitational potential energy at this point.
- 2 Draw a picture of the pendulum at its highest point after 10 swings. Calculate its potential energy at this point.
- 3 Calculate how much energy was 'lost' to air friction each swing of the pendulum (divide by 10 swings).
- 4 Calculate the energy efficiency of the pendulum. Set out your calculations clearly and accurately.



Figure 1 Setting up the experiment



Figure 2 The energy efficiency of the pendulum can be calculated.

9.3 Thermal energy versus temperature

EXPERIMENT

Aim

To investigate the difference between thermal energy and temperature.

Materials

> Water	> Bunsen burner
> Small iron weight	> Tripod
> Iron nail	> Heatproof mat
> 2 × 100 mL beakers	> 2 thermometers
	> Tongs

Method

- 1 Set up the experiment as shown in Figure 1.
- 2 Boil some water in a beaker.
- 3 Record the temperature in a table.
- 4 Using tongs, place the iron nail carefully in the beaker.
- 5 Continue to measure any changes in the temperature of the water after adding the iron nail.
- 6 Repeat steps 1–5 with the second beaker, this time using the small iron weight in place of the nail.
- 7 For each beaker, calculate the change in the temperature of the water when the metal object was added.

Results

Record your results in an appropriate table.

Discussion

- 1 Identify the object (the nail or the iron weight) that had the least change in water temperature. Contrast the definitions of 'temperature' and 'thermal energy' to explain why.
- 2 Identify which object had the most thermal energy. Justify your decision.

Conclusion

Use the results of this experiment to contrast 'thermal energy' and 'temperature'.

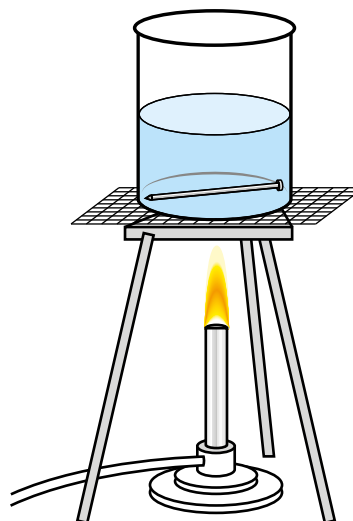


Figure 1 Experiment set-up

9.4 Investigating heating by convection

EXPERIMENT

Aim

To investigate heating water by convection.

Materials

> Water	> Bunsen burner
> Potassium permanganate crystals (or $\frac{1}{2}$ a teaspoon of red jelly crystals)	> Tripod
	> Gauze mat
	> 600 mL beaker
	> Teaspoon

Method

- 1 Set up the experiment as shown in Figure 1.
- 2 Fill the beaker with water. Put individual crystals of potassium permanganate on the bottom of the beaker, at the edge. Alternatively, add $\frac{1}{2}$ teaspoon of red jelly crystals to the bottom of the beaker using the teaspoon.
- 3 Heat the water gently over the Bunsen burner and observe the movement of the crystals. (If possible, use a small flame and no gauze mat between the Bunsen burner and the beaker – you can do this with Pyrex beakers.)
- 4 Note the path that the coloured water takes from the burner to the top of the water and back down again.

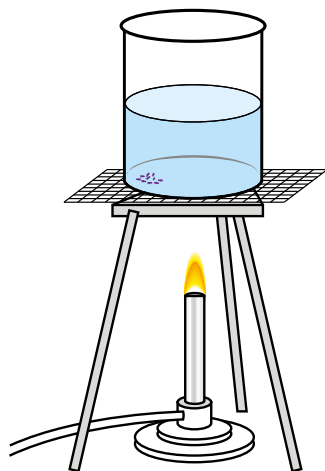


Figure 1 Experiment set-up

Results

Draw a labelled diagram showing the movement of the coloured water.

Discussion

- 1 Define the term 'convection'.
- 2 Define the term 'conduction'.
- 3 Describe the movement of the coloured water.
- 4 Use the terms 'conduction' and 'convection' to explain how the movement of water particles changes as they are heated.
- 5 Use the movement of the particles in the water to explain the movement of the coloured water.

Conclusion

Describe what you know about heating water by convection.



Figure 2 Potassium permanganate crystals

10.1A 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.

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		



Figure 1 What is the impact of damage to the different areas of the brain?

10.1B 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.

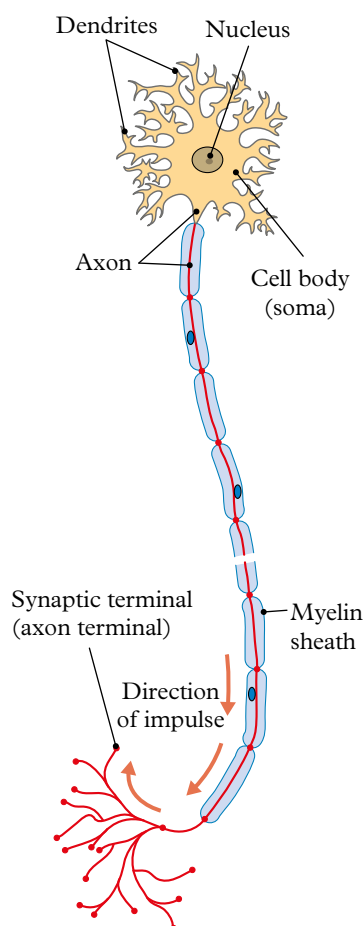


Figure 1 A typical neuron

10.1C Modelling brain structure and function

SKILLS LAB

Aim

To create a model of the different parts of the brain involved in learning and memory.

Materials

- > 5 different colours of play dough
- > A3 paper
- > Coloured marker pens

Method

- 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.

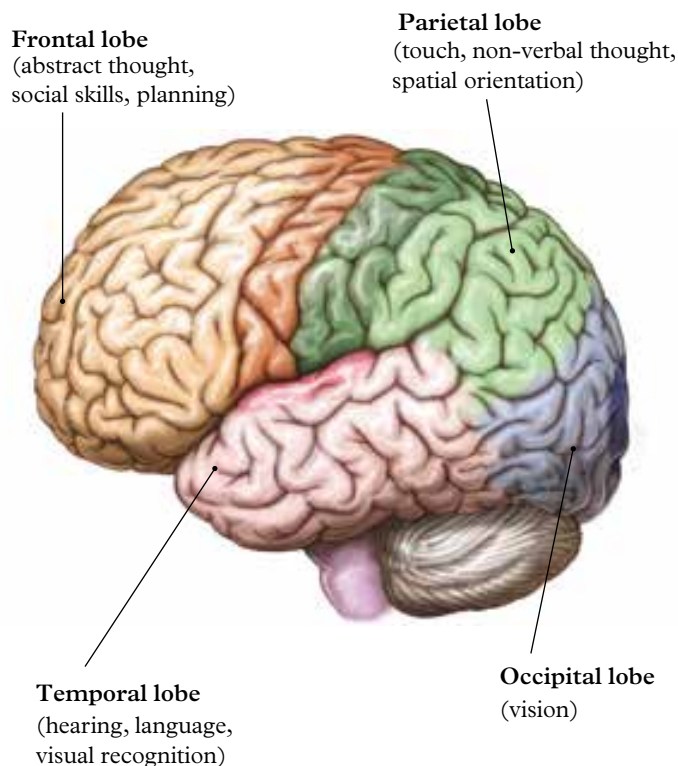


Figure 1 Lobes of the cerebral cortex

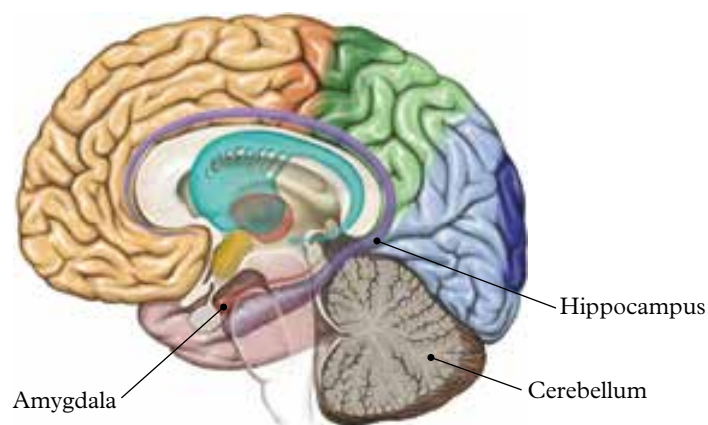


Figure 2 Parts of the brain

10.5 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 (as follows)
- > 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.

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 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 mobiles, 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 develop skills in business reasoning, and examine the trade-offs required when innovating a product or service and deciding on a course of action.

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 20 'The business environment' of *Oxford Humanities 10 Victorian 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 may also require your knowledge of financial mathematics.

You will find relevant mathematical and statistical concepts in Chapter 1 'Financial mathematics' and Chapter 10 'Statistics' of *Oxford Maths 10/10A Victorian 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 Victorian 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 a guideline 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.

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Student guidebook

This helpful booklet will guide you step-by-step through the project.



What is the design cycle?

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How to manage a 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.

Check your Teacher **obook pro** for these digital resources and more:



Implementation advice

Find curriculum links and advice for this project.



Assessment resources

Find information about assessment for this project.

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 CO₂ than oil or gas when used to produce energy. Measuring fossil fuel exports according to their potential to emit CO₂ 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.

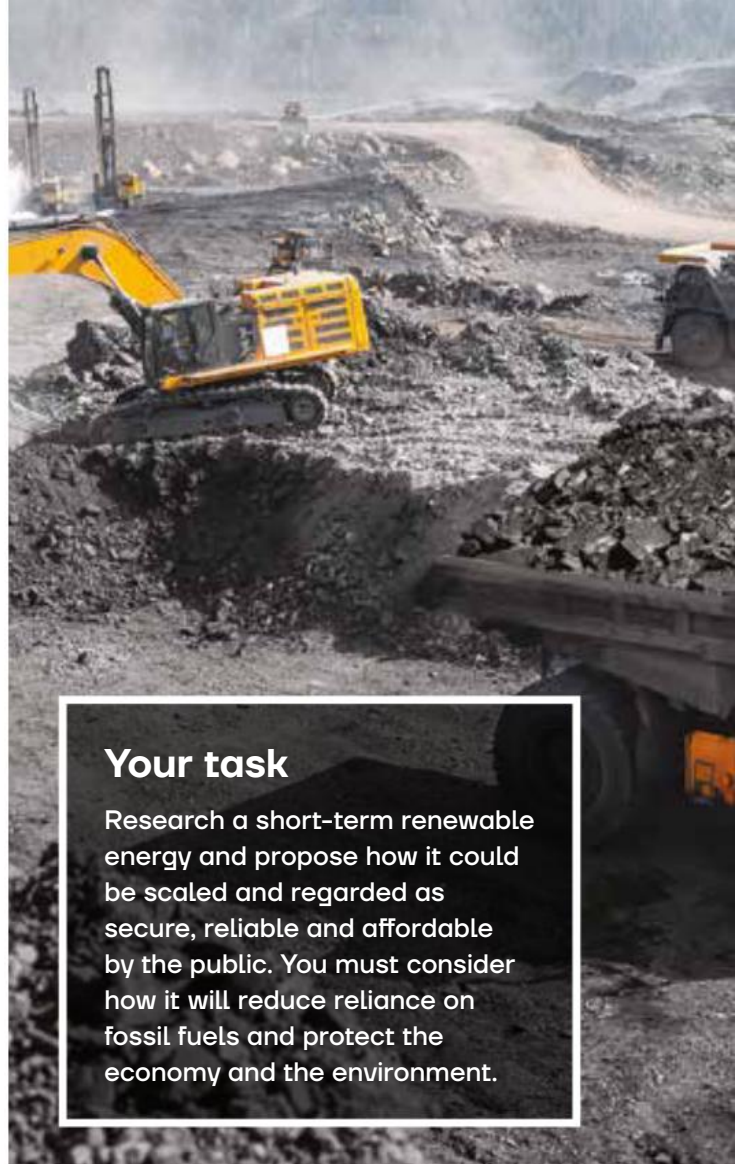


Figure 1 Most of Australia's energy is generated from coal. Almost 80 per cent of the coal produced in Australia is from open-cut mines.

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', Chapter 18 'Measuring the performance of Australia's economy' and Chapter 19 'Living standards' of *Oxford Humanities 10 Victorian Curriculum*.



MATHS

In Maths this year, you will extend your skills in representing and interpreting data, including multivariate data sets and time-series data. 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 1 'Financial mathematics' and Chapter 10 'Statistics' of *Oxford Maths 10/10A Victorian 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 6 'Global systems' of *Oxford Science 10 Victorian 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 a guideline 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.

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How to define a problem

This 'how-to' video will help you to narrow your ideas down and define a specific problem.

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Implementation advice

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Assessment resources

Find information about assessment for this project.



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, $g = 9.8$ or 10 m/s^2

achondroplasia

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

adaptation

a characteristic or behaviour of a species that allows it to survive and reproduce more effectively

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

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

atmosphere

the layer of gases surrounding the Earth

atomic number

the number of protons in an atom

autosome

a chromosome that does not determine the sex of an organism

B

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

biodegradable

describes an object or a substance that can be broken down by bacteria, fungi or other living organisms

biodiversity

the variety of life; the different plants, animals and micro-organisms and the ecosystems they live in

biosphere

a layer around the Earth's surface that supports life; consists of the atmosphere, hydrosphere and lithosphere

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

carbon tax

a tax levied on the carbon content of fuels used by businesses or homes

carbon trading scheme

the process of allocating a set limit of carbon credits to businesses, which can then trade the credits

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

closed system

a system with a boundary that does not exchange energy with its surroundings

cloud

a visible mass of condensed water in the atmosphere

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

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

conduction

the transfer of thermal energy by direct contact with no movement of material

confirmation bias

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

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 have had the independent variable changed

controlled variables

variables that remain unchanged during an experiment

convection

the transfer of thermal energy by the movement of molecules in air or liquid from one place to another

convection current

the current or flow of air or liquid that results from the transfer of thermal energy through convection

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

covalent bond

a bond formed when two or more atoms share electrons

cryosphere

the frozen water in the hydrosphere

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

denitrifying bacteria

bacteria that return nitrogen to the atmosphere

deoxyribonucleic acid (DNA)

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

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

diverge

in relation to two species: to become more different over time due to different selection pressures, possibly becoming reproductively isolated

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 displacement reaction

when two reactants exchange ions to form new products during a chemical reaction

double-blind study

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

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

elastic potential energy

the energy possessed by stretched or compressed objects

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

element

a pure substance made up of only one type of atom (e.g. oxygen, carbon)

emission spectrum

the pattern of wavelengths (or frequencies) that appear as coloured lines in a spectroscopy; it is unique to each element

encoding

the act of information moving into our memory

enhanced greenhouse effect

an increase in carbon dioxide and other heat-capturing gases in the atmosphere, resulting in increased warming of the Earth

entropy

the amount of energy in a closed system that is no longer available to be transformed

environmental stimulus

sensory information from the environment (sound, smell, feel) that can start a behaviour

eutrophication

a process whereby excessive levels of phosphorus in waterways result in excess growth of algae and bacteria, which consume oxygen, suffocating fish and other aquatic animals

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**first law of thermodynamics**

a rule stating that the internal energy of a thermodynamic system can change, increasing when heat is added and decreasing when work is done

first-hand data

data collected by the person writing the report

fossil

the remains or traces of an organism that existed in the past

fossilisation

the process of an organism becoming a fossil

frameshift

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 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

gravitational potential energy

the energy possessed by an object raised to a height in a gravitational field

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 structures

structures that are 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

hydrosphere

all the solid, liquid and gaseous waters on Earth that support life

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

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

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 molecule 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 possessed by moving objects

L**law of conservation of energy**

a scientific law stating that the total energy in a system is always constant and cannot be created or destroyed

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

lithosphere

the outermost layer of Earth consisting of the upper mantle and crust

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**magnetic resonance imaging (MRI)**

the use of magnetic fields and radio waves to produce detailed images of the brain

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 greenhouse effect

the natural warming of the Earth due to water vapour and other gases being present in small amounts in the atmosphere and affecting the Earth's radiation balance

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

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

nitrogen-fixing bacteria

bacteria that convert nitrogen from the atmosphere into various nitrogen compounds

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 DNA molecule

O**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

pendulum

a mass that is attached by a string to a pivot point

period

in chemistry: a horizontal list of elements in the periodic table

permafrost

permanently frozen ground

phenotype

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

photolysis

the breakdown of a chemical substance by light; an example is the breakdown of water into oxygen and hydrogen

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

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

in meteorology: the process in which water vapour in the upper atmosphere becomes liquid water in the form of rain, snow or sleet and falls to the ground

precipitation reaction

a reaction used to produce solid products from solutions of ionic substances

product

a substance obtained at the end of a chemical reaction; written on the right side of a chemical equation

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

reactant

a substance used at the beginning of a chemical reaction; written on the left side of a chemical equation

reaction force

the force acting in the opposite direction to an initial force

reaction rate

how fast or slow 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

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

second law of thermodynamics

a scientific rule stating that, over time, energy is transformed from one form to another, causing thermal energy to be produced and increasing the amount of entropy

second-hand 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

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

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 occurs when equipment has not been calibrated

T**tectonic plate**

a large layer of solid rock that covers part of the surface of the Earth; movement of tectonic plates can cause earthquakes

temperature

the average kinetic energy of the particles moving in a system

thermal conductor

a material that allows thermal energy to flow through

thermal energy

the scientific term for heat energy

thermal equilibrium

when the thermal energy of an object is equivalent to that of its surroundings

thermal insulator

a material that prevents or slows down the transfer of thermal energy

thermodynamic system

a quantity of matter that has a boundary around it

thermodynamics

the science of how heat and temperature are related to energy and the properties of matter

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

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

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**water vapour**

water in the gaseous state

weather

a snapshot of what the air and conditions are like in any one place on Earth at any one time

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

work

when an object is moved by a force



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A galaxy is a large group of stars, gas and dust bound together by gravity. The Milky Way galaxy contains the Earth and our entire solar system. This image shows how we see the Milky Way from Earth. It is a spiral galaxy that appears as a milky band of light to us because we view its disc-shaped structure from within.