PEARSON science
NEW SOUTH WALES
S.B.

10

AUSTRALIAN CURRICULUM

It's an exciting time to be in education.

We are embarking on a journey that unites two significant educational initiatives: the implementation of the NSW Syllabus for the Australian Curriculum and the ever-increasing use of technology in our students' educational experience.

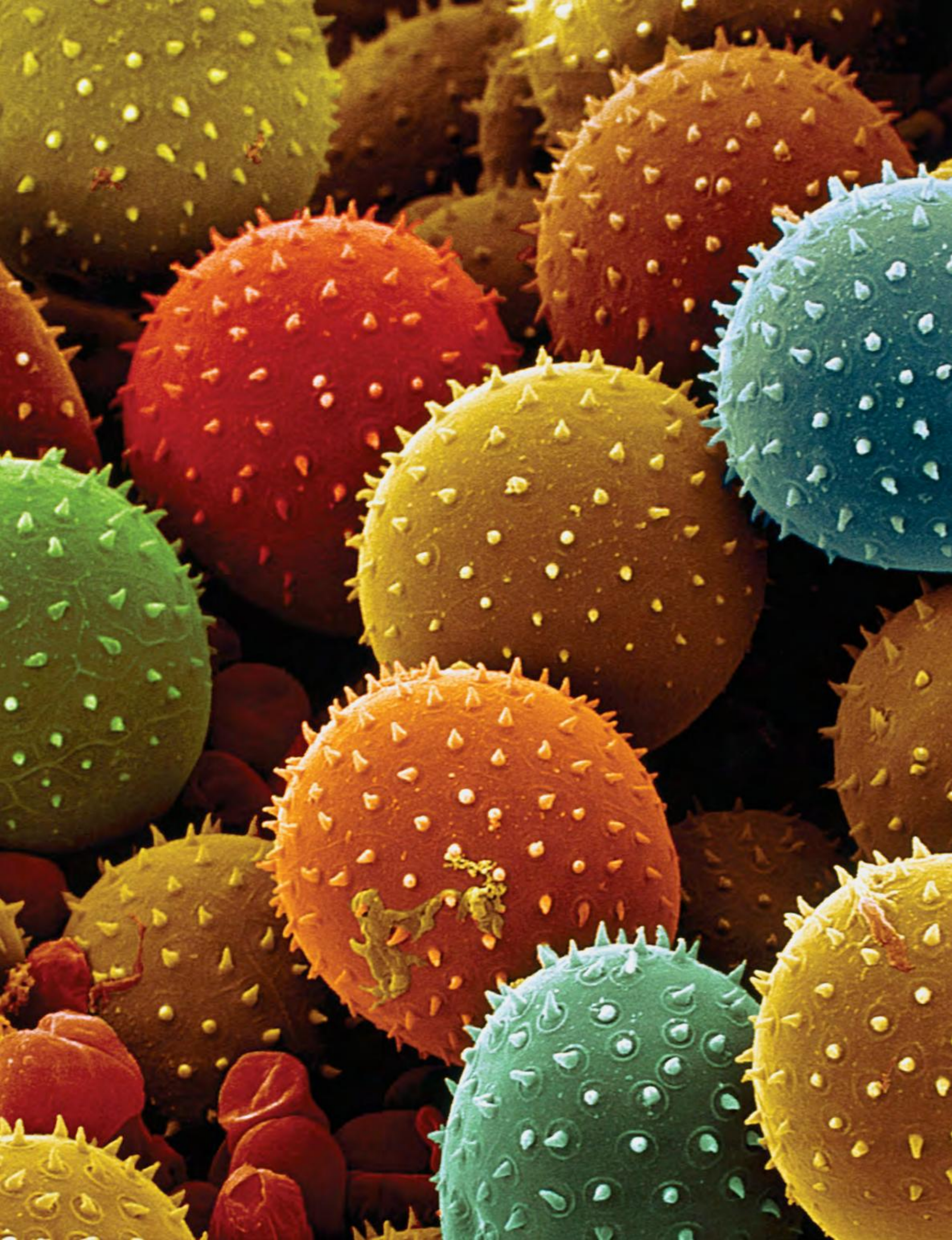
Pearson Australia is pleased to introduce their solution for the NSW Science Syllabus: **PEARSON science NEW SOUTH WALES**. It has been written from the ground up for the Australian Curriculum and developed specifically for the NSW Syllabus, and has been tested in focus groups and trialled in classrooms throughout Australia.

Whether you choose to use a printed book or a digital delivery medium, the **PEARSON science NEW SOUTH WALES** series can provide the content that you and your students need.

We hope you enjoy the journey you are about to take as much as we have enjoyed preparing for it. We look forward to working with you to implement the NSW Syllabus for the Australian Curriculum and to helping you manage your digital aspirations.

We would like to thank our authors for their extraordinary dedication and their contribution to the development of this project.

This is a coloured scanning-electron micrograph of spores from a rust fungus that infects rose plants. Scientists are able to extract DNA from the spores in order to better understand the fungus and lessen its impact on crop yields.



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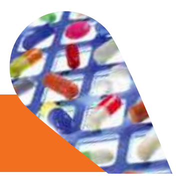


5 Chemical reactions

6 Global systems

7 The universe

8 Motion and energy

9 Forensic science

PEARSON science

NEW SOUTH WALES

Student Book

Written from the ground up for the Australian Curriculum and developed specifically for the NSW Science Syllabus for the Australian Curriculum, the student book acts as a guide for both student and teacher.

- Developed specifically for the NSW Science Syllabus
- Utilises an inquiry approach throughout
- The content is presented in a range of contexts within the interrelated strands of Knowledge and Understanding and Working Scientifically.

Activity Book

The activity book is a write-in resource designed to enrich students' skills by providing a variety of activities and questions to reinforce learning outcomes.

- Supports and extends the student book
- Caters for a range of learning styles.

Teacher Companion

The teacher companion makes lesson preparation easy by combining full-colour textbook pages with teaching strategies, ideas for class activities and fully worked solutions.

- Ties the entire **Pearson Science New South Wales** package together
- Includes all answers to the student and activity book.

EAL/D Activity Book

The EAL/D activity book incorporates tailored language and vocabulary support for English as an Additional Language or Dialect (EAL/D) learners. With activities matching page-for-page, the EAL/D activity book can be used alongside the standard activity book.

AUSTRALIAN CURRICULUM

How to use this book

PEARSON science NEW SOUTH WALES 10 Student Book

PEARSON science NEW SOUTH WALES 10 has been designed for Stage 5 of the NSW Science Syllabus for the Australian Curriculum. It includes content and activities that cover all learning outcomes within the interrelated strands of Knowledge and Understanding, and Working Scientifically. The content is presented through a range of contexts to engage students and assist them to make connections between science and their lives.

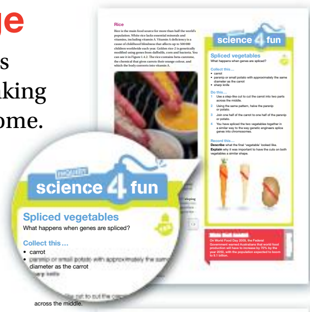
Additional syllabus content is clearly identified and carefully placed in the flow of core content. Learning Across the Curriculum content is addressed throughout the series and indicated using icons.

PEARSON science NEW SOUTH WALES 10 is designed for an inquiry approach to science learning. Its engaging design, unambiguous features and clear easy-to-understand language make this a valuable resource for students of all interests and abilities.

Chapter opening page

The chapter opener engages students through questions that get them thinking about the content and concepts to come.

The key ideas reflect the syllabus content relevant to the chapter.

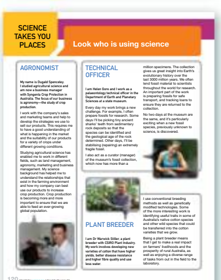


science4fun

Inquiry-based activities using everyday materials assist students to understand key concepts under development.

These can be used as a focus or context for the unit.

Icons indicate whether an activity is suitable to be done at home or requires teacher supervision.

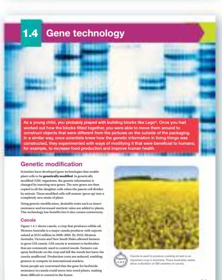


Look who is using science

Careers pages spread throughout the book look at careers that involve and use science.

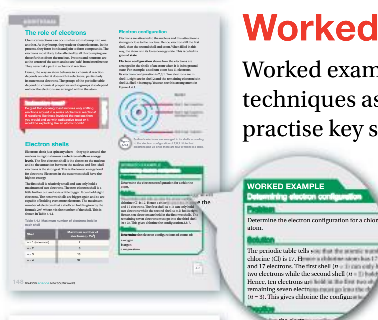
Skill builder

Key skills are outlined in clear steps to support science learning.



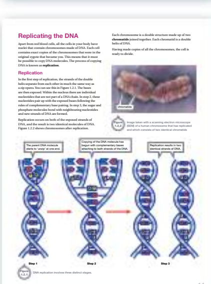
Unit opening

Each chapter is divided into self-contained units. The unit opener includes an introduction that places the material to come in a meaningful context.



Worked example

Worked examples of problems and techniques assist students to master and practise key skills.

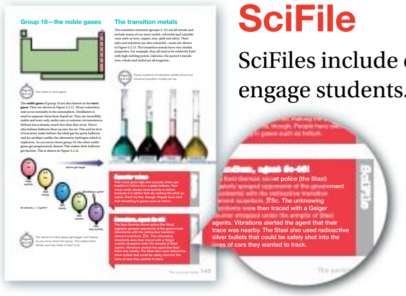


Photos and illustrations

Stunning and relevant photos and illustrations are clearly referenced from within the text to assist students to understand the idea being developed.

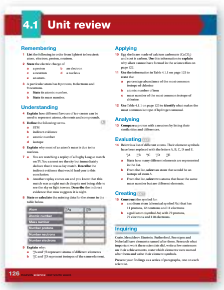
Additional content

Additional syllabus content is clearly identified using shading and icons.



SciFile

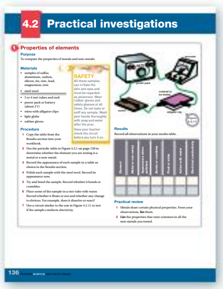
SciFiles include quirky information to engage students.



Unit review

Each unit finishes with a set of questions and activities organised under the headings of Bloom's Taxonomy of Cognitive Processes. To further students' understanding of the intent of a question and level of explanation expected, bolded verbs are used throughout. A list of all verbs and their meanings can be found on page xii.

The final heading is 'Inquiring'. These questions challenge students to use their inquiry skills to research additional syllabus content and to go beyond the unit content.



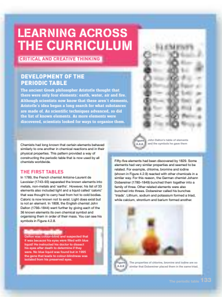
Practical investigations

Practical investigations are placed at the end of each unit. Practical investigation icons appear throughout the units to indicate suggested times for practical work.

A Student-design icon indicates that an activity includes student input and design.

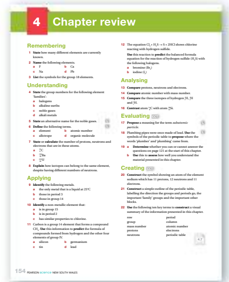
Safety boxes highlight significant hazards.

A safety glasses icon reminds students when appropriate to wear safety glasses.



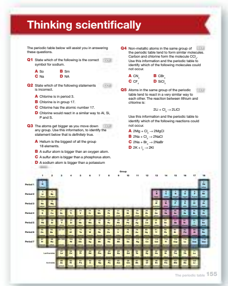
Learning Across the Curriculum

Learning Across the Curriculum content is addressed throughout the Student Book using icons and in Learning Across the Curriculum spreads. A full list of Learning Across the Curriculum icons can be found on page xiii.



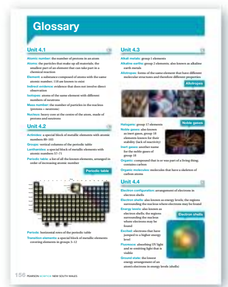
Chapter review

Each chapter finishes with a set of questions and activities organised under the headings of Bloom's Taxonomy of Cognitive Processes.



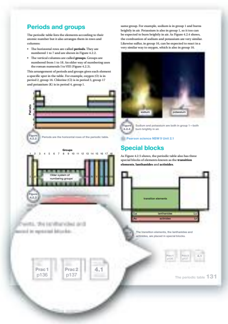
Thinking scientifically

Following the Chapter review are Thinking scientifically style questions relevant to that chapter. These test students' science and interpretive skills.



Glossary

Every chapter concludes with an illustrated glossary that engages students and provides a ready reference for the key terms of the chapter.



Activity Book icon

This icon indicates a related Activity Book worksheet that enhances or extends this area.

GO TO

Go to icon

Go to icons are used to make important links to relevant content within the student book and to the next student book in a stage.

The PEARSON science NSW 10 package

Don't forget the other PEARSON science NEW SOUTH WALES 10 package components that will help engage and excite students in science:
- Activity Book
- EAL/D Activity Book
- eBook 3.0
- Teacher Companion
- Pearson Assess New South Wales

Verbs

The verbs below, based on Bloom's Taxonomy, appear in **bold** text throughout this book. The verbs help students know the level of response required for a question. The verbs in black are consistent with the key verbs used in NSW syllabuses and examinations. The verbs shown in blue in this list may also feature throughout the book and are provided for additional support to teachers and students.

Remembering	
enter	Place data into a computer program by key strokes or copying from a digital source, e.g. CD, DVD, USB storage device
label	Add annotations to a diagram or drawing
list	Write down phrases or items only without further explanation
name	Present remembered ideas, facts or experiences
present	Provide information for consideration
recall	Present remembered ideas, facts or experiences
record	Store information and observations for later
specify	State in detail
state	Provide information without further explanation
Understanding	
account	Account for—state reasons for, report on. Give an account of—narrate a series of events or transactions
calculate	Ascertain/determine from given facts, figures or information (simply repeating calculations that are set out in the text)
clarify	Make clear or plain
construct	Prepare or devise something, such as a key or diagram
define	State meaning and identify essential qualities
describe	Provide characteristics and features
determine	Find out the size or extent, either by using an equation, counting, estimating, or similar method
discuss	Identify issues and provide points for and/or against
draw	Use a pencil to produce a likeness onto a page, or sketch to provide a representation or view
explain	Provide a sequence to make the relationships between things evident; provide why and/or how
extract	Choose relevant and/or appropriate details
gather	Collect items from different sources
modify	Change in form or amount in some way
outline	Sketch in general terms; indicate the main features
predict	Suggest what may happen based on available information
produce	Provide
propose	Put forward for consideration or action
rank	Place in order of size, age, or as instructed
recount	Retell a series of events
summarise	Express, concisely, the relevant details
write	Compose or construct a sentence that explains a feature
Applying	
apply	Use, utilise, employ in a particular situation
calculate	Ascertain/determine from given facts, figures or information
demonstrate	Show by example
examine	Inquire into
identify	Recognise and name
use	Employ for some purpose
Analysing	
analyse	Identify components and the relationship between them; draw out and relate implications
calculate	Ascertain/determine from given facts, figures or information (requiring more manipulation than simply applying the maths)
classify	Arrange or include in classes/categories
compare	Show how things are similar or different
contrast	Show how things are different or opposite
critically (analyse/ evaluate)	Add a degree or level of accuracy, depth, knowledge and understanding, logic, questioning, reflection and quality to (analyse/ evaluate)
discuss	Identify issues and provide points for and/or against

distinguish	Recognise or note/indicate as being distinct or different from; to note differences between
infer	Recognise and explain patterns and meaning and relationships
interpret	Draw meaning from
research	Investigate through literature or practical investigation
Evaluating	
appreciate	Make a judgement about the value of
assess	Make a judgement of value, quality, outcomes, results or size
conclude	Come to a judgement or result based on the reasoning or arguments that you present
critically (analyse/ evaluate)	Add a degree or level of accuracy, depth, knowledge and understanding, logic, questioning, reflection and quality to (analyse/ evaluate)
deduce	Draw conclusions
evaluate	Make a judgement based on criteria; determine the value of
extrapolate	Infer from what is known
justify	Support using an argument or conclusion
propose	Put forward (for example a point of view, idea, argument, suggestion) for consideration or action
recommend	Provide reasons in favour
select	Choose one or more items, features, objects
Creating	
construct	Make; build; put together items or arguments
design	Provide steps for an experiment or procedure
investigate	Plan, inquire into and draw conclusions about
synthesise	Put together various elements to make a whole

Learning Across the Curriculum

NSW Syllabus Learning Across the Curriculum content is addressed throughout the series and is identified using the following icons.

Learning Across the Curriculum icons	
AHC	Aboriginal and Torres Strait Islander histories and cultures
A	Asia and Australia's engagement with Asia
CC	Civics and citizenship
CCT	Critical and creative thinking
DD	Difference and diversity
EU	Ethical understanding
ICT	Information and communication technology capability
IU	Intercultural understanding
L	Literacy
N	Numeracy
PSC	Personal and social capability
S	Sustainability
WE	Work and enterprise

SCIENCE TAKES YOU PLACES

Look who is using science

PALAEONTOLOGIST

My name is Scott Hocknull, and I am a palaeontologist at a state museum. I have loved animals, especially dinosaurs, since I was a child. I was a volunteer at the museum for 10 years during my school and university holidays, when I found many new fossil sites for the museum. At 22, I was appointed Curator of Geosciences at the museum and I was named the Young Australian of the Year in 2002.

In my research, I have studied the evolution of Australia's fauna and flora and Australia's climate over the last 15 million years. Currently I am studying Australian dinosaurs discovered near the townships of Winton and Eromanga in Queensland. In 2009, my colleagues and I discovered and named three new species of dinosaur, including Australia's most complete theropod (a carnivorous dinosaur) skeleton, named *Australovenator wintonensis*. I also helped to discover 'Cooper', Australia's largest dinosaur. If you are interested in fossils, there is enough work in Australia to last you a lifetime.

GENETICIST

I am Kathy Belov, an Associate Professor in the Faculty of Veterinary Science. I loved biology at school and at university I completed a Bachelor of Science with honours. After working for two years, I began a PhD, studying the immunity genes of the brushtail possum.

An Australian Research Council fellowship allowed me to continue my work on genes for immunity—this time focusing on the platypus and echidna. Three years later I received a University of Sydney Fellowship and have been in the Faculty of Veterinary Science ever since.

I have a very exciting career. Every day is different—I teach, do research, work with animals, travel and get to meet many interesting people, including celebrities. I work on large international projects, which is a lot of fun and a great opportunity to see the world. My fantastic research team keep me motivated. They are all very passionate about conservation and work tirelessly to understand the role genes play in disease susceptibility in our native wildlife.

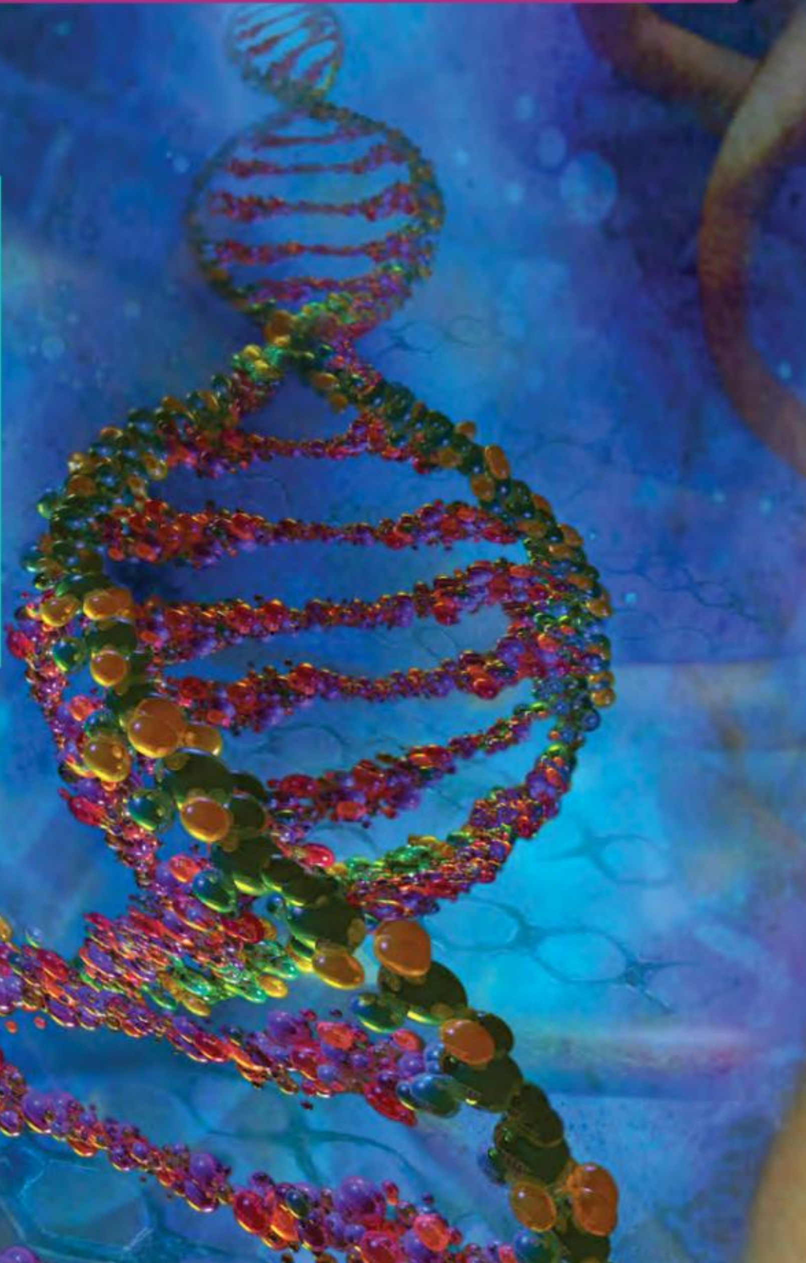
INSECTICIDE TOXICOLOGIST

I am Maggie Hardy, a PhD student at the Institute for Molecular Bioscience. My research focus is the discovery of new, environmentally friendly insecticides from the venom of native Australian spiders, such as funnel-webs and tarantulas. Over 400 million years of evolution has led spiders to produce hundreds of chemical toxins (poisons) in their venom.

First I 'milk' my spiders to get the venom. I test the venom for insecticidal activity and once I have a hit, I isolate the toxin of interest. I search for the matching DNA sequence in a library of known DNA sequences from the venom gland of the spider. Once

found, the DNA sequence can be inserted into bacteria, which then make large quantities of the toxin. The toxin is then tested to ensure that it is not dangerous to non-target organisms, such as beneficial insects, pets or people. If the toxin passes these tests, only then can it be used in farming.

1 DNA and genetics



Have you ever wondered...

- why people in families often look alike?
- where the differences between people come from?
- what is meant by a genetic disease?
- how scientists are able to change the genetic information in an organism?
- why discussion of genetic modification can lead to debate?

After completing this chapter students should be able to:

- relate the organs involved in human reproductive systems to their function
- identify that during reproduction the transmission of heritable characteristics from one generation to the next involves DNA and genes
- identify that genetic information is transferred as genes in the DNA of chromosomes
- outline how the Watson–Crick model of DNA explains the exact replication of DNA and mutations in genes
- describe how developments in technology have advanced biological understanding, leading to biotechnology, new vaccines, stem-cell research and IVF CCT EU PSC
- discuss advantages and disadvantages of biotechnology, including social and ethical considerations PSC EU

ADDITIONAL

- assess the role of the development of fast computers in the analysis of DNA sequences ICT
- research how information technology is applied in bioinformatics. ICT

1.1 DNA the molecule

Organisms on Earth have many differences. Not many people would confuse an elephant with an earthworm, a tree with a tarantula or a penguin with a python. However, at one level the differences between organisms are not as great as you might think. All the living things mentioned here, along with humans, have slightly different versions of the same chemical in the nuclei of their cells. This chemical is DNA and it controls the way you look and how your body functions.

INQUIRY
science 4 fun

What do you know?

YES

What do your friends and family know about DNA and what it does?

Collect this …

- notebook
- pen

Do this …

1 Make a list of the friends and family you are going to talk to.

2 Ask these people what they know about DNA.

Record this …

Describe what your family and friends know about DNA.

Explain why there may be differences in their understanding.

Deoxyribonucleic acid

Life on Earth is very diverse. However, for most living things **deoxyribonucleic acid (DNA)** is the molecule that determines their characteristics. It also contributes to the diversity of living things.

Prac 1 p8

As Figure 1.1.1 shows, DNA is a complex molecule. It wasn't until 1953 that James Watson and Francis Crick successfully described its structure. For this reason, the model used today to describe the DNA molecule is known as the **Watson–Crick model**.

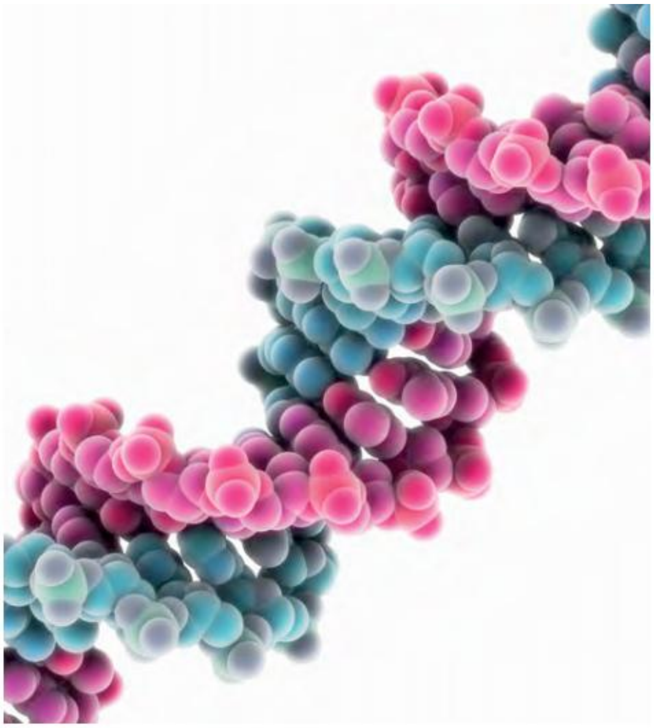


Figure 1.1.1 This model shows the double-helix structure of DNA. One helix is coloured pink, the other blue.

The Watson–Crick model of DNA

DNA has a similar structure in all organisms in that it is made up of smaller molecules called **nucleotides**. The basic structure of a nucleotide is shown in Figure 1.1.2. Nucleotide molecules have three parts:

- **phosphate group**
- **deoxyribose sugar**
- one of four **nitrogen-rich bases** (commonly called bases).

The nucleotides are organised in a way that makes DNA a **double helix**. The shape of a double helix is like that of a twisted rope ladder. The uprights of the ladder are made of alternating phosphate and sugar groups.

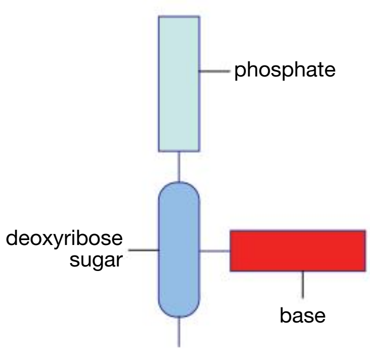


Figure 1.1.2 All the nucleotides of DNA have the same basic structure. It is the type of base that is different.

The nitrogen-rich bases pair up to form the rungs. The four bases **adenine (A)**, **thymine (T)**, **guanine (G)** and **cytosine (C)** all have different chemical structures. This means that they can only pair up in one way, a characteristic known as **complementary base pairing** – adenine can only form a complementary base pair with thymine (A–T) and guanine can only pair with cytosine (G–C). This is shown in Figure 1.1.3.

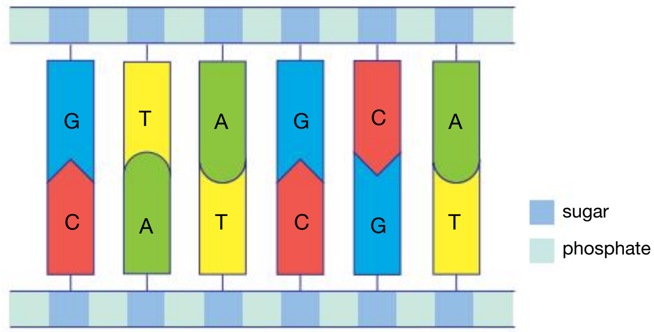
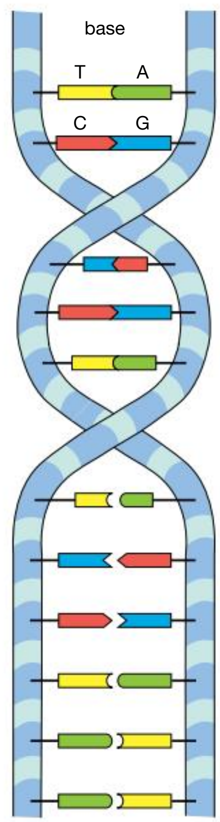


Figure 1.1.3 The chemical shape of adenine (A) complements (fits into) the chemical shape of thymine (T). The same is true of cytosine (C) and guanine (G).

Therefore there are two types of 'rungs' on the 'ladder': A–T rungs and C–G rungs. This can be seen in Figure 1.1.4.



Prac 2 p9
Prac 3 p9
1.1
1.2

Figure 1.1.4 DNA structure—the lower section is shown uncoiled to illustrate the pairing of the bases.

Genes and chromosomes

Chromosomes are long, thin, threadlike structures found in the nuclei of all cells in the human body that contain a nucleus. Chromosomes are made of DNA and protein. The cells in the human body each contain 46 chromosomes arranged in 23 pairs. The only exceptions are:

- gametes – the sperm and eggs cells – which only contain 23 chromosomes (one of each pair)
- red blood cells, which have no nucleus.

Other organisms have different numbers of chromosomes and chromosome pairs in their cells.

That much! SciFile

The nuclei of your cells are about 6 μm or six-thousandths of a millimetre in diameter. Each nucleus contains about 2 metres of tightly coiled DNA with about 6 billion base pairs.

Genes are sections of DNA. A single gene is marked in Figure 1.1.5. Each chromosome can have over 1000 genes.

The difference between one gene and the next is the:

- order of bases along the DNA strand
- length of the DNA strand.

The order of the bases along the DNA strand is the genetic code. Each gene codes (contains instructions) for a specific protein. Proteins may be:

- structural such as collagen (found in tendons and ligaments) and keratin (found in human skin, hair and nails)
- enzymes such as amylase (which helps digest starch) and lactase (which helps digest lactose, the sugar found in milk)
- regulatory in the form of hormones such as growth hormone (stimulates growth and cell reproduction) and insulin (controls blood glucose levels).

GO TO Pearson science NSW 9 Unit 6.1

No nucleus SciFile

Mature red blood cells are different from all the other cells in your body. They do not have a nucleus, so they do not have any chromosomes.

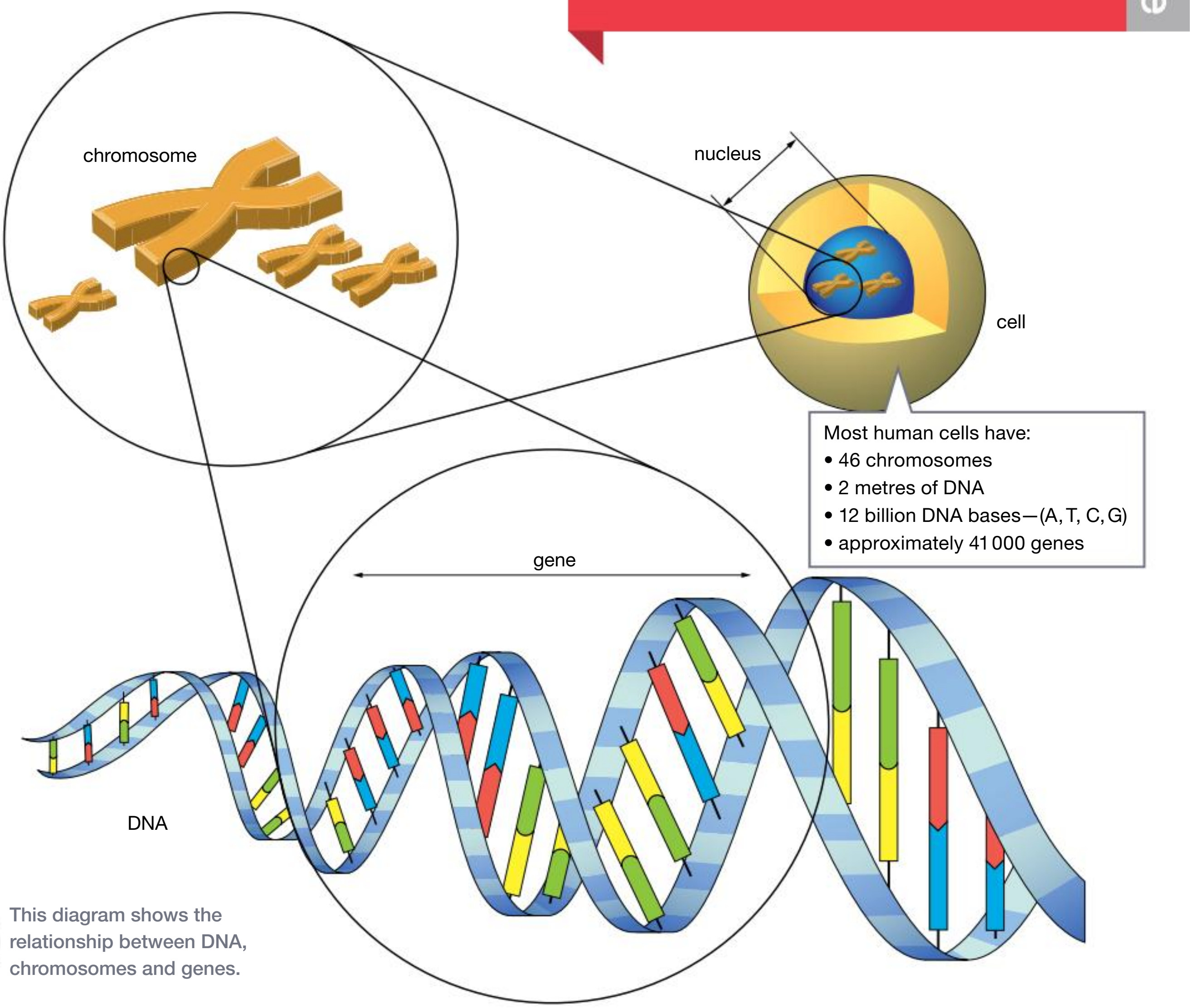


Figure 1.1.5 This diagram shows the relationship between DNA, chromosomes and genes.

LEARNING ACROSS THE CURRICULUM

CRITICAL AND CREATIVE THINKING

Figure 1.1.6 This DNA has been extracted from cells. Normally these fine strands are tightly coiled around proteins to form chromosomes.

DISCOVERY OF DNA

James Watson and Francis Crick are often credited with the discovery of DNA in 1953, but the history of the molecule extends further back in time.

In 1869, Johannes Friedrich Miescher (1844–95), a Swiss physician and biologist, isolated a previously unknown chemical from the nuclei of dead white blood cells. Miescher was looking for proteins when he identified a substance that was chemically very different. He called this new chemical *nuclein* because it was found in the cell nucleus. The name was changed to nucleic acid and eventually to deoxyribonucleic acid (DNA). DNA is shown in Figure 1.1.6. Miescher did not know that he had discovered the substance that is the genetic code.

Phoebus Levene (1869–1940) was a Russian–American biochemist who studied nucleic acids. He identified the components of DNA and the arrangement of the sugar, phosphate and base in a nucleotide. Levene thought the DNA molecule was too simple to store the genetic code.

In 1943, work by Oswald Avery (1877–1955), an American physician and medical researcher, proved Levene to be wrong—DNA does hold the genetic code.

In the 1940s, Erwin Chargaff (1905–2002), an Austrian biochemist, expanded on Levene's work. He made three significant discoveries.

- Nucleotides are not arranged in the same order in all species.
- In all species, the amounts of adenine and thymine in the DNA are always similar, as are the amounts of guanine and cytosine. This became known as Chargaff's rule.
- The amount of adenine plus guanine is always equal to the amount of thymine plus cytosine.

X-RAY CRYSTALLOGRAPHY

Much earlier (1913–14) and in a completely different field, British physicists Sir William Henry Bragg (1862–1942) and his son Sir William Lawrence Bragg (1890–1971) developed the new science of X-ray crystallography.

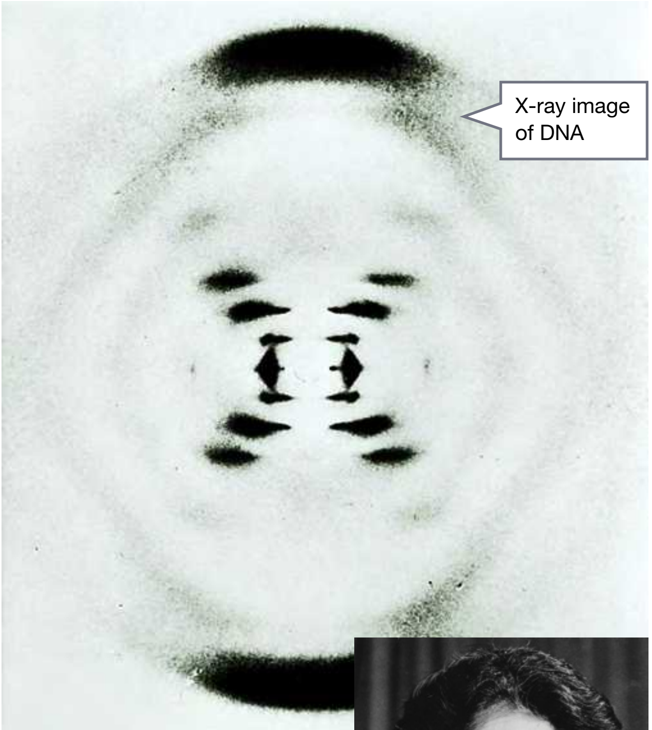


Figure 1.1.7

Rosalind Franklin obtained this image of DNA in 1953. James Watson and Francis Crick used it to work out the structure of the molecule.

In the early 1950s, Rosalind Franklin (1920–58), a British scientist, used her skills as an X-ray crystallographer to investigate DNA. She and fellow worker Maurice Wilkins (1916–2004), a New Zealander working in England, created an X-ray crystallograph of DNA. From the pattern seen in Figure 1.1.7, they deduced that DNA contained rungs like a ladder and had an X-shape—a pattern consistent with it being a helix.

In 1953, American molecular biologist James Watson (1928–) attended a lecture in which Franklin presented her research. Using this new information about DNA, Watson and his associate, Francis Crick (1916–2004), a British molecular biologist, refined the 3D models they had been building in attempts at discovering DNA structure. They used Franklin's image to fit all the parts together. Later that year they published their research with diagrams of the double helix structure of DNA (Figure 1.1.8).

In 1965, Watson, Crick and Wilkins jointly received a Nobel Prize for their work. Nobel prizes cannot be awarded posthumously (after death). This meant that Rosalind Franklin, who died in 1958, was not included in the award. The significant contribution that her work made was not acknowledged until Watson wrote his book *The Double Helix* in 1968.

REVIEW

1. a. **State** when the chemical now known as DNA was first identified.
   b. Name the scientist who first identified it.
2. **Explain** why Levene did not think that DNA was the chemical that carried the genetic code.
3. **Identify** the invention that lead to the discovery of the structure of DNA.
4. Edwin Chagraff could not explain why the amount of guanine plus adenine was always equal to the amount of thymine plus cytosine in DNA. In your own words, **explain** why this relationship is always found.
5. **Construct** a timeline from 1869 to 1965 showing the significant events leading to the scientific understanding of the structure of DNA.

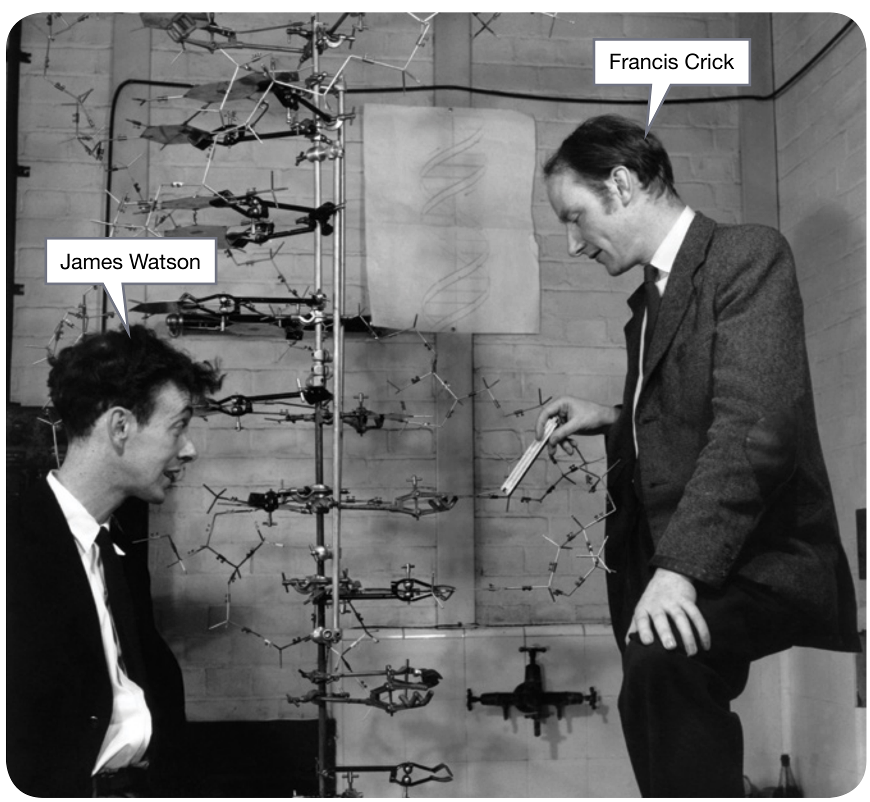


Figure 1.1.8

James Watson and Francis Crick explain the structure of their model of DNA.

1.1 Unit review

Remembering

1 **State** what the initials DNA represent.

2 **Name** the parts that are the building blocks of a DNA molecule.

3 **Name** the two scientists who first successfully described the structure of DNA.

4 **Recall** what the letters A, T, C and G represent in the context of DNA.

5 In the DNA molecule:

- **a** **recall** what makes the ‘rungs’ of the ladder
- **b** **name** the molecules that make the ‘uprights’ of the ladder
- **c** **recall** the molecule of the ‘upright’ to which the ‘rungs’ are joined.

Understanding

6 **Explain** why the DNA molecule is compared with a twisted ladder.

7 **Describe** where DNA is found in an organism.

8 **Describe** the relationship between DNA, chromosomes and genes in words or in pictures.

9 **Explain** in your own words what is meant by *complementary base pairing*.

10 **Explain** in your own words what characteristic of DNA creates the genetic code.

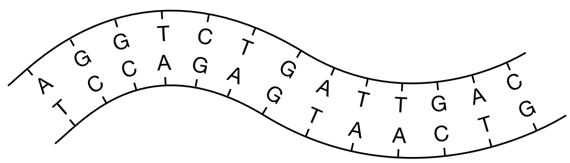
11 **a** **State** which of the following are complementary base pairs: CT, AT, GC, GT, TA, CG, AC, CT.

b **Describe** the feature that determines whether bases can form complementary base pairs.

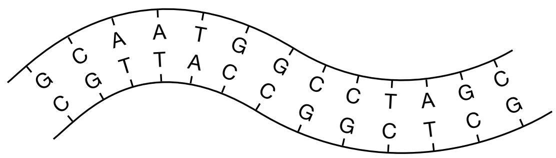
Applying

12 **Identify** the mistakes in the following sections of DNA.

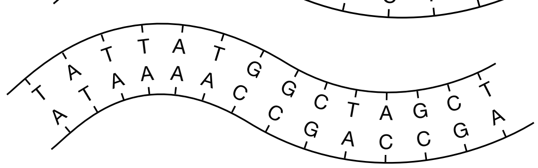
a



b



c



13 **Use** coloured pencils to **draw** and **label** a simple diagram representing a:

- **a** DNA molecule
- **b** nucleotide.

Analysing

14 **Compare** the amount of information that would be held in two chromosomes if one was shorter than the other.

15 **Compare** a gene and a chromosome.

Evaluating CCT

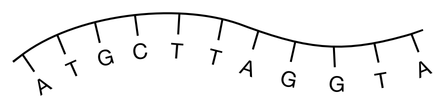
16 **Deduce** what similarities would be found in the DNA structure of genes from a cat, a human and a eucalyptus tree.

17 **Propose** reasons why different people might have different ideas about what DNA is and what it does.

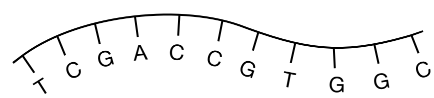
Creating CCT

18 **Construct** a diagram of the complementary DNA strand for these two examples.

a



b



Inquiring

Although you may think that there is great variation within the human population in terms of the way we look, 99.9% of all human DNA is identical.

Research the amount of DNA that humans have in common with:

- other animals such as chimpanzees, mice and jellyfish
- living things that belong to different kingdoms, such as ferns and bacteria.

Present your results in a table with the organisms that have most DNA in common with humans at the top and the organisms that have least DNA in common with humans at the bottom. Write a paragraph describing your reaction to the information you found and how this impacts on the way we should treat other animals, plants and other organisms. EU DD

1.1 Practical investigations

1 Investigating DNA

Purpose

To extract and examine DNA.

Materials

- 125 mL ($\frac{1}{2}$ cup) dried split peas (soaked overnight)
- 200 mL water
- 80 mL dishwashing detergent
- spatula of meat tenderiser
- methylene blue
- small beaker of alcohol
- dropping pipette
- fine-mesh kitchen strainer
- glass rod or skewer
- large beaker
- large test-tube
- light microscope
- microscope slide and coverslip
- paper towelling
- spatula
- test-tube rack
- vitamiser or blender
- rubber gloves

SAFETY

Take care when using the blender.

Methylene blue stains clothes and hands. Avoid contact by wearing rubber gloves.

Procedure

Part A: Extracting the DNA

1. Process the peas and water in the blender for about 20 seconds. The mixture should be a thin, soupy consistency.
2. Pour the mixture through the strainer into the large beaker.
3. Add about 80 mL of dishwashing detergent to the strained mixture. This will help break down the cell membranes. Stir thoroughly with the glass rod.
4. Add a spatula-full of meat tenderiser (to destroy any proteins). Continue stirring for about 5 minutes.
5. Quarter-fill the large test-tube with the pea mixture.
6. Holding the test-tube at an angle, gently pour about the same quantity of alcohol (about a quarter of a test-tube) down the side of the test-tube. The test-tube should now be about half full. The alcohol should form a layer on top of the pea mixture. Alcohol causes the DNA to come out of solution.
7. Observe the mixture for a few minutes. A white, threadlike substance should rise from the pea mixture to lie above the alcohol layer (Figure 1.1.9). This is the DNA that you have extracted from the cells of the peas.

Figure 1.1.9

8. Position the tip of the glass rod or skewer where you can see the threads of DNA. Slowly and steadily twist the rod or skewer as if you were making candy floss. You should be able to pull the strands of DNA out of the mixture.

Part B: A closer look

9. Use a pipette to carefully remove some of the DNA from the top of your preparation.
10. Place one or two drops onto a microscope slide.
11. Add 2 drops of methylene blue. Wait 3–4 minutes to allow the methylene blue to be absorbed by the DNA.
12. Place a coverslip on the slide. Soak up any excess liquid with a piece of paper towel.
13. Observe the DNA under low power, and then high power.

Results

Describe the appearance of the DNA under high power of the microscope. Sketch how it looked.

Practical review

1. **Describe** the material floating at the top of the test-tube after the alcohol was added.
2. **Explain** why each of the following chemicals was used in the extraction process:
   - detergent
   - meat tenderiser
   - alcohol.
3. **Explain** why methylene blue was used when observing the DNA under the microscope.
4. **Deduce** what factors affected your success in extracting and examining the DNA.

2 The Watson–Crick model of DNA

Purpose

To construct a model of DNA.

Materials

- 36 coloured paperclips (9 yellow, 9 green, 9 blue, 9 red)
- 2 strips of paper 1.5 cm × 30 cm
- coloured pencils

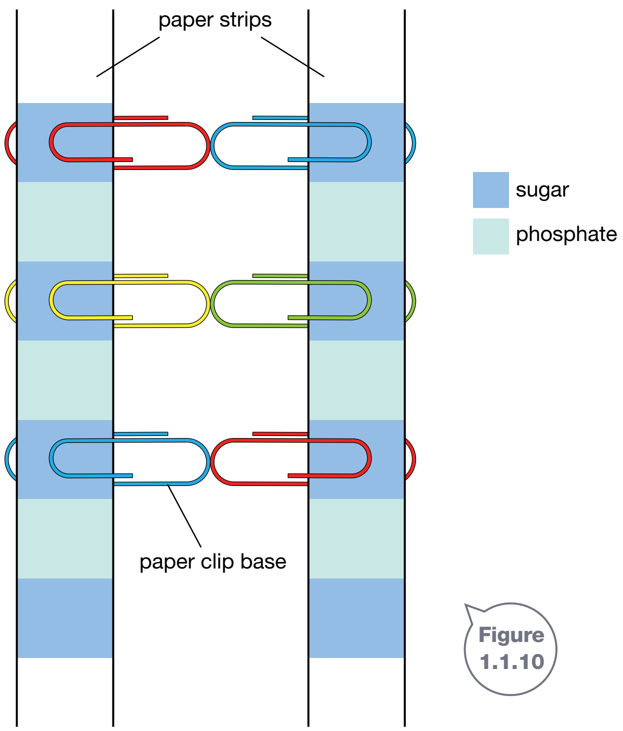


Figure 1.1.10

Procedure

1. Use paperclips to represent the bases in your DNA molecule. Choose a different colour for each of the bases adenine, guanine, cytosine and thymine. Make a note of the bases and their colours. (Note: If all groups use the same colours, it will be easier to compare results at the end of the experiment.)
2. Mark the two strips of paper into 2 cm sections.
3. Shade the two strips of paper in alternating blocks of colour to represent the sugar and phosphate molecules, as shown in Figure 1.1.10.
4. Attach ten of your coloured clips randomly (in any sequence you like) to the 'sugar molecules' along one of the strips.
5. Use the base-pairing rules described on page 3 to build and attach the complementary strand.

Results

Draw a diagram of the DNA molecule you have made.

Practical review

1. **Compare** your model to the others made in your class.
2. **Account** for any similarities and differences.
3. **Calculate** the number of different variations of single DNA strands that can be made using only the ten bases you started with. N
4. **Discuss** what would happen to the number of different models that could be made if the strand of DNA was thousands of bases in length.

STUDENT DESIGN

3 Make your own DNA

Purpose

To design and build a model of DNA.

Materials

- as selected by students

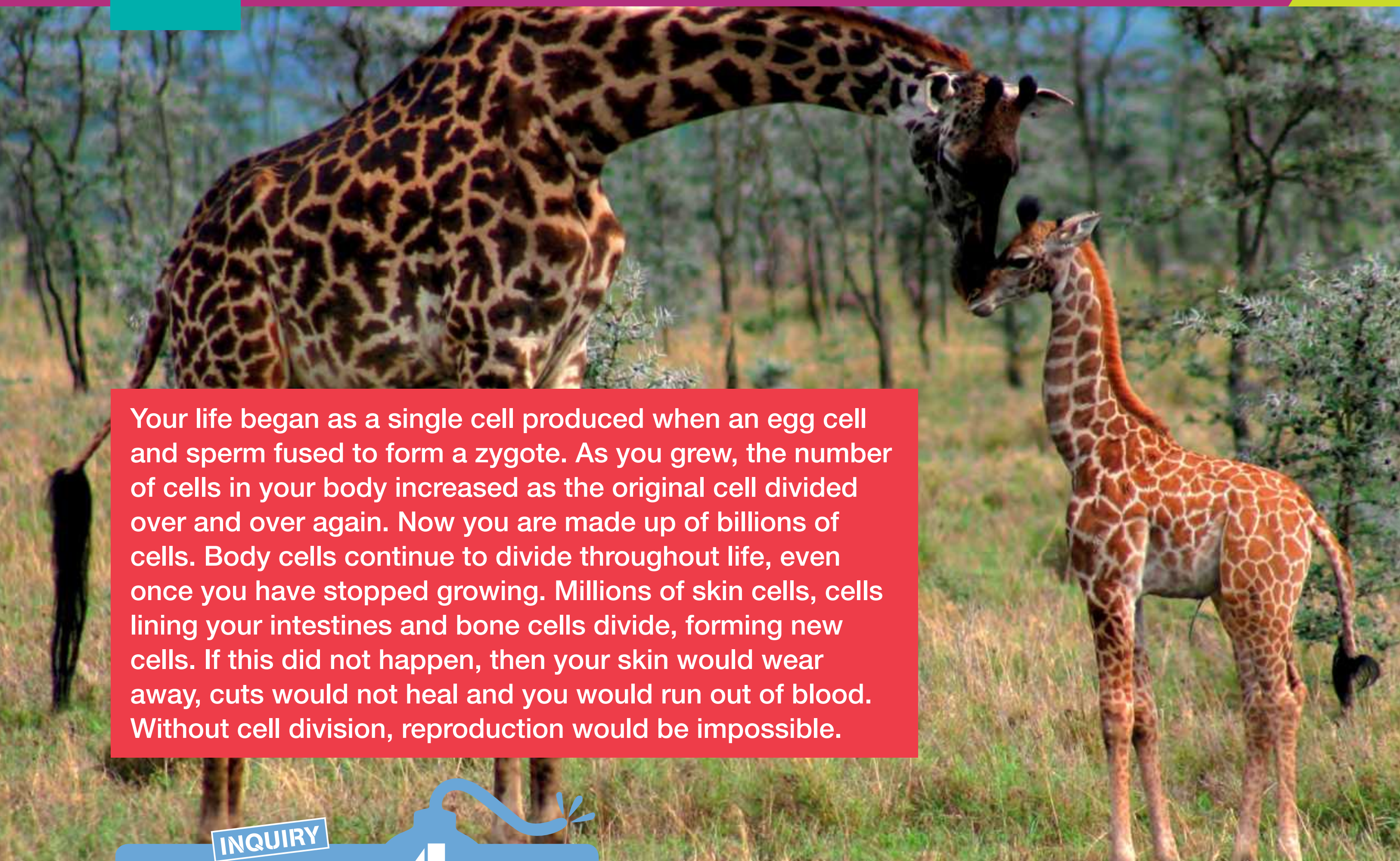
Procedure

Construct an accurate model of a strand of DNA using different coloured objects such as lollies, beads and pipe cleaners.

Practical review

Compare your model with the model shown in Figure 1.1.1 on page 3.

1.2 Making new cells



Your life began as a single cell produced when an egg cell and sperm fused to form a zygote. As you grew, the number of cells in your body increased as the original cell divided over and over again. Now you are made up of billions of cells. Body cells continue to divide throughout life, even once you have stopped growing. Millions of skin cells, cells lining your intestines and bone cells divide, forming new cells. If this did not happen, then your skin would wear away, cuts would not heal and you would run out of blood. Without cell division, reproduction would be impossible.

INQUIRY

science 4 fun

Variation

YES

How does increasing the number of variables affect the amount of variation?

Collect this …

- 8 toothpicks
- 4 colours of marker pen (such as red, blue, green and purple)

Do this …

1 Create a red pair of toothpicks by colouring the tip of one red and placing two or three red stripes on the other. Create blue, green and purple pairs in the same way.

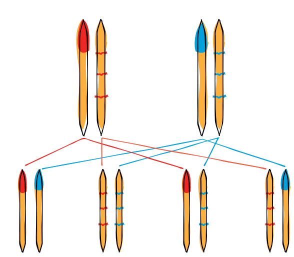
2 Sort the toothpicks into their colour pairs.

3 Sort the red and blue toothpicks into two groups with one red and one blue toothpick in each. Now try a different combination of red and blue. Make as many different groups as possible. Use the diagram on the right as a guide.

4 Record the number of pairs you created.

5 Add in the pair of green toothpicks. Again sort the toothpicks into two groups each with three toothpicks—one toothpick of each colour. Create as many different groups as you can.

6 Record the number of different groups you created.



7 Add in the purple toothpicks and sort all the toothpicks into two groups of four, following the same rules about colour.

8 Record the number of different groups you created.

Record this …

Describe how you were able to change the number of groups you created.

Explain why this happened.

Replicating the DNA

Apart from red blood cells, all the cells in your body have nuclei that contain chromosomes made of DNA. Each cell contains exact copies of the chromosomes that were in the original zygote that became you. This means that it must be possible to copy DNA molecules. The process of copying DNA is known as **replication**.

Replication

In the first step of replication, the strands of the double helix separate from each other in much the same way as a zip opens. You can see this in Figure 1.2.1. The bases are then exposed. Within the nucleus there are individual nucleotides that are not part of a DNA chain. In step 2, these nucleotides pair up with the exposed bases following the rules of complementary base pairing. In step 3, the sugar and phosphate molecules bond with neighbouring nucleotides and new strands of DNA are formed.

Replication occurs on both of the exposed strands of DNA, and the result is two identical molecules of DNA. Figure 1.2.2 shows chromosomes after replication. Each chromosome is a double structure made up of two **chromatids** joined together. Each chromatid is a double helix of DNA.

Having made copies of all the chromosomes, the cell is ready to divide.

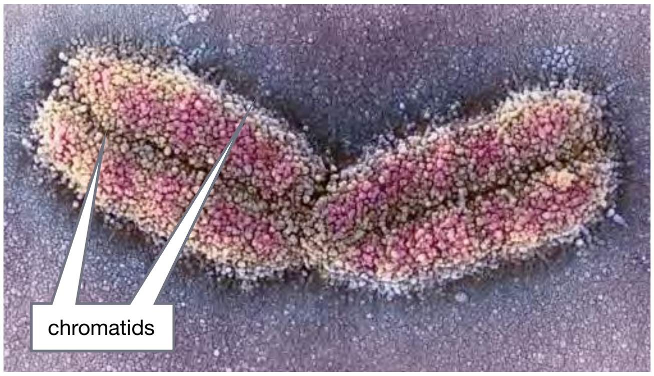


Figure 1.2.2 Image taken with a scanning electron microscope (SEM) of a human chromosome that has replicated and which consists of two identical chromatids

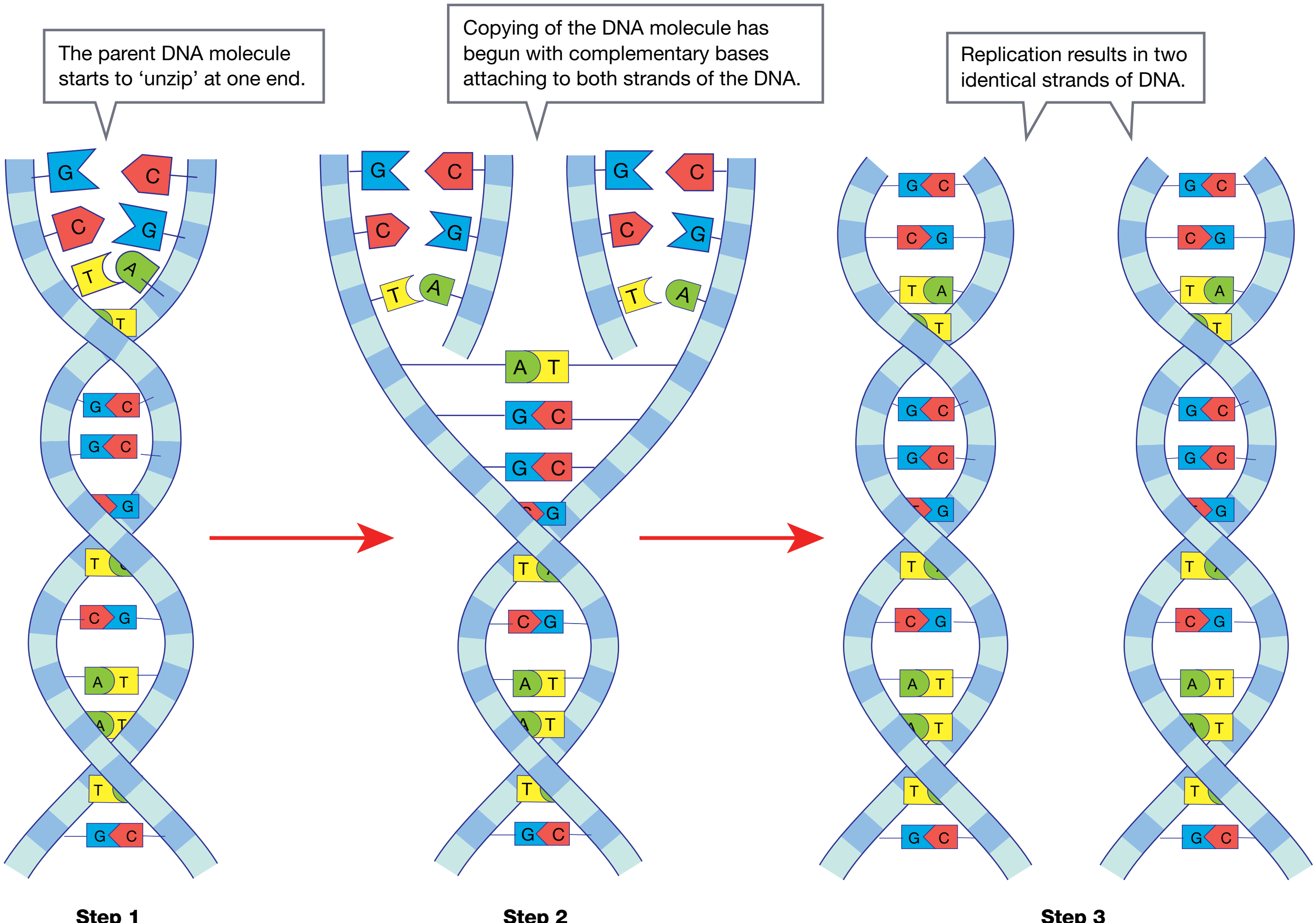


Figure 1.2.1 DNA replication involves three distinct stages.

Slow copy
It takes about 8 hours for one of your cells to completely copy its DNA.
SciFile

Cell division

There are two types of cell division:

- **Mitosis** produces two daughter cells that are identical to the parent cell. This is the type of cell division involved in growth and repair of the body.
- **Meiosis** produces gametes (eggs and sperm) that have half the number of chromosomes of the parent cell.

Mitosis

Mitosis is a continuous process. However, scientists have identified several distinct stages in the process. Different stages can be seen clearly in Figure 1.2.3.

When the cell begins to divide, the DNA coils up and separate chromosomes become visible. Each chromosome comprises two chromatids (stages 1 and 2 of Figure 1.2.4). The membrane surrounding the nucleus breaks down. Chromosomes line up across the equator (middle) of the cell and a network of fibres appears, extending from the poles of the cell to each chromosome (stage 3).

The chromatids separate to become two independent chromosomes. The network of fibres contracts, pulling the chromosomes to opposite poles (ends) of the cell (stage 4). A nuclear membrane encloses the chromosomes at each pole. The chromosomes uncoil and are no longer visible as individual strands (stage 5).

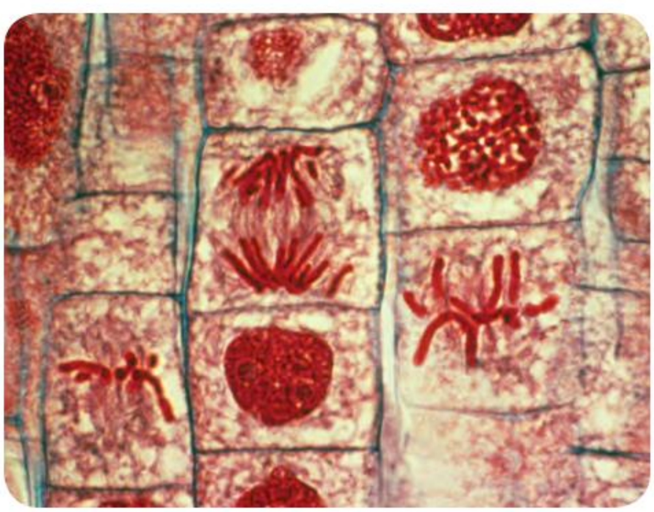


Figure 1.2.3 Light micrograph of phases of mitosis in cells from an onion

Prac 1 p19

1.3

Division of the nucleus is complete. The cytoplasm divides and the result is two identical daughter cells (stage 6). The daughter cells grow in size in preparation for the next round of cell division.

In the period between the actual divisions of the cell, the DNA replicates. At this stage, individual chromosomes are not visible.

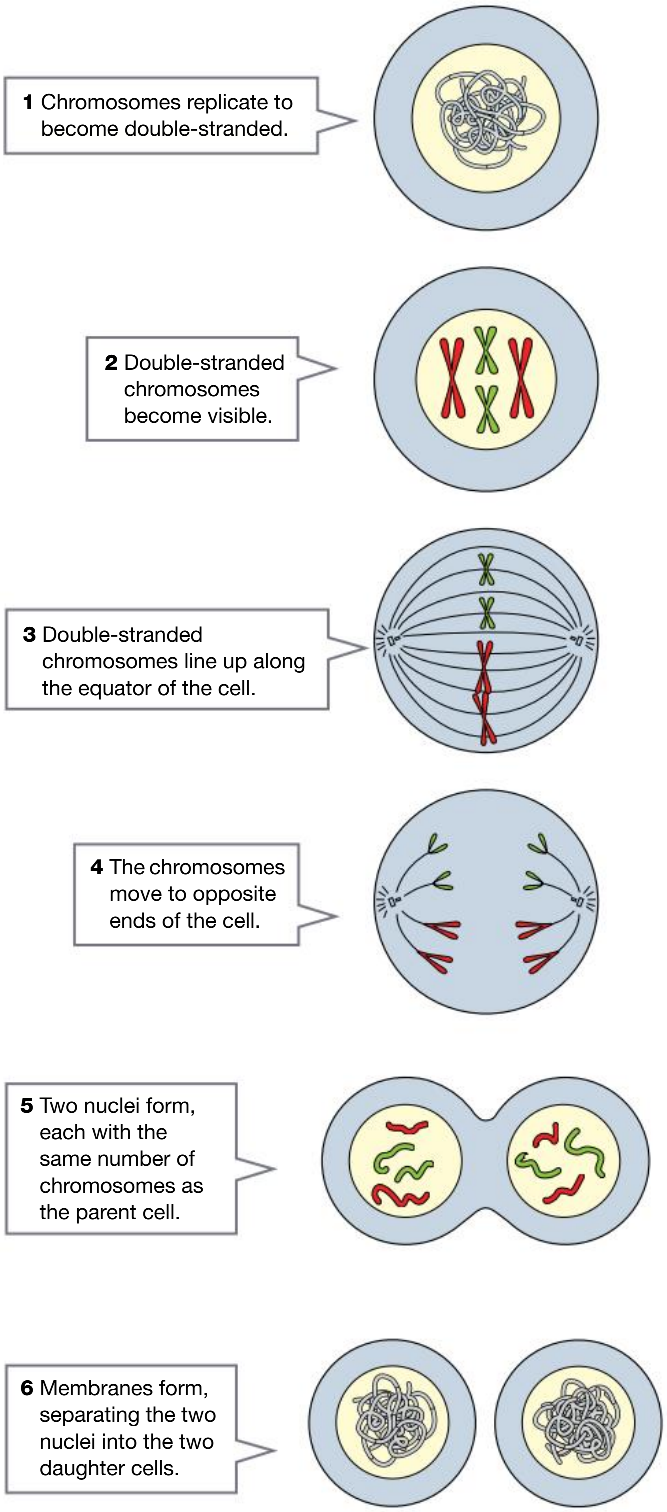


Figure 1.2.4 The stages of mitosis

Chromosome number

In your body cells, there are 46 chromosomes, half of which came from your father and half from your mother. The number of chromosomes in your body cells is known as the **diploid number**. The diploid number is also described as 2N, which means
two sets.

Gametes are the sex cells. They are the:

- eggs produced in the ovaries of the female reproductive system
- sperm produced in the testes of the male reproductive system.

In your gametes, there has to be half the diploid number of chromosomes. If each parent passed on their complete set of genetic information, then their offspring would have 4N chromosomes and then the next generation would have 8N and so on. By halving the number of chromosomes in the gametes, the number of chromosomes from generation to generation is kept constant at 2N.

Of the 46 chromosomes in your cells, two are **sex chromosomes**—the ones that determine whether you are male or female.

- In females, the sex chromosomes are a pair of X chromosomes (XX).
- In males, the sex chromosomes are one X and one Y chromosome (XY).

The other 44 chromosomes are not sex chromosomes and are known as **autosomes**.

The autosomes in your cells are grouped into 22 pairs. The chromosomes in the pair are homologous (the same). **Homologous chromosomes**:

- are the same length
- have the **centromere** (the point where the two chromosomes join) in the same position
- have genes for particular characteristics at the same location along their length.

For example, the gene for hair curliness is found in the same position on the pair of homologous chromosomes shown in Figure 1.2.5. Therefore, each new cell formed by mitosis of the zygote has two copies of the gene for each characteristic, one on each chromosome of the homologous pair.

One chromosome from each homologous pair must end up in each gamete that is produced. Therefore, the gametes have 23 chromosomes in total. This is known as the **haploid number** or N.

The female sex chromosomes are a homologous pair. The male X and Y chromosomes are not homologous but they behave as a pair during meiosis.

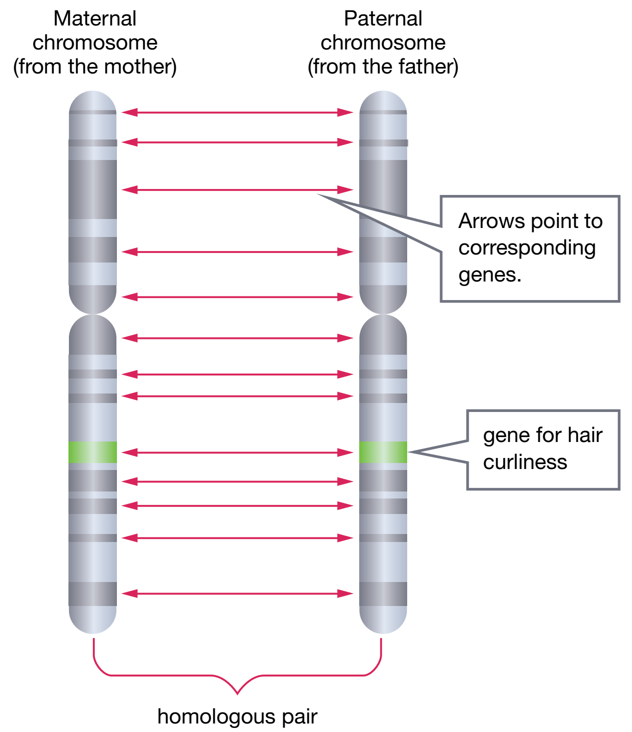


Figure 1.2.5 Homologous chromosomes showing the position of the corresponding genes for hair curliness

Meiosis

Meiosis is the process of cell division that produces the gametes—sperm and eggs. The chromosomes replicate in preparation for division just as they do for mitosis. The stages of meiosis are seen in Figure 1.2.6 on page 14.

The nuclear membrane breaks down and then, in preparation for the first part of meiosis, the homologous pairs of chromosomes line up on the equator of the cell. A network of fibres extends from the poles of the cell to each chromosome pair (stage 1). The fibres contract, drawing one chromosome from each pair to opposite poles of the cell (stage 2). At this stage, each chromosome is still two chromatids (stage 3).

A new network of fibres forms at right angles to the first. The fibres attach to the chromosomes that have lined up on the equator of the cell. This time when the fibres contract, the chromatids are pulled apart towards the poles of the cells (stage 4).

There are now bundles of 23 chromosomes. New nuclear membranes form and the cytoplasm divides to produce four new cells, each containing the haploid number of chromosomes. These cells are the gametes or sex cells (stages 5 and 6).

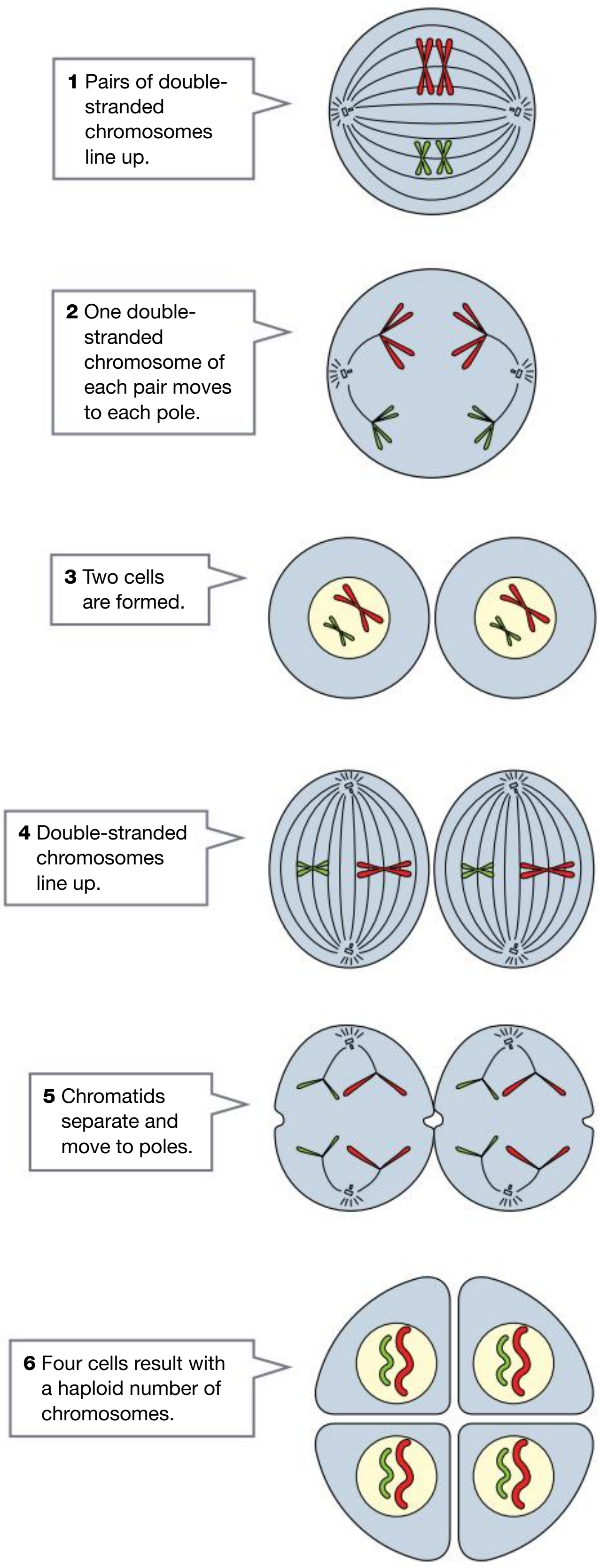


Figure 1.2.6 The stages of meiosis

Prac 2 p19

1.4

Asexual reproduction

There are plants and animals that sometimes reproduce asexually. This means that offspring are produced without any union of gametes. Instead they are produced through mitosis of particular cells. Hydra and grasses are examples of organisms that use asexual reproduction. The hydra in Figure 1.2.7 is a simple multicellular organism that reproduces by budding when conditions are favourable. Cells on the side of the body multiply by mitosis and a new hydra forms.

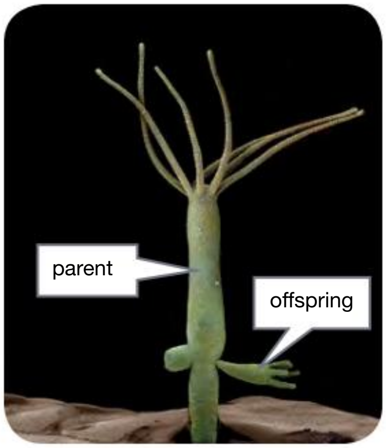


Figure 1.2.7 This small hydra will grow to almost adult size and then break off from the parent to become an independent organism.

Many grasses form stems (known as runners) that grow over the ground surface. At intervals, roots grow down, anchoring the runners. This is what is happening in Figure 1.2.8. Shoots grow up at this point, creating a new individual. In both these examples the offspring inherit all the genetic information from one parent only. Parent and offspring are genetically identical.

Figure 1.2.8 This grass is reproducing using asexual reproduction.

Sexual reproduction

Sexual reproduction creates variation in a population. It is the role of the male and female reproductive systems to ensure that:

- the male and female gametes meet
- fertilisation takes place
- the new individual has the best chances of survival.

Figures 1.2.9 and 1.2.10 show the structures of the human female and male reproductive systems and the function of each organ.

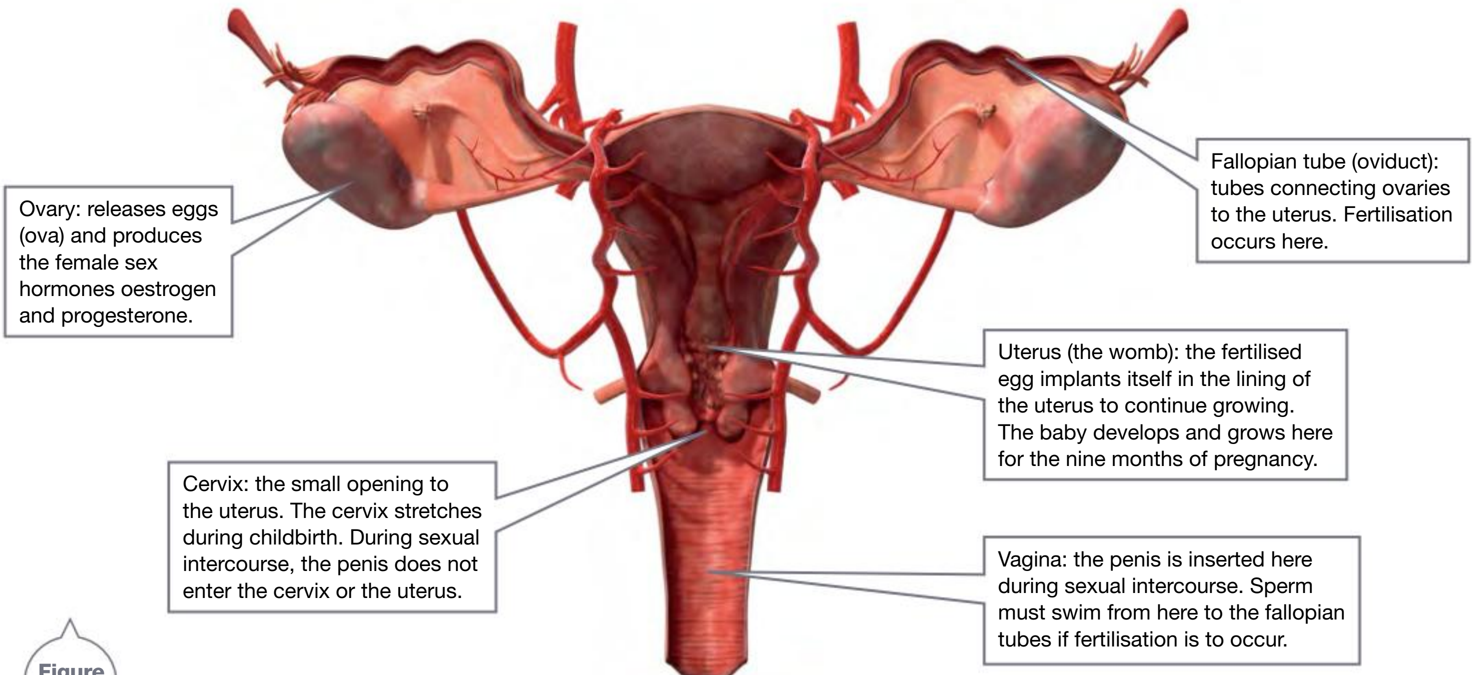


Figure 1.2.9 The human female reproductive system

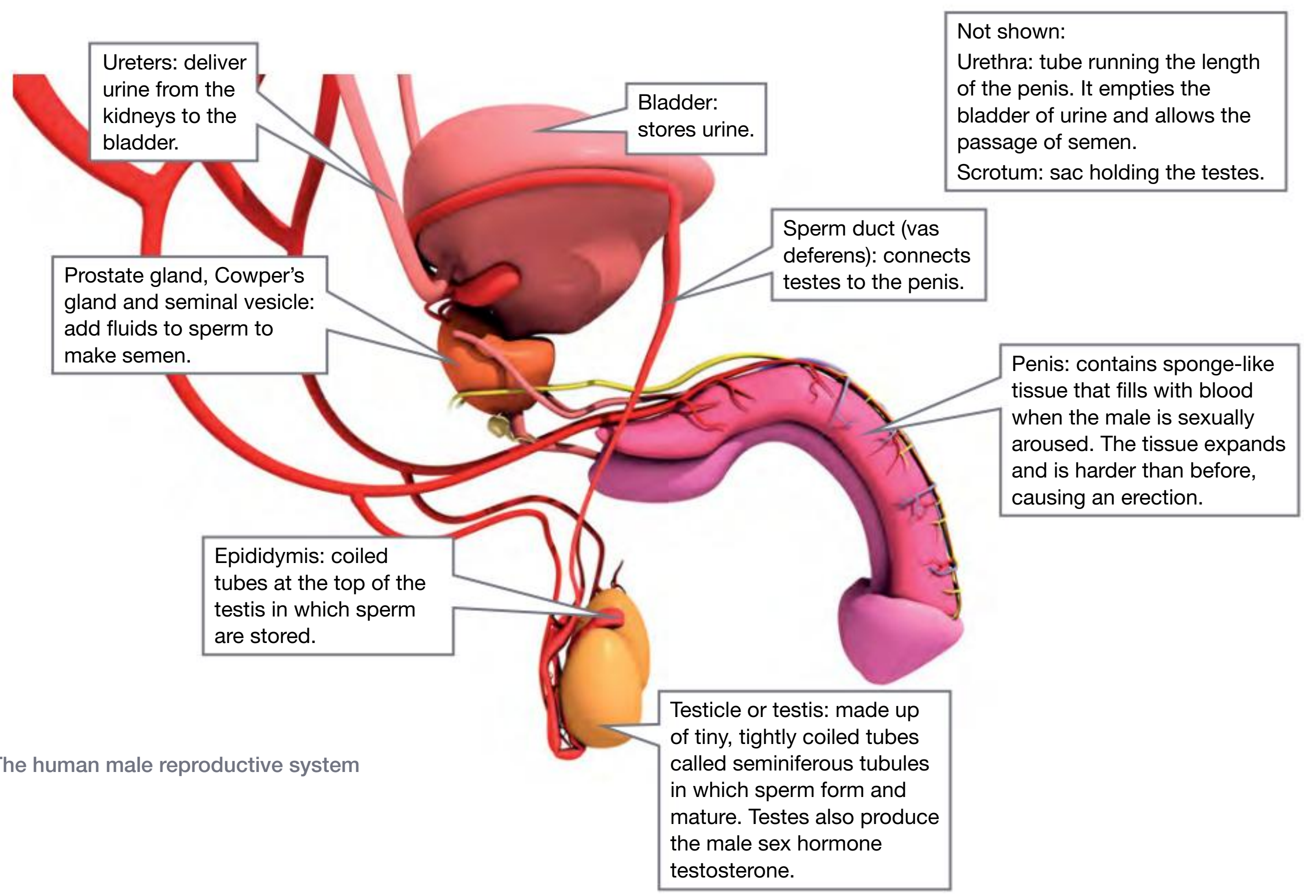


Figure 1.2.10 The human male reproductive system

Creating difference

The four gametes produced by meiosis of one cell are all different. They all have the same number of chromosomes and carry the information about the same characteristics. However, the specific information is different. Every one of the gametes that your body will ever produce will be different from every other.

Figure 1.2.11 is an example of a homologous pair of chromosomes carrying the gene for eye colour (Figure 1.2.12). In this example, one chromosome holds information for blue eyes, while the other specifies brown eyes. When this cell forms gametes, half will have the chromosome carrying information for blue eyes and the other half will have the information for brown eyes.

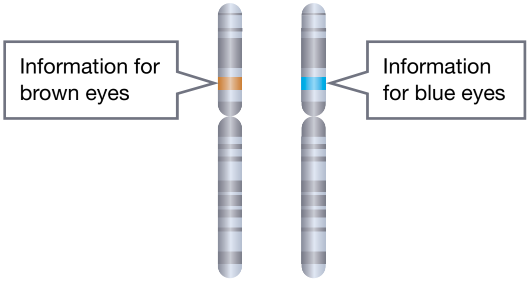


Figure 1.2.11 Homologous pair of chromosomes carrying the gene for eye colour

Figure 1.2.12 Chromosomes determine your eye colour.

Another example is shown in Figure 1.2.13, in which a different pair of homologous chromosomes carries information about the length of the second toe. Some people have a second toe that is longer than their big toe. In others the second toe is shorter. If one chromosome has the information for a long second toe and the other has the information for a short second toe, then half the gametes will have information for a short toe and half will have information for a long toe.

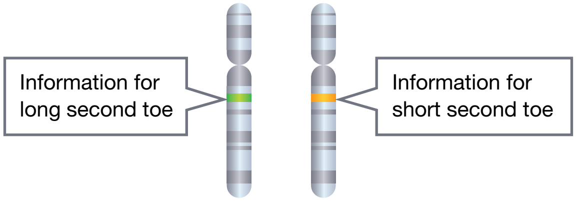


Figure 1.2.13 Homologous chromosomes for toe length

Consider the chromosomes for eye colour and toe length in one person. During meiosis when the chromosomes in a pair separate, the homologous chromosomes randomly go to either end of the cell. Figure 1.2.14 demonstrates that the four gametes produced could carry different combinations of the information about eye colour and toe length.

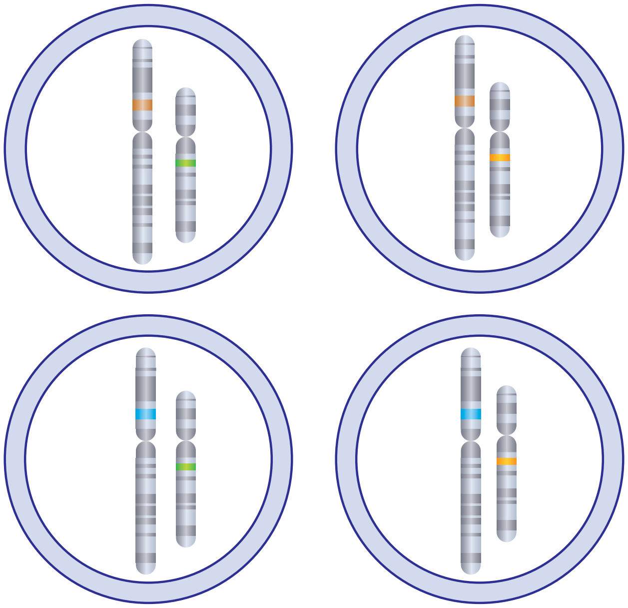


Figure 1.2.14 The gametes produced from the homologous chromosomes shown in Figures 1.2.11 and 1.2.13

1.2 Unit review

Remembering

1 **Name** the type of cell division that is responsible for growth and repair in the body.

2 **Recall** the key terms described by:
   a one of the strands of a chromosome following replication L
   b the process of making copies of DNA.

3 **State** the type of cell division that produces gametes.

4 **Name** the organ in the human female reproductive system:
   a in which the eggs are produced and mature
   b that carries the egg towards the uterus.

5 **Name** of the organ in the human male reproductive system:
   a in which the sperm are produced
   b that carries the sperm out of the body.

6 In the science4fun on page 10, toothpicks were coloured in different colours and with different patterns. Imagine you had six pairs of toothpicks. **State** how many different combinations of six toothpicks are possible.

Understanding

7 **Explain** why it is essential for chromosomes to replicate before cell division occurs.

8 A gamete (sex cell) is haploid. **Explain** what this means.

9 a **State** the types of cell division involved in creating a puppy.
   b **Explain** the role of each type of cell division.

10 **Describe** the role of the network of fibres in cell division.

11 **Explain** why it is important that the number of chromosomes is reduced when gametes are formed.

12 **Explain** what happens in the cell nucleus between cell divisions.

Applying

13 A horse has 64 chromosomes in its body cells. **Calculate** how many chromosomes will be in each of its gametes. N

14 **Calculate** how many chromosomes will be in the cells of an apple where there are 17 chromosomes in a gamete. N

15 a **Use** a diagram to **demonstrate** the structure of a double-stranded chromosome.
   b **Label** the chromatids.

16 **Identify** what Figure 1.2.15 represents.

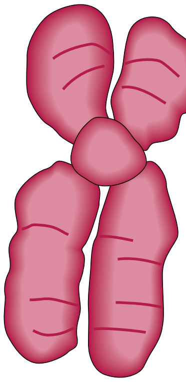


Figure 1.2.15

17 **Identify** the homologous pair in the chromosomes in Figure 1.2.16.

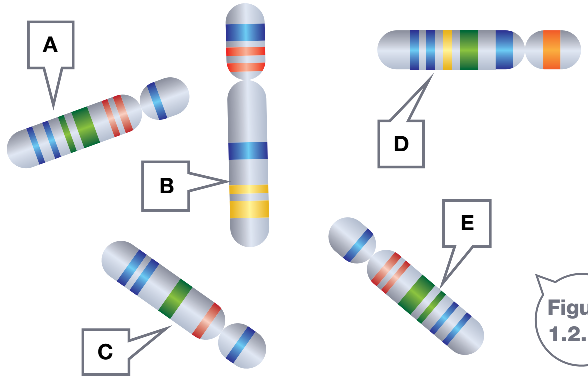


Figure 1.2.16

18 Characteristics of two pairs of chromosomes are shown in Figure 1.2.17. **Demonstrate** all the combinations that would be possible in gametes if this cell were to undergo meiosis.

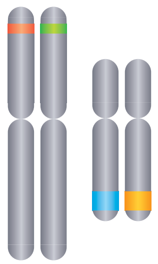


Figure 1.2.17

Analysing

19 **Contrast** haploid cells with diploid cells.

20 **Compare** chromosomes and chromatids.

1.2 Unit review

Evaluating CCT

21 **a** Figure 1.2.18 represents a section of single-stranded DNA. **Deduce** what the strand would be like after replication. **Use** a diagram to represent your idea.

b **Justify** your structure in part A.

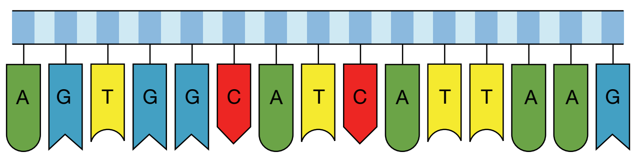


Figure 1.2.18

22 The following table shows the number of chromosomes in the body cells of different organisms.

a Copy the table into your workbook.

b **Deduce** the number of homologous pairs and the number of chromosomes in the gametes to complete the table. N

Organism	Number of chromosomes diploid number	Number of pairs of chromosomes	Number of chromosomes in the gametes
Dog	78		
Kangaroo	12		
Ant	2		
Mango	40		
Tomato	24		

23 **Propose** what is happening in the cells labelled A, B and C in Figure 1.2.19.

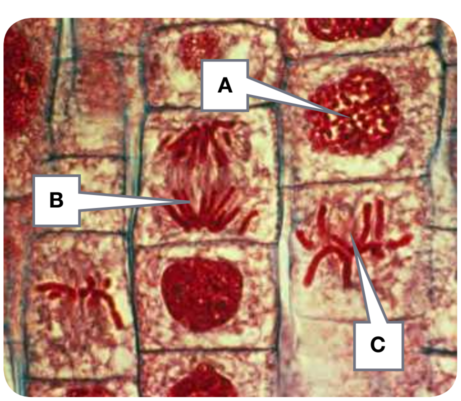


Figure 1.2.19

These cells are undergoing mitosis.

Creating CCT

24 **Construct** a table to compare mitosis and meiosis.

25 **Construct** a flow diagram for the process of DNA replication.

26 **Use** strips of paper to **construct** a simulation of mitosis in an organism with four chromosomes. You need to be able to move the chromosomes around and show where they go. Don't forget to make chromatids.

27 **Design** an activity in which kebabs are used to demonstrate the concept of homologous chromosomes.

Inquiring

1 Is there a relationship between the diploid number of chromosomes in a species and how complicated its structure is? Research:

- the number of chromosomes in a variety of species, making sure that species from all five kingdoms (animal, plant, fungi, protist, monera) are represented in your list
- how complicated its structure is.

Present your research in a few sentences describing any relationships that you found.

2 Growth is an increase in size. As you grew the number of cells in your body increased. Research:

- what controls the rate of cell division in your body
- the changes that take place leading to cancer in which cell division is out of control.

Present your findings as a short article for a magazine or for a teen health website. ICT

1.2 Practical investigations

1 Observing mitosis

Purpose

To observe mitosis in plant roots.

Materials

- prepared slides of onion root tips
- microscope

Procedure

1. Using a prepared slide and the low power on the microscope, focus on cells just behind the tip of the root (Figure 1.2.20).
2. Search for nuclei that appear to contain threads instead of appearing as dark circles. These are the cells that will be undergoing mitosis.
3. Focus on these cells and then switch to high power and focus on a cell where the chromosomes are clearly visible.
4. Find other cells that seem to be in different stages. For example, look for evidence of two newly formed cells.

Results

1. Draw diagrams of the cells you have found.
2. Organise your diagrams so that they represent the process of mitosis.
3. Draw a diagram showing where in the root mitosis is taking place.

Practical review

1. **Discuss** whether or not you would expect all cells in a root to be undergoing mitosis.
2. **Use** your observation to **assess** whether all of the cells in the area of the root tip you looked at were undergoing mitosis.
3. Growth due to mitosis occurs near the tip of the root rather than right on the tip or further back. **Propose** the benefits to the plant of this arrangement.

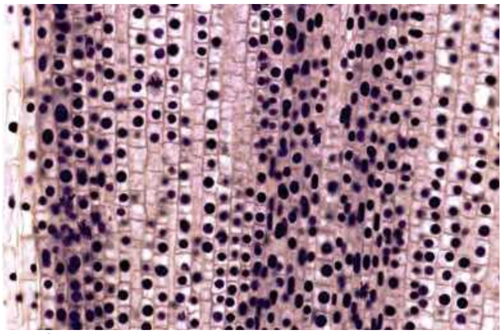


Figure 1.2.20 Stained onion root tip cells

2 Observing meiosis

Purpose

To observe meiosis in the anther of a flower.

Materials

- prepared slide of an anther
- microscope

Procedure

1. Using a prepared slide and the low power on the microscope, focus on cells inside the anther.
2. Search for nuclei that appear to contain threads instead of appearing as dark circles. These are the cells that will be undergoing meiosis.
3. Focus on these cells and then switch to high power and focus on a cell where the chromosomes are clearly visible.
4. Find other cells that seem to be in different stages. For example, look for evidence of two or four newly formed cells.

Results

Draw diagrams of the cells you have found.

Practical review

1. **Compare** your drawings and then place a number beside each diagram to represent the order they would appear in the process of meiosis.
2. **Explain** why meiosis would be occurring in the anther of a flower.
3. **Explain** how many chromosomes the gametes will have compared with the cell that divided to form them.
4. a. **Propose** where else in a flower you could look for meiosis taking place.
   b. **Justify** your proposal.

1.3 Characteristics and inheritance

At some time you have probably been told that you look like other members of your extended family. Relatives make comments such as ‘He’s got his father’s ears’ or ‘Her hair is the same colour as great Aunt Madge’s was when she was young’. Humans are fascinated by inheritance and the ways that characteristics pass from one generation to the next.

INQUIRY science 4 fun

Family resemblances

YES

What are your family’s traits?

Collect this ...

- photographs of close family members who are your relatives, such as your parents, grandparents, siblings, aunts and uncles (It is often easier to see resemblances in a photograph than by looking at the real person.)
- If you do not have photographs of close family, then find a suitable photograph of another family by searching the internet.

Do this ...

Look at the photographs to see where there are similarities.

Record this ...

Describe the resemblances you found.

Explain the relationship between the people displaying these characteristics.

Dominant/recessive inheritance

Genetics is the study of inherited characteristics called **traits**. In natural populations all the individuals are genetically different—they have different traits. However, some patterns of inheritance of these traits can be identified.

One pattern of inheritance can be illustrated using flower colour in pea plants. Pea plants can have red flowers or they can have white flowers. Flower colour is carried as one of the genes on a homologous pair of chromosomes. This gene comes in two varieties. Variations of genes are known as **alleles**. Alleles occupy the same position on homologous chromosomes. In the pea-plant example, the gene for flower colour has two alleles—one for the red flower trait and one for the white flower trait.

Plant breeders can create **pure breeding** lines of plants. In these all the individuals have the same genetic information. If pollen from a pure-breeding red-flowering pea plant is used to pollinate a pure-breeding white-flowering pea plant, all the flowers in the next generation will be red. The red allele is dominant to the white allele. (Figure 1.3.1)

The white allele has not disappeared. Each of the plants in this new generation—known as the F_1 generation—carries the white allele within it, but the white allele is not seen in the appearance of the individual. The red allele is the **dominant allele**—the one that is observed in the outward appearance of the individual. In this example, the white allele is the **recessive allele**—the one that remains hidden.

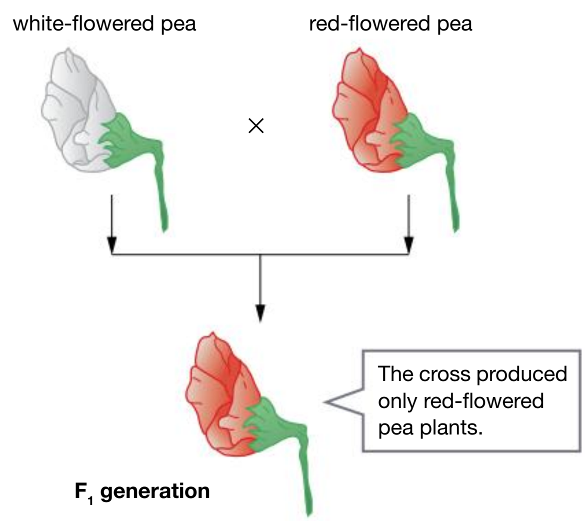


Figure 1.3.1 The cross between a pure-breeding red-flowered pea plant and a pure-breeding white-flowered pea plant produces only red flowered plants.

Representing alleles

When studying crosses and potential characteristics of offspring, geneticists use shorthand conventions. The dominant allele is represented by an upper-case letter related to the name. In this case, the red flower allele could be represented by the letter R (pronounced as 'big r'). The recessive characteristic (white flower) is then represented by the lower-case of the same letter—r (pronounced as 'little r'). By using R and r, it shows that a particular gene is being discussed.

The RR ('big r big r') combination of alleles will produce a red flower. Rr ('big r little r') will also produce a red flower because red is dominant to white. Only rr ('little r little r') will produce a white flower.

When an individual has two alleles the same, such as the RR and rr combinations shown in Figure 1.3.2, then the individual is said to be **homozygous** for that allele. The individual is described as a homozygote. Individuals with the Rr combination of alleles are **heterozygous**. These individuals are heterozygotes.

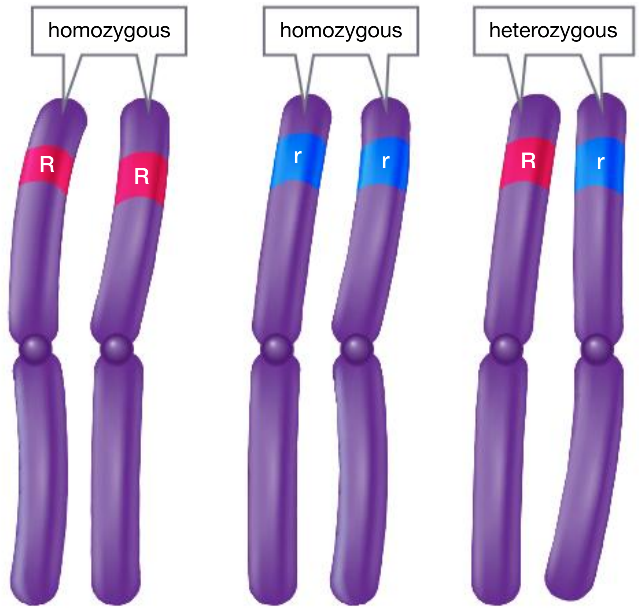


Figure 1.3.2 In a homozygous individual, both alleles are the same, either for the dominant allele (RR) or for the recessive allele (rr). A heterozygous individual has different alleles (Rr).

When working out the possible characteristics of offspring, it is important to refer back to meiosis and the movement of the genes as gametes are produced. Figure 1.3.3 on page 22 demonstrates how gametes of a heterozygote end up with the different alleles of the flower colour gene.

Fertilisation then determines which characteristics are present in each of the offspring.

Punnett squares

Figure 1.3.4 on page 22 shows a Punnett square. Punnett squares are one way of showing all the possible types of offspring that could result from a cross. You cannot assume that the offspring will appear in exactly this order and in this exact ratio. It represents a probability.

In a Punnett square, the possible gametes produced by one parent are shown across the top. The gametes from the other parent are shown down the side. In each square is a possible outcome of fertilisation.

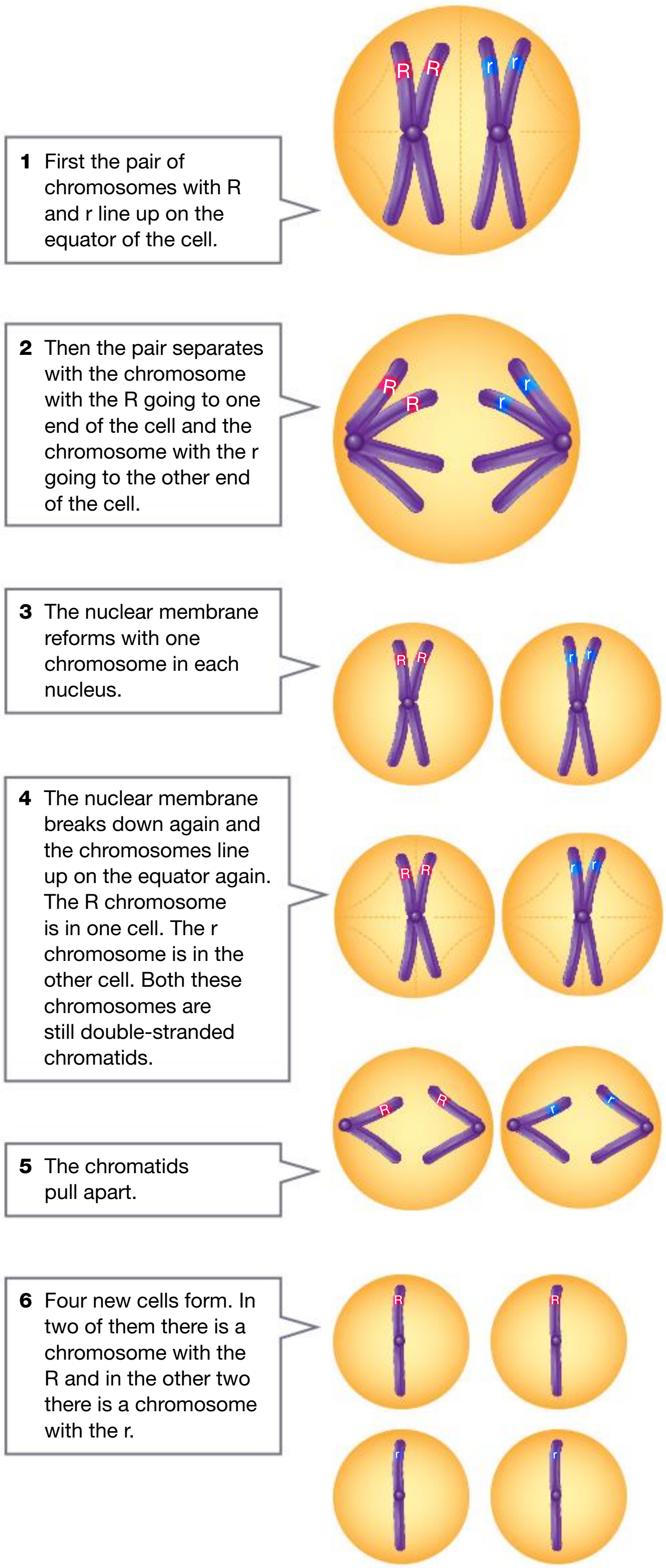


Figure 1.3.3 The behaviour of chromosomes during meiosis determines the alleles that end up in each of the gametes.

Gametes from one parent

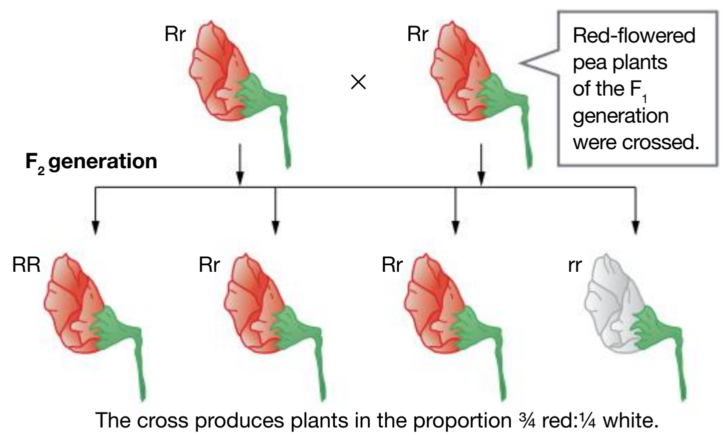
Homozygous

Gametes from other parent	r	r
R	Rr	Rr
R	Rr	Rr

Possible outcomes of fertilisation

Figure 1.3.4 This Punnett square shows the possible outcomes of a cross between two homozygous individuals.

An individual that is heterozygous produces gametes of two types. Half the gametes carry the dominant allele. The other half of the gametes carries the recessive allele. A Punnett square demonstrating this cross is shown in Figure 1.3.5. This Punnett square shows that both red-flowered and white-flowered plants can be produced in the next (F_2) generation. The expected proportion is $\frac{3}{4}$ red flowers and $\frac{1}{4}$ white flowers. These fractions represent a probability, so the exact proportions of red and white flowers might differ in reality.



Heterozygous

	R	r
R	RR	Rr
r	Rr	rr

R alleles for red-flowered pea

r alleles for white-flowered pea

Figure 1.3.5 The cross of two heterozygous individuals produces plants in the proportion $\frac{3}{4}$ red-flowered and $\frac{1}{4}$ white-flowered.

Genotype and phenotype

RR, rr and Rr represent the pea plants' **genotypes**—the actual genetic information carried by an individual.

The red or white colour of the flower is the **phenotype**—the observable characteristics of the individual.

The red rose in Figure 1.3.6 has the phenotype of 'red colour' but it could have a genotype of RR or Rr because the R allele is dominant to the r allele. The white rose has the phenotype of 'white flower' and the genotype rr.

Figure 1.3.6 Red roses all have the same phenotype (red) but can have different genotypes. White roses all have the same phenotype and genotype.

SKILL BUILDER

Predicting the results of a cross

It is possible to predict the results of a cross if you know the:

- genotypes of the parents
- relationship between the alleles of the trait (characteristic) of interest.

Consider two parents, P_1 and P_2, who are both heterozygous for the gene F. Gene F has two alleles F and f. F is dominant to f.

What are the expected outcomes of a cross between P_1 and P_2?

As both parents are heterozygous their genotypes are both Ff and each can produce gametes containing an F allele or an f allele.

A Punnett square can help you predict the outcomes.

P_1 gametes \ P_2 gametes	F	f
F	FF	Ff
f	Ff	ff

From the table the expected genotypes are:

¼ FF, ½ Ff and ¼ ff

Because F is dominant to f, the expected phenotypes are:

¾ trait F and ¼ trait f

If P_1 and P_2 had 12 offspring, you would expect about:

9 trait F and 3 trait f

WORKED EXAMPLE
Predicting the results of a cross

Problem

In peas, yellow colour is dominant to green colour. A pea plant heterozygous for the gene for colour is crossed with another pea plant heterozygous for the gene for colour and 100 offspring are produced.

Predict how many of the offspring will be yellow and how many will be green.

Solution

Step 1 Decide what letters you will give to the alleles for yellow and green colour.

As yellow is dominant—Y, green is recessive—y.

Step 2 Deduce the genotypes of the parent plants.

As both are heterozygous, they will have one of each allele and hence be Yy.

Step 3 Set up your cross in a Punnett square.

P_1 gametes \ P_2 gametes	Y	y
Y	YY	Yy
y	Yy	yy

Step 4 Write down the expected genotypes.

¼ YY, ½ Yy, ¼ yy

Step 5 Work out the expected phenotypes.

¼ YY + ½ Yy = ¾ yellow

¼ yy = ¼ green

Step 6 Work out how many of the 100 offspring will be yellow and how many will be green.

¾ × 100 = 75 yellow

¼ × 100 = 25 green

Practice

1. **Predict** the phenotypes of the offspring when a mouse homozygous for black fur is crossed with a mouse with white fur. Black is dominant to white.
2. In guinea pigs brown coat colour is dominant to white. **Predict** the phenotype of the offspring produced when a guinea pig heterozygous for brown coat is crossed with a white guinea pig.

1.5 1.6

Sex determination

You have two sex chromosomes and these determine which sex you are. Inheritance of these chromosomes can be seen clearly in Figure 1.3.7. All of the eggs produced by a female will have one X chromosome. Half the male's sperm will carry an X chromosome and the other half will have a Y chromosome. If a sperm containing an X chromosome fertilises an egg, then the offspring will be a female (XX). If a sperm carrying a Y chromosome fertilises an egg, then the offspring will be male (XY).

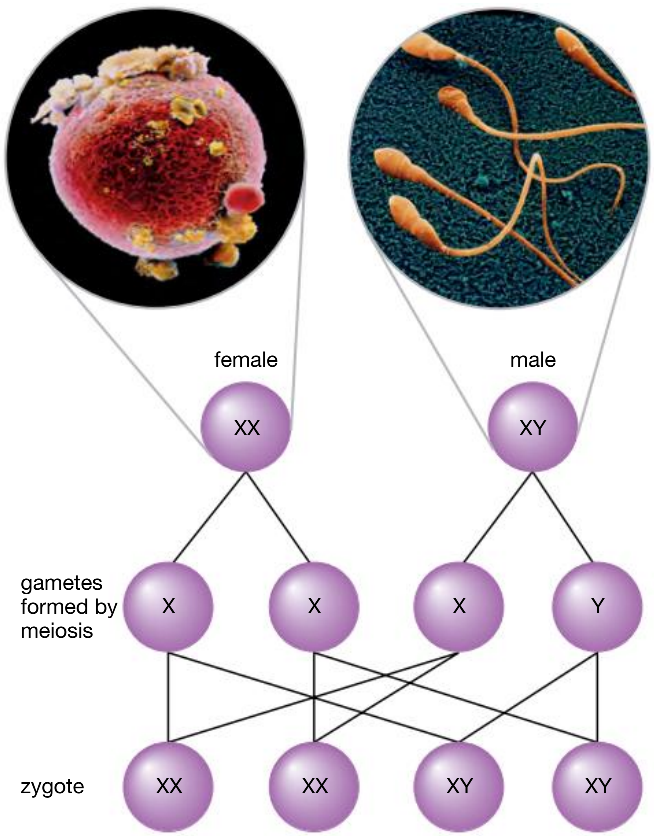


Figure 1.3.7 Inheritance of the sex-determining chromosomes

Sex linkage

Some genes are found on the sex chromosomes. These are called **sex-linked genes** because they are present on one of the chromosomes that are also responsible for the determination of sex. The X chromosome is longer than the Y chromosome and tends to carry more genes. Most sex-linked genes in humans are carried on the X chromosome.

The red–green colour-blindness gene is carried on the X chromosome. Normal vision (N) is dominant to red–green colour-blindness (n). Females who are heterozygous (X^NX^n) for colour-blindness will still have normal vision because the dominant allele masks the effect of the recessive allele. However, these females are carriers of the allele. Carriers are able to pass the trait on to their children.

The Y chromosome does not carry a colour-blindness gene. Therefore, the only possible genotypes for a male are X^NY and X^nY. In the genotype X^nY, the recessive allele is the one that is expressed in the phenotype and the male is colour-blind. Figure 1.3.8 demonstrates inheritance of the colour-blindness gene.

The daughter of a colour-blind male and a carrier female has a 50% chance of being colour-blind. Therefore, colour-blind females are not common. If a female with normal vision and a colour-blind male have only male children, then the boys will not be colour-blind and the disorder will not appear in subsequent generations unless it is re-introduced.

Haemophilia and Duchenne muscular dystrophy are two other examples of sex-linked characteristics.

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1.7

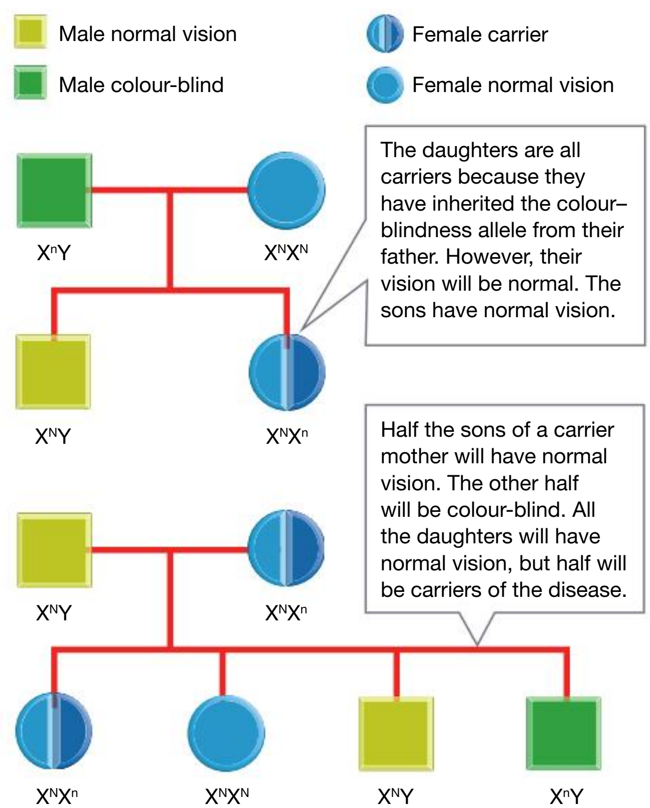


Figure 1.3.8 The gene affecting colour-blindness is carried by the X chromosome. This makes boys more likely than girls to be colour-blind.

Chromosomal abnormalities

Sometimes mistakes happen during meiosis when the sex cells are being produced and the information passed on to the next generation is changed.

If the chromatids fail to separate during meiosis, the child will be born with an extra chromosome or part of a chromosome. This is called chromosomal abnormality. Examples include Down syndrome and Klinefelter syndrome.

Mutations

Mistakes can happen as DNA is copied. The base sequence is changed and mistakes occur in the manufacture of proteins. This type of change is called a **mutation**. Mutations may arise spontaneously (by chance) or result from damage to a strand of DNA. UV radiation, nuclear radiation and certain chemicals such as nicotine and asbestos can cause mutations.

If the mutation occurs in the eggs or sperm, then there is a chance that it will be passed on to the next generation.

Types of mutations

The cells 'read' the genetic code a little bit like you read words on a page. A change to the order of the letters may have no effect on your understanding or it may mean that the text can no longer be understood (Figure 1.3.9).

- Silent mutations are changes in the genetic code that do not affect the individual. They occur when a single base on the DNA strand is changed and this does not affect the protein that is made using the information on that gene.
- Missense mutations are changes that don't stop the gene from making a protein. However, the protein produced is a different one. The protein may not function correctly and cause disease. A missense mutation is responsible for sickle cell anaemia.
- Nonsense mutations are more a significant type of mutation. The mutation causes the cells to stop reading the information on the gene before its end. The protein created is incomplete and cannot function at all. Cystic fibrosis, Duchenne muscular dystrophy and Beta thalassemia are diseases resulting from nonsense mutations (Figure 1.3.10).
- Frameshift mutations are caused by the insertion or deletion of a single base. The insertion or deletion causes all the information following it to become jumbled so that it cannot be 'read' to make a protein. Frameshift mutations frequently result in severe genetic diseases such as Tay-Sachs disease.

Mutations add to the diversity of organisms. Natural selection works on this diversity by selecting the individuals most suited to an environment. Farmers rely on this diversity to improve crops and to increase productivity.

GO TO Unit 3.2

Original sentence

THESE WORDS ARE EASY TO READ

Silent mutation

THESE WORDS ARE EESY TO READ

You may not have noticed the difference.

Missense mutation

THESE WOODS ARE EASY TO READ

Changing one word alters the meaning of the sentence.

Nonsense mutation

THESE WORDS AR

This sentence never finishes but stops in the middle.

Frameshift mutation

THESM EWORD SAR EEAS YT OREA D

The extra letter M has caused everything after it to be jumbled.

Figure 1.3.9 Different mutations affect how a gene is 'read'.

Figure 1.3.10 Cystic fibrosis is a genetic condition that causes the lungs to produce abnormal amounts of mucus. Intense physiotherapy is required to dislodge it.

1.8

1.3 Unit review

Remembering

1 **State** what is meant by a pure-breeding line of plants.

2 **Recall** the term used to describe: L

a alternative forms of a gene

b an organism with different alleles for a particular gene

c the observable characteristics of an individual

d an individual with two copies of the same allele of a gene.

Understanding

3 **Predict** the number of chromosomes that would be found in the following human cells. N

a ovum b muscle cell

c skin cell d sperm cell

4 **Explain** how sex is determined in humans.

5 **Explain** what is meant by sex linkage.

6 **Explain** why the children in a family will often have similar features to both their mother and father but still look quite different from each other.

Applying

7 **Use** an example to **explain** the relationship between genes and alleles.

8 **Identify** the option a–f that matches each description i–vi in the table below.

Symbol/Name	Description
a Mm	i A dominant allele
b XY	ii A phenotype
c X^nY	iii Genotype of a homozygous individual
d M	iv Genotype of an individual heterozygous for dominant/ recessive alleles
e PP	v A recessive sex-linked characteristic
f Red flower	vi Genotype of a male individual

9 In guinea pigs, black coat is dominant to brown coat colour.

a **Use** an appropriate symbol to represent the alleles for coat colour.

b **Use** a Punnett square to **demonstrate** the genotype and phenotype of the offspring you would expect from a cross between a heterozygous black and a homozygous brown guinea pig.

10 **Use** genotypes to **demonstrate** how a human female could inherit the trait for red-green colour-blindness.

11 **Use** the original sentence in Figure 1.3.8 on page 25 to **demonstrate** a frameshift mutation when a deletion of the third letter has occurred.

Analysing

12 **Contrast**:

a homozygous and heterozygous

b phenotype and genotype

c autosome and sex chromosome.

13 **Analyse** the following Punnett square where R is red and r is white. **Identify** the:

a type of inheritance

b ratio of genotypes in the offspring

c ratio of the phenotypes and appearance in the offspring.

	R	r
r	Rr	rr
r	Rr	rr

14 **Contrast** a chromosomal abnormality with a mutation.

15 **Compare** nonsense and missense mutations.

Evaluating CCT

16 **Deduce** the genotype of the parents, given the characteristics of the offspring.

a All the offspring for three generations had red flowers.

b All the plants in the study were tall but when the next generation came along about one-quarter of them were short.

Creating CCT

17 a **Design** an experiment that you could carry out to determine the dominance or recessiveness of black coat and white coat in mice.

b **Explain** why this experiment would provide the evidence you need to make your decision.

18 **Construct** Punnett squares to show the F_1 and F_2 generations of a cross between a pure-breeding wild rabbit (AA) and an albino rabbit (aa). Show both the genotype and phenotype of the offspring.

19 **Construct** a drawing of an imaginary animal or plant. Decide on a characteristic for which there will be two alleles. It could be something like flower colour or hair colour. Decide on letters to represent these alleles. Now make diagrams to represent the phenotype of your creature in each of the following situations. Include the genotype with each drawing.

- One allele is dominant to the other and the creature is heterozygous.
- The creature is homozygous for the recessive characteristic.
- The gene is carried on the X chromosome.

Inquiring

1 Figure 1.3.11 shows the Austrian monk Gregor Mendel (1822–1884) who carried out experiments on pea plants. Through his research he constructed theories that became the basis for the study of modern genetics. Research the work of Gregor Mendel on pea plants.

Present your findings as a multimedia presentation in which you use images and text to summarise the outcomes of his experiments with red and white flowering peas. ICT

Figure 1.3.11 Gregor Mendel

2 Not all characteristics are inherited through dominant and recessive alleles. Some alleles are co-dominant and others show incomplete dominance.

- Research these two types of inheritance.
- Describe a characteristic (trait) in humans that displays:
  - co-dominant alleles
  - alleles that are incompletely dominant.
- For both types of inheritance compare the characteristics of a heterozygous offspring with the parents.
- Compare the variation in the offspring resulting from these two types of inheritance with that resulting from dominant–recessive inheritance.

Present your findings as a Punnett square with pictures demonstrating the characteristics of the parents and offspring.

3 Research the symptoms and effects on the individual of the following genetic diseases: Down syndrome, Klinefelter syndrome, haemophilia, Duchenne muscular dystrophy, cystic fibrosis, Huntington disease, phenylketonuria and sickle cell anaemia (Figure 1.3.12).

- Describe the characteristics of the disease.
- Propose the effect that having this disease has on the lifestyle of the affected person.
- Summarise any treatments that are available to people with the disease.

Present your research in digital form. ICT

Figure 1.3.12 Sickle cell anaemia is a genetic condition caused by a missense mutation. It reduces the ability of red blood cells to carry oxygen. These mutated cells have a characteristic sickle shape.

1.3 Practical investigation

1 Chance variation

Purpose

To model the variation in potential offspring.

Materials

- dice
- 20 cards about the size of playing cards
- marker pen

Procedure

1 Use the information in Table 1.3.1 to make two identical sets of cards. Each card represents an allele on one of the five pairs of homologous chromosomes. For example, there should be two cards saying 'Can roll tongue (T)', two saying 'Cannot roll tongue (t)'. Follow this model until there are two cards for every allele. You will have 20 cards.

Table 1.3.1 Each gene is on a different chromosome.

Gene	Allele 1	Allele 2
1	Can roll tongue (T)	Cannot roll tongue (t)
2	Freckles (F)	No freckles (f)
3	Bent little finger (B)	Straight little finger (b)
4	Broad lips (L)	Thin lips (l)
5	Dimples (D)	No dimples (d)
	Evens	Odds

2 The 20 cards represent five pairs of chromosomes from two individuals. Each pair of cards represents a gene for a characteristic and there are two alleles for each gene.

Divide the cards into two sets of five pairs. These are the parents—P_1 and P_2. They are both heterozygous for each of the alleles.

3 Copy Table 1.3.2 into your workbook and record the genotype and phenotype for each parent. Look carefully at the symbols used for the alleles to identify the type of inheritance.

Table 1.3.2

Gene	Parent 1		Parent 2	
	Genotype	Phenotype	Genotype	Phenotype
1				
2				
3				
4				
5				

4 Now create the gametes. Start with gene 1 for parent 1. Toss the dice. If an even number is tossed, then select the 'Can roll tongue' card from the evens list in Table 1.3.1. If an odd number is tossed, then select the 'Cannot roll tongue' card from the odds list in Table 1.3.1. Continue in this way until one allele for each gene has been selected for the P_1 gamete. Place the cards for the gamete to one side. They will be used in step 6.

5 Create the P_2 gamete by repeating step 4 with the other set of cards.

6 Take the two gametes you have created and arrange the cards into the pairs. They represent the genotype of the first zygote. Copy Table 1.3.3 into your notebook and record the genotype and phenotype of this zygote.

7 Sort the cards back into the original piles for P_1 and P_2 and repeat the process of creating gametes and a zygote four more times.

Results

Copy and complete Table 1.3.3 by recording the genotype and phenotype of the zygote.

Table 1.3.3

Gene	Zygote 1		Zygote 2		Zygote 3		Zygote 4		Zygote 5	
	Genotype	Phenotype	Genotype	Phenotype	Genotype	Phenotype	Genotype	Phenotype	Genotype	Phenotype
1										
2										
3										
4										
5										

Practical review

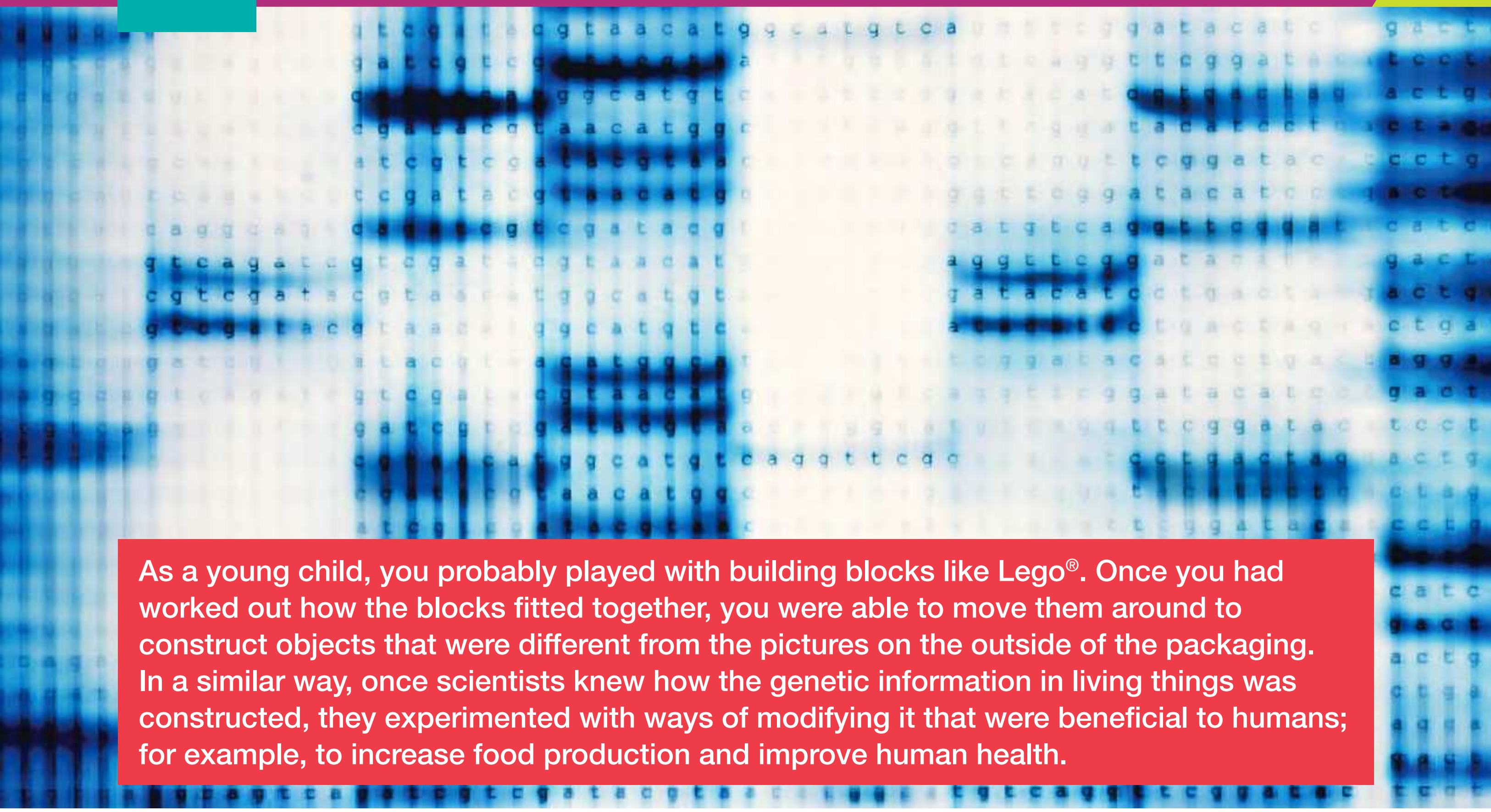
1 **Compare** the zygotes you created.

2 **Explain** why the zygotes were different even though the genotypes of the parents were identical.

3 In this model, you were looking at only five genes. **Predict** the amount of variation that would result if twice as many genes were modelled.

4 Each chromosome in your body carries more than one gene. **Deduce** how that would affect variability in offspring.

1.4 Gene technology



As a young child, you probably played with building blocks like Lego®. Once you had worked out how the blocks fitted together, you were able to move them around to construct objects that were different from the pictures on the outside of the packaging. In a similar way, once scientists knew how the genetic information in living things was constructed, they experimented with ways of modifying it that were beneficial to humans; for example, to increase food production and improve human health.

Genetic modification

Scientists have developed gene technologies that enable plant cells to be **genetically modified**. In genetically modified (GM) organisms, the genetic information is changed by inserting new genes. The new genes are then copied to all the daughter cells when the parent cell divides by mitosis. These modified cells will mature (grow up) into a completely new strain of plant.

Using genetic modification, desirable traits such as insect resistance and increased nutrient value are added to plants. This technology has benefits but it also causes controversy.

Canola

Figure 1.4.1 shows canola, a crop that produces edible oil. Western Australia is a major canola producer with exports valued at $535 million in 2008–2009. By 2010, Western Australia, Victoria and New South Wales allowed farmers to grow GM canola. GM canola is resistant to herbicides that are commonly used to control weeds. Farmers can spray herbicide on the crop and kill the weeds but leave the canola unaffected. Production costs are reduced, enabling growers to compete in international markets.

Some people are concerned that the gene for herbicide resistance in canola could move into weed plants, making them difficult to control in the future.

Figure 1.4.1 Canola is used to produce cooking oil and is an important crop in Australia. Three Australian states allow cultivation of GM varieties of canola.

Rice

Rice is the main food source for more than half the world's population. White rice lacks essential minerals and vitamins, including vitamin A. Vitamin A deficiency is a cause of childhood blindness that affects up to 500 000 children worldwide each year. Golden rice-2 is genetically modified using genes from daffodils, corn and bacteria. You can see it in Figure 1.4.2. The rice contains beta-carotene, the chemical that gives carrots their orange colour, and which the body converts into vitamin A.

Figure 1.4.2 The beta-carotene in Golden rice-2 makes it appear yellow when compared with white rice.

About 225 grams of cooked Golden rice-2 would provide 50–60% of the recommended adult dietary allowance of vitamin A.

Golden rice-2 was developed to help people in developing countries where blindness due to vitamin A deficiency is a problem. However, there has been significant opposition from environmental and anti-globalisation groups to the commercial production of Golden rice-2. At present, this GM product is still grown for research but it is not grown for human consumption.

1.9

INQUIRY science 4 fun

Spliced vegetables

What happens when genes are spliced?

YES

Collect this …

- carrot
- parsnip or small potato with approximately the same diameter as the carrot
- sharp knife

Do this …

1 Use a step-like cut to cut the carrot into two parts across the middle.

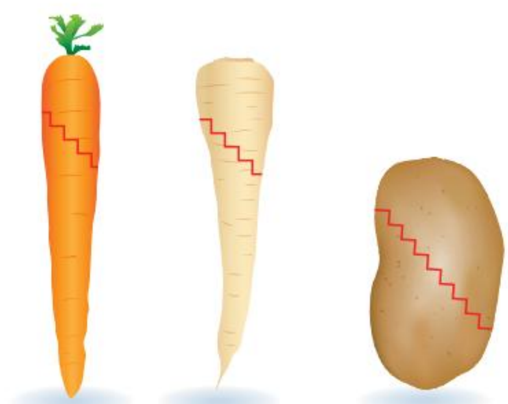
2 Using the same pattern, halve the parsnip or potato.

3 Join one half of the carrot to one half of the parsnip or potato.

4 You have spliced the two vegetables together in a similar way to the way genetic engineers splice genes into chromosomes.

Record this …

Describe what the final 'vegetable' looked like.
Explain why it was important to have the cuts on both vegetables a similar shape.



More food needed

On World Food Day 2009, the Federal Government warned Australians that world food production will have to increase by 70% by the year 2050, with the population expected to boom to 9.1 billion.

SciFile

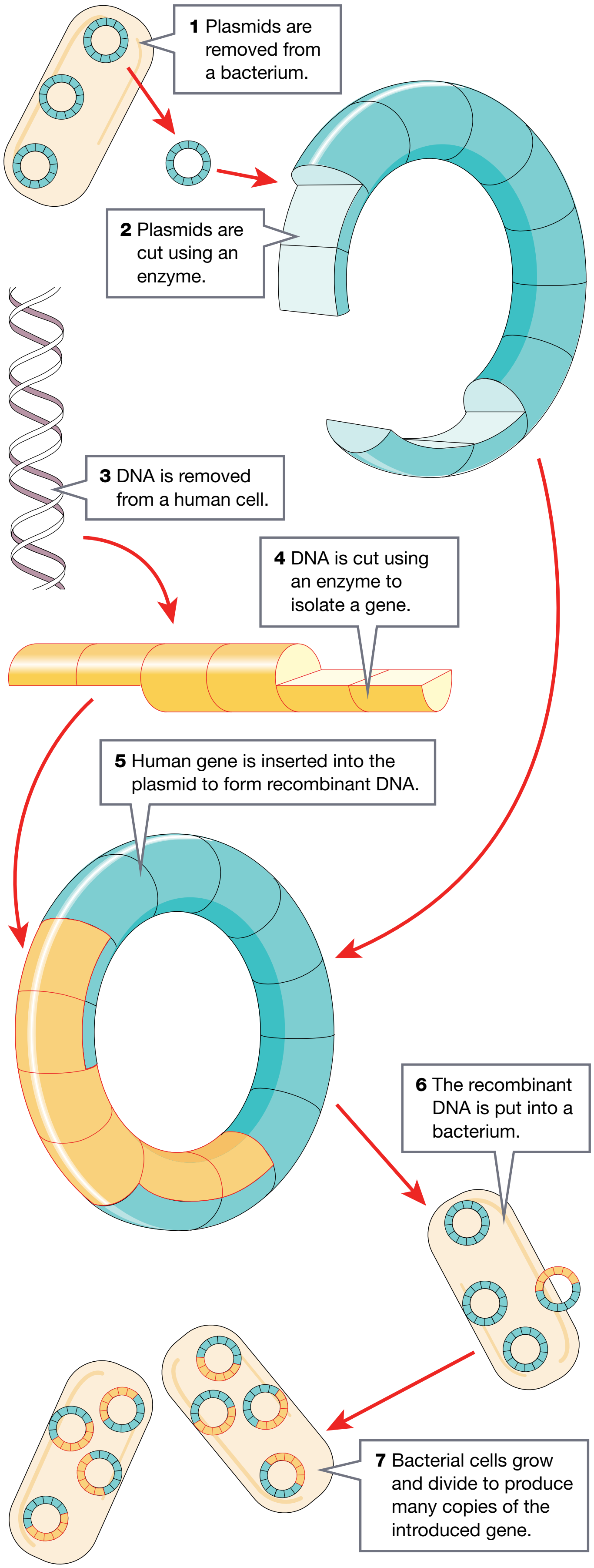


Figure 1.4.3 The process of gene splicing to create recombinant DNA

Gene splicing

Bacteria have DNA in chromosomes but they also have separate rings of DNA called **plasmids**. Using enzymes, scientists can cut these plasmids open and splice (insert) desirable genes into the plasmid. This process is called **gene splicing**. The technology of combining DNA from different genes is called **recombinant DNA technology** and the process is shown in Figure 1.4.3. Recombinant DNA technology has been used to splice the human gene that codes for insulin production into bacteria. These bacteria are stored in vats where they manufacture large quantities of human insulin for use by people with diabetes.

Human Genome Project

A **genome** is the genetic information carried by a haploid set of chromosomes. The **Human Genome Project** was an international project. It aimed to:

- identify all 20 000–25 000 genes in the human genome
- determine the sequence of the 3 billion base pairs that make up human chromosomes (Figure 1.4.4).

This information would be made available for further study and analysis. After working on the project for 13 years using very fast computers, a rough draft of the human genome was published in 2003. A more refined version followed in 2006. Although the project is finished, analysis of the data will continue for years.

Figure 1.4.4 The genetic code appears as dark and light bars, indicating the genes.

GO TO Unit 9.2

1.10

All humans share about 99.9% of their DNA. Figure 1.4.5 shows the variation caused by the other 0.1%. Scientists have identified millions of locations that differ by only one base from one human to another. These differences, known as **single nucleotide polymorphisms (SNPs)**, may be associated with common diseases such as cardiovascular disease, diabetes, arthritis and cancers.

Figure 1.4.5 Although people from different parts of the world may look quite different, only 0.1% of their DNA causes the differences.

Gene testing

Once the function of a gene is known, scientists are able to test for the gene. More than 400 genetic tests are available in Australia and people are using these tests for a variety of reasons.

Knowledge of your genetic make-up could help you avoid diseases that are controlled by lifestyle as well as genetics. For example, genetic testing could show that you were at risk of heart disease or type-2 diabetes. You could then make lifestyle choices that may reduce your chances of developing these diseases.

Genetic testing can tell if people are carrying specific disease-causing genes that could be passed on to their children. Cystic fibrosis, thalassemia and Huntington disease (Figure 1.4.6) are examples of genetic diseases. Knowledge of their genetic make-up can allow people to make decisions about whether or not to have children.

Genetic testing detects a particular problem gene. However, it cannot predict how severely the person carrying that gene will be affected. For example, some people with the gene for cystic fibrosis have mild problems with their lungs; others may have severe lung, pancreatic and intestinal problems that have major effects on their quality of life and life expectancy.

SciFile

Who owns your genes?

Gene technology has led to the situation where biotechnology firms are trying to patent genes and gene sequences. These are used for medical research or to develop drugs and other therapies. Patents are a way of recovering the costs of developing the treatments. These patented genes may be yours!

Figure 1.4.6 Huntington disease is a genetic disorder that causes degeneration in the brain. The symptoms do not usually appear until the person is 35–50 years old. Before genetic testing was available, an affected person could have had children (possibly passing on the disorder) before realising they had the disease.

Genetic testing can be used to diagnose genetic disorders in fetuses. Examination of whole chromosomes can indicate disease. For example:

- Down syndrome is the result of having an extra chromosome 21
- Turner syndrome is caused when a female only has one X chromosome
- Fragile X syndrome is the most common inherited cause of mental retardation (Figure 1.4.7).

With knowledge of genetic disease in the fetus, parents can decide whether or not to continue with the pregnancy.

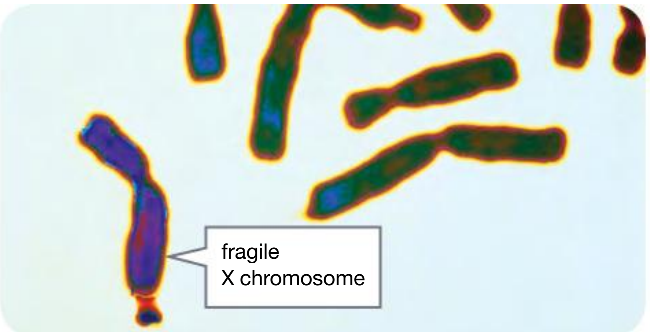


Figure 1.4.7 The defective end section of the fragile X chromosome is the fragile area. The body cannot use information in this area of the chromosome to manufacture a protein essential for normal brain development.

Other uses of genetic testing include:

- identification of a suspect in a criminal investigation by comparing their DNA with DNA found at a crime scene
- testing to identify the biological parent of a child in cases of adoption or disputed paternity (where the identity of the father is not known)
- analysis of the DNA of both the donor and the recipient (tissue typing) to reduce the chance of rejection in the case of bone marrow or organ transplantation.

Drawbacks

There are some drawbacks to genetic testing. For example, knowledge of genes that have the potential to cause disease may affect a person's ability to get life insurance cover. This does not only affect the individual. It affects the whole family.

If someone has disease-causing genes, then other members of the family may carry the same genes. Family members then have to decide whether to be tested and what they will do with the knowledge once they get it.

Before getting tested and after receiving the results, individuals and families are offered information on the nature of the tests and counselling. This may help them to understand and cope with the results.

Gene therapy

Gene therapy has the potential to cure genetic diseases. In **gene therapy**, the defective gene is replaced with a normal gene. The idea is simple, but gene therapy is still in the experimental stage for most genetic diseases.

Cystic fibrosis is the most common genetic disease in Australia. A person with cystic fibrosis is homozygous for a recessive allele of a gene called CFTR. Cystic fibrosis has many effects in the body. The main effect is on the lungs where thick mucus clogs the airways, making gas exchange difficult. Since 1989 when the CFTR gene was identified, scientists have researched ways of transferring normal CFTR genes into human lungs. So far they have not been successful.

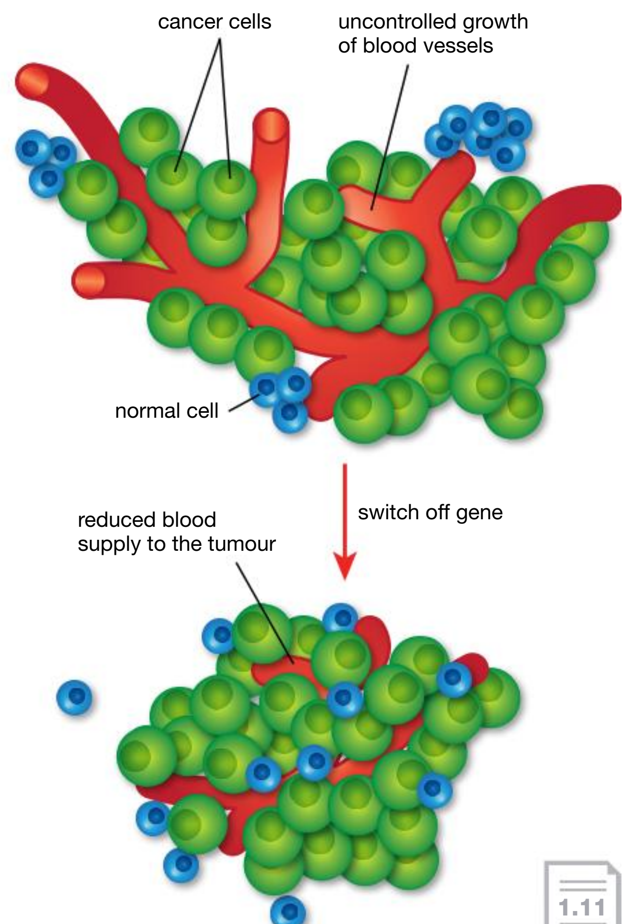
Prac 1 p35

Prac 2 p35

Treating cancer

Cancerous tumours are fed by uncontrolled growth of abnormal blood vessels. In 2008, researchers at the Western Australian Institute for Medical Research discovered a gene that can be switched off. This reverses the growth of blood vessels inside tumours, making the blood vessels more normal in size. This is shown in Figure 1.4.8. The hope is that being able to control the blood vessels will eventually lead to control of the tumour itself.

GO TO Pearson science NSW 9 Unit 7.3



1.11

Figure 1.4.8 By switching off the RGS5 gene, the blood supply to a cancerous tumour is reduced.

SciFile

Cancer

Cancer is not a single disease. It is many diseases all of which have similar characteristics. Cancers are uncontrolled cell growth that produces tumours. The tumours grow into and destroy nearby tissues. Cells break away from the tumours and may spread (metastasise) to other parts of the body through the lymphatic system.

1.4 Unit review

Remembering

1 **Name** a genetically modified crop grown in Australia.

2 **Name** the circular DNA structure found in many bacteria and used in gene splicing.

3 **State** how long it took for the complete human genome to be mapped.

4 **List** three reasons why individuals would be given genetic tests.

5 **State** in simple terms the concept of gene therapy.

Understanding

6 **Define** the term *recombinant DNA*. L

7 **Describe** the advantages that genetically modified plants have over other varieties of:

a rice

b canola.

8 a **Explain** what a single nucleotide polymorphism is.

b **Propose** ways that single nucleotide polymorphisms can occur.

c **Explain** why single nucleotide polymorphisms may be linked to human disease.

9 **Describe** four difficulties associated with successful gene therapy.

Applying

10 a The DNA profile of an individual can be shown as a series of bands. **Use** the DNA profiles in Figure 1.4.9 to **identify** the two people who are most closely related.

b **Explain** your choice.

Figure 1.4.9

Analysing

11 The human genome is mapped, but is the project finished? **Discuss**.

12 In the science4fun on page 30, vegetables were cut and 'spliced' together. **Compare** this activity with gene splicing.

Evaluating CCT

13 Reducing growth of blood vessels could be an effective treatment for cancer. **Deduce** why.

14 **Propose** how a relative of a deceased soldier could be used to identify a skeleton found in a wartime grave.

Creating CCT

15 **Construct** a model to **demonstrate** the process of splicing a gene into a plasmid.

Inquiring

1 Golden rice-2 is a genetically modified plant that has the potential to prevent disease in hundreds of thousands of children. There are arguments for and against Golden rice-2 being grown commercially and sold for humans to eat.

- Identify and outline the arguments that are used for and against growing Golden rice-2 commercially.
- Evaluate the arguments and decide what you think should happen to Golden rice-2 in the future.

Present your opinion in a letter, blog or an email to the World Health Organization with your recommendation. Make sure that you include arguments to support your decision. ICT

ADDITIONAL

2 Supercomputers have made analysis of the genome a reality. Research to:

- compare the capabilities of a supercomputer with a laptop, PC or tablet computer
- find how supercomputers are used to sequence DNA
- list other areas of biology that use supercomputers.

Present your findings as an article for a computer magazine or website. ICT

ADDITIONAL

1.4 Practical investigations

1 Genetic technologies

Purpose

To discuss some genetic technologies and to enable you to develop your own opinion on the ethics of each.

Materials

- access to the internet and other reference materials

Procedure

1. You are going to discuss four aspects of gene technology shown in the results table. You will be using a discussion strategy called Jigsaw. The class forms into four groups of approximately equal size. These groups are your Home groups. Each person in the Home group is given a number from 1 to 4. (There may have to be two students with the same number.) Your teacher will then assign a number to each of the technologies to be studied.
2. Students with the same number move into a group together. With this group, you will study the technology with the same number. This is the Expert group.
3. The job of the Expert group is to research and discuss the technology. Identify the positives and negatives of the technology. Record the number of people in the Expert group who were in favour of the technology.
4. Report back to the Home group.

Results

Each person in the Home group records what is said by the Expert groups. The following table could be used to record comments.

Technology	Positives	Negatives	Decision: for/against
Genetic modification of food crops (plants)			
Gene therapy			
Gene testing			

Practical review

1. a **Identify** the technologies supported by the majority of the class.
   b **Propose** reasons for this technology receiving the support.
2. a **Identify** the technology that had least support.
   b **Propose** reasons for the lack of support.
3. **Discuss** the technology that you are least willing to support.

STUDENT DESIGN

2 Genetic modification—public opinion

Purpose

To increase knowledge and understanding of issues surrounding GM technology and people's ideas on these issues.

Materials

- resources such as textbooks, encyclopedias and the internet
- questionnaire you have devised

Procedure

1. In your group, discuss what you know about genetic modification of plants and animals and identify questions as a starting point for your research.
2. Research genetic modification and through your research identify the issues that appear to be most controversial.
3. Devise a questionnaire as a research tool for gathering information from other community groups on this topic. Your teacher can provide guidance on how to do this from Pearson Reader.

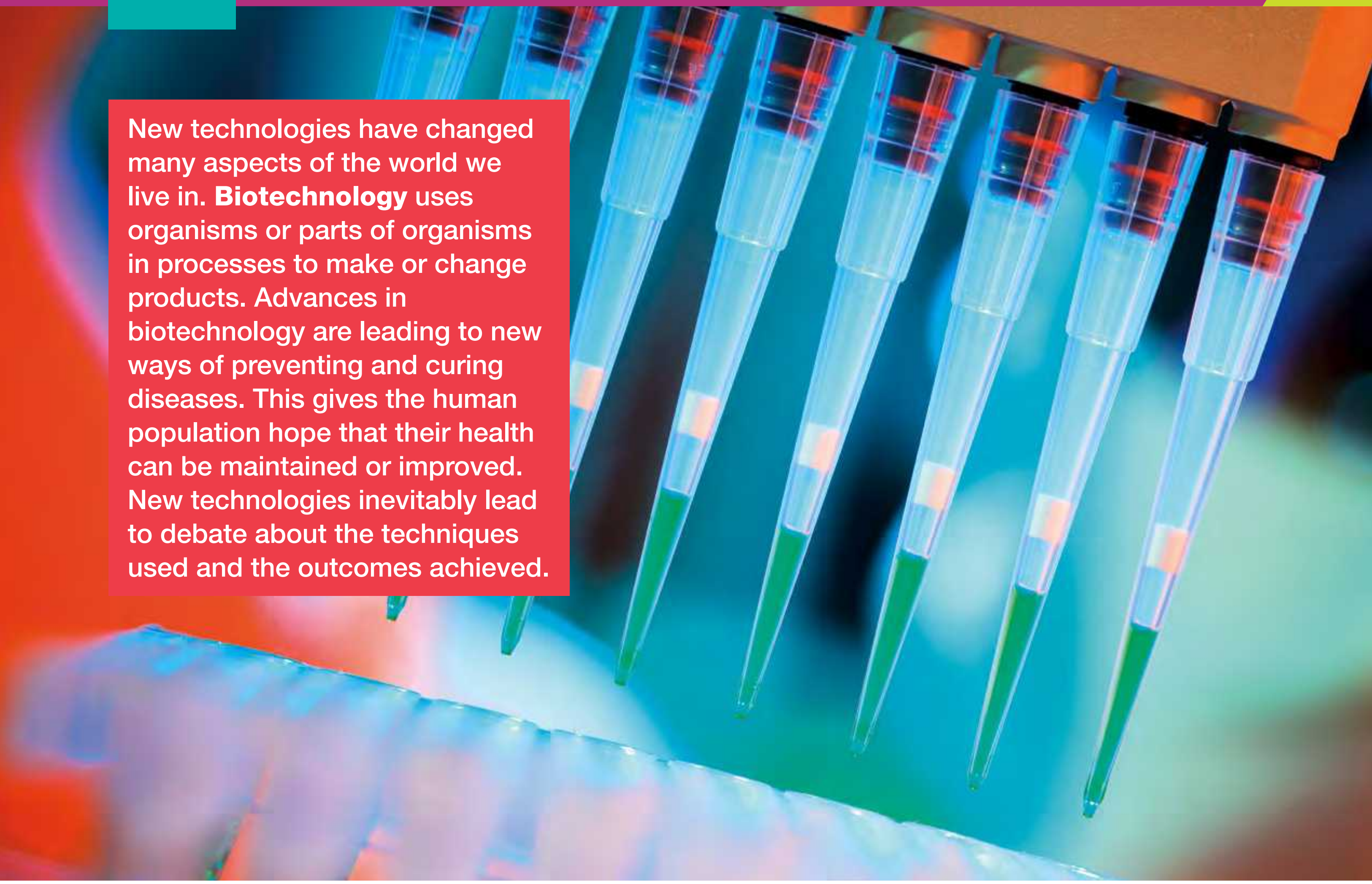
Results

Prepare a report on the topic of genetic modification. In the report, present the arguments supporting both sides of any issue and the results of the questionnaire.

Practical review

1. **Analyse** your own opinions of genetic modification and write a short summary of them.
2. **Justify** your points of view.

1.5 Biotechnology



New technologies have changed many aspects of the world we live in. **Biotechnology** uses organisms or parts of organisms in processes to make or change products. Advances in biotechnology are leading to new ways of preventing and curing diseases. This gives the human population hope that their health can be maintained or improved. New technologies inevitably lead to debate about the techniques used and the outcomes achieved.

Developing vaccines

Bacterial infections are a major threat to health worldwide. Vaccines control bacterial diseases such as tetanus, whooping cough and diphtheria. Vaccines work by causing your body to react as if it had been infected by a **pathogen** (disease-causing organism). The traditional approach to developing vaccines is to take a small amount of the poison produced by the bacterium and make it inactive, or use dead bacteria. Both the inactive poison and dead bacteria are harmless but your body responds to them by making antibodies. You become immune to the disease caused by that pathogen.

Once scientists had the ability to sequence genomes a new approach to developing vaccines was possible.

GO TO Pearson science NSW 9 Unit 7.1

Making vaccines using the genome

Bacteria have various proteins on their surface. Some of these proteins will cause your body to start producing antibodies when you are infected by the bacterium. Potentially a vaccine could be produced using any one of these proteins.

The first step in producing a new vaccine is for scientists to complete the genome of the bacterium to identify the genetic code that causes the surface proteins to be produced. Scientists analyse the surface proteins and identify those most likely to cause antibodies to be produced. There may be hundreds of proteins. The genes for these proteins are isolated and then spliced into the plasmids of the bacterium *Escherichia coli*. *E. coli* are bacteria found in the human intestine. They can be grown easily in a laboratory and are commonly used as the host organisms for work with recombinant DNA.

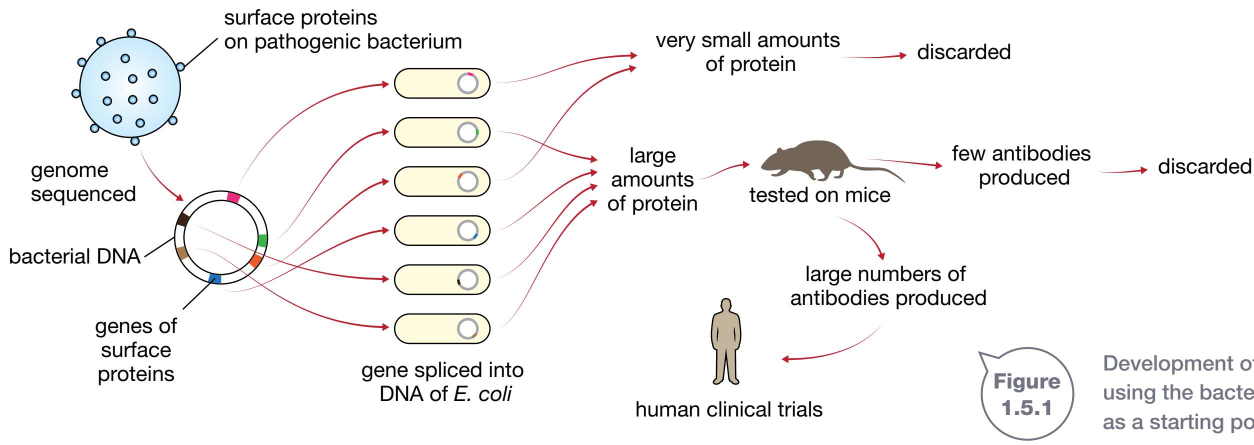


Figure 1.5.1 Development of a vaccine using the bacterial genome as a starting point.

E. coli produce the proteins coded for by the spliced genes. Some of the proteins will be produced in larger quantities than others. The proteins produced in large quantities are purified and then tested on mice. The blood of the mice is later analysed for antibodies. Proteins that caused the greatest antibody production are tested further. Finally two or three proteins go through human clinical trials before being released for general use. The process is shown in Figure 1.5.1.

Vaccines against *Neisseria meningitides* and *Streptococcus pneumoniae* are being developed in this way. *N. meningitides* is a bacterium that causes meningitis and *S. pneumoniae* causes a variety of diseases including pneumonia, bacterial meningitis and acute sinusitis.

Stem cells

When an embryo is a few days old, it contains cells that are **pluripotent**. Pluripotent cells are capable of becoming any one of the 220 different cell types found in the human body. These cells are known as **embryonic stem cells**.

In a late stage embryo, the cells have **differentiated** (changed) and become fixed as skin cells, cardiac muscle cells or nerve cells in the brain (Figure 1.5.2). However, some cells in your body remain capable of dividing to make new cells so that you can heal wounds or replace worn-out cells.

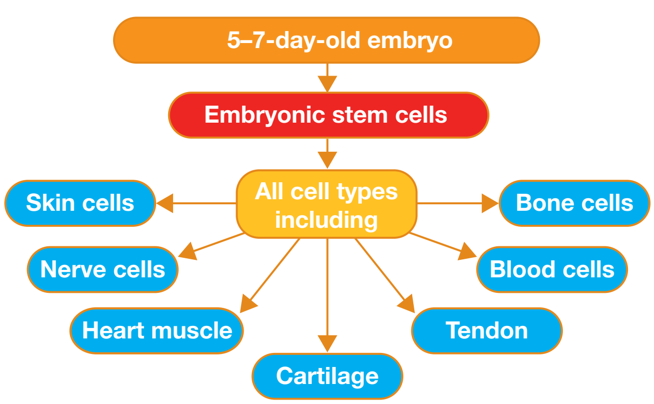


Figure 1.5.2 Embryonic stem cells can differentiate to become any of the types of cells found in the human body.

Adult stem cells

The harvesting (collecting) of embryonic stem cells destroys the embryo. Many people object to this on moral or religious grounds. For this reason, scientists began to look for other cells that were pluripotent and had the ability to change into other cell types.

Scientists experimenting with bone marrow for use in the treatment of leukaemia discovered **adult stem cells**. These cells allow you to regenerate and repair your tissues. For example, these are the cells that help your bones repair after being broken in an accident.

Adult stem cells lie deep within organs that need a constant supply of new cells, such as the skin. They are surrounded by millions of ordinary cells. Adult stem cells are specialised to some extent. This means that they are only able to make certain types of cells, as shown in Figure 1.5.3.

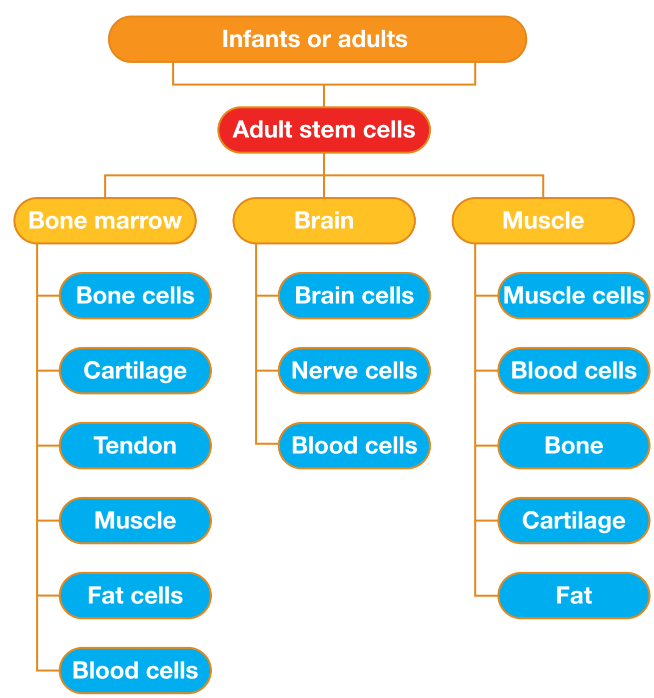


Figure 1.5.3 Adult stem cells can only differentiate to become certain types of cells.

Adult stem cells are found in the skin, the lining of the gut and the brain. There is a limit to the types of cells that they can differentiate into. For example, blood stem cells give rise to the different types of blood cells and stem cells in the skin regrow skin and hair.

Scientists believe that stem cells have the potential to treat and possibly cure diseases such as cancer, diabetes and heart disease and spinal cord injuries where cells have been damaged. However, adult stem cells are not always suitable and experimentation with embryonic stem cells is not accepted by many sectors of the community.

Induced pluripotent cells

In 2006, Shinya Yamanaka of the University of Kyoto in Japan discovered a way of returning mature skin cells from a mouse to their pluripotent state. An outline of the process is shown in Figure 1.5.4. Yamanaka called these cells **induced pluripotent skin cells** (**iPSCs**). Over the last few years, other scientists have successfully repeated Yamanaka's experiments.

More research is needed to make sure that these iPSCs behave in exactly the same way as embryonic stem cells. There have been times when the iPSCs have not functioned correctly.

Once these problems are solved, scientists believe that these cells have the potential to produce replacement parts of cells or organs damaged by disease. For example, they could replace nerve cells damaged through accidents (Figure 1.5.5), by Parkinson disease and multiple sclerosis, or replace cardiac muscle damaged by heart attack. There would be no problems with rejection of the replacement tissue because it could be made from the patient's own cells.

Scientists have demonstrated that iPSCs can cure the genetic disease sickle cell anaemia in animals, but there are many safety issues to deal with before there can be any human trials.

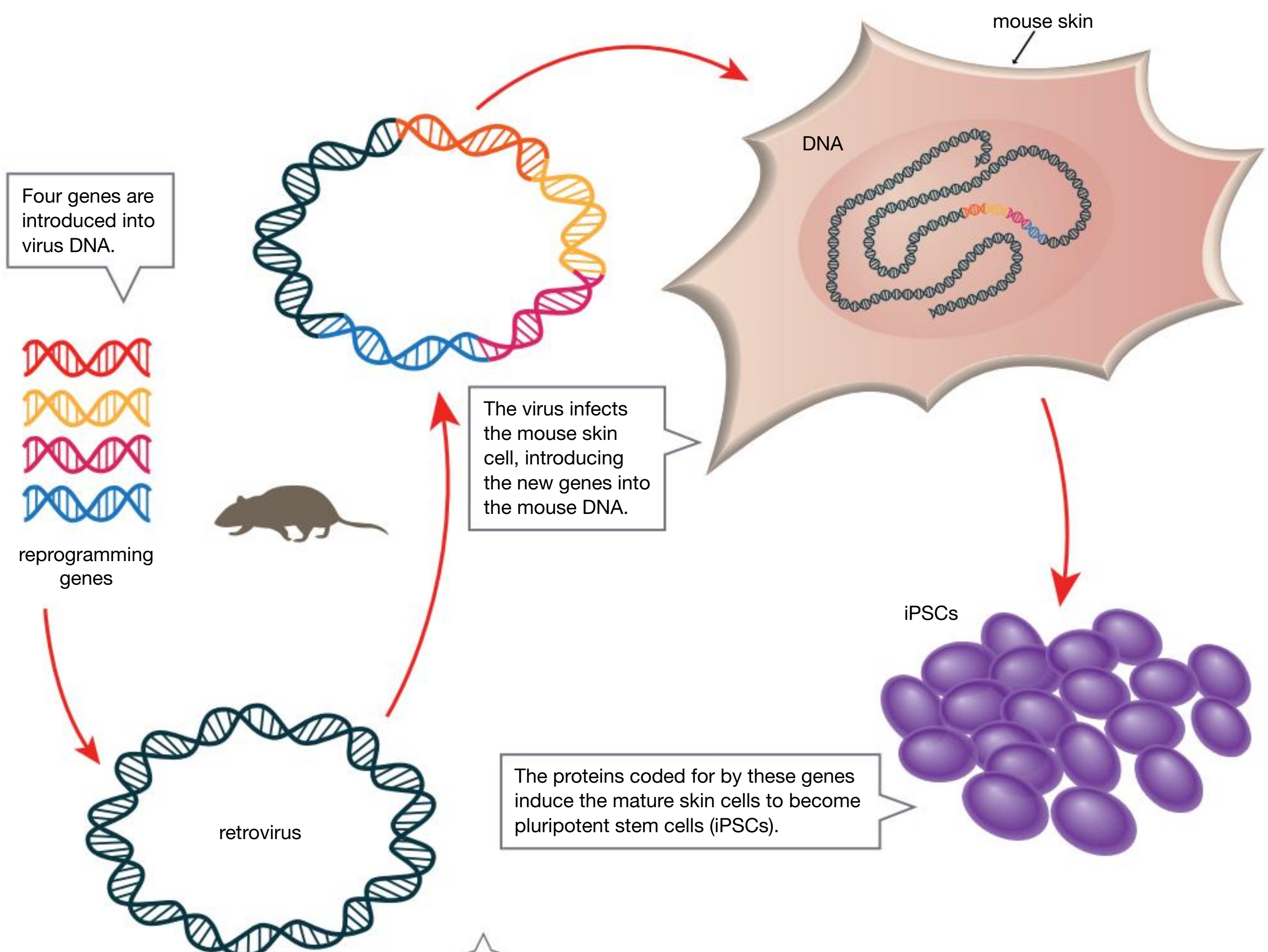


Figure 1.5.4 Four genes are introduced into the skin cells of a mouse by a virus. The genes become part of the mouse DNA and the genes begin reprogramming the skin cell to become a pluripotent cell.

In-vitro fertilisation

In-vitro fertilisation (IVF) is the process of fertilising eggs outside the human body then placing the developing embryo back into the woman's uterus. IVF is used to treat couples who are infertile or who have trouble conceiving a child naturally. Possible causes of infertility include:

- blocked oviducts preventing the egg and sperm meeting
- disease causing damage to the oviducts and ovaries
- abnormal or insufficient sperm
- blocked sperm ducts.

IVF is not a new technology. IVF techniques were trialled on rabbits in the 1940s and 1950s and in humans from about 1965. The first IVF baby was born in England in 1978. About 1% of the Australian population today was conceived using IVF.

IVF has obvious advantages. However, it is a very expensive and mentally demanding process for the couple trying to conceive. Some groups in society believe that it is interfering with nature and should not be used.

Figure 1.5.5 Many people who have suffered spinal injuries hope that stem cell research will find a way of repairing the damage.

IVF procedure

The IVF procedure involves a series of steps over a few weeks.

Stimulation of ovaries

Usually only one egg in one of the ovaries matures each month. The more eggs that can be collected for IVF, the greater the chance of creating embryos. To stimulate more eggs to mature, the woman is given follicle stimulating hormone (FSH) for 10 to 12 days. Ultrasound is used to determine the number of follicles that are growing and which ovary they are in (Figure 1.5.6). The eggs are collected when they are mature.

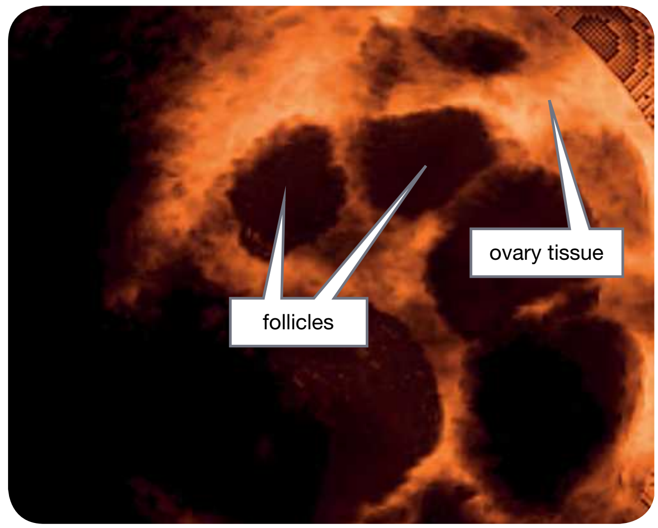


Figure 1.5.6 Mature follicles can be detected using ultrasound.

Collection of eggs

The eggs are collected under a light sedation. An ultrasound probe is used to show where the mature follicles are in the ovary. A fine needle is then passed through the wall of the vagina and into the ovary. Each mature follicle is pierced and the egg sucked into a hollow tube. The eggs are placed into a special solution in a sterile Petri dish in an incubator.

Sperm collection and fertilisation

Once the eggs are ready the male provides a sample of semen. The sample is washed to concentrate the sperm. The healthiest sperm are selected and added to the Petri dish containing the eggs. The Petri dish of eggs and sperm is placed in an incubator at 38°C. Fertilisation should occur within 18 to 24 hours.

Embryo transfer

Any embryos produced are allowed to develop in the Petri dish for between 2 and 7 days (Figure 1.5.7 on page 40). One or two embryos are then transferred to the woman's uterus. Sixteen days later a pregnancy test is carried out.

When more embryos are produced than are used, the remainder can be frozen and used later. In Australia the time limit for storing embryos varies between states.

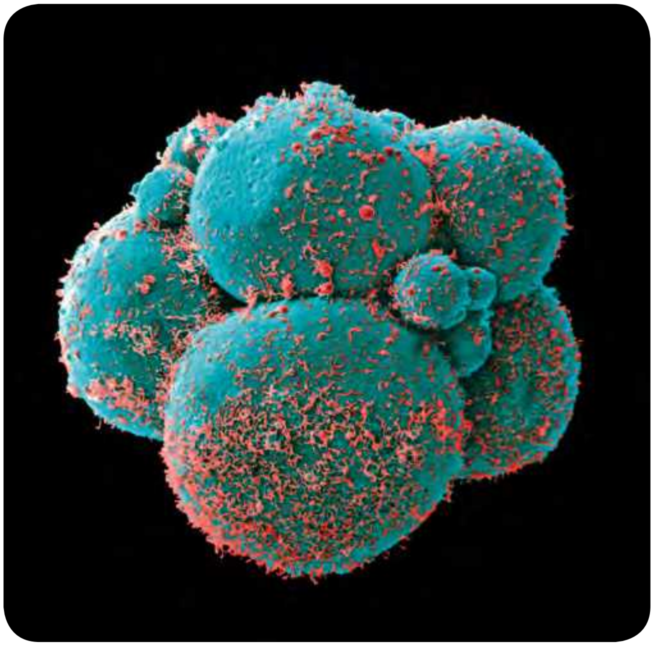


Figure 1.5.7 This three-day embryo is at the eight-cell stage. The embryo is ready to be transferred to the uterus.

Donor eggs and sperm

There are situations in which suitable eggs cannot be retrieved from the female or the male cannot produce suitable sperm. In these situations donor eggs or sperm are used. The baby conceived in this way will have the genetic information of only one of the parents.

When donor embryos are used the baby has no genetic link to either parent. Donors may be used if one or both parents have a genetic disease that they do not want to pass on to their children.

Embryo testing

It is now possible to test an embryo before implantation. When one of the couple is known to be a carrier of a sex-linked genetic disease, the couple may choose to use IVF rather than conceive naturally. In vitro the embryos can be tested and only embryos shown to be free of the disease are transferred. The couple can then be certain that the baby will not have the disease, but there is still a chance that the baby will be a carrier of the disease.

1.12

Ethical issues

New biotechnologies have raised a number of ethical issues. When ethics are involved, which stand to take is an individual decision. There is no right or wrong answer. It is important to consider the arguments presented by both sides, look at the sources of the information presented and then decide what you believe.

Tests using animals

Using animals for testing products such as drugs, vaccines and cosmetics is an area about which people have strong views. Some people who are against the use of animals believe that all tests using animals are unacceptable because they cause suffering. Supporters of testing might argue that testing on animals is acceptable as long as any pain and suffering is kept to a minimum.

Treatments such as some cancer and HIV drugs, improvements in insulin for diabetics, antibiotics and vaccines have only been made possible through testing on animals. If animals could not be used, testing of potential and new drugs would not occur or all tests would have to be carried out on humans. Animal tests cannot prove that a drug will be safe for humans. However, animal testing helps scientists to decide which experimental drugs should be abandoned and which should be put forward for human trials.

Guidelines for working with animals

Scientists working with animals are encouraged to follow three principles: reduction, refinement and replacement.

1 Reduction:
   - Reduce the number of animals involved in any experiment by improving the experiment.
   - Improve data analysis to reduce the number of experiments.
   - Share information with other scientists to avoid repeating experiments.

2 Refinement:
   - Refine the experimental method to reduce any harm to animals.
   - Improve the medical care and living conditions of the test animals.

3 Replacement:
   Where possible replace experiments on animals with
   - experiments on cells
   - computer modelling
   - studies using human volunteers.

In Australia, animal welfare is the responsibility of the states and territories. The states and territories make the laws that reflect *The Code and Practice for the Care and Use of Animals for Scientific Purposes* published by the National Health and Medical Research Council. The code was published in 2004 and updated in 2013, to take into account international breakthroughs in areas of biotechnology. All institutions using animals for scientific purposes must have an Animal Ethics Committee whose job it is to approve any experiment or activity using animals.

Prac 1 p42

1.5 Unit review

Remembering

1 **Recall** the characteristic of bacteria that scientists are now using as a potential source of vaccines.

2 **List** two possible causes of infertility in couples.

3 **State** the time it takes for fertilisation to be complete after the eggs and sperm are mixed.

4 **State** the age of the embryo when it is transferred to the uterus of the woman.

5 **Name** the three principles followed by scientists working with animals.

Understanding

6 **Explain** the link between the sequencing of genomes and current vaccine research.

7 **Define** the term *pluripotent*. L

8 **Explain** why scientists are excited about induced pluripotent stem cells (iPSCs).

9 **Describe** similarities between the diseases that scientists hope to treat using iPSCs.

10 **Clarify** the reason for a woman's ovaries being stimulated to produce multiple eggs as part of the IVF process.

Applying

11 The sperm retrieval procedure used in IVF collects only a few sperm cells. **Use** your knowledge of fertilisation to **explain** why only a few sperm cells can still result in an embryo being produced.

Analysing

12 **Compare** the traditional way of making vaccines with the new approach scientists are using.

13 **Compare** adult stem cells and embryonic stem cells.

Evaluating CCT

14 **Propose** reasons why only the healthiest sperm are selected for use in IVF procedures.

15 **Propose** reasons why a couple who do not show any symptoms of cystic fibrosis, but have relatives with the disease, might choose to use IVF rather than conceive a child naturally.

Creating CCT

16 **Construct** a flow diagram of the process used to create iPSCs.

17 **Construct** a flow diagram of the process of IVF.

Inquiring

1 The ability to sequence genomes has led to other advances in science.

Find four such advances and summarise the research involved. A starting point for your research could be the website of the National Human Genome Research Institute.

- Study one of the advances in more detail.
- Identify ways in which society or individuals will benefit from the research.
- Identify any issues the research raises that could cause ethical or social problems.

Present your research as an illustrated report for a science magazine or a website aimed at teenagers. EU

2 Stem cells are an important area of research into cures for disease and injury. Find out the:

- source of embryonic stem cells used in medical research
- regulations on research in this area
- diseases and injuries that researchers into the use of stem cells hope to cure
- arguments used for and against this research.

Present a report in which you put forward your opinion of whether or not research using embryonic stem cells should be allowed to continue. Make sure that you include reasons for your opinion. EU

ADDITIONAL

3 Developments in the area of information technology has given rise to the discipline of bioinformatics. Research to find:

- what bioinformatics is
- why bioinformatics has become an important part of many areas of biology
- two areas of genetics that have advanced because of developments in bioinformatics.

Present your research as an illustrated digital presentation for your fellow students. ICT

ADDITIONAL

1.5 Practical investigation

1 Ethical issues

Purpose

To examine public opinion on an ethical issue.

Materials

- access to the internet and other reference materials

Procedure

1 Working in small groups, identify at least four ethical issues about which you think people will have differing opinions.

2 Discuss what you know about each of the issues and decide on one that you wish to investigate further.

3 Identify questions to research to gather more information and to identify the areas of the topic that cause most controversy.

Hints

You will need to decide on:

- your target group (such as younger students, peer group, your parent's generation).
- the number of people to include in the target group
- up to ten questions to ask your target group
- how the answers are going to be recorded.

Make sure that you ask the people in the target group where they get their information about the topic.

Results

Prepare a report on the issue you have researched. Present a balanced view of the issue with some discussion about the reliability of the sources of information people use.

Practical review

1 **Compare** the sources of information used by people with differing opinions.

2 a **Analyse** you own opinions of the issue and write a short summary of them.

b **Justify** your opinions.

3 **Deduce** whether your opinions have been influenced by the people in the target group you talked to.

1 Chapter review

Remembering

1 **List** the bases found in DNA.

2 **Name** the sugar found in DNA.

3 **Name** the following processes:

a adding genes into or removing genes from DNA

b replacing a defective gene with a normal gene

c selective breeding where offspring that show the most positive traits and fewest negative traits are selected and then crossed with one of the original parents.

4 **Recall** the human reproductive organ in which fertilisation normally takes place.

5 **Recall** what is meant when chromosomes are described as homologous.

Understanding

6 **Explain** why the 46 chromosomes in the human body are often described as 23 pairs.

7 **Explain** what makes one gene different from all other genes.

8 **Predict** the base sequence in the complementary strand of DNA that has the base sequence ATGTTCCAGCGAAATG.

9 **Predict** what would happen if gametes were produced by mitosis.

10 **Explain** why the research that created iPSCs is so exciting for scientists.

11 **Describe** the function of the epididymis.

12 The male gametes of a eucalyptus tree have 11 chromosomes. **Predict** the number of chromosomes in:

- a the female gamete
- b a eucalyptus leaf cell.

13 **Describe** the outcome of gene splicing.

Applying

14 **Identify** the parts of the nucleotide labelled A, B and C in Figure 1.6.1.

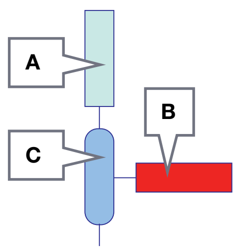


Figure 1.6.1

15 **Demonstrate** how the number of cytosine molecules in a DNA molecule can be used to predict the number of guanine molecules.

16 **Demonstrate** how two parents, homozygous for a trait, could have a child who is heterozygous for that trait.

17 a **Use** a Punnet square to **demonstrate** the expected genotypes of the offspring when a dog with a straight tail mates with a dog with a bent tail. The straight tail is dominant.

b **Identify** the phenotypes of the offspring and the ratio in which they could be expected to occur.

18 **Identify** the correct definition in column B for each of the terms listed in column A.

A	B
Genome	The chromosomes that are not sex chromosomes
Meiosis	Circle of DNA found in bacteria
Autosomes	The type of cell division that produces gametes with half the number of chromosomes of the parent cell
Plasmid	The genetic information carried by a haploid set of chromosomes

Analysing

19 **Compare** the possible effect on an individual of knowing that they have:

- a the genes that predispose them type-2 diabetes, making it more likely that they will eventually get the disease
- b the dominant allele that causes Huntington's disease.

20 **Discuss** the necessity of having two types of cell division—mitosis and meiosis.

21 **Compare** haploid and diploid cells.

22 **Compare** embryonic stem cells and adult stem cells.

Evaluating CCT

23 Mules (male) and hinnies (female) are bred by crossing a horse and a donkey. Horses have a diploid number of 62 chromosomes and donkeys have 64 chromosomes. **Propose** why mules and hinnies do not produce gametes and are sterile.

24 a **Determine** whether you can or cannot answer the questions on page 1 at the start of this chapter.

b **Use** this to **assess** how well you understand the material presented in this chapter.

Creating CCT

25 a **Use** the information in Table 1.6.1 to **construct** graphs showing the change in the area of land planted with three GM crops.

Table 1.6.1 Area of land planted with GM crops

GM crop	Area of land planted (millions of hectares)						
	1997	1999	2001	2003	2005	2007	2009
Sweet corn	3	11	9	16	25	39	45
Canola	1	13	11.5	15.5	18.5	23.5	26.5
Soy	5	26	46	50	64	72	82

b **Use** the information in Table 1.6.1 and the graphs you constructed to **calculate** the:

- i crop that had the largest percentage increase in area of land planted in the years 1997–2009
- ii years that showed the greatest increase in area of land planted with GM canola
- iii years that showed the smallest increase in area of land planted with GM soy.

c **Identify** the crop that has not experienced a decrease in the area of land planted.

26 **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter.

nucleotides	bases
chromosome	DNA
meiosis	mitosis
replication	plasmid
gene splicing	recombinant DNA

1.13

Thinking scientifically

Q1 In budgerigars, green feather colour (G) is dominant to blue feather colour (g). A blue budgerigar is mated with a heterozygous budgerigar. Identify the most probable genotypes of the offspring. CCT

A All the offspring will be blue.
B All the offspring will be green.
C ½ Gg: ½ gg
D ½ GG: ½ gg

Q2 In snapdragons, there are two alleles for the gene for flower colour—red and white. Red flower colour is incompletely dominant to white. CCT

A snapdragon homozygous for the red allele is crossed with a snapdragon that is heterozygous for flower colour. Which one of the following is unlikely to be correct?

A Half the offspring would be red and half the offspring would be pink.
B Half the offspring would be red, one-quarter would be pink and one-quarter would be white.
C The heterozygous parent had pink flowers.
D The homozygous parent had red flowers.

Q3 Identify the number of pairs of homologous chromosomes in the following diagram. CCT

A 7
B 6
C 5
D 4

Q4 Identify the small section of DNA that could be part of the longer DNA strand: CCT

TAGTAGTCATACCGAATTGCCGGAATACTAGTAGGATC
ATCATCAGTATGGCTTAACGGCCTTATGATCATCCTAG

A TACCGAATCCCGGAATTC
ATGGCTTAGGGCCTTAAG
B TACCGAATTGCCGGAATAC
ATGGCTTAACGGCCTTATG
C TACCGAATGCCGGAATAC
ATGGCTTACGGCCTTATG
D TACCGATGCCGCAATAC
ATGGCTACGGCGTTATC

Q5 The data in the table provides information on the costs to farmers from four different states in India of growing genetically modified cotton. CCT

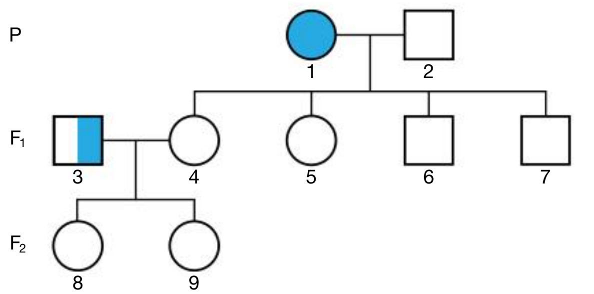
State in India	Performance advantage of GM cotton over non-GM varieties (percentage)				
	Yield	Income	Cost of chemicals	Total cost	Profit
Maharashtra	32	29	–44	15	56
Karnataka	73	67	–49	19	172
Tamil Nadu	43	44	–73	5	229
Andhra Pradesh	–3	–3	–19	13	–40
National average	34	33	–41	17	69

Analyse the data and decide which of the following statements is true.

A The state that made the greatest savings on chemicals also had the highest yield and the greatest profit.
B The states of Maharashtra and Kamataka both saved more than the national average on chemical costs and had a yield and profit above the national average.
C The state that had the greatest advantage in terms of total income also had the greatest advantage in terms of total cost and yield.
D Andhra Pradesh made a loss because the farmers in that state had to spend more on chemicals.

Q6 Hair curliness is an example of incomplete dominance in which the appearance of the heterozygote is a blend of the two traits. The diagram below illustrates a pedigree showing three generations of a family. The mother is homozygous for curly hair. The father is homozygous for straight hair. Individual 3 marries into the family and his genotype is shown to be heterozygous. The remaining phenotypes of the F_1 and F_2 generations are *not* shown. CCT

Identify which of the following alternatives is a true statement about the family shown.



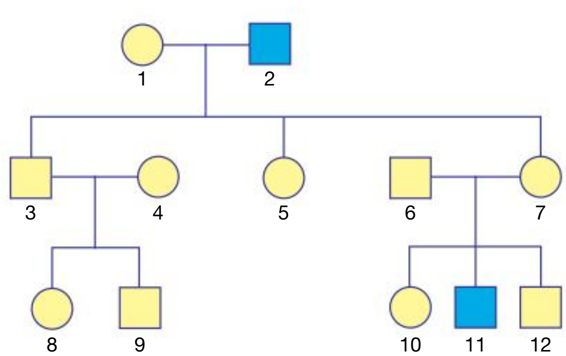
A Some of the F_1 generation will have curly hair and some will have straight hair.

B It is *not* possible for individual 9 to have straight hair.

C All of the F_1 generation will be different from their parents and have wavy hair.

D Individual 8 must have wavy hair.

Q7 In the pedigree below, the individuals shaded blue have thalassemia, a disease that is inherited according to the rules of dominant–recessive inheritance. Based on the information in the family pedigree, identify the option in which both statements are true. CCT



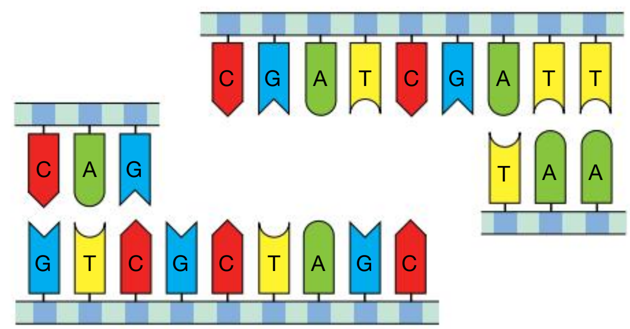
A 3 and 7 are both carriers of the disease. 8 or 9 must be a carrier.

B 6 and 7 are both heterozygous for thalassemia. 3 and 5 are carriers of thalassemia.

C 5 and 6 are heterozygous for the condition. 10 and 12 must be carriers of the disease.

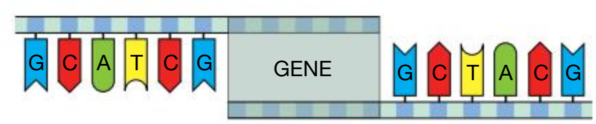
D 2 is homozygous for thalassemia. 3 and 4 must be carriers of the disease.

Q8 Scientists involved with research into genetic modification cut a piece of DNA using a particular restriction enzyme. The ends of DNA exposed are shown below. CCT

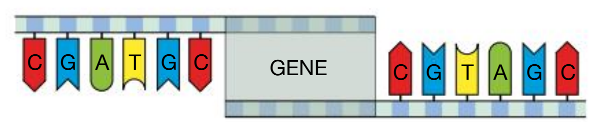


From the four genes below, identify the gene that could be spliced into that piece of DNA.

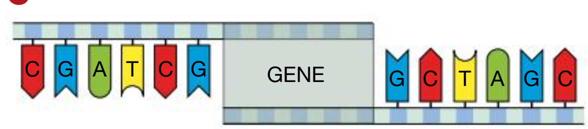
A



B



C



D

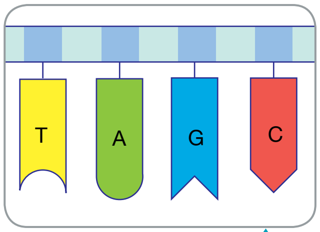
Glossary

Unit 1.1

Chromosomes: thread-like structures in the nucleus. Composed of DNA and proteins; contains the genetic information in the form of genes

Complementary base pairs: a pair of bases that can join to make the rungs of the DNA ladder—adenine and thymine, guanine and cytosine

Deoxyribonucleic acid (DNA): a double helix made of nucleotides; the molecule that determines the genetic characteristics of most living things



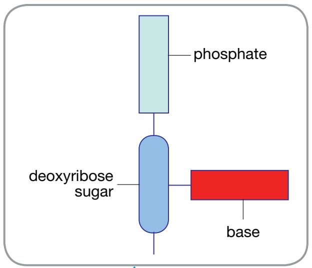
Deoxyribonucleic acid (DNA)

Deoxyribose sugar: one of the parts that make up a nucleotide

Gene: a section of DNA that carries the genetic code for a particular characteristic

Nitrogen-rich base: part of a nucleotide; the four types are adenine (A), guanine (G), cytosine (C) and thymine (T)

Nucleotides: the building blocks of DNA; comprised of deoxyribose sugar, a phosphate group and a nitrogen-rich base



Nucleotide

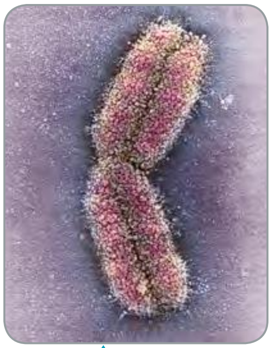
Phosphate group: one of the parts that make up a nucleotide

Traits: inherited characteristics

Watson–Crick model: the double-helix structure of the DNA molecule

Unit 1.2

Autosomes: all the chromosomes in a cell other than the sex chromosomes



Chromatid

Centromere: the point on a chromosome where the two chromatids are joined together

Chromatid: one of the strands of a chromosome following replication

Diploid number: the number of chromosomes in body cells; two sets or 2N

Gametes: sperm and egg cells

Haploid number: the number of chromosomes in gametes; one set or N

Homologous chromosomes: chromosomes with genes for particular characteristics at the same location

Meiosis: the type of cell division that produces gametes with half the number of chromosomes of the parent cell

Mitosis: the type of cell division that produces two daughter cells identical to the parent cell

Replication: the process of making copies of DNA

Sex chromosomes: the chromosomes that determine the sex of an individual; in humans they are the X and Y chromosomes

Unit 1.3

Alleles: different forms of the same gene located at the same point of homologous chromosomes

Dominant allele: allele for the trait that is observed in the outward appearance of an individual

Genotype: genetic information carried by an individual

Heterozygous: having two different alleles on homologous chromosomes

Homozygous: having two identical alleles on homologous chromosomes

Mutation: a mistake that happens as DNA is copied, causing a change to the base sequence

Phenotype: observable characteristics of the individual; the way the genotype is expressed

Pure breeding: where all individuals have the same genetic information for a characteristic generation after generation

Recessive allele: allele for the trait that remains hidden in the heterozygous condition

Sex-linked genes: genes present on the sex chromosomes

Unit 1.4

Gene splicing: the process used to add a gene into or remove genes from DNA

Gene therapy: the process of replacing a defective gene with a normal gene

Genetically modified: having the genes changed

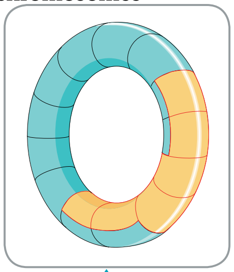
Genome: the genetic information carried by a haploid set of chromosomes

Human Genome Project: an international project that aims to identify all the human genes and determine the sequence of the base pairs that make up human chromosomes

Plasmid: ring of DNA found in bacteria

Recombinant DNA technology: technology that allows DNA to be recombined with other genes

Single nucleotide polymorphisms (SNPs): differences of only one base between one human and another



Plasmid

Unit 1.5

Adult stem cells: cells that can make certain types of body cells

Biotechnology: use of organisms or parts of organisms in processes to make or change products

Differentiate: become different from others

Embryonic stem cells: cells found in the embryo that are pluripotent

Induced pluripotent skin cells (iPSCs): skin cells that can be induced to become stem cells

In-vitro fertilisation: the process of fertilising eggs outside the human body then placing the developing embryo back into the woman's uterus

Pathogen: a disease-causing organism

Pluripotent: capable of becoming any one of the 220 different cell types found in the human body

2 Geological time

Have you ever wondered ...

- what life was like millions of years ago?
- where to find fossils?
- how we know when dinosaurs lived?
- how we know what a dinosaur would have looked like?
- how fossils form?

After completing this chapter students should be able to:

- describe scientific evidence that present-day organisms have evolved from organisms in the past
- describe how the fossil record is related to the age of Earth and the time over which life has been evolving

ADDITIONAL

- describe examples of advances in science in areas that involve biological science. CCT L WE

2.1 Fossils

Fossils provide a window into the past because they provide evidence about how life on Earth has changed over the 4.5 billion years of its existence.
For example, this is a fossil of an ancient reptile that lived in the sea about 160 million years ago. Unlike this reptile, most creatures don't become fossils when they die. The conditions required to form a fossil are relatively rare and so most organisms break down and decay after death, leaving no trace that they were ever there.

INQUIRY
science 4 fun

Fossil kits

What can you tell from fossils?

NO

Collect this …

- fossil kit

Do this …

Collect a fossil from the fossil kit. Handle it with care.

Record this …

Describe your fossil by sketching it and recording its name and age.
Explain how fossils like this tell you a little about past life.

What is a fossil?

Fossils are the preserved evidence in rocks or soils of organisms that once existed on Earth. The fossil may be the whole body of the organism, part of it or traces of its activities such as its burrows, tracks or dung (faeces).

Palaeontology is the study of past life, especially fossils. **Palaeontologists** are scientists who reconstruct past environments using fossils and geology.

The fossil record

The **fossil record** lists all the species of living organisms that have been found as fossils as well as their location and relative age. The record can be thought of as a timeline of Earth, tracking Earth's development since its formation 4.5 billion years ago. However, not all organisms are represented equally in the fossil record. To be preserved as a fossil, a dead organism must not be eaten by scavengers and must then decay very slowly. The soft parts of organisms decay much faster than the hard parts and so it is extremely rare for soft parts to be preserved. Hard objects such as skeletons, shells, teeth and wood are most commonly found as fossils. Hence fossils of dinosaurs, crabs and trees are more likely to be found than fossils of slugs, mosses and algae.

Formation of fossils

Being quickly covered by sediment will stop a dead organism from being eaten and will slow or even stop its decay. These conditions usually occur at the bottom of an ocean, lake or river. Sediments in the water sink to the bottom and cover any dead organism lying there. The sediment slowly builds up and natural cements and the drying of the sediment eventually turn it into sedimentary rock. This process is shown in Figure 2.1.1. A similar process can also happen on land if windblown sediment covers the dead organism. Erosion and movements within the soil and rock can then expose the rock layers containing the fossil or bring them to the surface.

Fossils are found in sedimentary rock and never in igneous or metamorphic rocks. The heat and pressure needed to form igneous and metamorphic rocks destroy any traces of organisms in them. In contrast, sedimentary rock traps the remains for possible future discovery.

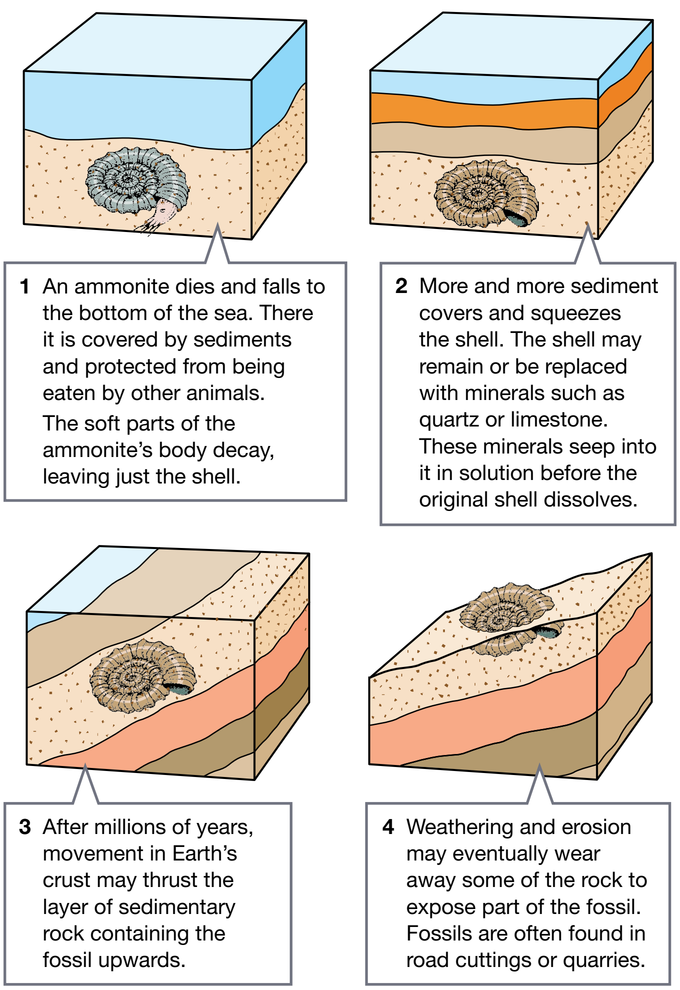


Figure 2.1.1 Fossilisation can happen when the remains of an organism are trapped in the layers of a sedimentary rock.

Types of fossils

The many types of fossils are due to the different ways in which they can form. The type of organism being fossilised also affects what the fossil will eventually be like.

Fossils can be classified in different ways, including:

- original
- replacement
- carbon film
- indirect.

Original fossils

Original fossils form when a part of the organism is preserved, with its chemical composition being about the same as it was when it was living. An original fossil could be a complete skeleton, bones, a tooth (or teeth) or a shell. Bone is composed of minerals (such as calcium carbonate) that are resistant to decay and which scavengers find difficult to eat. The flexibility of living bone comes from proteins within it. These proteins normally quickly decay after death, leaving behind the minerals as hard but brittle bones. Original fossils commonly include:

- sea creatures that had shells, such as molluscs like scallops, mussels and clams
- vertebrates, because they had teeth and a bony skeleton. Examples are the remains of dinosaurs and of Australian megafauna such as 3-metre-tall giant kangaroos, sheep-sized echidnas, diprotodons, 3-metre-long wombats and marsupial lions, a skull of which is shown in Figure 2.1.2.

Figure 2.1.2 This original fossil was found on the Nullarbor Plain in Western Australia. It is the remains of a *Thylacoleo*, a marsupial lion that died 45 000 years ago.

Turkana Boy

SciFile

Original fossils of many early humans have been discovered, including the Turkana Boy. The fossil was found in Lake Turkana, Kenya, in 1984. This is a fairly complete skeleton of a young boy. His teeth indicate that he was about 9–12 years old. He lived about 1.6 million years ago.

INQUIRY science 4 fun

Bendy bone

YES

Can bone change the way it behaves?

Collect this …

- chicken bone, cooked or fresh
- vinegar
- jar with lid covered with cling film
- tongs
- rubber gloves

SAFETY

Wear gloves and wash your hands after handling raw or cooked chicken.

Do this …

1 Put the chicken bone in the vinegar. Leave it for 1–3 days depending on the thickness of the bone.

2 Next day, use tongs to hold the bone under running water to wash it thoroughly. Do not touch the water run-off or the bone until it is thoroughly cleaned.

3 Try to bend the bone. If the bone is thin enough, try to tie a knot in it.

Record this …

Describe what happened.

Explain why you think this happened.

Replacement fossils

A **replacement fossil** forms when a part of the organism is chemically changed into another mineral. This takes a long time to happen so most of these fossils date back to over 60 million years ago. Replacement fossils commonly form when the calcium carbonate found in shells and bony skeletons is replaced by another mineral such as silica, also called silicon dioxide (SiO_2). Silica is like sand. Sometimes the bone or shell even turns into opal, another form of silica. This means that the bone or shell is now a lump of solid silica or opal. This is what has happened in Figure 2.1.3.

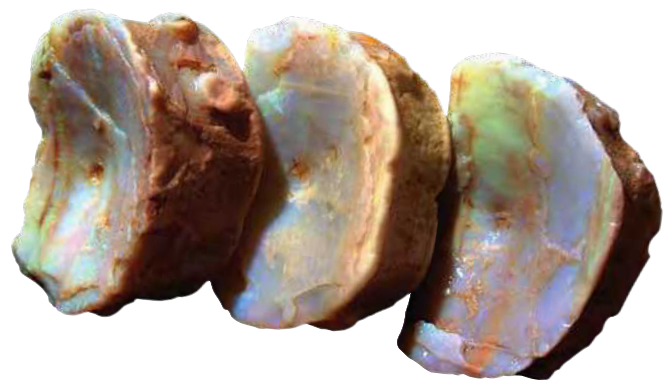


Figure 2.1.3 This plesiosaur backbone is a replacement fossil. The vertebrae have slowly been replaced by silica, turning them into opal.

If the material being replaced and fossilised is wood, then scientists refer to the wood as being **petrified**. Sometimes whole tree trunks or stumps are petrified, having been turned into stone-like silica (Figure 2.1.4).

Figure 2.1.4 Petrified trees are the replacement fossils of ancient trees. 'Forests' of petrified pine tree trunks exist near Lake Macquarie in New South Wales, in Arizona, USA, and on the island of Lesvos, Greece.

Petrified forests

SciFile

Some structures look like petrified tree trunks and roots but aren't. Despite this the structures at Cape Bridgewater (Victoria) and Cape Northumberland (South Australia) are commonly called 'petrified forests' when they are really just interesting formations of sand and rock.

Carbon film fossils

Carbon film fossils (or carbon trace fossils) occur when the dead body partially decays and leaves a thin black deposit of carbon. Figure 2.1.5 shows the carbon film fossil of an ancient fern. Plant fossils are commonly carbon film fossils. The traces of carbon left are still in the shape of the organism that decayed and often show its finer details. Coal is formed by this process, although no traces of the plants that were part of the coal can be identified in it.

Figure 2.1.5 These are carbon film fossils of ancient fern fronds.

Indirect fossils

Indirect fossils (or trace fossils) are not part of the organism itself but instead are preserved remains of things such as imprints of the body, (such as footprints and tracks), burrows and fossilised dung (known as coprolites).

A **mould** is usually an imprint left in the rock showing the outside of an organism. A mould is a 'negative' image, meaning that it is a space where there is no body. Mollusc shells commonly form moulds. To form a mould, the shell is first covered in sediment, which then turns into rock. Then the original shell is dissolved by acids or other agents, leaving an imprint in the rock. This is common deep in the ocean because calcium carbonate dissolves faster at the higher pressures found there. Arthropods, such as crabs, lobsters and prawns, can also leave moulds. A fossil of an arthropod is shown in Figure 2.1.6.

It is possible to have a mould of the inside of an organism. This is referred to as an internal mould. For example, an internal mould could form if the shell from a sea snail fills up with mud, which then turns to rock. Then the shell breaks up and dissolves, leaving the rock behind. This rock will be a copy of the inside of the shell.

Figure 2.1.6 These fossils are moulds of an ancient arthropod called a trilobite. The original animal has decayed and been lost. Only its imprint is left in the rock.

Good fossil footprints have been left behind by many organisms such as crabs, lizards, dinosaurs and early humans. One set of footprints found at Laetoli in Tanzania, Africa, provides evidence that 3.6 million years ago early human-like organisms walked upright on two legs, much as we do today. These footprints are shown in Figure 2.1.7.

Figure 2.1.7 These fossil footprints are 3.6 million years old. They were left by an animal that walked on two legs, much as humans do today.

A **cast** forms when an organism in rock decomposes and the space in the rock fills with soil and turns to rock. This leaves a copy of the outside of the organism in a solid piece of rock. This is a positive image and is a three-dimensional 'model' of what the organism looked like in life.

Artificial casts can be made by pouring plaster into footprints or into fossil moulds. This gives a more realistic 3D 'positive' version of the organism than the 'negative' provided by the mould.

Prac 1 p58

Prac 2 p58

Preserving environments

Hard parts such as skeletons and shells always have a better chance of surviving as a fossil than the soft parts of an organism. However, some environments will encourage the preservation of soft parts. These preserving environments include permafrost, amber, tar, peat and dry air.

Permafrost

Near the Arctic Circle, the land is permanently frozen. Bacteria and fungi that cause decay cannot grow if the temperature is below freezing. This has preserved some amazing original fossils. The most famous are the fossil mammoths of Siberia, Russia. You can see one in Figure 2.1.8.

Figure 2.1.8 This baby mammoth was preserved in permafrost for over 40 000 years. It was discovered in 2007 in Russia.

Amber

Amber is solid plant sap or gum. Insects, spiders and even small vertebrates such as frogs and lizards get caught in the sticky sap, which seeps out of trees. When amber sets and hardens, it can perfectly preserve whatever is entombed inside it, including the spider in Figure 2.1.9.

SciFile

Jurassic mosquitoes

Amber has preserved intact mosquitoes and sometimes the blood of animals the mosquitoes bit. In the 1993 film *Jurassic Park*, scientists extracted fragments of dinosaur DNA from the blood found in these mosquitoes. The recreation of extinct species using fossilised DNA is currently considered extremely unlikely.

Figure 2.1.9 This spider is preserved in amber. It was trapped in sticky plant sap, which then turned solid.

Tar

Tar pits occur where oil seeps naturally out of the ground and onto the surface. Tar pits are fairly rare, but the preservation of animals in them is spectacular wherever it occurs. Some of the best known have been found in the la Brea tar pits in Los Angeles, USA. Many animals such as mammoths, bison and sabre-toothed cats became stuck in the sticky tar (Figure 2.1.10).

Figure 2.1.10 This sabre-toothed cat was trapped by tar, died and was fossilised.

Dry air

Bacteria and fungi need moisture to survive. As a result, extremely dry conditions can preserve a body too, since the bacteria and fungi that decompose soft tissues cannot survive under these conditions. The dry air dehydrates the soft tissue, which fossilises, and turns it into a 'mummy'. This can occur in hot deserts, as well as in cold frozen places where there is ice but no liquid water. The mummified skin then forms a mould in sediments.

The fossil record is incomplete

The fossil record is more complete for some organisms than others. Fossils form in sedimentary rock and so the best chance of an organism being fossilised is if it lives in water and if it has some hard body parts. Therefore, the most likely organisms to be fossilised and have a good fossil record are marine organisms with skeletons or shells. These include molluscs, corals, arthropods and vertebrates.

Marine organisms with soft bodies such as jellyfish and worms are unlikely to form fossils. They have delicate soft bodies, which decay quickly and squash under pressure. Despite this, there are some fossils of jellyfish and worm-like creatures in South Australia, one of which is shown in Figure 2.1.12.

Peat

Peat is the partly decomposed remains of plants such as moss and is commonly found in swampy areas or bogs. The layers of peat can be very deep and oxygen and bacteria are often absent in the lowest layers. This gives the soft tissue trapped in these layers some chance of being preserved. The peat is generally acidic and this dissolves the hard minerals in the bone, making them very soft. In Europe, ancient human bodies have been found preserved in swamps. Tollund man is a good example. As you can see in Figure 2.1.11, his skin is well preserved.

Figure 2.1.11 Tollund man was found in a peat swamp which was acidic and had little oxygen. His remains were so well preserved that they even indicated how he died: he was hanged and then thrown into the swamp in about 400 BCE!

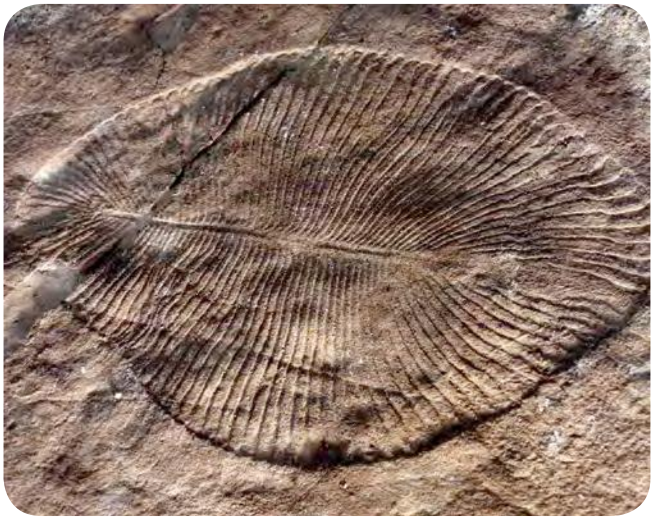


Figure 2.1.12 This fossil is thought to be of a flat worm from Ediacara in the Flinders Ranges of South Australia. A new geological period called the Ediacaran was named after these fossils.

Land organisms with soft bodies are extremely unlikely to form fossils. This means that groups such as earthworms and slugs would rarely be fossilised. Land organisms with hard parts such as vertebrates (for example, mammals and reptiles) and arthropods (such as insects and spiders) may become fossilised if they die in water or where windblown sediment could cover them. However, this would not happen as often as water organisms being covered by sediment after death.

2.1

Famous fossil sites

Famous sites with many fossils are:

- Ediacara, Flinders Ranges in South Australia
- the la Brea tar pits in Los Angeles, California, USA
- the Burgess Shale in Canada
- Chengjiang in China
- Solnhofen in Germany.

Ediacara and the Burgess Shale are particularly important because together they provide two consecutive chapters in the fossil record. The organisms of the Burgess Shale are very simple and many bear little resemblance to those in the earlier Ediacaran period and to those existing today. Figure 2.1.13 shows an artist's impression of two such organisms.

SciFile

Spot the relative

Opabinia was about 7 centimetres long, had five eyes and a long proboscis (snout) with spikes on the end. It probably lived on the sea floor where it used its proboscis to hunt for animals hiding in the sediments. *Opabinia* died out, leaving no descendents. *Pikaia* had bilateral symmetry and a rod like structure running along its body. It may be one of the first chordates, the group to which humans belong.

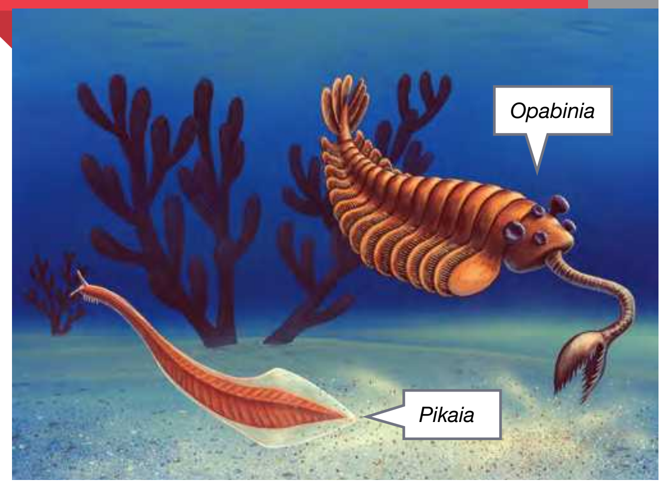


Figure 2.1.13 This is an artist's impression of two organisms from the Burgess Shale, which has some very well-preserved soft-bodied organisms.

An important fossil site in NSW is located at Canowindra, near Cowra. In 1956, a road worker uncovered fossils of freshwater fish that lived 360 million years ago. Since that first discovery, more than 4000 fossils have been found (Figure 2.1.14). These fossils indicate that an incredible variety of fish lived at that time – some had armoured shells, some were ferocious predators with crocodile-like jaws and some breathed using both gills and lungs. The 'Age of Fishes' museum in Canowindra displays many of these fossils.

Figure 2.1.14 One of the many fossils of fish found at Canowindra, NSW.

LEARNING ACROSS THE CURRICULUM

CRITICAL AND CREATIVE THINKING

Figure 2.1.15 An artist's impression of life in the Ediacaran period

EDIACARAN FAUNA

Some fossil sites are famous for one or two very important fossils, such as the Laetoli footprints, and the Turkana boy. Other fossil sites have a large range of different species. These sites can give palaeontologists a picture of what the environment was like in the past.

In Australia, the most famous site for a wide range of fossils is the Ediacaran Hills in the Flinders Ranges of South Australia. It was there that Australian geologist Reg Sprigg (1919–94) discovered in 1946 what it now believed to be the oldest group of multicellular organisms yet found. These fossils were dated by measuring the magnetic field of the rock that contained them. Earth's magnetic field periodically changes direction, so a rock's magnetic field provides a way of determining its age. Many of these early species are the ancestors of multicellular organisms that have lived since then, including those alive today.

GO TO Pearson science NSW 9 Unit 9.1

In 2004, scientists gave the name Ediacaran to this group of fossils, one of which is shown in Figure 2.1.16. The **Ediacaran period** is the first new geological period to be named in the past 120 years. It spans 635–542 million years ago and is the first ever to spring from the Southern Hemisphere. The Ediacaran Hills are now part of the Flinders Ranges National Park.

REVIEW

1. **Clarify** why the rocks were checked for the direction of Earth's magnetic field.
2. **Explain** the significance of the fossils found in the Ediacaran Hills.
3. The recognition of the Ediacaran fauna was an advance in biological and geological sciences. **Explain** why.
4. **Propose** a reason why the organism in Figure 2.1.16 got its common name of sea pen.

Figure 2.1.16 A 600 million-year-old fossil of a sea pen, one of the earliest multicellular organisms yet found.

2.1 Unit review

Remembering

1 **List** four types of fossils and give an example of each.

2 **State** what a palaeontologist does.

Understanding

3 **Define** the term *fossil*. L

4 **Describe** the type of environment in which a fossil bone would behave like the chicken bone in the science4fun on page 51.

5 **Describe** two environments that can preserve the soft parts of organisms.

6 **Describe** conditions that assist in the preservation of bone as a fossil.

7 **Outline** how fossils form in sedimentary rocks.

8 **Explain** why Tollund Man and the Siberian mammoths are so well preserved.

9 **Outline** how a replacement fossil forms.

10 **Explain** why the fossil record is good for marine organisms, but poor for many land organisms.

11 Imagine you found some worm burrows (worm holes) preserved in rocks. **Discuss** whether they are fossils or not.

Applying

12 **Identify** the type of fossil in each of the following:
- a a dinosaur skeleton that has turned to opal
- b the mummified skin of a bird covered by sand
- c a snail shell that has turned into the mineral iron pyrite (fool's gold)
- d footprints of dinosaurs in rock
- e blackened fossil leaves.

Analysing

13 **Compare** moulds and casts by listing their similarities and differences.

14 **Compare** tar and peat as environments that preserve the soft bodies of organisms.

15 Wood can be preserved as a replacement fossil and carbon film fossil.
- a **Compare** these two methods of formation.
- b **Describe** how you would distinguish between the fossils formed.

Evaluating CCT

16 Sea reptile fossils have been found in the opal fields in South Australia. Palaeontologists believe that these fossils are extremely old. **Propose** reasons for this conclusion.

17 a For each of the following pairs of organisms, **identify** which one is more likely to be fossilised.
- i a swamp plant or a woodland plant
- ii a cat or an earthworm
- iii a forest bird or a water bird
- iv a clam or a sea slug
- v a human or a frog
- vi a whale or a bat

b In each case, **justify** your answer.

18 The White Cliffs of Dover in England are limestone cliffs thought to have been formed in a shallow sea rather than the deep ocean. **Propose** what evidence leads geologists to think this.

Creating CCT

19 **Design** an investigation to determine whether a fossil skeleton of a reptile is a replacement fossil or an original fossil.

Inquiring

1 Research two human fossils from different environments (such as from ice or swamps) that preserved the soft tissues. Find:
- a map showing where these different fossils were found
- images of the fossils
- why they were so well preserved.

Present your findings as a digital presentation. Include a comparison of the fossils and an explanation of their preservation. ICT

2 Western Australia was the first Australian state to declare a fossil emblem to represent it. Research to find:
- which fossil was chosen as the fossil emblem of WA
- the official emblems of NSW
- whether NSW has a fossil emblem
- what important fossils have been found in NSW
- a fossil emblem you think is appropriate for NSW.

Present your research in the form of an article to be published in the daily newspaper and on its webpage. ICT

2.1 Practical investigations

1 Making fossils

Purpose

To make fossil moulds and casts.

Materials

- modelling clay
- plaster of Paris
- objects to mould, such as shells and bones
- petroleum jelly

- margarine container
- wooden spatula for mixing plaster
- rubber gloves

SAFETY

Do not mix plaster with your bare hands. It can cause skin irritation and burns.

Wear safety glasses and rubber gloves.

Never tip plaster down the sink.

Procedure

1 Soften the modelling clay into a flat sheet about 1 cm thick.

2 Smear some petroleum jelly onto the shell or bone and then press it into the modelling clay.

3 Carefully remove the shell or bone without breaking the modelling clay. This imprint in the modelling clay is known as a mould

4 Using the spatula, mix some plaster and water in the margarine container

5 Pour the plaster mix into the mould in the modelling clay. Flatten the surface of the plaster.

6 Leave the plaster to set. When the plaster is solid, carefully remove it from the modelling clay. This is the cast.

Practical review

1 **Compare** your plaster cast and mould with the original shell or bone.

2 **Describe** how you think a mould could form naturally.

3 **Explain** what would have to happen for a cast to form naturally.

4 **Identify** information that a cast gives that a mould may not give.

STUDENT DESIGN

2 Modelling fossils

Purpose

To model the formation of different types of fossils.

Materials

- modelling clay
- plaster of Paris
- variety of objects such as shells, leaves, bones, and nuts
- petroleum jelly

- plastic container for mixing
- stirring rod
- newspaper for keeping the desk clean
- rubber gloves

SAFETY

A risk assessment is required for this investigation.

Procedure

1 Design a way in which the materials provided can be used to model the following fossils:
- a mould of one side of a leaf or shell
- a cast of the outside of a shell or a gumnut.

2 Write your procedure in your workbook.

3 Before you start any practical work, assess all risks associated with your procedure. If using chemicals, then refer to their MSDS. Construct a risk assessment that outlines these risks and the precautions you need to take to minimise them.

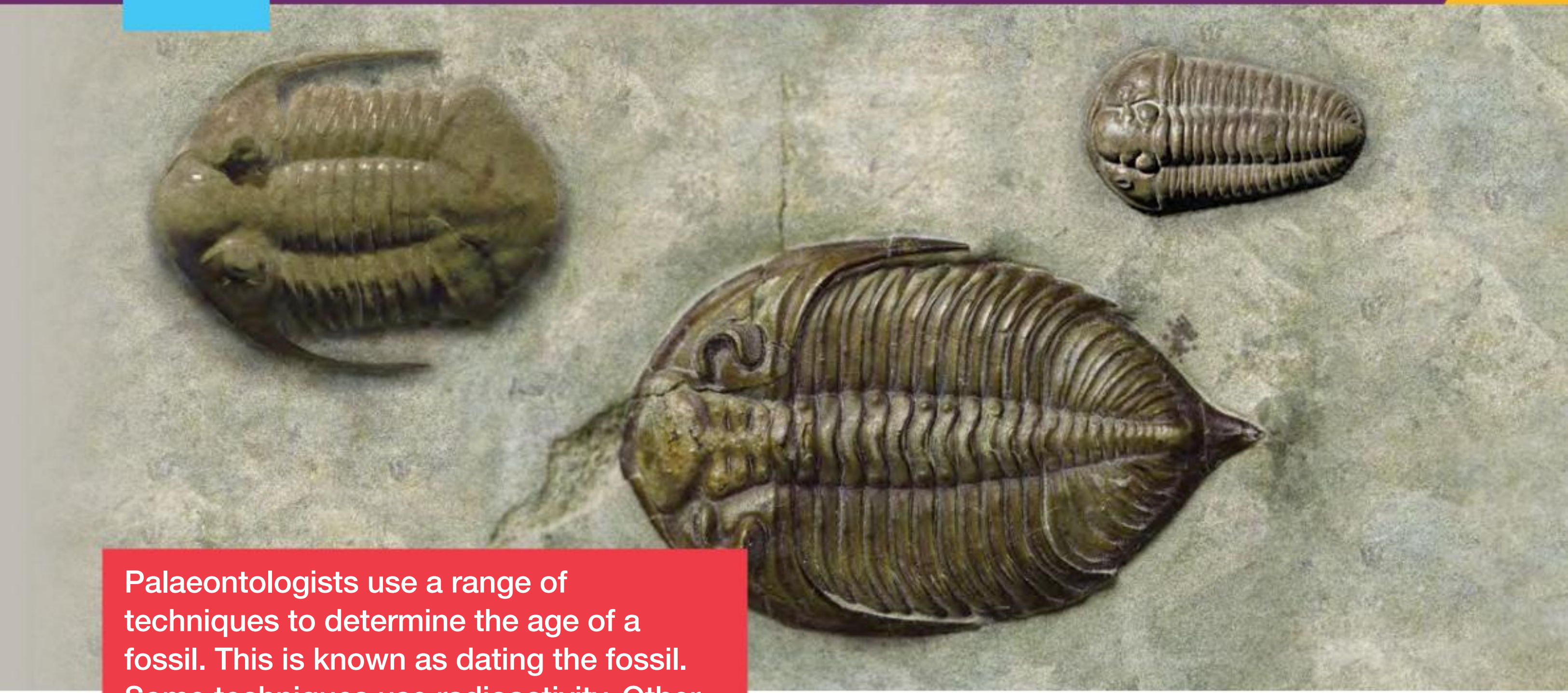
4 Show your teacher your procedure and your risk assessment. If your teacher approves, collect all the required materials and start work.

Practical review

1 **Assess** whether your method worked well and if you could improve on it.

2 **Identify** what material the plaster is modelling.

2.2 Dating techniques



Palaeontologists use a range of techniques to determine the age of a fossil. This is known as dating the fossil. Some techniques use radioactivity. Other techniques depend on the type of fossil found (like the trilobites shown here) and its location when found. Dating fossils allows palaeontologists to construct a timeline showing when each organism lived on Earth.

Relative dating

Relative dating is a technique that compares the age of one fossil or rock with another to determine which is older. Relative dating relies on two basic facts:

- Sedimentary rocks form in layers.
- Fossils are the same age as the rocks in which they are found.

Layer by layer

Sedimentary rock forms in layers called **strata**. A single layer is called a stratum. Sediment always settles and so the first and oldest stratum is found at the bottom. Newer sediment then settles on top. This means that lower strata are usually older than strata above them. This gives a way of determining which organisms lived earlier than others. The fossils from the bottom layers of rock should be oldest.

However, sometimes the lowest stratum will not be the oldest. This is because the layers of rock have folded over each other and been turned upside down by movements in Earth's crust.

Index fossils

Evidence from the fossil record and rock strata indicates that most species only existed on Earth for a relatively short time. Each fossil species is only found in a narrow band of the rock strata in any one location. So, all rocks containing a particular species of fossil should be the same age as each other. This would be true even if the rocks are different, such as limestone and shale. This is an example of relative dating—it allows palaeontologists to determine how old one fossil is relative to another, but not the actual age for each.

Fossils that can be used to compare the ages of strata in different locations are called **index fossils**. To be used as an index fossil, the species must:

- have been fairly widespread
- have lived in a fairly narrow period of time
- have been abundant (there were many of them)
- be easy to identify.

Index fossils allow rock layers in different locations to be compared and dated. Comparing layers like this is called **stratigraphy**.

SKILL BUILDER

Using stratigraphy

Deeper rock layers are usually older than shallower ones. Index fossils within the rock layers can be used to determine the relative ages of the fossils and the rock layers they appear in.

In Figure 2.2.1, layers A3, B1 and C5 contain the same long shell-like fossil species. Hence, these layers are the same age.

Locality C has four layers above C5. This implies these four layers are younger than C5, with C1 being the youngest.

The same round, shell-like fossil is in A5 and B4. Hence, these layers are the same age.

Locality B has one layer below B4, implying that B5 is older than B4 and A5 (which contains the same species).

Hence, the oldest rock layer is B5 and the youngest is C1.

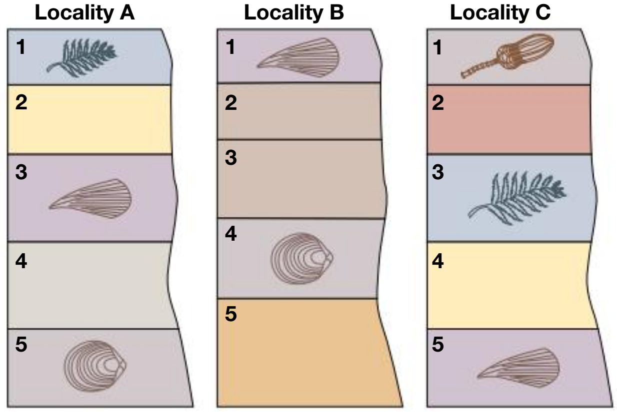


Figure 2.2.1 Rock layers can be compared in different places by using index fossils.

Examples of index fossils

There are many types of index fossil. Two animal groups that make good index fossils are trilobites and ammonites. Trilobites are now extinct, but are classified as arthropods because of their external skeleton and jointed limbs. This places them in the same phylum as current-day insects, crabs and spiders. A reconstruction of what trilobites were like is shown in Figure 2.2.2.

Not all structures are preserved in every trilobite fossil. The legs and antennae are often not preserved because they were so delicate. Many trilobite fossils do not seem to have any legs or antennae because of this.

SciFile

Three lobes

Trilobites have two furrows that run along their bodies from head to tail. This makes them look as though they were made from three lobes, so the words *tri* and *lobe* were combined to name them.

SciFile

Trilobite eyes

Scientists have discovered that trilobites were the first organisms to have complex eyes. X-ray images of these eyes show that they had a special type of lens to help them focus.

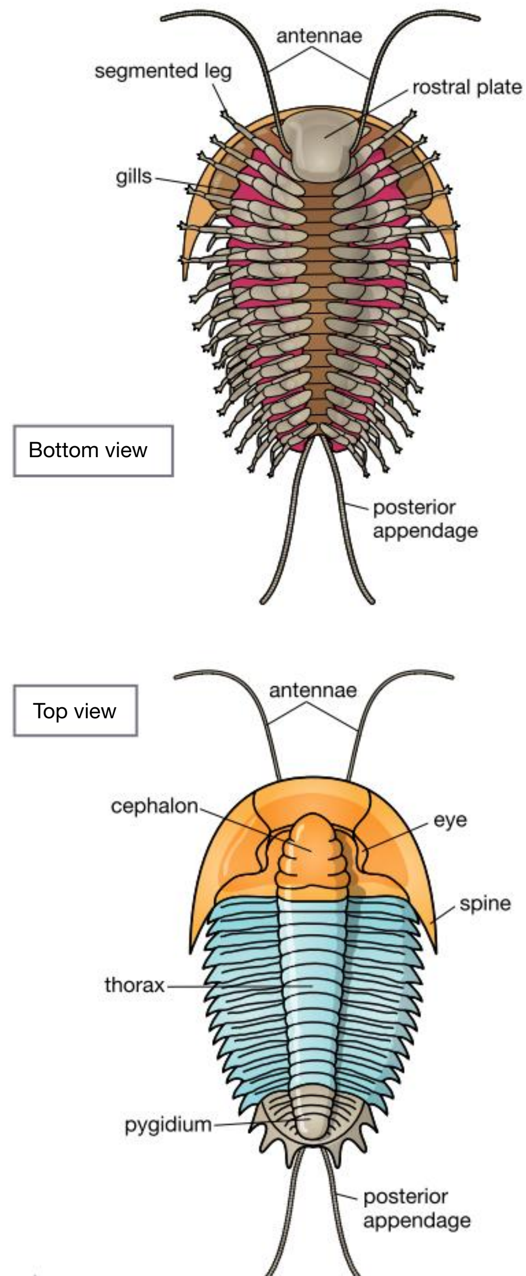


Figure 2.2.2 Trilobites are useful index fossils.

Trilobites as index fossils

Figure 2.2.3 shows the order in which different trilobites lived. It was constructed by studying many different rock strata around the world. These same trilobites kept occurring in the same order, with *Ceraurus* and *Isotelus* consistently lowest (and therefore oldest) in the rock strata. Hence, rocks with *Ceraurus* in them can be considered to be older than rocks with *Dalmanites* in them.

Geologists have given each of the layers names, such as Silurian and Devonian.

Dalmanites and *Calymene* occur in rocks in New South Wales and Victoria, which were covered by an ancient sea at the time when the trilobites were fossilised. Geologists finding rocks with these trilobites in them would then classify the rocks as being the same age. They would classify the rocks as Silurian.

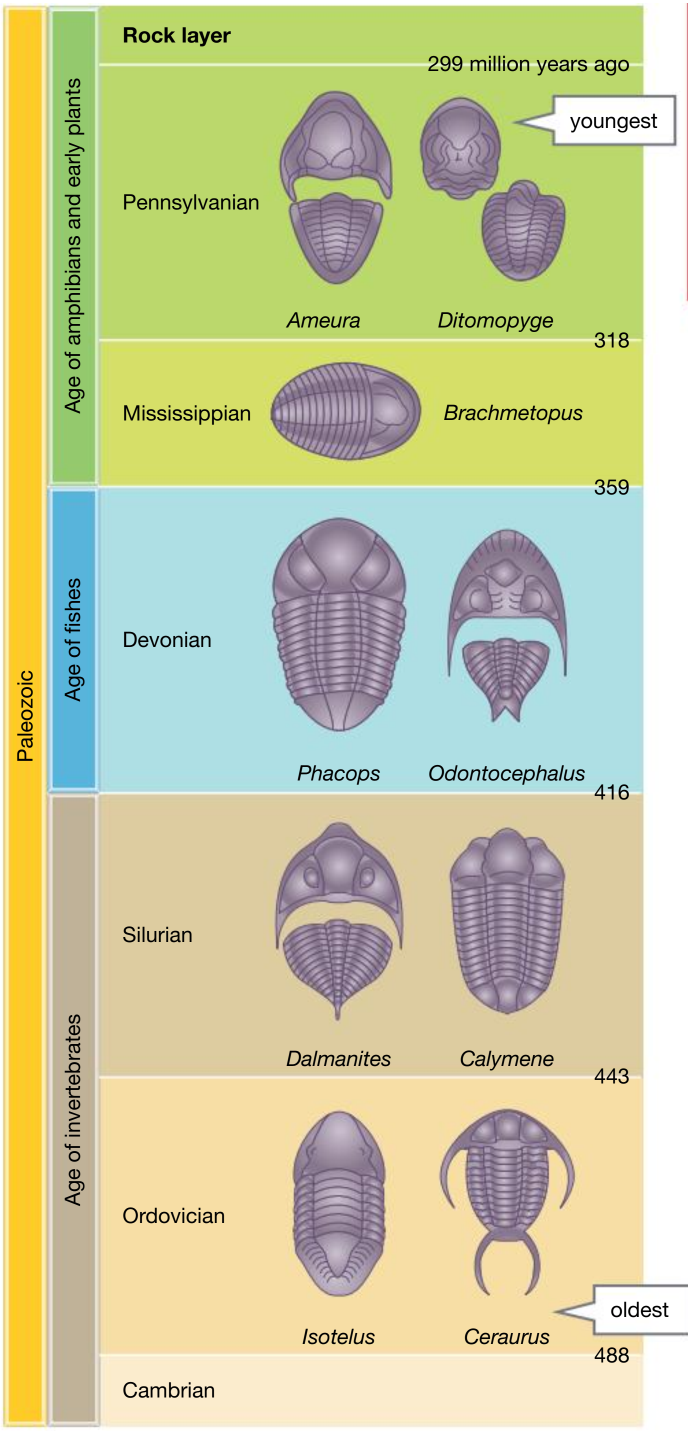


Figure 2.2.3 Trilobites are good index fossils because they were relatively common, widespread and different species existed at different times.

Naming rock layers

SciFile

The names of the rock layers came from the places where the fossils were first discovered. Devonian, for example, is named after a part of England called Devonshire. The Silurian is named after an ancient Welsh tribe called the Silures, because the rock strata were found in Wales, now part of the United Kingdom.

Prac 1 p66

2.2

Fluorine analysis

Fluorine dating is another relative dating method. It compares the amounts of fluorine in different bones found in the same rock. Bones absorb fluorine from the water in the surrounding rock. This happens at a slow rate and depends on how much fluorine is in the water surrounding the bone. The technique was used to show that the famous Piltdown Man skull was a forgery (Figure 2.2.4). The Piltdown Man consisted of bone fragments collected in 1912 from a gravel pit at Piltdown, England. The palaeontologists who discovered them claimed that the bones were the fossilised remains of an early human. Others were sceptical. In 1953, fluorine analysis proved that the bones came from different layers of the rock, and therefore could not be part of the same animal.

Figure 2.2.4 Fluorine analysis proved Piltdown Man to be a forgery. These bones came from three different animals. No one knows for certain who was responsible for the hoax.

Absolute dating

Dating methods that give the actual age of rocks and fossils are called **absolute dating** methods. There are many methods of absolute dating, including radioactive dating and tree rings.

Radioactive dating

Radioactive dating is a method that uses the natural rate of decay (breakdown) of radioactive isotopes. The process is shown in Figure 2.2.5. **Isotopes** are atoms of an element that have different numbers of neutrons and so have different atomic masses. For example, the element carbon exists as three isotopes, each with six protons but different numbers of neutrons. Almost all carbon is carbon-12, with a small amount being carbon-13 and even less being carbon-14. Carbon-14 is radioactive, but carbon-12 and carbon-13 are not. Likewise, naturally occurring potassium is made up of potassium-39 (93%), potassium-40 (0.012%) and the rest potassium-41. Potassium-40 is radioactive, but the other two isotopes are not.

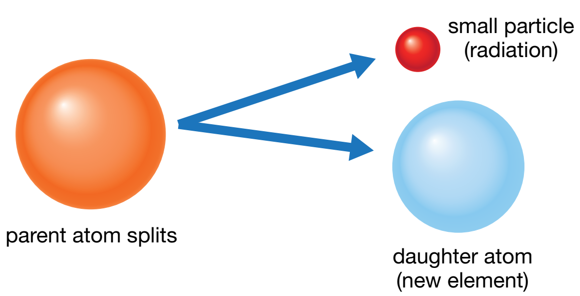


Figure 2.2.5 Radioactive elements break down to form new elements and release radiation.

Radioactive elements decay at a known rate and release particles that form radiation. This radiation can be detected by equipment such as Geiger counters. The elements that decay turn into new elements, the amount of which can then be measured.

This decay allows scientists to estimate how long ago the rock was laid down. There are many elements that can be used, depending on the type of fossil and the type of rock. For example, radioactive potassium-40 is found mainly in rocks containing volcanic ash. Potassium-40 decays into argon. You can estimate how old a rock is by measuring how much argon has been formed in it and how much potassium-40 is left. From this, the fraction of potassium-40 remaining in the rock can be calculated. You can then determine the age of the rock using a graph called a decay curve. You can see the potassium–argon decay curve in Figure 2.2.6.

From a decay curve, you can estimate the element's **half-life**. The half-life is the time it takes for half of a radioactive sample to decay. For example, the half-life of potassium-40 is 1251 million years. Carbon-14 has a much shorter half-life of 5730 years, so carbon-14 radioactivity disappears much more quickly from a fossil than potassium-40.

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2.3

GO TO Pearson science NSW 9 Unit 2.4

WORKED EXAMPLE
Calculating fossil age

Problem

The fraction of potassium-40 left in a sample of rock containing a fossil was 0.75 or $\frac{3}{4}$. Calculate the age of the fossil.

Solution

Using the graph in Figure 2.2.6, run a horizontal line across from 0.75 or $\frac{3}{4}$ on the vertical axis. Where it meets the plotted line of the graph (the green line), draw a vertical line down to the horizontal axis. This gives an age of about 600 million years.

Practice

N

1 **Calculate** the age of a fossil if the fraction of potassium-40 left is 0.25 or $\frac{1}{4}$.

2 A rock had $\frac{3}{8}$ of its potassium-40 left. **Calculate** the age of the fossil.

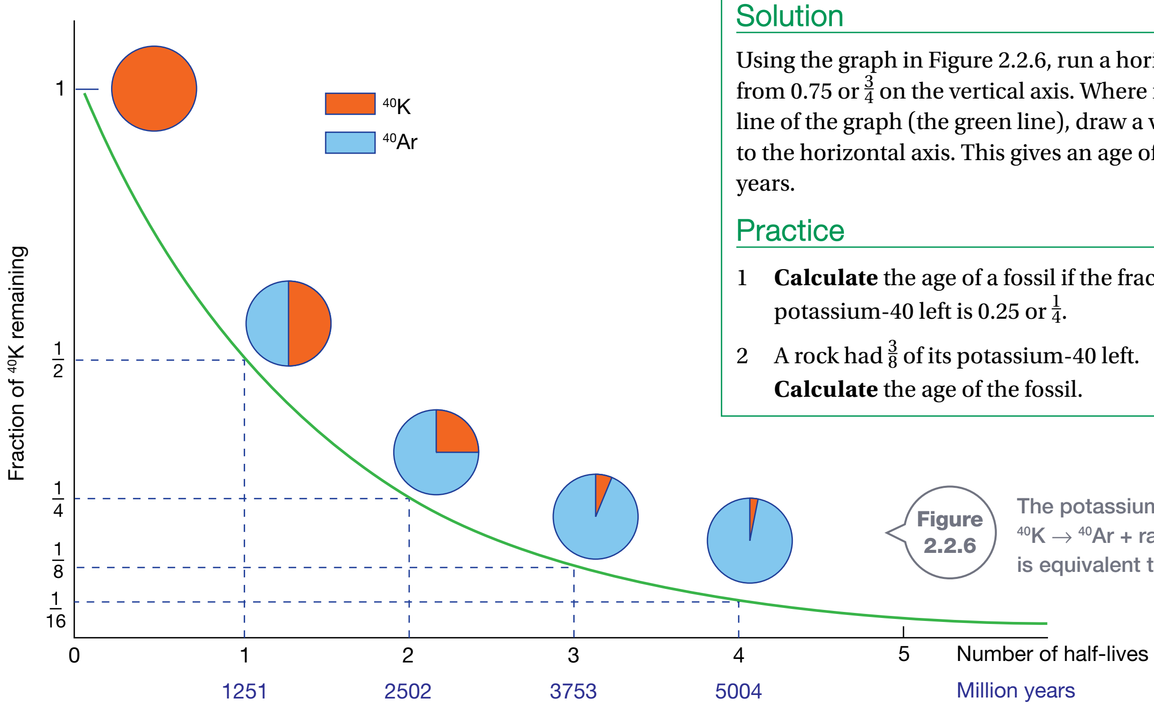


Figure 2.2.6 The potassium–argon decay curve: $^{40}K \rightarrow {}^{40}Ar$ + radiation. Each half-life is equivalent to 1251 million years.

Tree rings

A useful method of absolute dating for wood is **tree ring dating**. This method can give a date to several thousand years ago. Tree ring dating involves counting growth rings in the woody trunks of trees. Many woody trees grow by adding layers on the outside of the stem each year. This leaves a line in the wood that is easy to see. Tree rings (like those in Figure 2.2.7) are visible whenever you cut down a tree or cut off a branch or if you drill through the tree to form a cross-section of the piece of wood.

In this way, the growth rings in pieces of old or fossilised wood can be compared with a standard scale of growth rings. The standard scale is constructed by analysing many different trees in a particular region and devising a pattern to show the growth rings. The process is shown in Figure 2.2.8. This method can only be used by comparing wood with trees from the same climatic region, because the climate affects how trees grow. For example, a piece of wood from Australia cannot be dated by using tree growth rings from another country. You could not even compare a piece of wood from Victoria with one from the Northern Territory because they have different climates and so different growth rates.

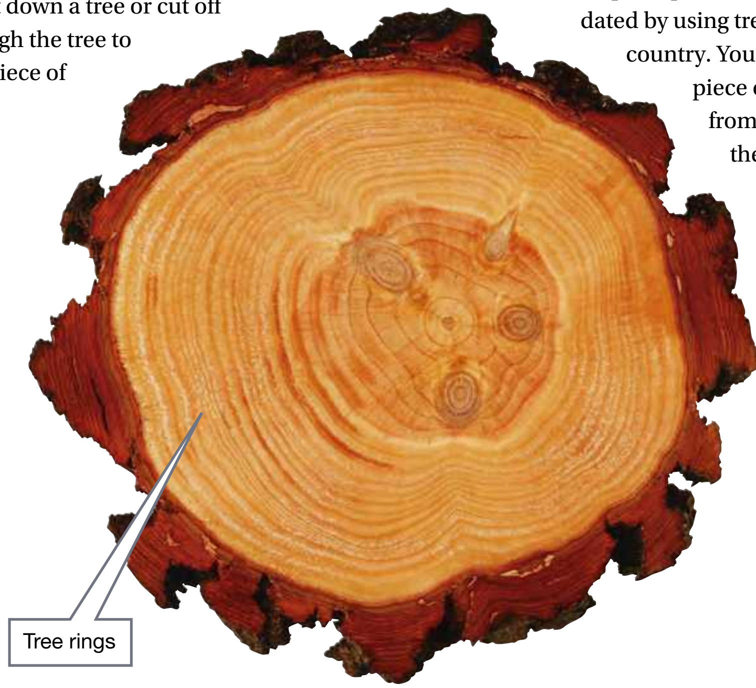


Figure 2.2.7

Growth rings in the trunk of a tree. A new ring is laid down each year.

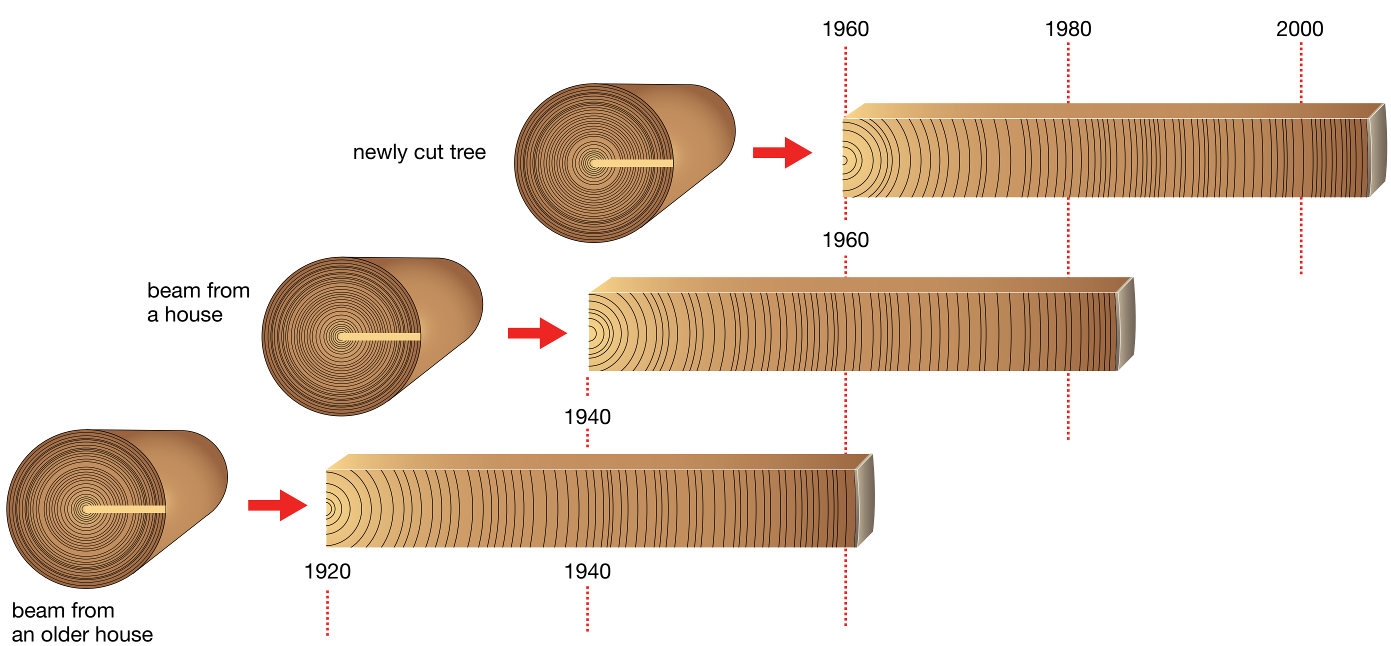


Figure 2.2.8

Growth rings are compared to find an age. By starting with a piece of wood of known age, similar spaced rings in different samples of wood can be matched and overlapped. In this way, a continuous record can be produced that extends back many thousands of years.

2.2 Unit review

Remembering

1 **List** two types of relative dating.

2 **Name** two animal groups commonly used as index fossils.

3 **List** three characteristics a fossil must have to be useful as an index fossil.

4 **List** two types of absolute dating.

5 **State** the meaning of half-life in radioactive decay.

Understanding

6 **Define** these terms. L

a index fossil

b stratigraphy

c isotopes

7 **Explain** why fossils in the lower layers of rock are usually older than ones in higher layers.

8 **Outline** how trilobite fossils could be used to compare the relative ages of two rock layers from different countries.

9 **Explain** how fluorine analysis helps to date a fossil.

10 **Explain** how radioactive isotopes can be used to date the age of a rock.

Applying

11 **Use** Figure 2.2.3 on page 61 to **identify**:

a the types of trilobites shown in the introductory image on page 59.

b two trilobites that lived towards the end of trilobite history.

12 The potassium-40 left in different rock strata are shown below. **Use** Figure 2.2.6 on page 62 to **calculate** the age of any fossils found in these layers. N

a 0.5 b $\frac{1}{8}$ c $\frac{1}{16}$

d 0.6 e 0.2

13 Figure 2.2.9 shows a trilobite called *Ptychagnostus atavus*. This is one of the earliest trilobites yet discovered. It was only a few millimetres long and had no eyes. Scientists have concluded that it lived in the depths of the ocean. Fossils of this species have been found in Australia, Greenland, parts of Asia, Europe and North America. Dating by stratigraphy placed the first appearance of this species at 506 million years ago. In 2005, scientists agreed to make this trilobite an index fossil for this time in Earth's history. The species was shown to only occur in strata from 500 to 506 million years ago.

a **Use** Figure 2.2.3 on page 61 to **identify** the name of the time period in which this species lived.

b **Identify** two trilobite species that appeared in the fossil record not long after this species.

c **List** the rules for index fossils and **demonstrate** how they apply to this trilobite species.

Figure 2.2.9 *Ptychagnostus atavus*

Analysing

14 **Compare** relative dating with absolute dating.

15 At Emu Bay on Kangaroo Island, South Australia, there is an important well-preserved Early Cambrian fossil site. One species called *Anomelocaris* is identical to fossils found at the Burgess Shale and Chengjiang in China. Several trilobites found at Emu Bay also occur at Chengjiang. However, Emu Bay also has some unique trilobites that have not been found anywhere else. They are called *Emuella* and one is shown in Figure 2.2.10.

a **Analyse** the information here and discuss how Emu Bay could be dated.

b **Critically analyse** the information and comment on whether *Emuella* could be used as an index fossil.

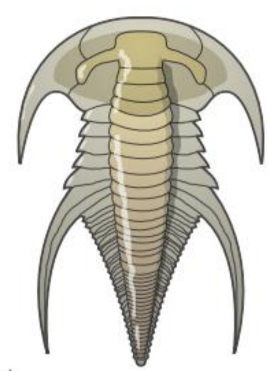


Figure 2.2.10 *Emuella polymera*

16 **Compare** tree ring dating and radioactive dating as possible methods for wood preserved as a:

a carbon film fossil

b replacement fossil.

Evaluating CCT

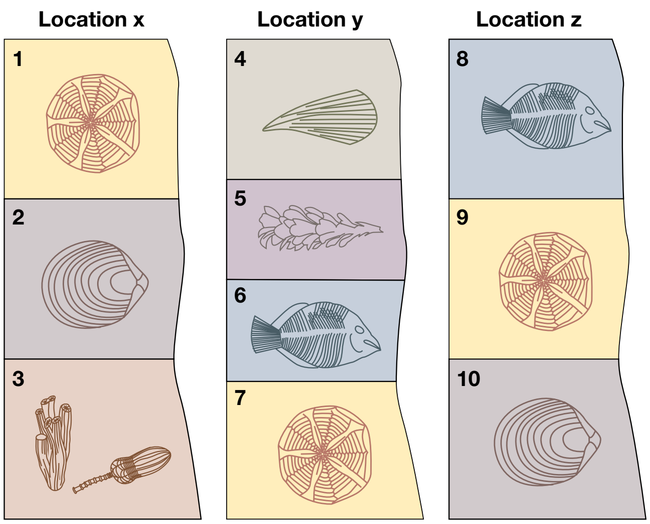


Figure 2.2.11

17 a **Deduce** the strata that are of the same age in Figure 2.2.11.
   b **Justify** your choice in part **a**.
   c **Deduce** the layers in order from the oldest to the youngest.

18 **Justify** why trilobites are suitable as index fossils and birds and humans are not.

19 **Propose** a suitable method of dating for each of the following situations.
   a Showing that two bones were not from the same cave
   b Proving a piece of wood was about 30 000 years old
   c Dating a wooden box found in an Egyptian tomb
   d Dating a primitive looking stone tool found in a rock layer near an extinct volcano
   e Comparing two rock layers from different countries that cannot be radioactively dated but which contained fossils such as trilobites and ammonites

20 **Propose** reasons why all trilobite fossils would not look like the one in Figure 2.2.2 on page 60.

21 **Propose** a reason why tree rings might not be able to be used to date wood found in an ancient sunken ship.

22 **Propose** where the first fossils of the following rock layers were discovered:
   a Mississippian
   b Pennsylvanian

Creating CCT

23 Artefacts are objects made by humans, such as pottery and paintings. Index artefacts such as stone tools can be used to determine the age of human remains.
   a **Identify** what you think could be used as an index artefact for the 21st century. Imagine that many thousands of years into the future another civilisation will look back at us and use the artefact to place our time on a scale compared with earlier centuries. Your index artefact needs to have the same requirements as index fossils.
   b **Construct** an argument for your artefact as an index artefact for the 21st century.

Inquiring

1 Research the extinct animal group called ammonites. In particular:
- describe what they looked like
- identify when they lived
- include a diagram of a typical ammonite
- explain how ammonites are useful as index fossils.

Present your research as a single page in a textbook. You can present the page in digital form or as a single printed page. ICT

2 Research trilobites by using the key term *trilobite orders* in an internet search engine. In particular:
- identify some different groups (orders) of trilobites
- locate important trilobite fossil sites
- name some trilobites found in NSW.

Present your findings in a way that could be used to create a large billboard in your local museum.

3 All living tissues such as skin and muscle contain organic matter that contains very small amounts of radioactive carbon-14. Carbon dating uses the decay of carbon-14 to determine the age of fossilised tissues. Research carbon dating and find:
- how carbon-14 enters living tissue
- why this entry stops with the death of the organism
- a graph showing the decay curve of carbon-14
- the maximum age that can be reliably determined using this method
- examples of fossils or other objects that have been dated this way.

Present your findings in digital form. ICT

2.2 Practical investigations

1 Interpreting fossils

Purpose

To interpret fossils and propose how they could be used as index fossils.

Materials

- access to a range of fossils including different species (include trilobites and ammonites if possible) and different methods of fossilisation
- labelled container for each fossil
- notes on each fossil (include species, origin, age but not method of fossilisation)
- hand lens and/or stereomicroscope

Procedure

Move around the laboratory and observe each specimen. Next to each specimen are notes on it.

Results

1 For each fossil, record your observations. Include:
   - a brief description of the rock (such as colour and layering)
   - a brief description of the organism (such as colour and body shape).

2 From the notes next to each fossil, record its:
   - name or group (such as trilobite, ammonite, mollusc)
   - age and location (if known)
   - other relevant information such as whether it is an index fossil.

Practical review

1 a For each specimen, **propose** the most likely method of fossilisation (e.g. original, carbon film, mould or cast).
  b **Justify** your choices for each method of fossilisation.

2 **Assess** how sure you are of the method of fossilisation of each fossil.

3 **Define** the term *index fossil*. L

4 Choose one of the fossils and **explain** how it could be used as an index fossil to date rocks found far apart (for example in NSW and in Antarctica).

2 Radioactive decay

Purpose

To model radioactive decay and construct a decay curve.

Materials

- 100 counters or similar with one side marked
- container to shake up counters
- graph paper or graph-plotting software

Procedure

1. Shake up your 100 counters in your container so that they are thoroughly mixed. Tip the counters onto the bench. Spread them out so that none is being covered by another.
2. In this model the counters that have their marked face showing represent decayed atoms. Put these in a pile on a piece of paper labelled 'Time 1'. On your piece of paper write the number of decayed atoms and the number of undecayed atoms. Because there are 100 counters, this figure represents a percentage.
3. Leave the decayed atoms on the paper until the end of the investigation. Return the remaining counters (the undecayed atoms) to your container and shake them thoroughly again. Repeat step 2 but put this pile of counters on a different sheet of paper labelled 'Time 2'. Again record how many decayed and undecayed atoms there are on the paper.
4. Repeat these steps until all atoms are decayed.

Results

1. Copy and complete the following table by writing in your results from the record sheets. Your table will start like the one shown here, but have many more rows.

Time	% Undecayed
0	100
1	
2	

2. Collect results from the whole class and obtain a class average for the table.
3. Use the class results to construct a line graph. Place Time (0, 1 etc.) on the horizontal axis and % undecayed on the vertical axis (from 0 to 100).

   Your graph should be similar to Figure 2.2.12.

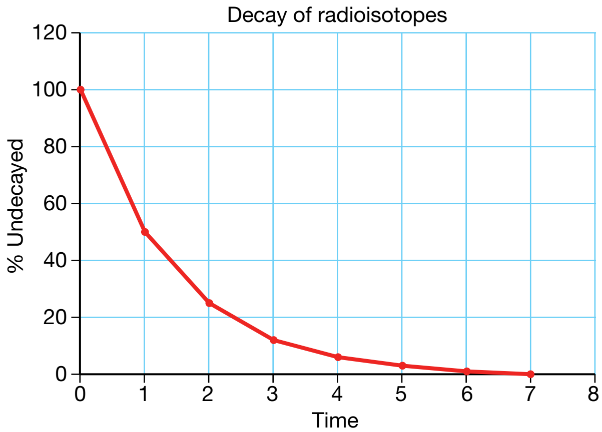


Figure 2.2.12

Practical review

1. In this investigation, **identify** what represents a decayed atom.
2. a **Describe** the shape of your graph.
   b **Compare** its shape with Figure 2.2.6 on page 62.
3. **Use** the graph to **estimate** how many throws it took for half (50%) of your atoms to decay. This is the half-life of your radioactive source. N
4. The half-life in this experiment should have been 1 throw, because every counter had a 50% chance of decaying. So half of the counters should have decayed. **Compare** your estimate from the graph with what was expected. N
5. **Propose** how you could make this investigation more reliable.

2.3 Geological time scale

Dinosaurs, diprotodons and mammoths are extinct. Over 4.5 billion years, many organisms have lived on Earth. The fossil record of these organisms can be used to construct a likely time scale that tracks the history of life on our planet. New fossils are constantly being found that require adjustments to be made to this time scale.

Creating a time scale

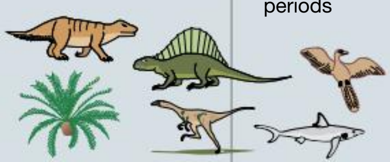
Palaeontologists have constructed a time scale showing the sequence in which all the different fossil species are found in strata throughout the world. This time scale of past life and geology is called the **geological time scale**. By constructing it, scientists have tracked the history of life on Earth.

The geological time scale was constructed by combining relative and absolute dates.

- **Relative dates**: Stratigraphy and the index fossils of many different plants and animals (including the trilobites) were used to first construct a continuous sequence of rock strata back into the past. The particular time span covered by each set of index fossils was referred to as a geological period. Each period was given a name that referred to the place where that group of fossils was originally discovered.
- **Absolute dates:** the development of techniques such as radioactive carbon dating allowed palaeontologists for the first time to calculate the actual age of each index fossil and the rocks they were found in. These dates were added to the sequence of geological periods. The periods were further organised into sets based on major events such as dramatic changes in climate, which tied them together. The sets were referred to as eons, eras and periods.

The combined information from both dating methods became the geological time scale. You can see a simplified version of it in Figure 2.3.1. The scale starts at the bottom, which represents the formation of planet Earth itself 4.5 billion years ago.

NOW

Cenozoic era 	Quaternary periods	Holocene (current)	Some mammals disappear. Modern humans. Warmer climate	0.015 million years ago (mya) to present
		Pleistocene	Ice ages. Large mammals. Primitive humans	2–0.015 mya
	Tertiary periods	Pliocene Miocene Oligocene Eocene Paleocene	Large rise in numbers of birds and mammals Ancestors of modern apes appear Huge reptiles disappear Flowering trees and shrubs replace giant ferns and mosses Dinosaurs become extinct	5–2 mya 23–5 mya 36-23 mya 53–36 mya 65–53 mya
Mesozoic era 	Secondary periods	Cretaceous	Flowering plants	145–65 mya
		Jurassic	Reptiles dominate—dinosaurs. First birds and mammals. Widespread lowlands	200–145 mya
		Triassic	Land vertebrates increase in number Reptiles increase in number	251–200 mya
Palaeozoic era 	Primary periods	Permian	Many plants and ferns Dinosaurs evolve	299–251 mya
		Carboniferous	Tropical coal swamps formed Giant insects dominate First reptiles	359–299 mya
		Devonian	Vertebrates colonise the land. First insects Development of amphibians Land supports large tree plants	416–359 mya
		Silurian	Primitive animal life First land plants	443–416 mya
		Ordovician	Sea invertebrates (starfish, coral) Primitive fish	488–443 mya
		Cambrian	First abundant fossils—trilobites, molluscs, sponges	542–488 mya
Precambrian era 		Many periods here	630 mya Ediacaran fauna—worms and jellyfish	2500–542 mya
			Life develops: stromatolites and blue-green bacteria	3600–2500 mya
			Formation of crust. No life	4500–3600 mya

FORMATION OF EARTH

Figure 2.3.1 The geological time scale is divided into eras and periods based on the types of fossils found.

SciFile

The Jurassic

The name Jurassic refers to the Jura mountains in Europe, where the fossils of the period were first named and described.

The earliest organisms

The geological time scale shows that there was a time in the Earth's history for which there are no fossils. This may be due to the difficulty of fossilising tiny, delicate creatures but it is more likely that it indicates that no life existed at all at that time.

Despite a lack of fossil evidence, palaeontologists have concluded that the very first forms of life on Earth would have been single-celled organisms like bacteria.

All the oldest fossils found have been from the oceans. This suggests that life began there. The most ancient organisms for which there are fossil records were a type of bacteria called cyanobacteria (blue-green bacteria). They lived in the shallow waters of early seas, where they appear to have formed structures called **stromatolites**. These are circular rocky structures which grow as columns. Some are shown in Figure 2.3.2. These structures are found mainly in Western Australia, the most ancient preserved ones coming from the Kimberley region. Living structures similar to stromatolites have been found in several places in Western Australia at Shark Bay, Bunbury and Lancelin. These 'living relatives' have helped palaeontologists understand how the early stromatolites may have formed. These significant locations are recognised as world heritage sites.

Figure 2.3.2 Living stromatolites at Shark Bay. Stromatolites are some of the most primitive life forms ever to exist on Earth.

One study in 2006 claimed that the fossil stromatolites from the Kimberley are the most ancient life form discovered so far. The rocks are over 3400 million years old. You can see a cutaway section of a stromatolite in Figure 2.3.3.

The next major event on the geological time scale is the Ediacaran, followed by the appearance of the more complex Cambrian life forms such as those found in the Burgess Shale in Canada.

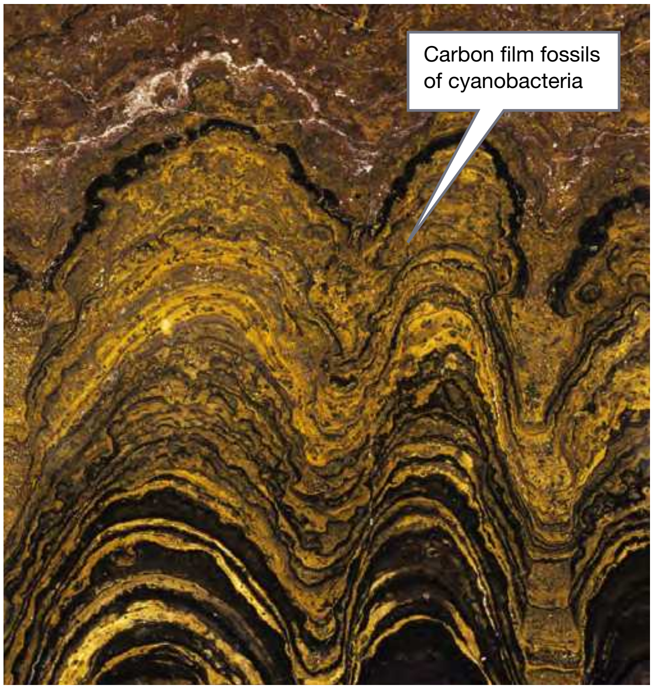


Figure 2.3.3 A cutaway section through a stromatolite. The black layers are carbon film fossils of the bacteria that formed the layers.

Vertebrate fossil history

Vertebrates are animals with a bony inner skeleton and include fish, amphibians, reptiles, birds and mammals. The earliest known vertebrate ancestors are primitive fish from the Cambrian era dated at about 525 million years. These were found at the Chengjian fossil site in China.

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Moving from water to land

The first land plants appeared in the fossil record in the Silurian period, about 416 million years ago. This was an extremely important event because it allowed life to spread from the sea to the land. The fossil record shows that animals such as insects and vertebrates followed soon after these first land plants.

Many fish belonging to a group called the **lobe-finned fish** have been discovered from the Devonian period about 400 million years ago. Lobe-finned fish had bones in their fins similar to land animals. One example is *Eusthenopteron*, which is related to modern **lungfish**. Figure 2.3.4 compares them. The current view is that some of these lobe-finned fish may have been able to pull themselves up onto land with their fins at least for a brief time. These fish probably had a lung and are likely to have lived in shallow water in estuaries or rivers. Palaeontologists are fairly sure that the lobe-finned fish are the ancestors of the group of life forms that finally made the move to land.

Coelacanths

SciFile

Not all lobe-finned fish lived in the shallows of rivers or estuaries. Two different species of lobe-finned fish of the group called **coelacanths** exist today. One lives in undersea caves off the Comoro Islands off Africa and the other is from Indonesia. This indicates that not all the lobe-finned fish moved onto the land.

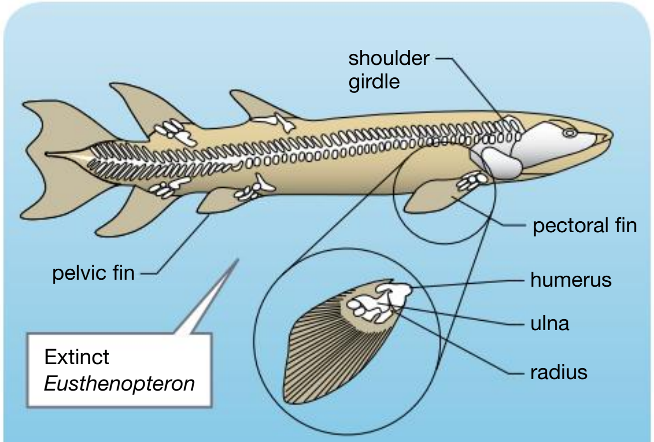


Figure 2.3.4 Lobe-finned fish like the extinct *Eusthenopteron* are likely ancestors of today's lungfish. One species of lungfish is still found in the Mary River in Queensland.

Land vertebrates

The first land vertebrates in the fossil record were amphibian ancestors something like ***Ichthyostega*** shown in Figure 2.3.5. These early amphibians were the first of the group called **tetrapods** (meaning they have four limbs). Living tetrapods are now are classified as amphibians, reptiles, birds and mammals. Palaeontologists are searching for more fossils to fill in gaps in the fossil record to increase their understanding of how the change from land to water may have occurred.

2.4

Figure 2.3.5 An artist's impression of *Ichthyostega*, an early amphibian-like animal.

The fossil record shows reptiles appearing after the amphibians at around 315 million years ago in the Carboniferous period. The reptiles became the dominant animal group in the fossil record through the Triassic, Jurassic and Cretaceous periods of the Mesozoic era. This is when dinosaurs appear (Figure 2.3.6). They were the dominant animal group from about 250 million years ago until about 65 million years ago.

Figure 2.3.6 Dinosaurs dominated Earth in the Mesozoic era.

Birds

Bird-like animals appear in the Jurassic period around 200 million years ago. The oldest true birds date from about 110 million years ago. Birds shared many features with a small group of dinosaurs called **theropods**. These similarities have led most scientists to believe that birds probably developed from the dinosaurs. There are several different early bird-like creatures, which are like dinosaurs with feathers.

One early example was ***Archaeopteryx*** (which means 'ancient wing'), an organism known from eleven fossils found in Germany. Figure 2.3.7 on page 72 shows one fossil with impressions of feathers. Other fossils of the species also show a wishbone in their chest. Both these features are important for flight in modern birds.

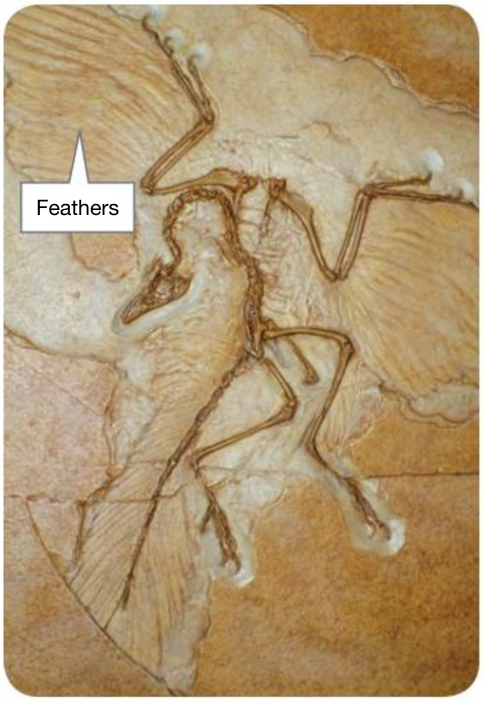


Figure 2.3.7 This *Archaeopteryx* fossil shows the imprint of feathers.

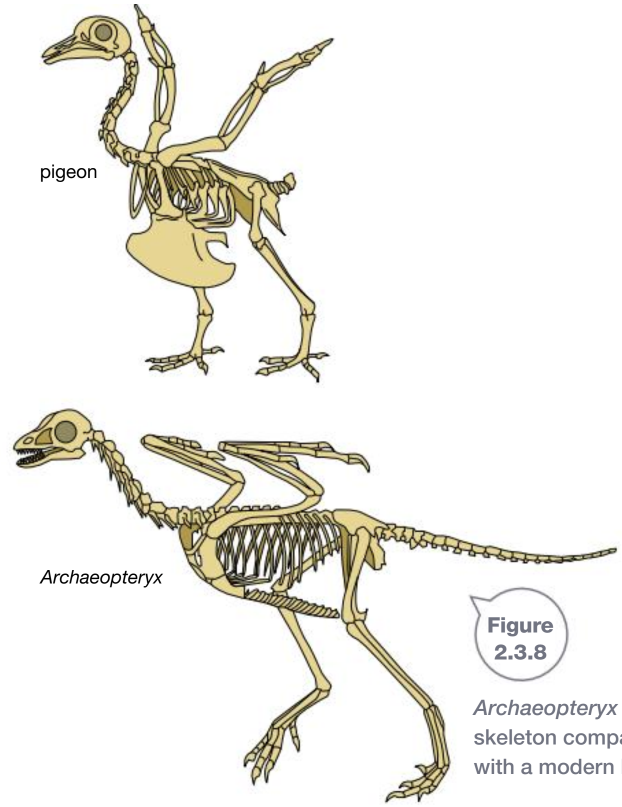


Figure 2.3.8 *Archaeopteryx* skeleton compared with a modern bird

Figure 2.3.8 shows how similar *Archaeopteryx* was to a modern bird. However, *Archaeopteryx* had teeth, a long tail of bones and fingers at the tip of its front limbs. So this creature had features of both reptiles and birds. It probably could not fly as a modern bird can. *Archaeopteryx* is currently classified as the oldest known bird.

There are many more ancient bird fossils being found in China. These are much more like modern birds than *Archaeopteryx*, and yet they too have some dinosaur-like features.

2.5

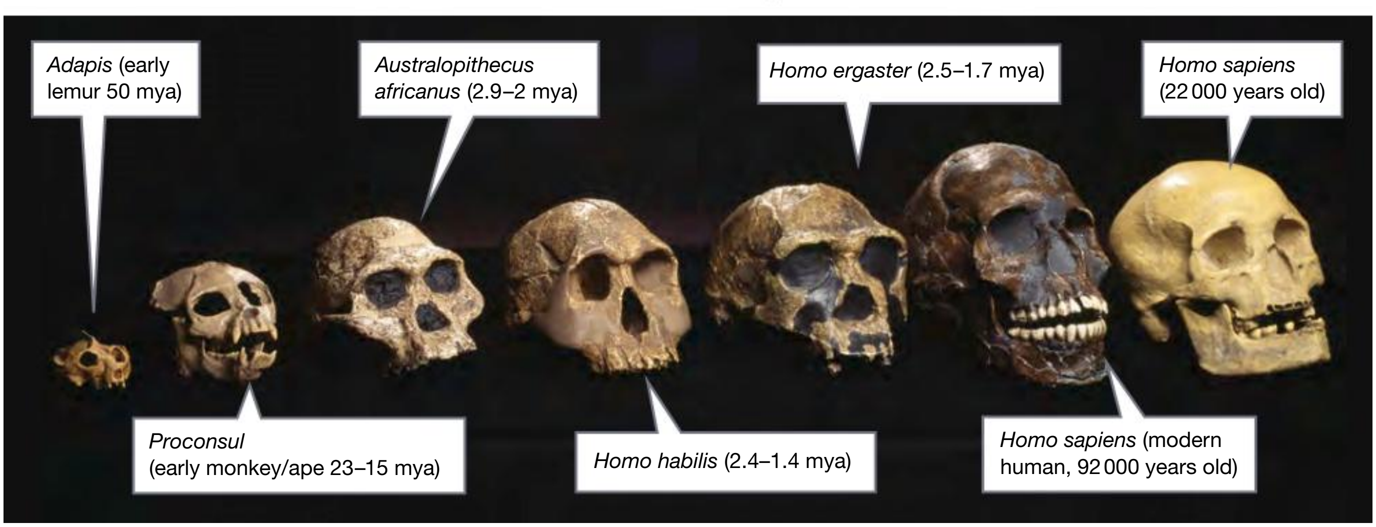
Mammals

The earliest mammal-like fossils appeared in the Triassic period 190 million years ago. *Hadrocodium* is the oldest true mammal yet discovered. It is closely related to living mammals.

Humans belong to the order of mammals called **primates**. Other members of this group are apes, monkeys and gibbons. The oldest known primate fossils date to about 60 million years ago. The earliest members of the human sub-tribe date to about 4 million years ago from Africa. These are ape-like creatures called Australopithecines (which means 'southern ape'). There are many other similar creatures found in the fossil record from around this time, one of which may well be our ancestor. The oldest known fossils of our species, *Homo sapiens*, date to over 130 000 years ago in Africa. Figure 2.3.9 compares the skulls of some primates.

Prac 2 p77

Figure 2.3.9 Some fossil primate skulls, including members of the human family. The abbreviation mya stands for 'millions of years ago'.



LEARNING ACROSS THE CURRICULUM

CRITICAL AND CREATIVE THINKING

Figure 2.3.10 TV shows often reconstruct what dinosaurs might have looked like.

RECONSTRUCTING DINOSAURS

Palaeontologists use evidence to reconstruct the appearance of organisms. TV documentaries often show how dinosaurs moved, what they ate, how they raised their young, who ate who and if they were 'warm blooded' or not. Some critics suggest that these representations are just made up. However, there is evidence to support much of what is portrayed about dinosaurs.

APPEARANCE

The techniques used to reconstruct a dinosaur are similar to those used in forensic science. The dinosaur's appearance can be predicted from its skeletal structure.

One problem in reconstruction is missing bones. This can sometimes be overcome if there is a similar bone on the other side of a skeleton. For example, a missing leg bone such as a femur can be copied from the other leg. Another technique is to study living species that are related to the specimen and use their bones as a guide. Anatomists can also relate bone size to body mass. For example, bones become larger and stronger as body size increases.

When as much as possible of the skeleton is present, it is arranged in a posture suggested by the bones. Then the bones are carefully studied for marks left by muscle attachment. This can indicate how large the muscles were and where they were positioned. This is shown in Figure 2.3.11. The muscle bulk of living relatives can also be used as a guide.

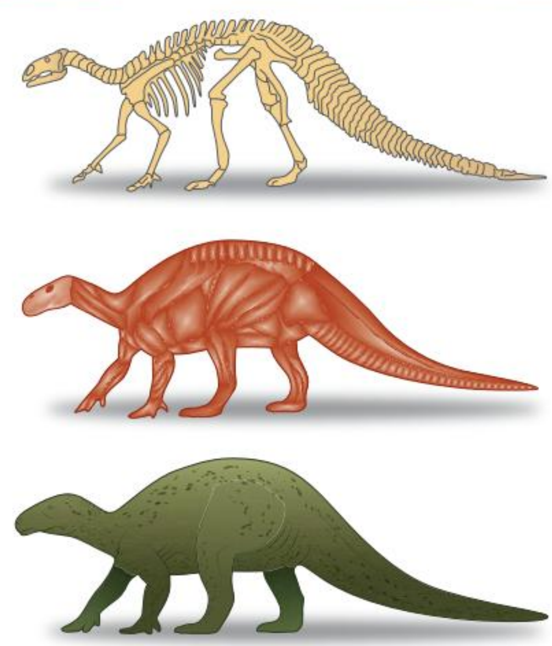


Figure 2.3.11 Constructing dinosaurs using clues from the skeleton to work out muscle size and position

Skin is then placed on the muscle masses and a texture and colour pattern given to it, or the fur or feathers that covered it are reproduced. That is done by studying the colour patterns of the nearest living relatives. The skin covering is known for some dinosaurs. A few dinosaurs had feathers, and some were slightly furry. Fossil moulds indicate that some dinosaurs had leathery skin.

REPRODUCTION

Dinosaurs laid eggs. Scientists know this because many eggs and nests have been found. Intact eggs can be studied with X-rays. There are some examples of eggs just hatching. You can see one in Figure 2.3.12. Some fossils even show parents guarding nests.

Figure 2.3.12 This dinosaur baby had just hatched out of the egg when it died and was fossilised.

MOVEMENT

Estimates of how fast dinosaurs could move are based partly on their fossilised footprints like those in Figure 2.3.13. They are also based on computer simulations. By measuring the distance between footprints and comparing this with body size, scientists can estimate the dinosaur's running speed.

Prac 3 p77

Figure 2.3.13 The distance between dinosaur footprints enables an estimate of their running speed.

BODY TEMPERATURE

Currently, there is disagreement among scientists on whether dinosaurs were **endothermic** (able to control body temperature) or **ectothermic** (depending on their environment for warmth). Some dinosaurs may have been endothermic like mammals and birds—these dinosaurs were most likely small, fast-moving ones or large predators. Others probably resembled current reptiles—most likely they were herbivores. Although fossilised dinosaur bone looks more like that of mammals and birds than that of reptiles, more research needs to be done in this area.

DIET

Teeth are a good guide to diet. Carnivores have many sharp teeth to cut flesh, whereas herbivores generally have flatter teeth to grind plant material. So scientists are fairly sure what type of food each dinosaur ate. Another guide to diet is the fossilised dinosaur dung (faeces) known as coprolites. These showed that herbivorous dinosaurs mainly ate plants called gymnosperms. The carnivorous dinosaurs often ate each other, according to fossil sites showing dinosaurs that died in a battle with each other.

SOCIAL BEHAVIOUR

Dinosaur tracks indicate that many dinosaurs lived in groups—multiple footprints at some fossil sites indicate that some dinosaurs formed herds. A recent discovery of multiple coprolites indicates that some species of dinosaurs may have used particular areas as communal 'toilets'.

2.6

REVIEW

1 **Name** another branch of science that uses techniques similar to those used by palaeontologists when determining the appearance of a dinosaur.

2 **Explain** how palaeontologists reconstruct a skeleton when there are missing leg bones.

3 **Outline** how scientists determined the size of the dinosaur's muscles.

4 Imagine the two sets of fossilised dinosaur footprints described below were found in different locations. **Propose** what these fossils indicate.

   a sets of identical footprints spaced well apart and heading in the same direction

   b fragments of shells surrounded by large and small footprints pointing in different directions

5 **Outline** evidence that helps indicate the diet of particular dinosaurs.

2.3 Unit review

Remembering

1 **State** what geological eras are divided into.

2 **State** two possible reasons why the early part of the geological time scale does not show any living organisms.

Understanding

3 **Outline** how the geological time scale was constructed.

4 **Define** the term *stromatolite*. L

5 **Explain** the importance of the following organisms in the history of life on Earth.
- a stromatolites
- b lobe-finned fish
- c *Ichthyostega*
- d *Archaeopteryx*

6 **Explain** why scientists think some dinosaurs and birds are related.

Applying

7 **Use** Figure 2.3.1 on page 69 to **identify** the geological era, geological period and time in which the following events occurred.
- a the dinosaurs become extinct
- b primitive humans appear
- c first land plants appear
- d stromatolites first appear

8 *Archaeopteryx* would not be a useful index fossil. **Demonstrate** why.

Analysing

9 **Use** Figure 2.3.8 on page 72 to **compare** the skeletons of *Archaeopteryx* and modern birds, listing their similarities and differences.

Evaluating CCT

10 **Propose** why plants would need to spread to the land first before animals could live on land.

11 Some major differences between amphibians and reptiles are their method of respiration, how the young are born and what the body is covered with. Amphibians are thought to be the ancestors of reptiles. **Use** Table 2.3.1 below to **propose** why reptiles were successful in moving into a wide range of habitats on land.

Creating CCT

12 **Construct** a notice to be posted at the Shark Bay stromatolite site detailing reasons why tourists should protect the area.

Inquiring

ADDITIONAL

1 Research three theories about the extinction of dinosaurs.
- Briefly describe each theory.
- State the evidence for each theory.
- Critically analyse the evidence for each theory.

Present your research findings in digital form or as a poster. ICT

2 In Nettle Cave (part of the Jenolan Caves of NSW) a very rare form of stromatolite has recently been discovered. Research these stromatolites to find:
- a map showing the location of the Jenolan Caves
- descriptions and images of the stromatolites found there
- how these particular stromatolites were formed
- why these stromatolites are important.

Present your findings as a tourist brochure for Nettle Cave.

ADDITIONAL

Table 2.3.1

Feature	Amphibian	Reptile
Respiration	Live in water as young and breathe by gills. Develop lungs as adults and breathe air	Live on land and breathe by lungs
How young are born	Eggs with thin membrane easily dehydrated. Laid in water and hatch into water	Eggs with waterproof flexible membrane. Hatch in air
Body covering	Thin moist skin	Thick leathery scaly waterproof skin

2.3 Practical investigations

1 Vertebrate skeletons

Purpose

To compare different vertebrate skeletons.

Materials

- skeletons of human, cat, bird, frog, bony fish and lizard
- if actual skeletons are not available, then use images from the internet

Procedure

1. Copy Tables 2.3.2 and 2.3.3 shown in the Results section into your workbook.
2. Carefully observe each specimen and complete Table 2.3.2 by placing a tick in the table if the feature is present.

Results

Use Table 2.3.2 to complete Table 2.3.3 in your notes. You can observe the animals again if necessary. Record the animals that are most alike and least alike for each of the features.

Practical review

1. Using Table 2.3.3, **deduce** which two animal skeletons seem to be most alike, and which two are least alike.
2. Fish live in the ocean and the rest of these animals live on land. Look very carefully again at the specimens and note how the fins and limbs are attached to the rest of the skeleton. **Propose** how the large differences in these parts of the skeletons are related to the environment in which these creatures live.
3. Most of these animals have remarkably similar skeletons. They have many bones that are in the same places and doing the same jobs. **Describe** some examples of this.
4. **Propose** why these animals have skeletons which are so similar.
5. Imagine that fossil bones from the limbs of these creatures were discovered. **Discuss** whether you think you could easily identify which of these creatures the bones belonged to.
6. The fish fins were very different from the frog limbs. **Discuss** whether there is any evidence of fish fins having bones in them as land animals do.

Table 2.3.2 Vertebrate skeletons

Animal	Skull	Vertebral column	Ribs	Front limbs	Rear limbs	Front limb girdle	Rear limb girdle
Human							
Cat							
Bird							
Frog							
Bony fish							
Lizard							

Table 2.3.3 Comparing vertebrate skeletons

Feature	Most alike	Least alike
Skull		
Vertebral column		
Ribs		
Front limbs		
Rear limbs		
Front limb girdle		
Rear limb girdle		

STUDENT DESIGN

2 Geological time scale

Purpose

To construct a diagram showing the geological time scale.

Materials

- as selected by students

Procedure

1. Your task is to construct a diagram of the geological time scale on paper.
2. On your diagram, include:
   - times and names for the geological eras and periods
   - drawings/pictures of the major fossil groups of each era or period
   - descriptions of important events of life on Earth
   - descriptions/drawings of major climatic events.

Hints

- Use a timescale of 1 mm = 1 million years.
- Your paper needs to be nearly 4 m long.

Practical review

Evaluate your timescale and those of other groups.

STUDENT DESIGN

3 How fast could a dinosaur run?

Purpose

To calculate the running speed of a dinosaur.

Hypothesis

Imagine a dinosaur that was about your height. How fast do you think it could run? Before you go any further with this investigation, write a hypothesis in your workbook.

Materials

- as selected by students

SAFETY

A risk assessment is required for this investigation.

Procedure

1. Dinosaur tracks have been found. The tracks cover 40 m and the distance between successive footprints averages at about 1.5 m. Design a way of calculating how fast this dinosaur ran. Assume that the dinosaur was about the same height as a human.
2. Brainstorm in your group and come up with several different ways you could investigate the problem. Select the best procedure and write it in your workbook.
3. Before you start any practical work, assess all risks associated with your procedure. Construct a risk assessment outlining the risks and the precautions you must take to minimise them.
4. Show your procedure and risk assessment to your teacher. If your teacher approves, then collect all the required materials and start work.

Hints

- Wet sand is a good way of recording footprints.
- Average speed = $\frac{\text{distance}}{\text{time}}$

Results

1. Construct a table showing your results.
2. Collect results from other groups in the class, along with a description of any differences in the methods they used.
3. Decide whether it is appropriate to calculate an average of the class results.

Practical review

1. a **Construct** a conclusion for your investigation.
   b **Assess** whether your hypothesis was supported or not.
2. **Justify** your decision whether or not to calculate a class average.
3. **Assess** which group in the class performed the most reliable and valid experiment.
4. **Evaluate** whether your experiment is likely to be a good predictor of the running speed of a dinosaur. To do this you must consider any variables that may affect your results.

2 Chapter review

Remembering

1 **List** the sequence of appearance for the vertebrate groups in the geological time scale.

2 **Name** a major event from the geological record for each of the following:

a Ediacaran
b Cambrian
c Devonian
d Permian
e Triassic
f Jurassic
g Cretaceous
h Pleistocene

Understanding

3 **Define** the following terms. L

a fossil
b index fossil
c radioactive dating
d geological time scale

4 **Describe** five different types of fossils and how they form.

5 **Discuss** whether an ancient Egyptian mummy could be considered to be a fossil.

6 **Explain** why the fossil record is incomplete.

7 **Describe** how the age of a fossil or rock can be determined.

8 **Explain** how the geological time scale was constructed using absolute and relative dating methods.

9 **Describe** how a replacement fossil of a trilobite may form.

10 **Modify** the following statements to make them correct.

a Only a preserved body part can be considered a fossil.
b Palaeontologists cannot interpret fossils to determine the appearance of an organism.
c There is no way to tell how long ago a particular fossil was formed.
d All species lived at all times throughout the history of the Earth.
e All species were equally distributed over the Earth in the past.
f The fossil record would be complete if all the sedimentary rocks with the fossils could be exposed.
g Palaeontologists should stop looking for fossils because they already know the history of life on Earth.
h The geological time scale will not change as new fossils are discovered.

Applying

11 Some scientists have estimated that only 25% of the dinosaurs that existed have been discovered as fossils. **Use** your knowledge of fossils to **explain** why we will never find examples of all the dinosaurs.

12 **Use** the decay curve for potassium-40 to argon in Figure 2.2.6 on page 62 to **calculate** the age of a fossil that had 0.1 or one-tenth of its potassium-40 remaining. N

Analysing

13 Birds and bats that fly over swamps can sometimes be exposed to poisonous gases. **Analyse** how this may affect their chances of being fossilised.

14 **Compare** relative and absolute dating.

15 **Contrast** a fossil mould and a cast.

Evaluating CCT

16 Scientists have extensive knowledge of trilobites, ammonites, molluscs, coral and fish, but know very little of ancient marine worms, earthworms and desert plants. **Propose** reasons why.

17 a Refer to Figure 2.3.1 on page 69 and **assess** which are the ten most important events in the history of life on Earth.
b **Justify** your choice.

18 a **Determine** whether you can or cannot answer the questions on page 48 at the start of this chapter.
b **Use** this to **assess** how well you understand the material presented in this chapter.

Creating CCT

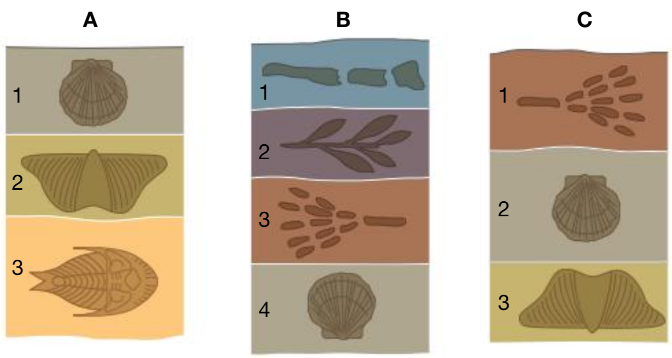
19 **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter.

fossil
fossil record
relative dating
stratigraphy
vertebrate history
preserving environments
absolute dating
index fossil
geological time scale
dinosaurs

2.7

Thinking scientifically

Questions 1 to 4 are based on the following diagram showing ten strata in three different locations, A, B and C. The strata are numbered.



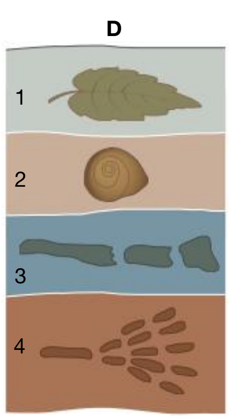
Q1 Which of the following strata are the same age? CCT

A A1, B1, C1
B A3, B4, C3
C A1, B4, C2
D A2, B3, C3

Q2 Which is the oldest of the ten strata? CCT

A A3
B B4
C C3
D B1

Q3 At location D, the following strata and fossils were discovered. CCT



Which layer found in location B appears to be missing from location D when it would have been expected to be found at D? CCT

A B1
B B2
C B3
D B4

Q4 Which is the youngest layer in the four sites? CCT

A A1
B B4
C C1
D D1

Q5 In which of the following environments are soft-bodied animals least likely to form fossils? CCT

A In a peat swamp
B In a rain forest
C In the ice of the tundra
D In dry deserts which have strong winds and dust storms

The following information applies to questions 6 and 7.

The half-life for a radioactive substance is the time it takes for half of the original radioactive material to break down. The half-life for dating using carbon-14 is 5730 years. Carbon-14 decays to form nitrogen-14. For the decay of potassium-40 to argon, the half-life is 1251 million years. Fossil birds date from about 150 million years ago. House roof beams are usually no older than a few hundred years even if the timber has been reused.

Q6 Which of the following is a correct deduction using the above information? CCT

A Potassium-40 decays faster than carbon-14.
B Potassium-40 could not be used to date rocks older than 500 million years.
C Carbon-14 could not be used to find the age of the oldest fossil bird discovered.
D Carbon-14 would not be useful to date wooden beams from a house.

Q7 How many years would it take before a 1 gram sample of carbon-14 decayed to a mass of less than 0.1 gram? CCT

A less than 11 460 years
B between 11 460 and 17 190 years
C between 17 190 and 22 920 years
D more than 22 920 years

Glossary

Unit 2.1

L

Carbon film fossil: when the dead body partially decays and leaves a thin black deposit of carbon

Carbon film fossil

Cast: when an organism in rock decomposes and the space in the rock fills with soil that turns to rock

Ediacaran period: time period on the geological time scale when complex life forms were developing

Fossil record: a list showing the classification of all the species that have been found as fossils

Fossils: the preserved evidence in rocks or soils of organisms that were once alive

Fossils

Indirect fossils: preserved remains of things such as imprints of the body (such as footprints), fossilised dung and burrows

Mould: an imprint of the outside of the body in rock

Original fossils: when a part of the organism such as a skeleton is preserved and remains in its original form

Palaeontologist: scientist who studies prehistoric life

Palaeontology: the study of prehistoric life

Petrified: when wood is replaced by minerals and fossilised

Replacement fossil: when a part of the organism is changed into another mineral

Replacement fossil

Unit 2.2

L

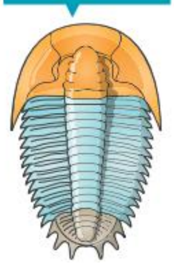
Absolute dating: a way of determining the actual age of rocks and fossils

Fluorine dating: finding a relative age for two bones from the same area by comparing the amount of fluorine in them

Half-life: the time it takes for half of a radioactive sample to decay

Index fossil: fossil that can be used to compare the relative age of rock strata in different locations

Index fossil



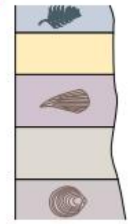
Isotope: different forms of the same element with different numbers of neutrons, and so different atomic masses

Relative dating: comparing the age of one fossil or rock against another to see if one is older or younger than the other

Strata: layers of sedimentary rock

Stratigraphy: comparing strata in different locations to determine their relative ages

Stratigraphy



Tree ring dating: counting growth rings in the woody trunks of trees to find their age

Tree ring dating

Unit 2.3

L

***Archaeopteryx*:** bird-like dinosaur that had feathers

Coelacanths: ancient group of fish related to the lobe-finned fish ancestors of the amphibians

Ectothermic: depending on surroundings for warmth

Endothermic: able to control body temperature

Geological time scale: a scale showing the history of life and geology

***Ichthyostega*:** early amphibians which were the first of the group called tetrapods

Lobe-finned fish: fish with bones in their fins similar to land animals

Lungfish: relatives of the lobe-finned fish that made the move from water to land

Primates: order of mammals to which humans belong

Stromatolite: circular rocky structures thought to be the earliest evidence of living organisms called the cyanobacteria

Stromatolite

Tetrapods: land animals with four limbs. Living tetrapods are now classified as amphibians, reptiles, birds and mammals

Theropods: a dinosaur group closely related to birds and from which birds probably developed

Tetrapod

3 Natural selection and evolution

Have you ever wondered ...

- why there are so many different species of organisms on Earth?
- where new species in the fossil record came from?
- why your skeleton is so similar to that of other vertebrates, such as apes?
- how organisms become adapted to their environment?
- why new antibiotics are urgently needed?

After completing this chapter students should be able to:

- describe evidence that present-day organisms have evolved from organisms in the past
- relate the fossil record to the age of Earth and the time over which life has been evolving
- explain how natural selection relates to changes in a population, such as the development of resistance of bacteria to antibiotics and insects to pesticides L
- outline the roles of genes and environmental factors in the survival of organisms in a population CCT

ADDITIONAL

- describe examples of advances in science in areas that involve biological science CCT L WE
- investigate how models can be used to predict the changes in populations due to environmental changes CCT L
- research how information technology is applied in bioinformatics. ICT

3.1 Changes over generations

The discovery of dinosaur fossils thrilled the public of the 1800s and museums would display the latest wonders for people to view. Scientists tried to explain where such organisms had come from. Their early studies of fossils and living organisms led to the revolutionary view that a species can change over many generations. This produces variety, as seen in the squashes and pumpkins pictured here.

INQUIRY science 4 fun

Plant structures

YES

Do this …

1 Go into the garden, park or bushland. Look for any plants that are flowering, particularly Australian native plants such as the eucalypt (gum tree), grevillea or hakea shown here.

2 Look for any major structural differences between two of these plants, especially their flowers.

Record this …

Describe the differences you see.
Explain these differences.

Fossils and evolution

Fossils have shown that birds and one branch of the dinosaurs (the theropods) have many similarities in their structure. For example they:

- both have feathers (Figure 3.1.1)
- have similar bone structures, such as collarbones forming wishbones
- lay eggs.

They are so similar that biologists are now convinced that theropod dinosaurs were the ancestors of birds.

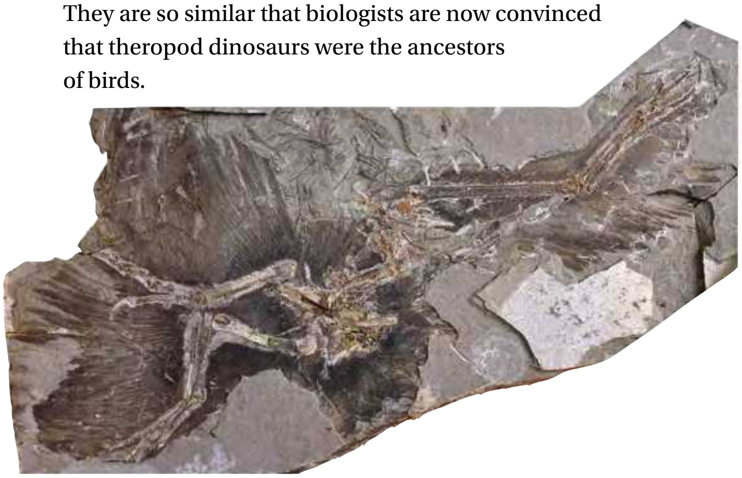


Figure 3.1.1 Fossilised feathers on a dinosaur called *Anchiornis* discovered in China in 2009. These fossil feathers were so well preserved that scientists could determine their colour.

GO TO Unit 2.3

Fossils of the lobe-finned fish and amphibians of the Devonian period (419 to 358 million years ago) show many similar bones in the limbs. These limbs have more than just bones in common. They also show a gradual change in the structure of the whole limb over geological time. Each different species seemed to have small changes in its general structure, such as bone shapes and the number and position of toes.

This apparent change in species over time is called evolution. **Evolution** is defined as a genetic change in the characteristics of a species over many generations, resulting in the formation of new species. A **generation** is the time between the birth of an individual and when that individual produces their own offspring.

Fossil history of the horse

The fossil history of the horse is a good example of changes occurring over many generations. Fossil skeletons have been found of a horse-like animal that was about the size of a small dog. The scientific name of the genus of this animal is *Hyracotherium* (Figure 3.1.2). It is not classified as a horse, but is similar enough that biologists consider it to be a likely ancestor of horses. Radioactive dating methods show that *Hyracotherium* lived about 52 million years ago.

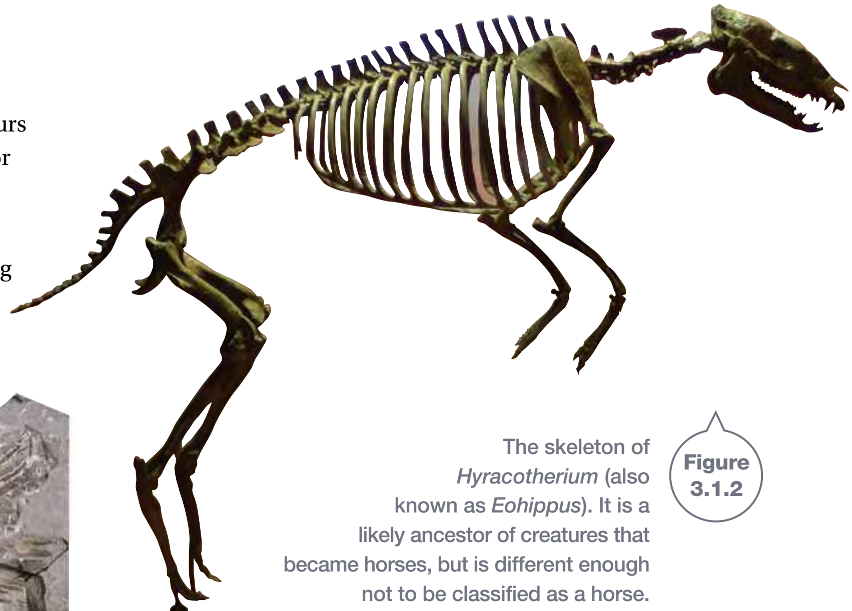


Figure 3.1.2 The skeleton of *Hyracotherium* (also known as *Eohippus*). It is a likely ancestor of creatures that became horses, but is different enough not to be classified as a horse.

The fossil skeletons of at least 17 different genera and many more species of horse have been found and dated. All these different types of horse form a complex family tree with many side branches. Some of these branches lead nowhere. These represent the development of new types of horses that then died out, becoming extinct. Other branches evolved with species steadily changing into another. Despite the complexity of the horse family tree, palaeontologists have been able to trace a path through it that leads to the modern horse. In this way, they have established its family line and the genus and species of its ancestors. One of those ancestors is *Mesohippus*, a genus of horse that lived around 40 million years ago. You can see it in Figure 3.1.3.

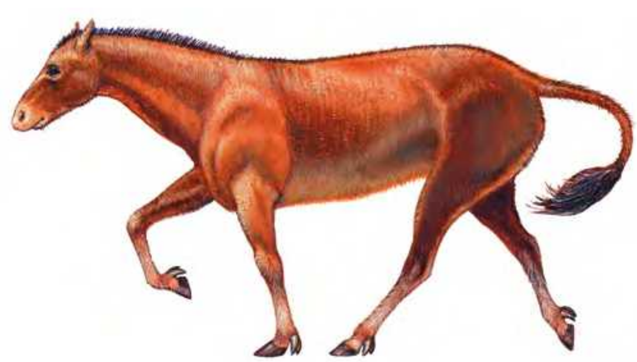


Figure 3.1.3 An artist's impression of *Mesohippus*, an ancestor of the modern horse.

There seems to be a gradual change in many parts of the skeletons of the different fossil horses (Figure 3.1.4). Some obvious changes are that the:

- body increases in size
- legs become longer
- number of toes decrease.

The change in the number of toes is of particular interest to scientists. *Hyracotherium* had four toes on its front legs. *Mesohippus* appears fairly early in the horse family, at about 40 million years, and had three toes. Compared with those of earlier horse genera, the middle toe of *Mesohippus* is thicker while the side toes are smaller.

At about 20 million years ago, a genus called *Merychippus* appeared in the fossil record. *Merychippus* also had an enlarged middle toe. Many other genera and species appeared after this and eventually the genus *Equus* appeared in the fossil record about 3.5 million years ago. This genus includes modern horses, zebras and donkeys.

SciFile

On your toes

Modern horses run on one large ‘toe’ on each foot. This toe is comparable to your middle finger. Biologists think the loss of the other ‘toes’ is an adaptation that allows faster running while supporting a large body.

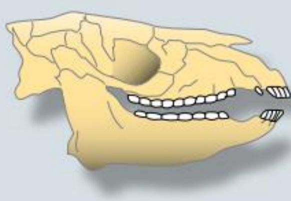
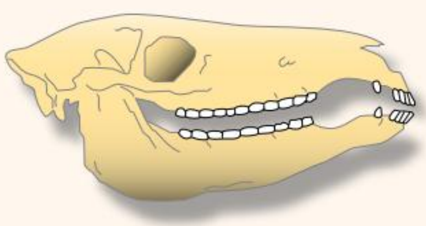
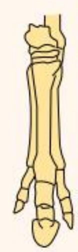
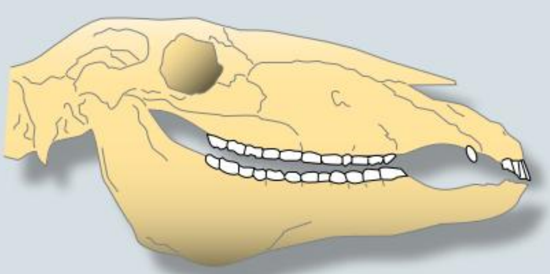
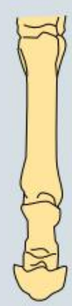
Time	Head	Fore-foot	Hind-foot	Teeth
52 mya	 *Hyracotherium (Eohippus)*			
40 mya	 *Mesohippus*			
20 mya	 *Merychippus*			
Today	 *Equus* (the modern horse)			

Figure 3.1.4 The fossil record of horses shows that the structure of the skull, jaw and feet changed over millions of years. Note: mya = million years ago.

Structure and relationships

When organisms are classified on the basis of their structure, some groups seem very similar. An example is cats and lions. Others, such as cats and jellyfish, seem quite different. The first biologists who studied evolution over 150 years ago proposed that organisms with very similar structures must be related. This view was based on the knowledge that organisms seemed to inherit their characteristics from their parents. However, at that time nothing was known about genetics.

Genetics has since shown us that species with the same basic structure share many identical genes or have genes that are similar in their effect. It is the genes that control structure and function in organisms. Organisms that share genes must be related. This is because during meiosis genes are copied from previously existing genes. The obvious inference is that two species that share genes must have had the same ancestor at some stage. Many of the same genes have then been passed down to both species.

GO TO Unit 1.1 GO TO Unit 1.2

Hox genes
SciFile

Most species contain Hox genes, a group of genes that control where body parts such as the head and legs occur. These genes can be taken out of one species (such as a chicken) and put into another (such as a fly) where they work in exactly the same way. Scientists see this as evidence that all life is related.

Homologous structures

In related species, characteristics that have the same basic structure are called **homologous** characteristics. These characteristics are controlled by particular inherited genes. For example, the foot bones of the different fossil horses are homologous. A cat's paw and a lion's paw are considered homologous, but a cat's paw and an insect's foot are not homologous. A cat's paw and an insect's foot may have the same function, but their structure is very different.

The more alike two organisms are, the more genes they share. As you move from higher levels of classification (kingdom) to the lower levels (genus and species), the more alike those genes become.

A homologous structure does not necessarily have the same function in all the groups that share it. For example, humans, whales and bats all have pentadactyl limbs—they have five digits at the end of each limb. In humans, these digits form a foot for walking and a hand for gripping. In whales, the digits form a flipper for swimming and in bats a wing for flying.

A human hand, a whale's flipper and a bat's wing are homologous structures, despite having very different functions.

Prac 1 p91
3.1

Analogous structures

Not all similar structures are homologous structures. For example, the dolphin and shark in Figure 3.1.5 have similar streamlined bodies and similar dorsal fins on their backs. However, these are not homologous structures because different genes are involved in their inheritance. Dolphins and sharks differ in most other structures. This shows that these animals are not similar to each other except at the simplest (phylum) level—they are both chordates. The fossil record shows that sharks evolved over 460 million years ago, while dolphins evolved about 10 million years ago.

Dolphins and sharks have similar body shapes and fins because they evolved in similar marine environments. Structures that look similar on genetically very different organisms are known as **analogous structures**.

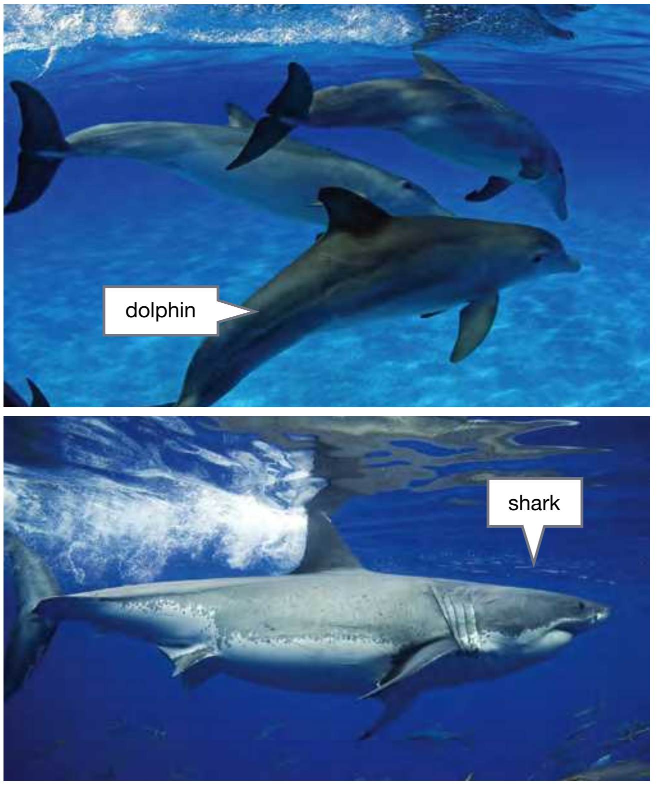


Figure 3.1.5 Sharks and dolphins are not closely related but look similar due to evolving in similar environments.

Dolphin ancestors
SciFile

Dolphins are air breathers, and scientists think their ancestors must have been land-living animals that went back into the water. That probably explains why they have lungs and breathe air.

Artificial selection

For many centuries, humans have bred different animals and crossed different plants to gradually change the features of a species. This process is commonly called selective breeding or artificial selection.

Artificial selection is the process by which we choose to breed particular organisms with desirable features. One example is the breeding of budgerigars. Wild budgerigars are usually green and yellow. You can see one in Figure 3.1.6.

Figure 3.1.6 The wild budgerigar is usually green and yellow.

All the different pet budgerigars we have today have come from this wild type of budgerigar. Figure 3.1.7 shows some of the different colours possible. The different colours and patterns are the result of breeders choosing particular budgerigars as parents and breeding from them. They used wild budgerigars that showed small differences in colour, patterning and body size. These variations in the wild budgerigar population were all originally the result of mutations.

Occasionally new mutations occurred that the breeders had not seen in the wild birds. These were selected by the breeders and passed on to the offspring. For example, the blue colour in some budgerigars originated as a mutation of the gene controlling the green feather colour. Most wild budgerigars are green, but occasionally blue ones and sometimes all yellow ones are born. In this way, many new features were developed in pet budgerigars that are markedly different from those of the original wild birds.

Artificial selection only happens over generations.

Figure 3.1.7 These budgerigars were all bred by artificial selection.

The breeders cross (mate) the selected parents and then have to allow the offspring to reach maturity before selecting which will be bred.

There are hundreds of other examples of species being changed by artificial selection. Domestic dogs are all one species (Figure 3.1.8). So are the domestic cats in Figure 3.1.9. The different breeds in these two species have come from artificial selection.

Figure 3.1.8 All these dogs belong to the same species *Canis lupus familiaris*.

SciFile

Big and small

The biggest dog breed is the Irish wolfhound, and the smallest is the chihuahua. Both are the same species and the differences in them have been developed by artificial selection.

Figure 3.1.9

All domestic cats belong to the same species regardless of their breed. Different breeds are produced through artificial selection.

Selective breeding methods

Selective breeding is used in two main ways. The first method is called **cross-breeding**. This is the process of combining in the offspring a desirable feature of one individual with a different desirable feature from another individual. An example is the creation of the dog breed called labradoodle. This is a cross between a labrador and a poodle, combining the features of both dogs. You can see a labradoodle in Figure 3.1.10.

Another method of selective breeding is **inbreeding**, or line-breeding. In this process, related individuals are allowed to mate. This method is not often used in animal breeding, as there can be health issues in the offspring. Deformities, sterility and genetic disease can be caused by inbreeding.

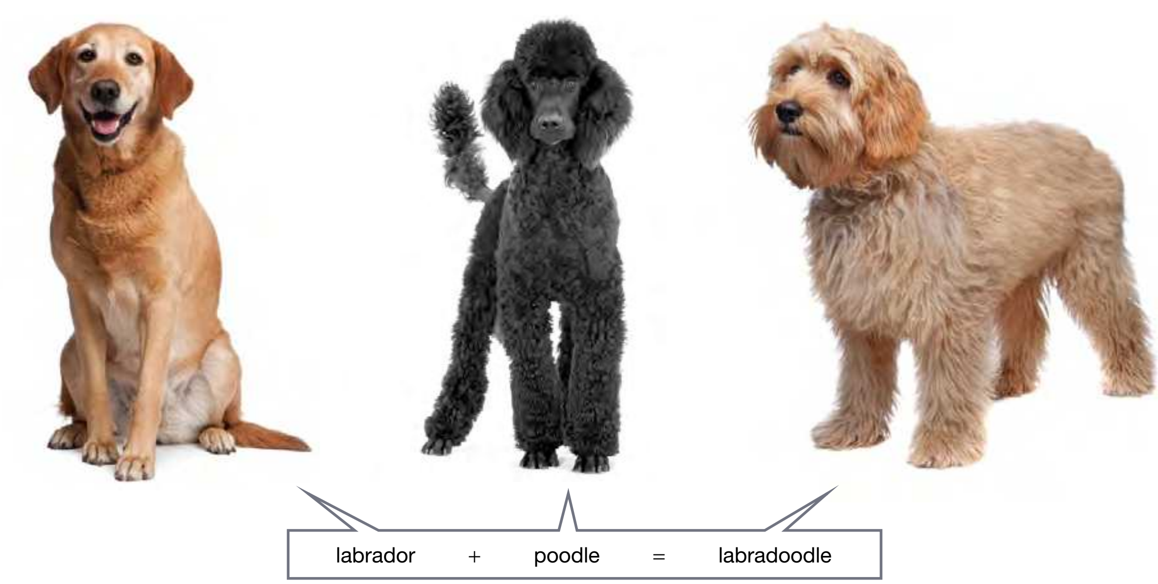


Figure 3.1.10

The labradoodle is the result of a cross between a labrador and a poodle.

ADDITIONAL

LEARNING ACROSS THE CURRICULUM

WORK AND ENTERPRISE

Figure 3.1.11 A wild lupin plant

BREEDING A BETTER LUPIN

Lupins are plants used as animal feed on farms. Wild lupin plants originated in the Mediterranean region and were exported around the world. There were problems with the original plants, so selective breeding was used to improve them.

When farm animals were fed dried or fresh lupins, they generally only ate the leaves (Figure 3.1.12). This was because wild lupin seeds had a bitter taste. Another problem with wild lupins was that farmers could not harvest any of the seeds for future planting because the seed pods shattered and scattered the seeds.

Figure 3.1.12 Lupins are used as animal feed on farms.

John Gladstones is a plant breeder from Western Australia. He thought he might be able to change lupins to make them into a better animal stock feed. He particularly wanted to produce seeds that animal stock would eat, and that would be easier to harvest. Gladstones began his research by searching through fields of lupins, looking for mutants that didn't have shattering pods. He eventually found two plants in which the seed pods had only partially shattered.

Studies of these two plants showed that pod shattering was controlled by two independently inherited recessive genes. These genes affected the seed pods in different ways to stop them shattering. Gladstones cross-bred these two plants and managed to produce a plant with completely non-shattering pods. Figure 3.1.13 compares these non-shattering pods with their shattering ancestors.

Figure 3.1.13 Wild lupin pods shatter but artificial selection produced non-shattering pods.

However, these lupins still had bitter seeds, which animals did not eat. So he crossed the bitter-seeded, non-shattering plants with lupins that had sweeter tasting seeds, but shattering pods. As Table 3.1.1 shows, some of the offspring were plants that had non-shattering pods and sweet seeds.

Gladstones then crossed these plants with lupins that had white flowers. He wanted to be able to easily spot the sweet-seeded non-shattering plants if they became mixed up with others. He finally succeeded in producing lupins that had non-shattering pods, sweet seeds and white flowers. This resulted in a stock feed that was worth many millions of dollars to farmers around Australia.

Table 3.1.1 Steps in selective breeding of lupins

Step	Plants crossed	Offspring included desired phenotype
1	Partially shattering pod × partially shattering pod	Non-shattering pod
2	Non-shattering pod with bitter seeds × shattering pod with sweet seeds	Non-shattering pod Sweet seeds
3	Non-shattering pod with sweet seeds and blue flowers × shattering pod with sweet seeds and white flowers	Non-shattering pod Sweet seeds White flowers

In terms of evolution, the story of lupins is important because it shows that the characteristics of a species can be changed by selecting which individuals breed. Selecting the phenotype (appearance) of the individuals means selecting their genotype (genetic make-up). In this way, the genetic make-up of a species can be altered by selection.

REVIEW

1 **List** the disadvantages of using natural lupins as animal feed.
2 **Describe** the advantages to farmers of lupins with non-shattering pods.
3 **Describe** what Gladstones found when he searched through fields of wild lupins.
4 **Explain** where the genes for non-shattering pods would have come from originally.
5 **Explain** how this story of lupin breeding is similar to the one about breeding budgerigars.
6 **Outline** how artificial selection changed the genotype (genetic make-up) of the lupins.
7 **Describe** the benefits to society of this research on lupins.

3.1 Unit review

Remembering

1 **List** changes shown by fossil horses over geological time.

2 **List** examples where artificial selection has changed a species.

3 **Recall** the fossil group that birds are most closely related to and the characteristic that these groups can share.

Understanding

4 **Define** these terms. L
a evolution
b generation
c homologous

5 **Explain** how fossils can provide evidence for changes in the structure of a species over geological time.

6 **Explain** why scientists consider that species with the same basic structure are related.

7 Breeders have bred blue budgerigars. **Outline** how they did this given that the wild population is commonly green and yellow.

Applying

8 **Use** an example to **explain** how artificial selection can alter a species.

9 **Demonstrate** that organisms whose appearances are very similar are not always closely related.

10 In the science4fun on page 82, two plants were compared that had very different flower structures. **Apply** your knowledge of genetics to **account** for different structural features in different species of plants.

Analysing

11 For the different species of horse shown in Figure 3.1.4 on page 84, **compare**:
a foot structure
b head structure.

12 **Use** examples to **contrast** homologous and analogous structures.

13 a **Compare** cross-breeding with inbreeding.
b **Explain** why inbreeding is rarely used to breed animals commercially.

14 **Use** a bat limb and a mouse limb to **justify** the statement:
Homologous structures do not have to perform the same function in different species.

Figure 3.1.14

Evaluating CCT

15 Palaeontologists believe that birds and dinosaurs are related. **Use** evidence to **justify** their view.

Creating CCT

16 a **Design** a series of steps to produce a rose with white flowers and no thorns from a rose with dark pink flowers with no thorns and a white flowered rose with thorns.
b **Explain** the processes used at each step.

Inquiring

Research the fossil history of mammals. Find:

- the current view of the origin of mammals
- the earliest mammal fossils
- the probable relationships between reptiles, birds and mammals
- the evolutionary history of whales and dolphins.

Present your findings in digital form. ICT

3.1 Practical investigations

1 Signs in the skeletons

Purpose

To compare vertebrate limbs.

Materials

- skeletons of human, cat, bird, frog, fish and lizard

Procedure

1. Copy the table below into your workbook.
2. Use the labelled diagram in Figure 3.1.15 of the human arm to identify the same bones in the human skeleton.
3. Move around to the various specimens and carefully observe their front and rear limbs.
4. Identify any bones that are similar to the human forearm or leg. List similarities and differences between the different animals and the human.

Results

Complete your results table for each animal.

Practical review

1. **Use** your table to **identify**:
   a. the two animal skeletons that are most alike in their limb structure.
   b. two that are least alike.
2. a. **Identify** animals that you think may have homologous limb bones.
   b. **Identify** the particular bones involved.
3. **Propose** how these animals could have skeletons that are so similar.
4. The bony fish is a vertebrate, but an extremely distant relative of these other vertebrates. **Assess** any evidence in the skeletons that indicates that fish are related to these other vertebrates, but very distantly. (Hint: Look for other homologous structures.)

Animal	Description of front limbs	Description of rear limbs
Human		
Cat		
Bird		
Frog		
Fish		
Lizard		

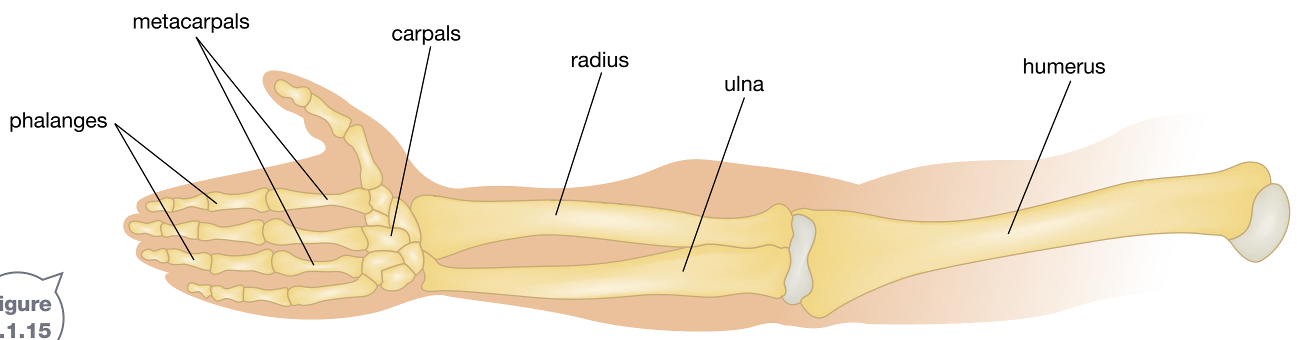
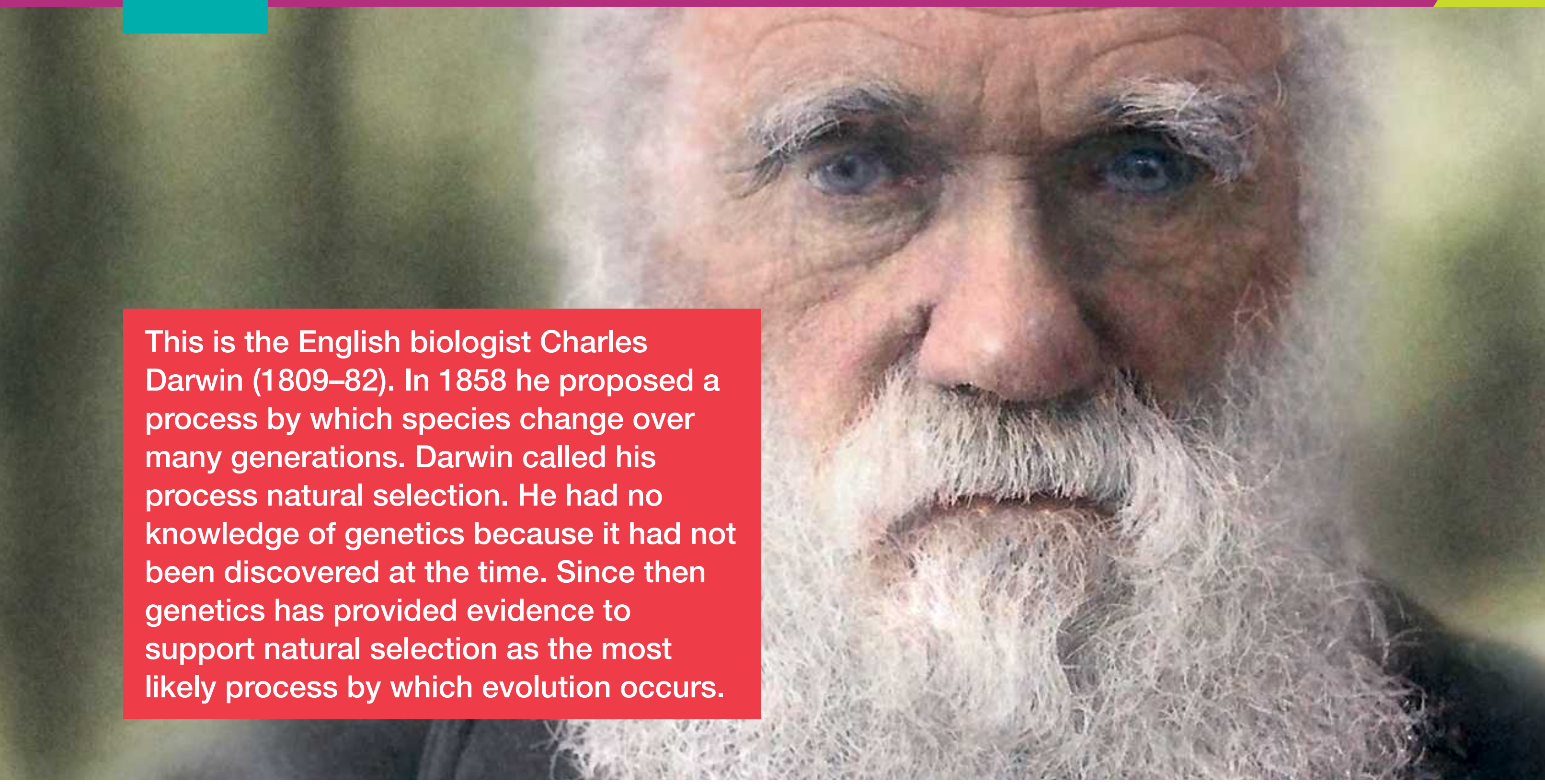


Figure 3.1.15

3.2 Natural selection



This is the English biologist Charles Darwin (1809–82). In 1858 he proposed a process by which species change over many generations. Darwin called his process natural selection. He had no knowledge of genetics because it had not been discovered at the time. Since then genetics has provided evidence to support natural selection as the most likely process by which evolution occurs.

Darwin's ideas of natural selection

The following example will help you understand what Charles Darwin meant by natural selection.

Consider a population of mice being preyed upon by owls. The mice have two different coat colours, dark brown and light brown. These colours are inherited. The owls swoop down to catch mice that are in the fields.

Imagine that there are equal numbers of dark-brown and light-brown mice. In areas where the ground is dark brown, the owls would find the light-brown mice easier to see (Figure 3.2.1). The owls would catch more light-brown than dark-brown mice. As a result, more dark-brown mice would survive and breed. The next generation would then have more dark-brown mice than light-brown mice.

The dark-brown mice have been 'naturally selected' by the owls, as opposed to artificially selected by humans. Darwin meant that the selection was done by 'nature,' not humans. The dark-brown mice had been selected to breed, but it was not intentional. They were favoured by selection to produce the next generation of offspring. Over many generations, this process would continue and the population would gradually become all dark brown and therefore better adapted to its dark brown environment.

This example of natural selection came from a study in Arizona, USA. In this study, the researchers also found that on light brown soil, owls caught more dark brown mice than light brown mice. More light brown mice survived and so the population gradually changed to have a higher proportion of light brown mice.

This story of the mice shows how natural selection might change the characteristics of a population. Studies like this have been performed on a wide range of species.

Figure 3.2.1 Camouflage enhances the chance mice will survive. Predators will see mice more easily if the mice are a different colour to that of the ground.

Natural selection defined

Natural selection is the process where an environmental factor acts on a population and results in some organisms having more offspring than others.

The environmental factor that acts on the population is known as the **selective agent**. The selective agent may be a biotic factor (another living thing), such as a bacterial infection, a competitor or a predator such as the falcon in Figure 3.2.2. It could lso be an abiotic factor (a physical factor), such as temperature, water, soil nutrients or fire (Figure 3.2.3).

Figure 3.2.2 The falcon is a selective agent on the pigeon population. It affects features such as how fast and how agile the pigeons become.

Figure 3.2.3 Fire is a selective agent in Australia. Trees with thicker bark are more likely to survive a fire because the bark can protect the living tissue underneath.

Many selective agents act by killing individuals. Such individuals are often less suited to surviving and are referred to as 'poorly adapted' or 'less fit'. For example, predators may find them easier to catch because they are slower runners, have poorer eyesight or are more easily seen. For example, light-coloured mice are poorly adapted and less fit to survive on dark soil.

Selective agents do not always act by killing. For example, female birds often select brighter coloured males for breeding. Those males will produce more of the offspring in the next generation (Figure 3.2.4). Darwin called this **sexual selection**, because he thought of natural selection as being something that kills. Nowadays sexual selection is considered to be an example of natural selection because both change the characteristics of a species through selection.

Figure 3.2.4 This male great frigate bird with his air-filled throat pouch is trying to attract the female. Females are attracted to males with the most prominent red pouch.

The individuals that are favoured by the selective agent pass on their features to the next generation. So the next generation inherits those selected features. One outcome of natural selection is that the species gradually becomes better adapted to its environment. For example, the whole population of mice becomes more like the colour of the ground it lives on.

Variation

Darwin concluded that natural selection could only act if there is **variation** (natural differences) in the population. However, genetics was unknown in his time and so he did not know how or why this variation happened.

Since then, scientists have shown that variation is caused by differences in genes, which result in different characteristics. As genes are inherited, so too are the characteristics they carry. Hence, variation is inherited too. Variation in most organisms is relatively easy to see. For example, humans show variation in height, nose shape, hairiness, baldness, leg length, and hair, eye and skin colour.

INQUIRY science 4 fun

Observing variation

YES

Do this ...

1 Go outside into the garden or the bush. Try to find many plants of the same type (species).

2 Choose a particular feature such as flower structure or colour; leaf shape, size and colour; or fruits (seed cases).

3 Study many examples of your chosen feature, looking for any variation you can see in it.

Record this ...

Describe any differences you observed.

Explain what you observed.

Genetics and natural selection

A more modern definition of natural selection can be expressed in terms of genetics. Natural selection is the change in proportion of a particular genetic make-up (genotype) of a species over many generations due to environmental selection of a particular characteristic (phenotype). In simpler terms, this means the proportion of a particular characteristic (phenotype) in a species changes because individuals with a particular genetic make-up (genotype) within it are being favoured to breed.

GO TO Unit 1.3

Evidence for natural selection

The effects of natural selection only become obvious after many generations. This makes it nearly impossible to observe in organisms that have long generation times, such as humans and elephants. The effects of natural selection are easier to observe in organisms that produce many generations in a short time, such as rabbits, cane toads, insects and bacteria.

The peppered moth

One of the first studies to collect evidence for natural selection was conducted last century in England. Henry Bernard Kettlewell studied the peppered moth, which existed in two forms. The normal colour was white with black specks. Occasionally all-black mutant moths were born.

Kettlewell found that in the cities, almost all the peppered moths were black. In rural areas, they were almost all white. He concluded that this difference was due to selective agents acting on the populations. The selective agents were birds preying on the moths.

Kettlewell explained the process as follows:

- In the cities, all the building and tree trunks had been blackened by soot from over 150 years of industrial pollution. Any white moths resting on the trees could be seen more easily than the black moths (Figure 3.2.5). So the birds removed white moths faster than they removed the black ones. Black moths produce black offspring and so the population eventually became mainly black. So, the black form was considered to be better adapted to its polluted city environment.
- In rural areas, the air was cleaner and tree trunks were of a lighter colour. This made the white moths harder to see (Figure 3.2.6). The black moths were eaten more often and so the population eventually became nearly all white. Now the white moths were better adapted to their environment.

Figure 3.2.5 Black and white peppered moths on a dark background

Figure 3.2.6 Black and white peppered moths on a light background

Kettlewell carried out experiments in which he placed the two different colours of moths on tree trunks and then observed birds feeding on the moths. He counted the numbers of light and dark moths eaten. His results showed that the birds ate mostly the dark moths on the light-coloured tree trunks and light-coloured moths on dark tree trunks. Some results are shown in Table 3.2.1.

Table 3.2.1 Natural selection of moths by birds

Place and background colour	Number of moths observed	Percentage dark eaten	Percentage light eaten
Birmingham Wood—dark tree trunks	58	26%	74%
Dorset—light tree trunks	190	86%	14%

More than 100 species of moth in England have since been shown to demonstrate the same colour changes as observed by Kettlewell. Several of these studies have shown that the dark form of moth has declined in numbers in cities where pollution is now controlled.

Similar examples of camouflage against background colour have been found in many other places around the world in species as varied as mice, snakes and snails.

Natural selection highlights how much the environment affects living organisms, causing the characteristics of a species to change over many generations.

Prac 1 p98
Prac 2 p99
3.2

Natural selection of insects

In the middle of last century, chemical insecticides began to be sprayed onto crops to kill insects and reduce crop damage caused by them (Figure 3.2.7). It was thought the insecticides would kill all the insects and that food production would rise greatly. However, these insecticides were only effective for a few years, requiring farmers to increase the concentrations of the insecticides they used. Also, not all the sprayed insects died. Eventually the sprays had no effect, and none of the insects died. The scientists called this ability of insects to survive the poison spray **resistance** (Figure 3.2.8).

Figure 3.2.7 Spraying crops with insecticides to kill insect pests

Figure 3.2.8 The diamond backed moth is a pest in vegetable crops such as cabbage and broccoli. It was the first crop pest in the world to develop resistance to the insecticide DDT. The moth is now resistant to all insecticides used before the mid-1990s.

Although triggered by humans, the development of resistance to insecticides by insects is an example of natural selection.

The resistance that developed in insects was due to several mechanisms. One was that some insects could destroy the poison in their bodies. They had inherited cell chemistry that could do this. So there was variation in cell chemistry.

The resistant insects survived when the population was sprayed, but the non-resistant insects all died. The resistant insects then bred and produced offspring, most of which inherited resistance. Every time the farmers sprayed, there would be a larger proportion of resistant insects on the crops. As many farmers sprayed over a large area, the insect population quickly became resistant. This process is shown in Figure 3.2.9.

1 Some insects have a natural resistance to pesticides.

2 Plants are sprayed. Only the resistant insects survive.

3 Other insects move into the area. These breed with the resistant ones. Some of the offspring are resistant.

4 When plants are sprayed again, more resistant insects survive.

Figure 3.2.9 Insects become resistant to insecticides by natural selection.

Natural selection in bacteria

Bacteria are microscopic single-celled organisms. Some cause infectious diseases such as cholera, typhoid and pneumonia. In 1928, Scottish scientist Alexander Fleming found a way to kill bacteria. He discovered that some fungi make special chemicals to defend themselves against bacteria. The chemicals were given the name **antibiotics**. The first one to be isolated was called penicillin. Many more types of antibiotic have since been discovered.

Doctors sometimes prescribe antibiotics to kill any bacteria that are infecting you. This practice became widespread in medicine in the last few decades of the 20th century, and several types of antibiotics lost their effectiveness against many different bacteria. The bacteria had become resistant to them. You can see this in Figure 3.2.10.

GO TO Pearson science NSW 9 Unit 7.1

Bacteria became resistant to antibiotics by natural selection. In the millions of bacterial cells infecting a person, some may have inherited cell chemistry that can destroy the antibiotic molecules, or may resist the antibiotic in some other way. This is similar to the resistance insects had to pesticides. When you take the antibiotic, it kills all the bacterial cells that are not resistant. Any resistant ones may survive and reproduce, forming resistant offspring.

Bacteria reproduce by dividing in half, producing two copies of themselves. Each half divides again, often within 20 minutes. Hence, every 20 minutes or so the number of bacteria inside you could double. Eventually there will be enough resistant bacteria to make you ill. At this stage, taking more of the antibiotic will not work. You will need a different antibiotic, one to which the bacteria is not already resistant.

One very dangerous type of bacteria is golden staph, *Staphylococcus aureus*, seen in Figure 3.2.11. Golden staph is resistant to many antibiotics, and is very difficult to kill. It became resistant because of the widespread use of antibiotics in hospitals. Constant antibiotic use in hospitals kept selecting the resistant bacteria to survive. Eventually the species became resistant.

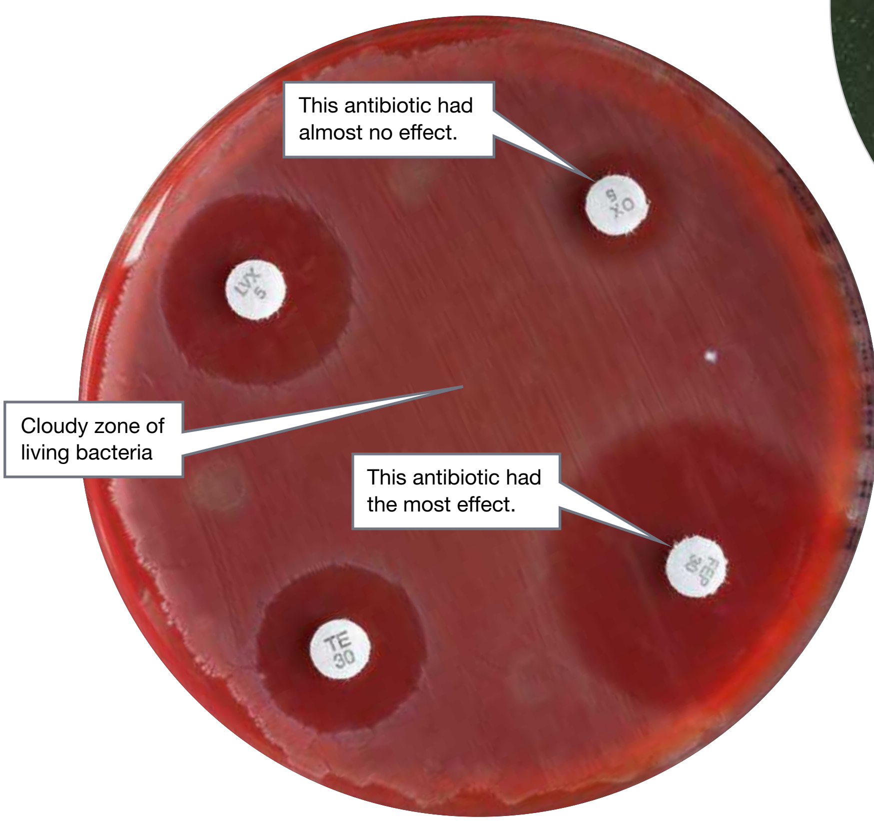


Figure 3.2.10 Testing antibiotics on bacteria growing in a dish. Each white disc contains a different antibiotic. The clear zone around a disc shows that the antibiotic killed the bacteria around it. The antibiotic at the top right had little effect because the bacteria were resistant to it.

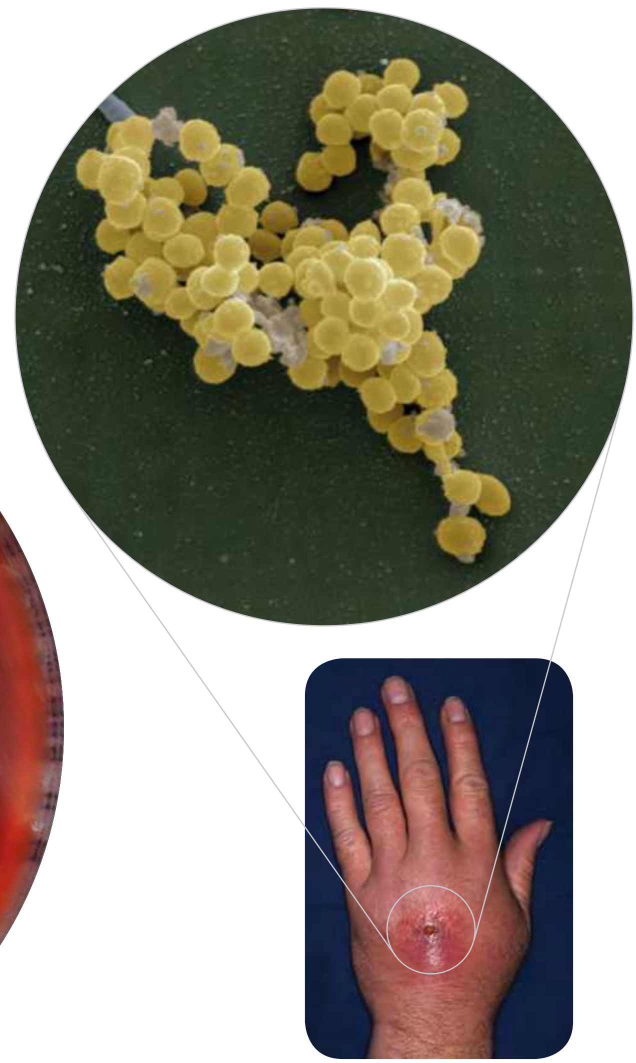


Figure 3.2.11 *Staphylococcus aureus* bacteria and a surgical wound infected with *Staphylococcus aureus*

3.2 Unit review

Remembering

1 **Name** the process proposed by Charles Darwin that explained how a species can change over many generations.

2 **List** four different selective agents.

3 **List** five examples of variation in humans.

Understanding

4 **Modify** the following definition of natural selection to make it correct.

Natural selection is the change in proportion of a particular phenotype of a species over many generations, due to environmental selection of a particular genotype.

5 *Eucalyptus regnans* (mountain ash) is a tall, straight gum tree that grows in dense forests. *Eucalyptus pauciflora* (snow gum) is short and twisted and grows in the Snowy Mountains. **Explain** why these different species of gum trees would be unlikely to survive if they swapped locations.

6 **Define** the term *resistance*. L

7 **Explain** how light-coloured peppered moths gradually died out in the cities where pollution had changed the environment.

8 **Explain** why variation is necessary before natural selection can occur.

Applying

9 Consider the examples of natural selection in insects and bacteria in this unit.
- a **Identify** the selective agents in each case.
- b **Identify** the inherited variation in each case.

10 By 1950, wild rabbits had become such a pest in Australia that the myxoma virus was released. The virus initially killed 99.8% of wild rabbits. Only 25% of wild rabbits were killed by the disease a decade later. **Use** natural selection to **explain** why:
- a the rabbit population became more resistant to the disease
- b the myxoma virus may have become weaker.

Analysing

11 **Compare** natural selection and artificial selection.

12 Charles Darwin described natural selection as the *preservation of favourable variations and the rejection of injurious variations*. **Compare** his definition with those given on pages 98 and 99.

Evaluating CCT

13 **Analyse** the data in Table 3.2.1 on page 95 and **justify** the conclusion made by Kettlewell.

14 **Propose** what would happen to populations of dark- and light-coloured mice living on light-coloured soil.

15 **Evaluate** whether humans have been and are still subject to natural selection.

16 **Evaluate** whether an individual organism can become adapted during its lifetime.

17 Spraying crops with pesticides has caused the development of pesticide-resistant insects. This is given as an example of natural selection at work despite humans being involved in the spraying.
- a **Identify** the agent for natural selection in this case.
- b **Assess** whether the example would be better classified as an example of artificial selection.
- c **Justify** your answer.

Creating CCT

18 **Construct** a flow chart explaining how one of the following adaptations might have developed through natural selection: bright warning colours in poisonous insects, venom in snakes, wings on dinosaurs.

19 Several early science fiction movies showed humans several million years in the future. They showed us with a huge brain and a head about twice as big. **Construct** an argument opposing this point of view.

Inquiring

1 Research ways wild rabbits have been controlled in Australia since 1950.
- List the various methods used.
- Explain how these methods worked.
- Use natural selection to explain why many of these methods do not work today.

Present your findings as a page for the CSIRO website, to be accessed by farmers. ICT

2 Research recent evolutionary changes in Australian animals due to the invasion of cane toads. Find evidence:
- of evolutionary change in predators of the toads
- that the toad has evolved to spread faster.

Present your research findings in a form that would be suitable to be used in a museum, as a slide show or as an information poster. ICT

3.2 Practical investigations

1 Natural selection modelled

Purpose

To use a model to investigate natural selection and the effect of camouflage.

Materials

- 2 different-coloured A3 sheets of paper
- 2 sets of 20 toothpicks of two different colours, to match the sheets of paper
- stopwatch
- tweezers
- cup

Extension

- safety glasses smeared with petroleum jelly, or muslin material or bubble wrap

Procedure

1. Work with a partner. One person is the experimenter and the other is the subject. The subject is to copy the table in the Results section into their workbook.
2. The experimenter mixes up the coloured toothpicks and spreads them evenly over one of the sheets of paper while the subject is copying the table. Place a cup 50 cm away from the edge of the paper.
3. The subject stands up. They will have 20 seconds to use the tweezers to pick up as many of the toothpicks as they can, one at a time. Pick them up off the paper and put them in the cup at the side of the paper. The experimenter will say when to start and when to stop.
4. When the time is up, the experimenter must count the number of each colour of toothpick the subject picked up. Write the results in your table and on the board.
5. Repeat the experiment with the other coloured sheet of paper.

Extension

6. Repeat the experiment but this time the subject needs to have 'poor vision'. You can simulate poor vision by wearing safety glasses smeared with petroleum jelly, or by blindfolding the subject's eyes with muslin or bubble wrap.

Results

1. Record all counts in your results table.
2. Calculate the percentage of toothpicks that are a different colour from the background paper. Enter these percentages into your results table.

	Toothpick		Percentage of toothpicks a different colour from paper
	Colour A	Colour B	
Good vision			
Paper colour A			
Paper colour B			
Poor vision (Extension)			
Paper colour A			
Paper colour B			

3. Collect the results from other groups in your class. Calculate a class average for each set of data. N
4. Copy the class results into your workbook.

Practical review

1. **Identify** which were picked up more often: toothpicks the same colour as the background paper, or toothpicks a different colour from the paper.
2. **Compare** the effect of good vision and poor vision on the results.
3. **Discuss** how this experiment models the effect of camouflage on natural selection.
4. **Evaluate** whether this experiment was effective in modelling the effect of camouflage on natural selection.

2 Deciphering natural selection

Purpose

To construct two flow charts describing natural selection.

Materials

- 4 sheets of paper
- scissors
- sticky tape or glue

Procedure

1 Copy the sentences in List 1 in the table below onto a sheet of paper. Put the heading *Darwin and natural selection* at the very top.

List 1: Darwin and natural selection		List 2: Genetics and natural selection	
1	Population becomes more like the better adapted individuals.	1	Resources are food, shelter, mates etc.
2	Variation is inherited.	2	Genetic variation is inherited.
3	Many of least adapted individuals die or produce few young.	3	Better adapted phenotypes produce more offspring.
4	All organisms struggle for resources and to avoid disease and predators to survive.	4	All organisms struggle for resources and to avoid disease and predators in order to survive.
5	There is natural variation in a population.	5	Phenotypes surviving or gaining the most resources are better adapted.
6	Better adapted individuals produce more offspring.	6	There is natural genetic variation in a population.
7	Resources are food, shelter, mates etc.	7	The proportion of the better adapted genotype increases in the population.
8	Individuals surviving or gaining the most resources are better adapted.		

2 Cut around each sentence to create eight cards.

3 With your prac partner, discuss how to arrange the cards so that they accurately describe the process of natural selection.

4 Once satisfied with your arrangement, paste the sets of cards onto a page.

5 Evolution was described above using descriptions in List 1 similar to those Darwin used.

Evolution can also be described using genetics. Copy the sentences in List 2 onto another sheet of paper. Put the heading *Genetics and natural selection* at its very top.

6 As before, cut around each sentence. Arrange the seven cards to accurately describe natural selection.

Practical review

1 **Compare** each of your flow charts with those produced by other prac groups.

2 **Assess** how this activity helped you understand how a species might change over time.

3.3 Speciation and evolution

The theory of evolution by natural selection proposes that all species are related. Some species, like these finches collected by Charles Darwin, are more closely related than others. However, ultimately all life should be able to be traced back to one original species. An important process in evolution is speciation—the formation of new species.

Evolution

Charles Darwin proposed that natural selection could result in the formation of new species. In his 1859 book *On the Origin of Species*, he called this 'modification by descent' rather than evolution. The term *evolution* was applied to his work by other scientists.

The earliest hints of Darwin's theory can be found in his first book *The Voyage of the Beagle*, written in 1845. This book describes his epic journey around the world between 1831 and 1836. On this voyage, Darwin studied many different species in many different environments, including the Andes Mountains, the coast of Australia and the Galapagos Islands. It was on these islands that he studied differences in the beak shapes of finches. Some of his results are shown in Figure 3.3.1.

Each of the fifteen finch species had beaks that seemed as if they had been 'selected' for the different food sources found on the different islands. Some beaks were perfect to suck nectar from a flower while others were better shaped to crack seeds open or catch insects. Darwin proposed that the birds were all related to each other and had somehow changed to suit the different islands on which they lived.

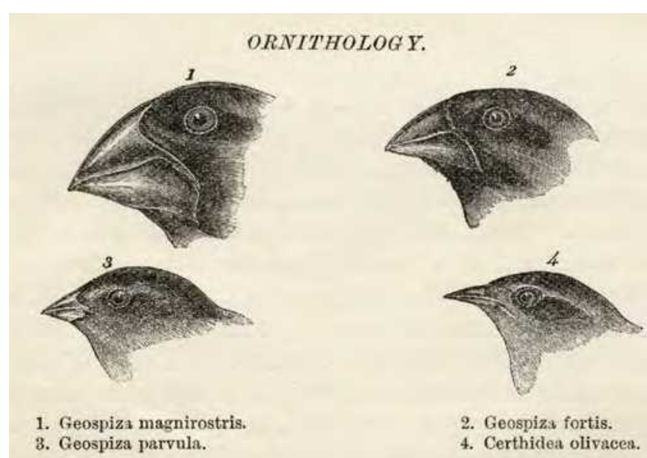


Figure 3.3.1 This illustration from Darwin's book *The Voyage of the Beagle* shows the finch beaks that started him thinking about species being able to change.

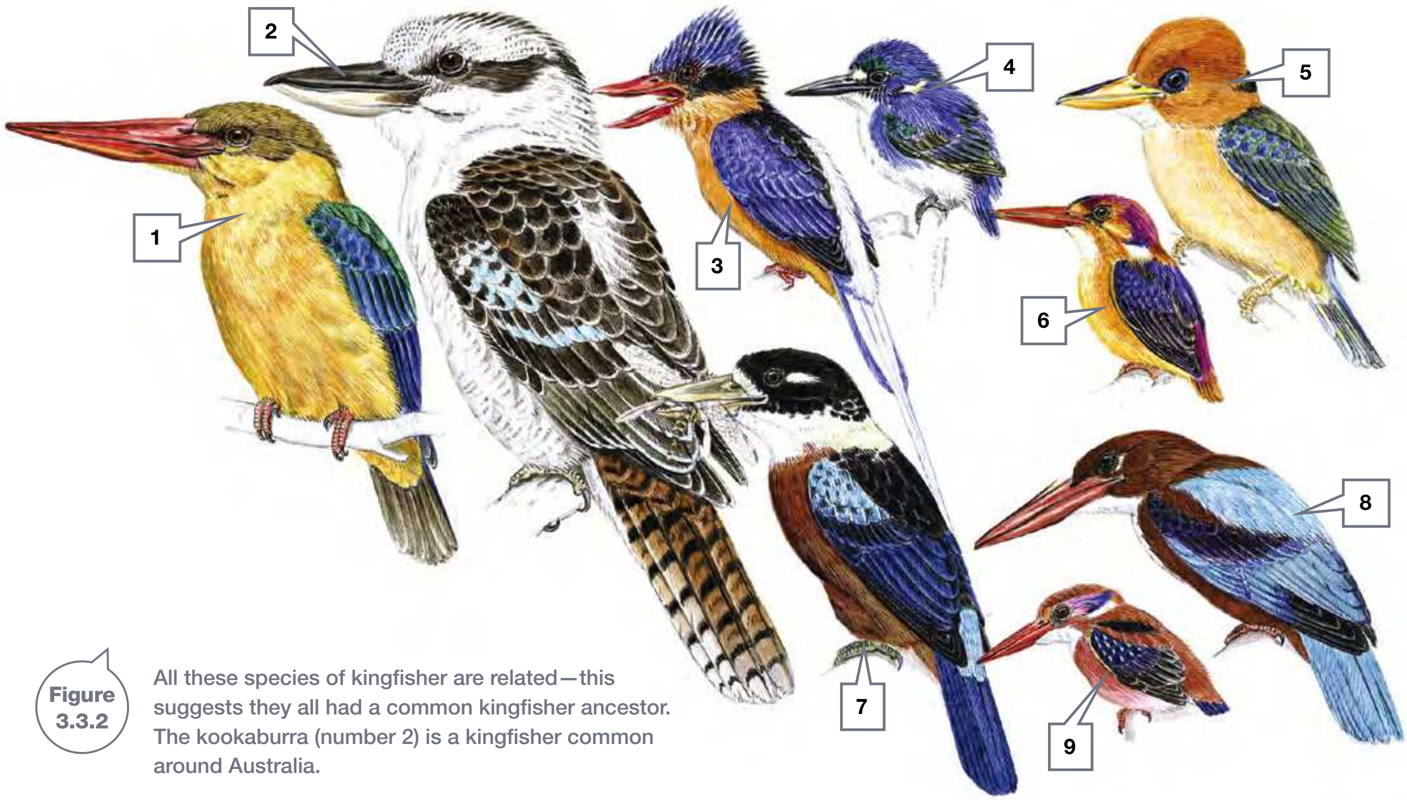


Figure 3.3.2 All these species of kingfisher are related—this suggests they all had a common kingfisher ancestor. The kookaburra (number 2) is a kingfisher common around Australia.

What is a species?

It is impossible to determine whether two organisms are the same species from their anatomy. In the past, the test for a **species** was to see if two organisms could interbreed to produce fertile offspring under natural conditions. They were only considered to be the same species if they could produce fertile offspring. For example, a horse can breed with a donkey to produce a mule. The mule produced is always sterile and so the horse and donkey are different species.

This interbreeding test can still be used to classify living organisms at the species level. However, these days biologists study DNA and also identify the similarities in the amino acid arrangement in the proteins they make. Since proteins are made by genes, identical proteins must mean identical genes (or at least genes that are very similar). Fossil DNA and proteins are also being analysed to help define relationships. There are now laboratories that specialise in analysing DNA samples from ancient fossilised bones.

The theory of evolution states that similar species must be closely related to each other. For example, all nine species of kingfisher in Figure 3.3.2 have some similarities and so all descended from the same ancestral kingfisher.

However, some of these kingfishers are more closely related than others:

- The kingfishers labelled 4, 6 and 9 are commonly called river kingfishers. All belong to the same sub-family and so all are related to one another.
- Kingfishers 6 and 9 belong to the same genus *Ceyx*. This makes them very closely related.
- Kingfisher 4 belongs to the genus *Alcedo*. This makes its relationship with kingfishers 6 and 9 more distant than if they all belonged to the same genus.
- The other six species of kingfishers are much more distantly related to the river kingfishers. This suggests that these six species separated into a different breeding line at a different time.

Speciation

Speciation is the process by which one species splits into two or more separate species. It is responsible for the formation of any new species that appear in the fossil record.

Speciation has resulted in the high level of biodiversity on Earth. **Biodiversity** refers to the number and range of different species that exist, either on the whole Earth or in any of Earth's ecosystems.

The process of speciation occurs in three basic steps:

- variation
- isolation
- selection.

Step 1. Variation

There must be variation in the population or speciation cannot occur. This is because natural selection is involved, and selection can only act on variation that is already present in the population.

Step 2. Isolation

The formation of new species requires **isolation**. This means that different groups of the population are prevented by some mechanism from interbreeding. Isolation prevents gene flow throughout the population, stopping any differences in one population from reaching the other population. For example, any new genes that arise by mutation in one isolated population cannot spread to the other isolated population. Figure 3.3.3 shows an example of one way in which speciation can occur.

Isolation into separate populations occurs in several ways, for example by a geographical or climatic barrier. Geographical barriers are oceans, rivers, mountain ranges and gorges. Climatic barriers include rainfall, temperature, salinity, ocean currents and sunlight.

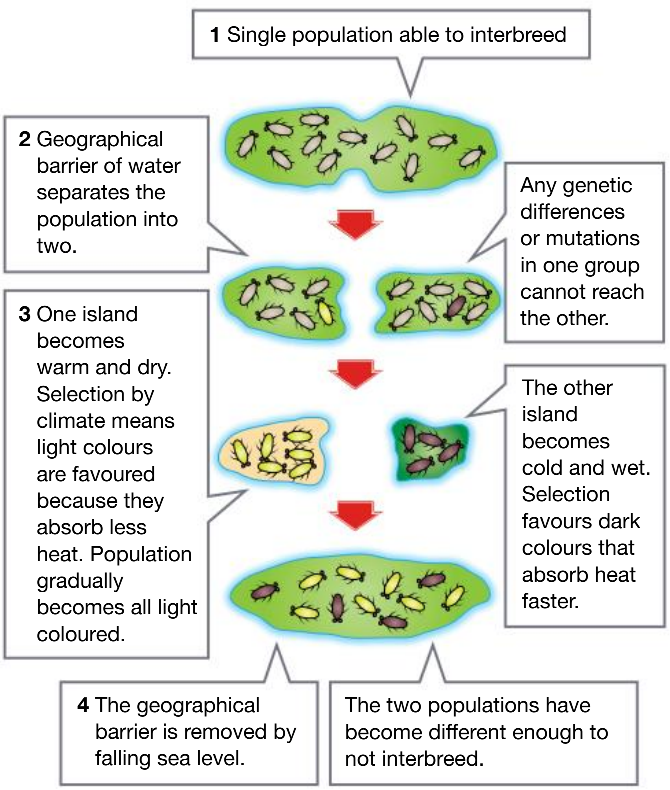


Figure 3.3.3 Speciation is the formation of new species from a common ancestor.

Step 3. Selection

Once isolated by barriers, natural selection affects the genotype and causes changes that prevent the groups breeding even if they came back together again at some time in the future. There are many possible changes. A few examples are:

- courtship behaviour—animals may develop different breeding songs, displays and rituals
- breeding seasons—animals may breed at a different time of year
- sterility—animals may breed but the offspring are sterile (like mules)
- chemical barriers—sperm may be killed by the chemistry of the female.

Prac 1 p108

Evidence for evolution

The theory of evolution by natural selection is supported by a great deal of evidence.

Fossils

Early fossils are of fairly simple organisms and later ones are increasingly complex. This makes sense in terms of genetics because new alleles and genes develop from existing genes by mutation. It seems unlikely that complex organisms (with many different genes) would develop first and become simpler (with fewer genes).

The fossil record also shows that there is an increasing number of species that have lived on Earth. Many of these species became extinct along the way, such as the dinosaurs, the diprotodons and marsupial lions. The increasing number of species (increased biodiversity) supports the theory of evolution because that is what you would expect if species continually split into two or more other species over time.

Fossils showing **transitional forms** have also been found. For example, there are transitional forms that show that a group of small dinosaurs had feathers. *Archaeopteryx* and *Anchiornis* (Figure 3.3.4) are examples. Their fossils suggest that one group was in the process of changing from dinosaurs to birds. Transitional forms are hard to classify because they have features of two different groups. In the case of feathered dinosaurs, they have the features of both reptiles (class Reptilia) and birds (class Aves).

Lobe-finned fish are another transitional fossil group that are part fish and part amphibian. They suggest a way in which life moved from the sea and onto the land.

Figure 3.3.4 An artist's impression of the feathered dinosaur *Anchiornis*. Studies of fossilised feathers enabled scientists to decide what colour the feathers would have been in life.

Comparative anatomy

Comparative anatomy compares the structures of organisms of both living species and fossils. Homologous structures fit into this category. Homologous structures such as pentadactyl limbs provide strong evidence for evolution from a single vertebrate ancestor (Figure 3.3.5).

Prac 2 p109 3.4 3.5

GO TO Unit 2.3

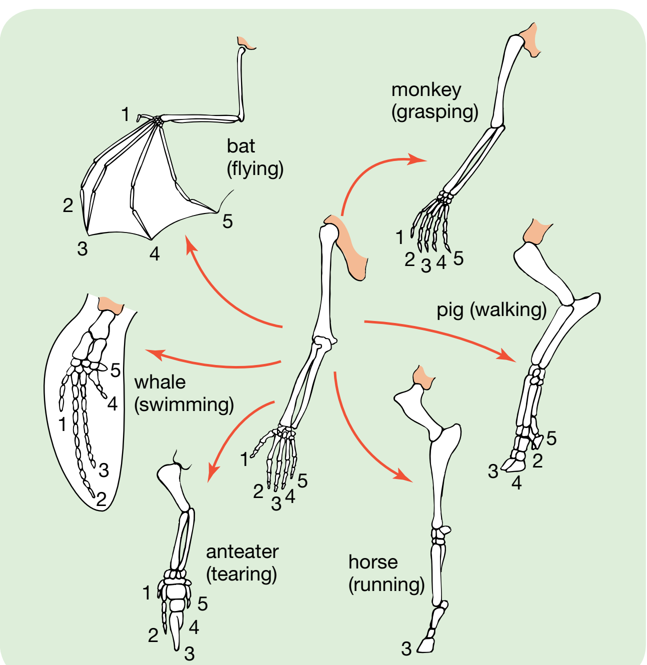


Figure 3.3.5 The pentadactyl limb of vertebrates is a homologous structure that provides evidence for evolution.

DNA and protein structure

All living cells have the same basic DNA structure and use the same genetic code. Organisms that have similar anatomy show more genes in common than organisms that are less alike. For example, 96% of the genes in humans and chimpanzees are identical. This is strong evidence supporting evolution—you would expect that two species and their common ancestor would have much of their DNA the same.

Proteins are made up of amino acids arranged in a sequence, much like beads on a chain. The sequence of these amino acids is controlled by genes. These sequences can be used to compare how closely related species are. This is mostly done with living species, but the DNA and proteins from fossils can be analysed as well.

Cytochrome c is a protein found in all living organisms. Comparing how many amino acids are in the same positions on the cytochrome c protein chain can provide some idea of how closely two species are related. For example, cytochrome c of humans and rhesus monkeys differ only at one position. In contrast, cytochrome c of humans and bullfrogs differ at 18 positions. All this suggests that we are closely related to monkeys but much more distantly related to frogs. However, studying only one protein like this is unlikely to give a definite answer about how closely two species are related. Many more proteins need to be studied to make such judgements. You can see more of these comparisons in Table 3.3.1 and Figure 3.3.6 on page 104.

Table 3.3.1 Number of positions with differences in the amino acid present in cytochrome c protein

	Human	Monkey	Kangaroo	Chicken	Turtle	Tuna	Moth
Human	0	1	10	13	15	21	31
Monkey	1	0	11	12	14	21	30
Kangaroo	10	11	0	12	11	18	28
Chicken	13	12	12	0	8	17	28
Turtle	15	14	11	8	0	18	28
Tuna	21	21	18	17	18	0	32
Moth	31	30	28	28	28	32	0

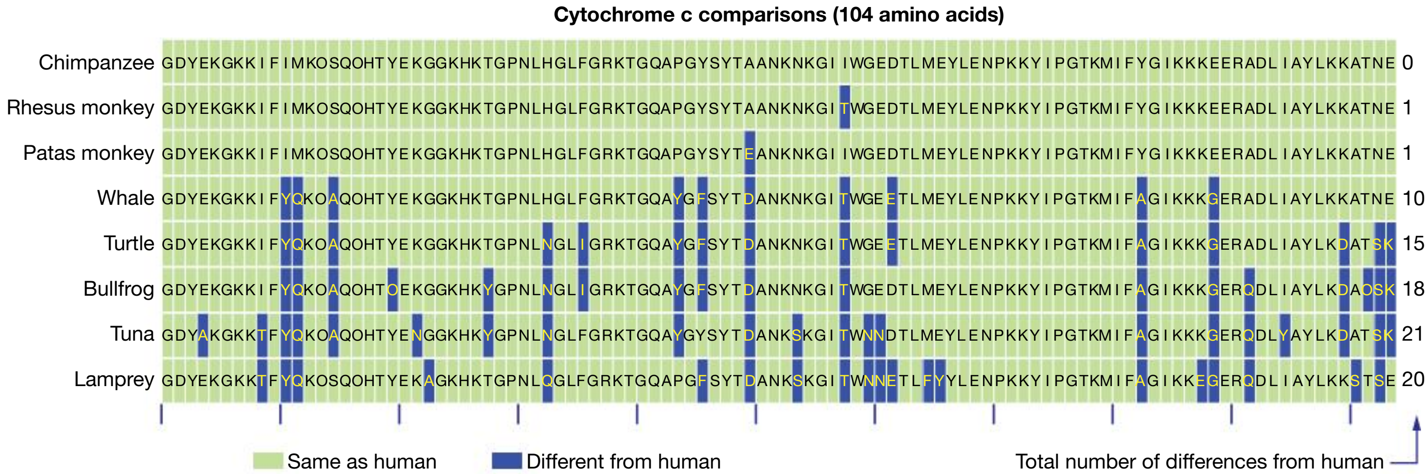


Figure 3.3.6 The amino acid sequences in cytochrome c are shown here for eight different vertebrates. The letters stand for different amino acids.

Distribution of current species

Scientists call a map of all the places where a species occurs the **distribution** of the species. When studying distributions, it is very obvious that many unique species occur on isolated islands. With evolution, you would expect to find unusual species on particular islands because isolation is necessary before speciation can occur.

An example is the honeycreeper bird found only on the Hawaiian islands. Two of their many species are shown in Figure 3.3.7.

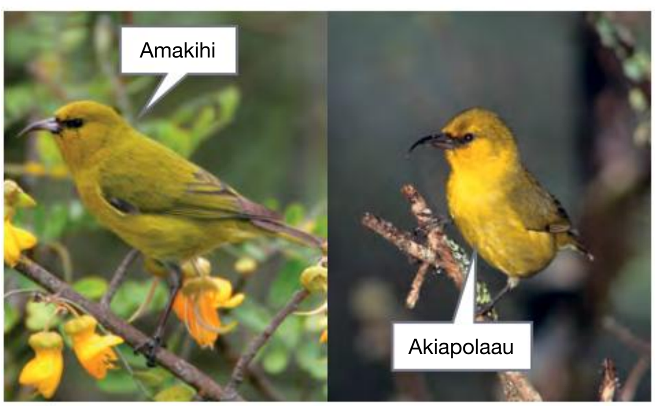


Figure 3.3.7 The Amakihi and Akiapolaau evolved 450 km apart on different Hawaiian islands. The birds are different species but belong to the same genus, indicating that they are closely related.

Embryology

Embryology is the study of the development, structure and function of embryos like the one in Figure 3.3.8. Comparisons of vertebrate embryos show striking similarities in the early stages of their development. For example, they all have a 'tail.' There is also a time during the embryonic development of fish, lizards and humans when all have branchial arches. These are arch-shaped structures in the throat region.

In humans, the parathyroid glands (endocrine glands in your neck) develop from the branchial arches. Two of the arches grow into the bones in your middle ear. In reptiles, their lower jaws grow from one of the arches. In fish, a gene called Gcm-2 controls the development of the branchial arches into gills. If the gene mutates (or if scientists prevent it working), then the gills fail to develop. In chick embryos, the Gcm-2 gene turns two of the arches into the parathyroid gland. When scientists prevent the gene from working, the parathyroid gland fails to develop. So vertebrate embryos have structures that appear to be homologous on the basis of anatomy. Studying the relevant genes shows the same gene has produced different effects in two different species. Somehow the Gcm-2 gene has changed in its effect on the branchial arches from one species to another.

So the development of mammals, reptiles, birds and fish are linked to the branchial arches. Biologists long ago proposed that fish evolved into amphibians, which evolved into reptiles, which evolved into birds. Evidence from studying embryos including branchial arches supports this idea.

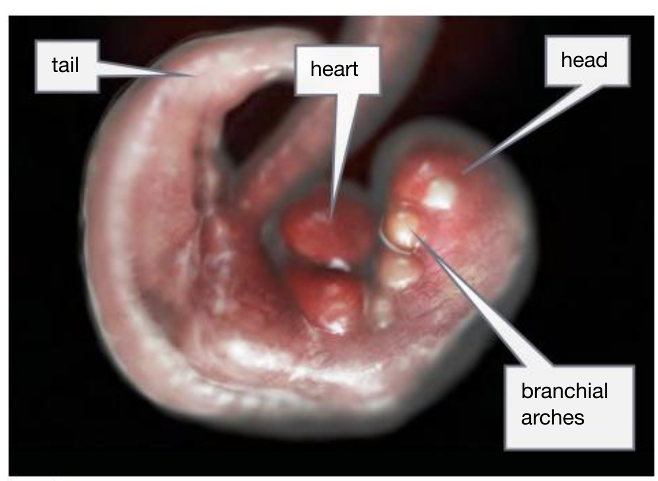


Figure 3.3.8 Human embryo at 4 weeks, showing the branchial arches typical of vertebrate embryos

LEARNING ACROSS THE CURRICULUM

CRITICAL AND CREATIVE THINKING

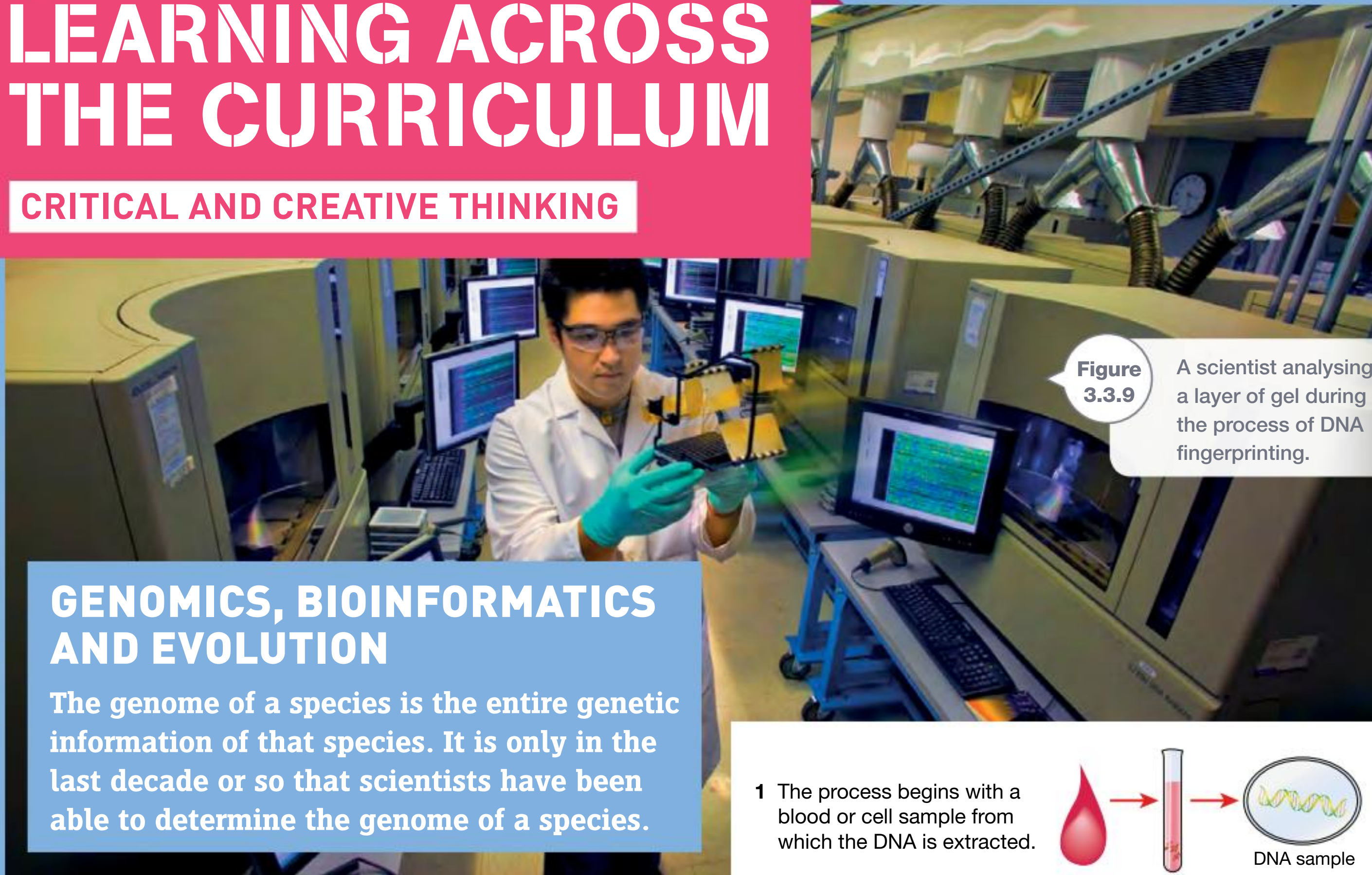


Figure 3.3.9 A scientist analysing a layer of gel during the process of DNA fingerprinting.

GENOMICS, BIOINFORMATICS AND EVOLUTION

The genome of a species is the entire genetic information of that species. It is only in the last decade or so that scientists have been able to determine the genome of a species.

Bioinformatics assists scientists in the use of this genetic information to understand evolutionary relationships. Bioinformatics is the use of computers to store detailed information such as genetic codes of species for use by researchers around the world.

Genomics is the study of the genome structure and function. Comparing the genomes of different species has given biologists a better understanding of evolution and the classification of organisms.

Genomics uses many techniques, one of which is DNA profiling, also known as DNA fingerprinting. Part of the process is shown in Figure 3.3.9.

The process of DNA fingerprinting is very complex, but a simplified version is shown in Figure 3.3.10.

REVIEW

1 **Define** these terms. L

- a genome
- b bioinformatics

3 **State** the importance of bioinformatics in evolutionary research.

4 **Outline** the process of DNA profiling.

5 **List** two important findings from genomics that support the theory of evolution.

1 The process begins with a blood or cell sample from which the DNA is extracted.

2 The DNA is cut into fragments using a restriction enzyme. The fragments are then separated into bands using a technique called electrophoresis.

3 The DNA band pattern is transferred to a nylon membrane.

4 A radioactive DNA probe is introduced. The DNA probe binds to specific DNA sequences on the nylon membrane.

5 The excess probe material is washed away, leaving the unique DNA band pattern.

6 The radioactive DNA pattern is transferred to X-ray film. When developed, the resultant visible pattern is the DNA fingerprint known as an autoradiogram (Figure 3.3.9).

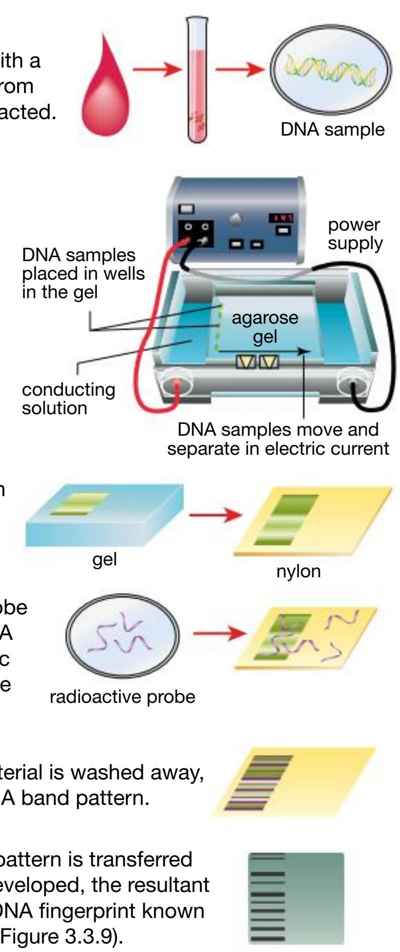


Figure 3.3.10 The steps involved in DNA fingerprinting

GO TO Unit 9.2

3.3 Unit review

Remembering

1 **Name** the term now used for the process that Charles Darwin called *modification by descent*. L

2 **List** three ways of determining if two organisms are the same species.

3 **List** the three main steps in the process of speciation.

4 **List** four reasons why two very similar animals might not be able to mate.

5 **List** homologous structures in fish and bird embryos that have been shown to be affected by the gene called Gcm-2.

Understanding

6 **Explain** what is meant by *genetic isolation*.

7 It has long been known that horses and donkeys are different species. **Explain** the evidence that shows this.

8 **Discuss** how the fossil record supports the theory of evolution.

9 **Explain** why a barrier is necessary before speciation can occur.

10 **Summarise** six important pieces of evidence that support evolution.

11 **Explain** how the Gcm-2 gene observed in fish and bird embryos supports the theory that birds are related to fish.

Applying

12 **Use** the model of speciation to **explain** why isolated islands often have a high proportion of species not found elsewhere, even on neighbouring islands.

13 Some early lobe-finned fish are difficult to classify into fish or amphibians, because they have features of both. **Demonstrate** how such difficulties support the theory of evolution,

14 **Use** the concept of speciation to **demonstrate** how biodiversity (a wide variety of species) developed on Earth.

Analysing

15 **Distinguish** between:

a evolution and natural selection

b speciation and natural selection

c evolution and speciation.

Evaluating CCT

16 There is no difference in the sequence of amino acids on the cytochrome c molecules of present-day humans and apes. However, monkeys and humans have one difference, while humans and kangaroos have ten differences.

a **Use** this information to **identify** whether apes, monkeys or kangaroos shared the most recent common ancestor with humans.

b **Justify** your answer.

17 Scientists studying vertebrates in the 1800s and 1900s proposed that they had a common fish ancestor. They proposed that lobe-finned fish evolved into amphibians, which evolved into reptiles, while mammals and birds both evolved from separate branches of the reptiles. **Evaluate** whether the newer evidence in Table 3.3.1 on page 103 supports the proposal of the early biologists.

Creating CCT

18 **Construct** a series of steps by which two different species of mice could develop from one species after the formation of a deep canyon.

19 **Construct** a diagram showing a series of steps by which two different species of frogs could develop after the formation of the desert of the Nullarbor Plain. Both species came from one species that was originally spread from Western Australia to Victoria (Figure 3.3.11).

Figure 3.3.11 The Nullarbor Plain separating the original distribution of a frog species (in blue) into two groups.

20 Mimicry is a process by which one species of animal (known as the mimic) evolves to look like another species (known as the model). For example, consider the insects in Figure 3.3.12.

Construct a likely sequence of events that could explain how the mimic evolved to appear like the wasp.

Figure 3.3.12 The German wasp (European wasp) has a painful sting and is usually avoided by predatory birds. The hoverfly is preyed upon by the same birds and is considered to be a mimic of the wasp.

Inquiring

1 Darwin's theory of evolution through natural selection caused controversy at the time of its publication. Research:
- the reactions to Darwin's theory
- why Darwin was commonly portrayed as an ape or monkey in cartoons of the time
- the names of scientists who supported and rejected Darwin's theory.

Present your research in digital form. ICT DD

2 Research the contribution to evolutionary thought in two books written by Charles Darwin. The books are online at several sites. ICT
- Read the first paragraph of Chapter 4 of his 1859 book *On the Origin of Species*. Clarify his definition of natural selection.
- State Darwin's proposal about the origin of the finches he referred to in Chapter 17, dated 8 October, in his 1845 book *The Voyage of the Beagle*.
- Comment on the influence Darwin had on scientific thought.

Present your findings in written form.

3 Alfred Russel Wallace developed the theory of natural selection at about the same time as Charles Darwin. Research Darwin and Wallace and compare:
- the backgrounds of each scientist
- where each worked while developing their theories
- how and when each first published their ideas of natural selection.

Present your findings as a digital presentation. ICT

ADDITIONAL

4 Investigate computer models that use the theory of evolution through natural selection to predict the changes in a population. Several websites use models in which imaginary creatures are subjected to environmental changes.

When searching, use the key terms *evolution animations* or *evolution survival game*. Describe one computer model you investigated. Assess the strengths and weaknesses of using a model such as this to understand evolution. ICT

5 Research how information technology is involved in bioinformatics. In particular:
- outline the scope of bioinformatics
- discuss the meaning of computational evolutionary biology
- give examples of how bioinformatics has assisted in evolutionary research
- outline the information technology jobs that are related to bioinformatics.

Present your research findings in digital form. ICT

ADDITIONAL

3.3 Practical investigations

1 Camouflage in the garden

Purpose

To find examples of animal camouflage.

Materials

- hand lens or magnifying glass
- digital camera or mobile phone with camera function
- notepaper and pen
- access to a garden

SAFETY

Do not touch any of the animals. If you are allergic to insect stings inform your teacher. Be careful of snakes and other dangerous animals.

Procedure

1. Find an area of the garden where there are many small bushes in which insects and other small animals could be hiding.
2. Make sure there are no dangerous animals hiding in the bush. Carefully search each bush looking for examples of camouflage. Do not touch any animal. If you find an example then take a photo of it.

Results

From first-hand observations or from your photos, record:

- the type or name of the plant (if you can; examples are grevillea, wattle, camellia)
- where on the plant the animal was seen (such as stem, leaf)
- a description the animal (such as type, size, colour, behaviour)
- whether the animal was well camouflaged or not.

Share your observations and/or photos with other students.

Practical review

1. **Describe** the best example of camouflage that your class found.
2. **Outline** how the animal in question 1 may have evolved to become camouflaged. Use terms such as *natural selection, selective agent, variation, isolation, genetic change, phenotype* and *genotype*.

Figure 3.3.13 This insect is camouflaged to look like real leaves. It even has brown bits as if the leaf has been damaged!

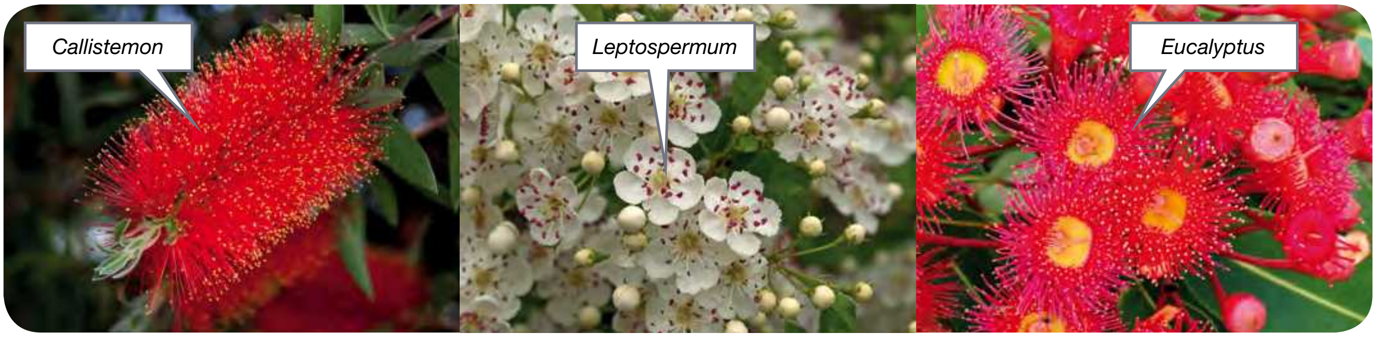


Figure 3.3.14 All these plants belong to different genera but all belong to the family Myrtaceae. This means they are distantly related.

2 Family relationships

The Myrtaceae family includes many different genera such as *Callistemon* (bottlebrush), *Leptospermum* (tea tree) and *Eucalyptus* (gum tree). Some examples are shown in Figure 3.3.14.

Purpose

To compare the structure of flowers from different genera in the family Myrtaceae.

Materials

- specimens from genera in the family key shown right
- hand lens or stereomicroscope
- Stanley trimmer for cutting through fruits
- forceps
- Petri dish
- books with illustrations or photos of members of the Myrtaceae family or access to the internet

SAFETY

Be careful handling blades.

Wash your hands after handling plant material.

Procedure

1 Your task is to use the key shown right to identify the name of the genus to which each of the plants belongs. This will involve cutting into some flowers and fruits. Your teacher will show you how to do this, or will display cut sections for you to observe. You will be using the hand lens or microscope to observe flower parts. You will need to know the names of the parts of a flower to do this activity.

2 Collect one specimen from the selection at the front of the room. Note down its number. You must write down each of the choices you make for the specimen as you proceed through the key. Finally, write down the name of the genus for the sample.

3 Use the books or internet to see if your specimen looks like the images shown for that genus. If you appear to be incorrect, go back over your choices to see if you made an error.

4 Repeat steps 2 and 3 for as many other specimens as you can in the time you have.

Practical review

1 **Explain** what is meant by a family, genus and species.

2 **Propose** some characteristics of flower structure that members of this family share.

3 **Assess** whether any of these genera seem to have more in common with some genera than with others.

4 **Explain** why classifying a plant into this family on the basis of its flower structure also suggests that it is related to the other members of this group through inheritance.

5 **Explain** why the genera in this family would have some genes the same.

Key to some genera in family Myrtaceae

1a	Ovary with between 3 and 10 sections.	Go to 2.
1b	Ovary with 1 section.	Go to 8.
2a	Stamens separate.	Go to 3.
2b	Stamens in 3–5 bundles, joined for part of length of stamen.	Go to 7.
3a	Flowers with no stalk. Stamens no longer than petals.	Go to 4.
3b	Stamens longer than petals, in two rows.	Go to 5.
3c	Stamens longer than petals, in single row.	*Kunzea*
4a	Leaves in pairs and opposite each other.	*Baeckea*
4b	Leaves alternating.	*Leptospermum*
5a	Flowers with no stalk, in a cylindrical column. Fruit woody. Shrubs.	*Callistemon*
5b	Trees with flowers at ends of branches and each with a stalk.	Go to 6.
6a	Flower with petals. Trees.	*Angophora*
6b	Flower bud covered by a cap which falls off when flower opens. Trees.	*Eucalyptus*
7a	Flowers with no stalk and in cylindrical heads or ball shaped heads. Stamens in five bundles joined at the base for less than ¼ length of the stamen.	*Melaleuca*
7b	Flowers with stalks growing from leaf base. Trees.	*Tristania*
7c	Stamens joined over ¾ length. 3–4 stamens per bundle. Small shrubs.	*Beaufortia*
8a	Flowers waxy and in open groups of 2–4 each with stalks at tip of branches. Shrubs less than 2 m.	*Chamelaucium*
8b	Flowers in terminal heads often covered by petal-like coloured bracts.	*Darwinia*

3.4 Human evolution

The name of our species, *Homo sapiens*, means ‘wise man’. According to the fossils so far discovered, we have been around for about 200 000 years. Fossils indicate that other species of human-like animals have existed too. Biologists and palaeontologists have a good idea about how humans came to be here, but more fossil evidence is needed to trace our origins.

INQUIRY science 4 fun

Mammals

YES

Do this …

1 If you have a cat or dog at home, carefully observe its face and describe where its eyes are.

2 Observe the paws and describe where the toes are and what is on the toes.

3 Compare these with your own features.

Record this …

Describe what you observed.

Explain why these features might be similar or different.

Primates

Humans are classified into the class Mammalia, order Primates, family Hominidae, genus ***Homo***. **Primates** include the lemurs, tarsiers, monkeys, apes, gibbons and humans. There is no one specific feature that puts an animal into this order. However, most of them have ‘grasping’ hands, nails rather than claws and forward-facing eyes. You can see a typical primate in Figure 3.4.1.

Figure 3.4.1

A lemur shows the typical primate features of forward-facing eyes, nails and grasping hands.

Dud genes

SciFile

Not all genes you inherit actually function. For example, all humans inherit the GULOP gene, which would allow us to make vitamin C if it functioned. However, this gene is defective and has many mutations within it. Some distant cousins of humans, the more 'primitive' primates such as lorises, galagos and pottos, still have a working GULOP gene. No higher primates have a GULOP gene that works.

The living animals most like humans are gorillas and chimpanzees, which live only in Africa. On the basis of our similar anatomy, Charles Darwin predicted that the best place to find fossils of human origins would be in Africa—the ancestors of apes and humans should be found there.

Humans and apes

Our species is part of the family **Hominidae**, along with chimpanzees and gorillas. However, humans and these two apes are different mainly in the way they stand and walk.

Humans are placed in a level of classification called a sub-tribe. The key features that place a species in the human sub-tribe involve walking upright on two legs. These features are in the skull, vertebral column, pelvis, femur, knees and feet. There are other characteristic features as well, such as the shape of the jaw and the hand structure. Figure 3.4.2 compares us with a chimpanzee.

3.7 Prac 1 p115 Prac 2 p116

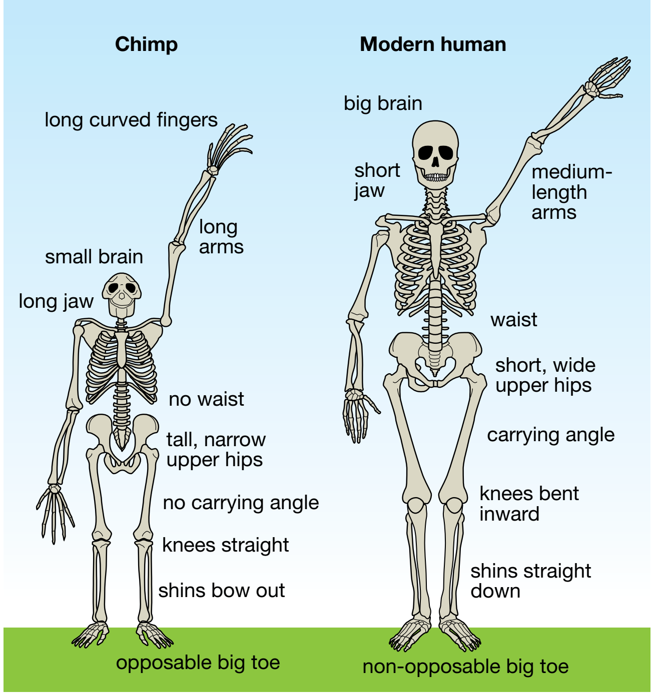


Figure 3.4.2 Some of the distinguishing features of humans and apes

Australopithecines

One early group that most anthropologists are fairly sure is ancestral to our genus *Homo* is the genus ***Australopithecus***. This group contains at least six species, who are often referred to as 'ape-men'. Species belonging to Australopithecines lived in Africa about 3.7 million to 1.8 million years ago. Among them is probably the group that were ancestors to our genus *Homo*, but more fossils are needed of early *Homo* to better identify this link. The most likely candidate for the ancestor of the genus *Homo* is *Australopithecus afarensis* (see Figure 3.4.3).

Australopithecus afarensis lived in East Africa between about 3.7 million and 2.5 million years ago. They were about 1.3 metres tall and had a mass of about 30 kg. Their brain, at 410 cm^3, was about the size of a chimpanzee's, but they had a much smaller body mass. *Australopithecus afarensis* walked upright on two legs as shown by the shape of their pelvis and the carrying angle of the femurs. The carrying angle is the inward slope of each femur towards the knee. A carrying angle means that the knees are closer together than the hips, making upright walking more efficient. This upright walking on two legs placed them on the path towards being human.

Figure 3.4.3 *Australopithecus afarensis* is the earliest known likely ancestor of humans. The fossilised footprint shown here is about 3.7 million years old.

Early genus *Homo*

The earliest known member of our genus *Homo* dates from about 2.4 million to 1.4 million years ago. This is a species called *Homo habilis* (Figure 3.4.4). However, another early human called *Homo ergaster* (also known as *Homo erectus*) is more likely to be our ancestor. If both *Homo habilis* and *Homo ergaster* lived at the same time, then they cannot both be our ancestors.

Homo ergaster existed about 1.9 million years ago. The best fossilised example of this species is specimen KNM WT 15 000, commonly known as Turkana Boy (Figure 3.4.5). This specimen is about 1.5 million years old. Turkana Boy was 1.6 m tall, and was about 9–12 years old when he died. This suggests his final adult height might have reached an impressive 1.85 m. Almost 90% of his skeleton was recovered. Turkana Boy had a tall, slender body adapted for walking long distances. He had a more human-like face than *Homo habilis*, with a nose that projected outwards and a larger space for the brain at 880 cm^3. His brain would probably have reached about 910 cm^3 in adulthood.

Figure 3.4.4

Homo habilis may be ancestral to our species, but more fossils are needed to test this view.

Figure 3.4.5

Homo ergaster migrated out of Africa around 1.9 million years ago. This is the Turkana Boy fossil. Most scientists call the fossils of this species found outside Africa *Homo erectus*.

Other fossils have been found that may also have been part of the line from Australopithecines to modern-day *Homo sapiens*:

- *Homo rudolfensis* is known by a single skull (KNM 1470). No other bones have been found, making classification difficult.
- *Homo heidelbergensis* (Figure 3.4.6) may have evolved from *Homo ergaster* then migrated out of Africa into Europe. There it seems to have evolved into *Homo neanderthalensis*.

Homo heidelbergensis may also have evolved in Africa into *Homo sapiens*. These new humans then migrated out of Africa to the rest of the world, replacing all other forms of *Homo* that existed elsewhere, such as *Homo neanderthalensis*.

Figure 3.4.6

Homo heidelbergensis. European populations of this early human species were the ancestors of the Neanderthals. African populations probably gave rise to our own species.

Out of Africa

At the present time, the most widely accepted view among scientists of the origins of our species is the **Out of Africa model**. This model proposes that a common ancestor of all modern humans evolved in East Africa between 200 000 and 100 000 years ago. Around 60 000 years ago, a small subgroup left Africa and ended up colonising the whole Earth except Antarctica by about 15 000 years ago.

The Out of Africa model is supported by evidence from mitochondrial DNA testing and Y chromosome testing of modern humans. **Mitochondrial DNA (mtDNA)** is DNA contained within the cell mitochondria. This mtDNA is only passed from a mother to her children. As Figure 3.4.7 shows, mitochondria separate into each gamete (sex cell) during meiosis (division of the nuclear DNA) in the ovary. This mtDNA is not shuffled around between cells like the chromosomes are. The only changes that occur in mtDNA are mutations. These mutations are used to track the migration routes of our ancestors. Using mtDNA analysis and Y chromosome analysis, scientists have concluded that all human beings can trace their ancestry back to a small group who lived in Africa less than about 60 000 years ago (Figure 3.4.8).

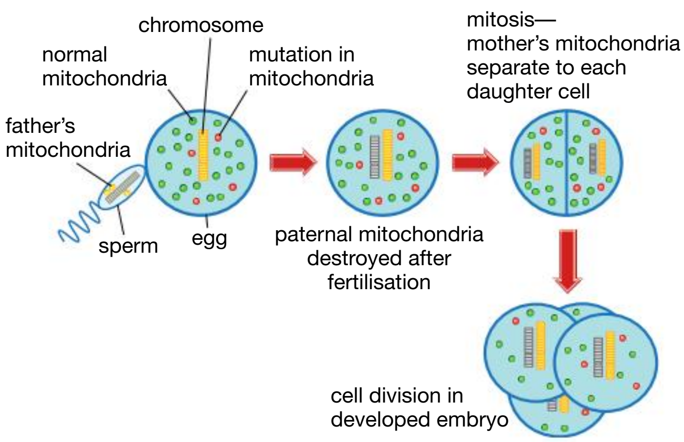


Figure 3.4.7 Mitochondrial DNA stays in the cytoplasm and generally does not affect the genes in the nucleus. The mtDNA is copied to each egg and to each cell when it divides in mitosis.

Unit 1.2
Unit 9.2

Neanderthal DNA

Mitochondrial DNA extracted from Neanderthal bones show that they were quite different from *Homo sapiens*, but more like us than chimpanzees. The scientists concluded that *Homo sapiens* and *Homo neanderthalensis* became separate species approximately 400 000 years ago. Recent studies of ancient nuclear DNA from a Neanderthal bone suggest that there was some interbreeding with *Homo sapiens*.

SciFile

Figure 3.4.8 Migration routes out of Africa using Y chromosome analysis (red lines) and mtDNA analysis (blue lines) traced in the Genographic Project. The letters M and the numbers represent mutant genes. For example, M91 occurred about 60 000 years ago in Africa.

Signs in the skulls

When the skulls of all the different likely members of the human family are compared, there appear to be some striking changes that have occurred during their evolution. Figure 3.4.9 shows some of these changes clearly.

- The face becomes 'flatter', meaning more vertical.
- The lower jaw shortens and does not project out as much.
- A chin develops.
- The forehead becomes more vertical.
- The cranium (brain space) enlarges and becomes more rounded.
- The cranial capacity (brain size) increases.

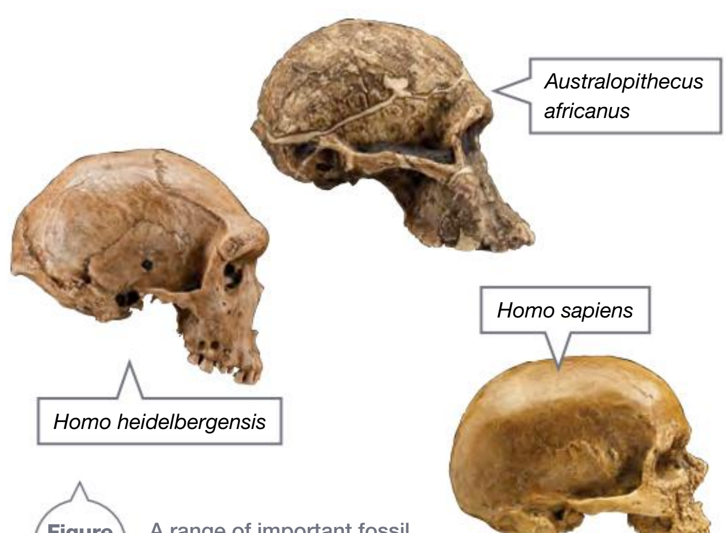


Figure 3.4.9 A range of important fossil skulls in the human family

3.4 Unit review

Remembering

1 **List** terms used to classify modern humans from class to species.

2 **Name** ten primates other than humans.

3 **List** the characteristics of primates.

4 **Name** three species in the family Hominidae.

5 **Name** the two living species most closely related to humans.

Understanding

6 **Describe** the Australopithecines.

7 a **Outline** the Out of Africa model.
  b **Describe** evidence supporting this model.

8 **Explain** how mitochondrial DNA (mtDNA) is passed on.

Applying

9 **Identify** the person from whom you received your mtDNA.

10 In 2003, Australian scientists discovered fossils of nine individuals of a tiny species of human on the island of Flores in Indonesia. They classified it as a new species, *Homo floresiensis*. It had a brain volume about one-third the size of that of modern humans, and a height of about 109 cm. **Apply** the Out of Africa hypothesis to **discuss** the possible origins of this species.

Analysing

11 **Compare** *Homo ergaster* with *Homo sapiens*.

12 **Contrast** the origins of your nuclear DNA and mtDNA.

Evaluating CCT

13 At the current time, biologists should not make too many judgements about where *Homo rudolfensis* stands in the story of human evolution. **Justify** why.

14 **Deduce** whether upright stance or increased brain size was the first feature that evolved in the lineage (line of descent) that led from apes to humans.

15 In 2001, fossils were found in Georgia, between the Black Sea and the Caspian Sea. These fossils were classified as a new species named *Homo georgicus* (Figure 3.4.10). The almost-complete skull had a cranial capacity of about 600 cm^3, and the body height was about 1.3 metres. The fossils were dated to 1.77 million years ago.

  a **Propose** a possible origin for this species.
  b **Justify** your decision.

Figure 3.4.10
Homo georgicus

Creating CCT

16 **Construct** an argument that could explain how *Homo habilis* evolved from *Australopithecus afarensis*.

Inquiring

1 Research the Neanderthals. Find:
- their characteristics
- their likely origin
- our relationship to them based on DNA analysis of Neanderthal bones
- where and when the last Neanderthals lived.

Present your findings as a digital presentation or poster. ICT

2 Research the *National Geographic* Genographic Project. Find:
- the aims of the project
- a brief description of the type of DNA evidence collected
- how genetic markers can be used to indicate time in the past
- how migration routes were determined
- how to find out your own genetic history.

Present your research findings in digital form. ICT

3.4 Practical investigations

1 Hand adaptations

Purpose

To identify some adaptations of the human hand.

Materials

- human skeleton
- hand X-rays
- ruler
- pencil

Procedure

1 Hold your left hand out in front of you palm face down and fingers spread out. Observe the position of the thumb compared with the fingers. Write a description of the differences.

2 Turn your left hand palm upwards. Touch each of the four fingertips on this hand with your left thumb. Observe carefully how the thumb can move. Describe how your thumb moves across the palm.

3 Grasp a ruler with your left hand the way you would hold a hammer. This is called the power grip. Describe how the thumb assists in holding the ruler.

4 Hold a pencil for writing. This is called the precision grip. Describe the difference in the position of the thumb and fingers in this grip compared with the power grip.

5 The trapezium bone enables you to move your thumb to touch your little finger. Hold your left hand palm upwards, with fingers together and thumb out to the side. Move your thumb across to touch your little finger. Describe which way the thumbnail points before and after moving your thumb.

Results

Record the observations you made in each part of the Procedure.

Practical review

1 **Propose** reasons for the names *power grip* and *precision grip*.

2 Look at Figure 3.4.11. **Use** it to **identify** the trapezium on your own hand. Show your partner where you think this bone is.

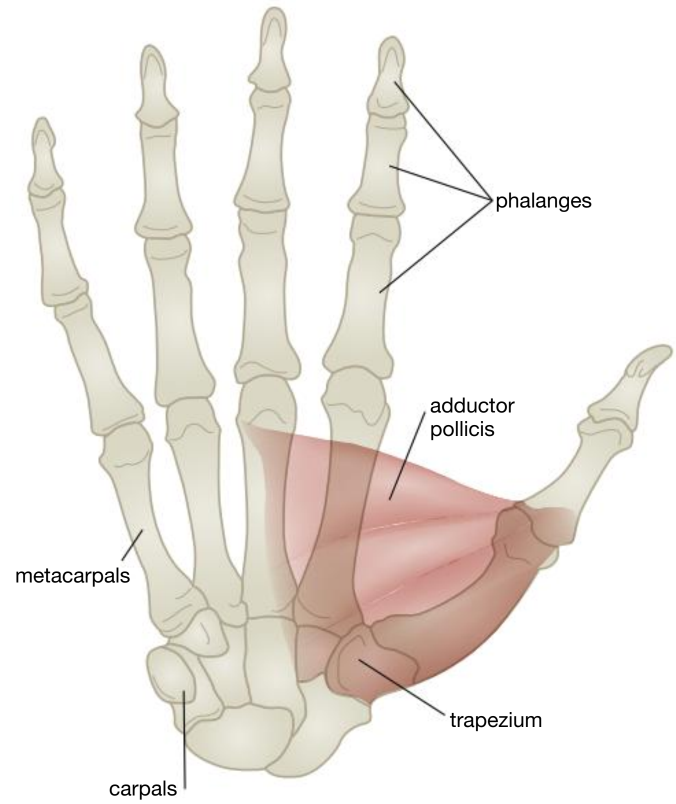


Figure 3.4.11 Bones of the human hand and thumb muscles

3 a **Identify** the muscles involved in moving the thumb.
b **Describe** the role each has in moving the thumb.

4 **Discuss** the adaptations of the human hand for object manipulation.

5 **Propose** how the human hand may have evolved from the hand of an ape ancestor.

2 Foot adaptations

Purpose

To compare the human hand and foot structure as adaptations of homologous structures.

Materials

- human skeleton
- X-rays of hands and feet
- ruler
- pencil

Procedure

1. Remove your shoe and sock from your left foot. Describe the position of the big toe and other toes.
2. Observe the instep of your foot (or someone else's foot). Describe the shape of the foot from the heel to the toes.
3. Observe a skeleton and X-rays of the foot. Describe how it looks from the side.
4. Observe the heel and the toes of the skeleton and X-rays. Compare the size of the toes and describe the heel.

Practical review

1. **Compare** the position of the thumb with that of the big toe.
2. **Use** Figure 3.4.12 to **propose** how the heel, first metatarsal and big toe could be considered adaptations of the foot for walking.
3. **Discuss** how the same homologous structure could evolve into a hand and a foot.

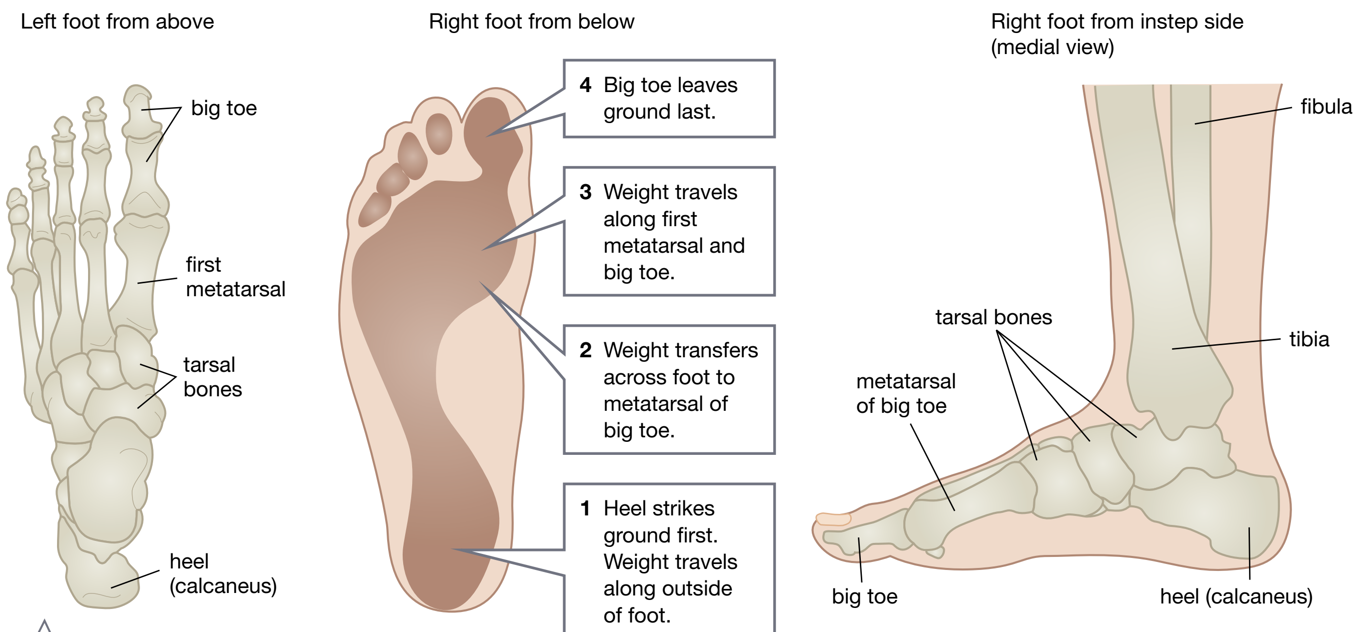


Figure 3.4.12

3 Chapter review

Remembering

1 **Name** the first person to propose the process of natural selection.

2 **List** the steps involved in speciation.

3 **List** the evidence that supports the theory of evolution.

Understanding

4 **Modify** the following statements to make them correct.
  a Natural selection is the process in which an individual is acted upon by its environment and produces more offspring.
  b A selective agent acts on a population and improves the survival of some individuals more than others.
  c Homologous structures have to perform the same function in different species.
  d Any differences in the position of amino acids in a protein show that species are not related.
  e Organisms that look similar must have the same genes causing the similarity.
  f All variation in a species is caused by natural selection.
  g Natural selection acts on the genes in an organism.

5 **Explain** how fossils support the theory of evolution.

6 Natural selection has been demonstrated in organisms in recent times.
  a **List** two organisms in which these changes have been obvious.
  b **Explain** how natural selection caused the change.

7 **Explain** how domesticated animals and plants were altered through artificial (directed) selection.

8 **Explain** why genetic isolation is vital in evolution.

Applying

9 Humans, lemurs, monkeys, gorillas and chimpanzees are classified into one group. **Identify** three structural features they all share that place them in this group.

10 **Demonstrate** how an adaptive feature, such as coat colour in mice, can change when their environment changes in some way.

11 **Use** the fossil record of birds and dinosaurs to **demonstrate** that transitional forms occur between levels of classification.

Analysing

12 **Compare** the importance of variation in both artificial selection and natural selection.

13 **Contrast** homologous and analogous structures.

14 The flying possums of Australia are marsupials that are able to glide from tree to tree because of a thin webbing of skin between their front and back legs that catches the air like a parachute. Despite being very different animals, there are some flying lemurs (primates) and flying squirrels (rodents) elsewhere in the world that have similar webbing. They too glide from tree to tree. **Classify** the webbing as a homologous or analogous structure.

Evaluating CCT

15 **Propose** a reason why natural selection is more likely to be visible in organisms such as bacteria and insects than in kangaroos and humans.

16 **Justify** the conclusion that species with the same basic structure are related.

17 *Australopithecus* and *Homo* are both classified into the same sub-tribe. **Propose** what features placed *Australopithecus* in the same sub-tribe as us.

18 There is much more variation in domesticated species such as budgerigars than in the wild species. **Propose** why there is less variation in the wild.

19 a **Determine** whether you can or cannot answer the questions on page 86 at the start of this chapter.
  b **Use** this to **assess** how well you understand the material presented in this chapter.

Creating CCT

20 **Construct** a sequence of events by which a brown-coloured frog that is not poisonous could evolve to look like another species that lives nearby and is coloured bright red and very poisonous.

21 **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter.

natural selection	selective agent
evolution	homologous
speciation	fossils
DNA	variation
comparative anatomy	embryology

3.8

Thinking scientifically

Questions 1 and 2 refer to the following information.

A biologist was studying a population of mice that lived in an area with few trees and scattered low shrubs separated from each other by large areas of bare soil. He found that the mice had two genes that controlled their coat colour. One tended to give the coat a dark-brown colour, while the other produced a lighter yellowish brown colour.

The area contained three different soil types: dark red clay, pale yellow sand and light grey sand. Studies of the proportion of mice with the different coat colour were done and are shown in the table. The area was a very dry semi-desert climate. The mice were preyed upon by hawks that hunted mainly in the morning and late afternoon.

Site	Soil colour	Per cent of mice with brown coat	Per cent of mice with yellowish coat
1	Red	82.0	18.0
2	Light grey	52.0	48.0
3	Pale yellow	41.0	59.0

Q1 Which of the following is a fair interpretation of the data? CCT

A There are more brown-coated mice than yellow-coated mice in the population.

B Brown coats are more suited to red clay than they are to light-grey sand.

C Yellowish coats are more suited to the light-grey sand.

D Brown-coated mice are moving from pale-yellow sand and light-grey sand to the red clay.

Q2 Considering the information in the table, which of the following conclusions is likely? CCT

A Hawks always prefer to eat mice with a yellowish coat colour.

B The climate is selecting for lighter coloured mice because they will absorb less heat.

C The coat colour provides the mice with camouflage protection from the hawks.

D Lighter colour soil selects for the yellowish coat colour.

Q3 Domestic dogs were originally bred from ancestors of the wolf. There are now hundreds of different dog breeds with characteristics varying from tiny chihuahuas to the massive Irish wolfhounds. Natural selection acts to allow survival of offspring most suited to their environment. The environment of the wolf is forests of the Northern Hemisphere. The environment of domestic dogs is the homes of people around the world, where they are cared for and fed by their owners. CCT

Consider the following suggestions. Which most likely explains why there are many different breeds of domestic dog and only one species of wolf, which is fairly alike over the whole Northern Hemisphere?

A Not all variations would be suited for survival in the wolf's environment.

B Wolves are artificially selected.

C Domestic dogs are not being selected by the environment.

D Natural selection acting on the wolf made it evolve into many different types of dog.

Q4 Bacteria divide asexually approximately once every 20 minutes in ideal conditions. Fruit flies reproduce sexually in a life cycle of about 11 days. Why might an experimenter choose bacteria rather than fruit flies in an experiment on natural selection? CCT

A Asexual reproduction cannot produce any genetic change so bacteria are useful as a control in experiments.

B Variation, isolation and selection can not occur in bacteria so there will be no speciation.

C There will not be any variation in the bacteria for natural selection to act on.

D A short generation time means any evolution in the species should occur faster.

Glossary

Unit 3.1

Analogous: structures that appear similar or have the same function but are controlled by different genes

Artificial selection: the process by which people choose to breed particular organisms with desirable features; also known as selective breeding or directed selection

Artificial selection

Cross-breeding: selective breeding by combining in the offspring a desirable feature of one individual with a different desirable feature in another

Evolution: change in the characteristics of a species over many generations

Generation: the time between the birth of an individual and when they produce their own offspring

Homologous: structures that are controlled by some of the same inherited genes

Inbreeding: selective breeding between two closely related individuals

Unit 3.2

Antibiotics: chemicals made by organisms such as fungi to defend them against bacteria

Natural selection: the process in which an environmental factor acts on a population and results in some organisms having more offspring than others

Resistance: inherited ability of a species to withstand chemicals such as pesticides

Selective agent: the environmental factor that acts on the population during natural selection

Sexual selection: a special case of natural selection in which the environmental factor is the selection of a mate

Variation: differences in characteristics due to different genes

Sexual selection

Unit 3.3

Biodiversity: the number and range of different species that exist on Earth or in an ecosystem

Distribution: a map of all the places where a species occurs

Embryology: the study of the embryos of different species

Isolation: keeping interbreeding groups apart by some barrier or mechanism

Species: group of organisms that can interbreed to produce fertile offspring under natural conditions

Embryology

Speciation: the process by which one species splits into two or more separate species

Transitional form: fossils that have features of two or more different groups

Unit 3.4

***Australopithecus*:** a genus in the family Hominidae that is probably ancestral to our genus *Homo*

Hominidae: the family to which humans and the extinct genus *Australopithecus* belong

***Homo*:** the genus to which human beings, and several other extinct species, belong

Mitochondrial DNA (mtDNA): DNA contained within the cell mitochondria and passed from mother to sons and daughters

Australopithecus

Out of Africa model: model (hypothesis) proposing a common ancestor of all modern humans evolved in Africa and then migrated out to colonise the whole Earth

Primates: order of animals with 'grasping' hands, nails rather than claws and forward-facing eyes

SCIENCE TAKES YOU PLACES

Look who is using science

AGRONOMIST

My name is Dugald Spenceley. I studied agricultural science and am now a business manager with Syngenta Crop Protection in Australia. The focus of our business is agronomy—the study of crop production.

I work with the company's sales and marketing teams and help to develop the strategies we use to sell our products. This requires me to have a good understanding of what is happening in the market and the suitability of our products for a variety of crops under different growing conditions.

Studying agricultural science has enabled me to work in different fields, such as land management, agronomy, marketing and business management. My science background has helped me to understand the relationships that exist in the farming environment and how my company can best use our products to increase crop production. Crop production is becoming more and more important to ensure that we are able to feed an ever-growing global population.

TECHNICAL OFFICER

I am Helen Gore and I work as a palaeontology technical officer in the Department of Earth and Planetary Sciences at a state museum.

Every day my work brings a new challenge. For example, I often prepare fossils for research. Some days I'll be picking tiny ancient sharks' teeth from sedimentary rock deposits so that the species can be identified and the geological age of the rock determined. Other days, I'll be stabilising (repairing) an extremely fragile fossil.

I also act as a curator (manager) of the museum's fossil collection, which now has more than a million specimens. The collection gives us great insight into Earth's evolutionary history over the last 3000 million years. We often lend fossil material to scientists throughout the world for research. An important part of the work is preparing fossils for safe transport, and tracking loans to ensure they are returned to the collection.

No two days at the museum are the same, and it's particularly exciting when a new fossil species, previously unknown to science, is discovered.

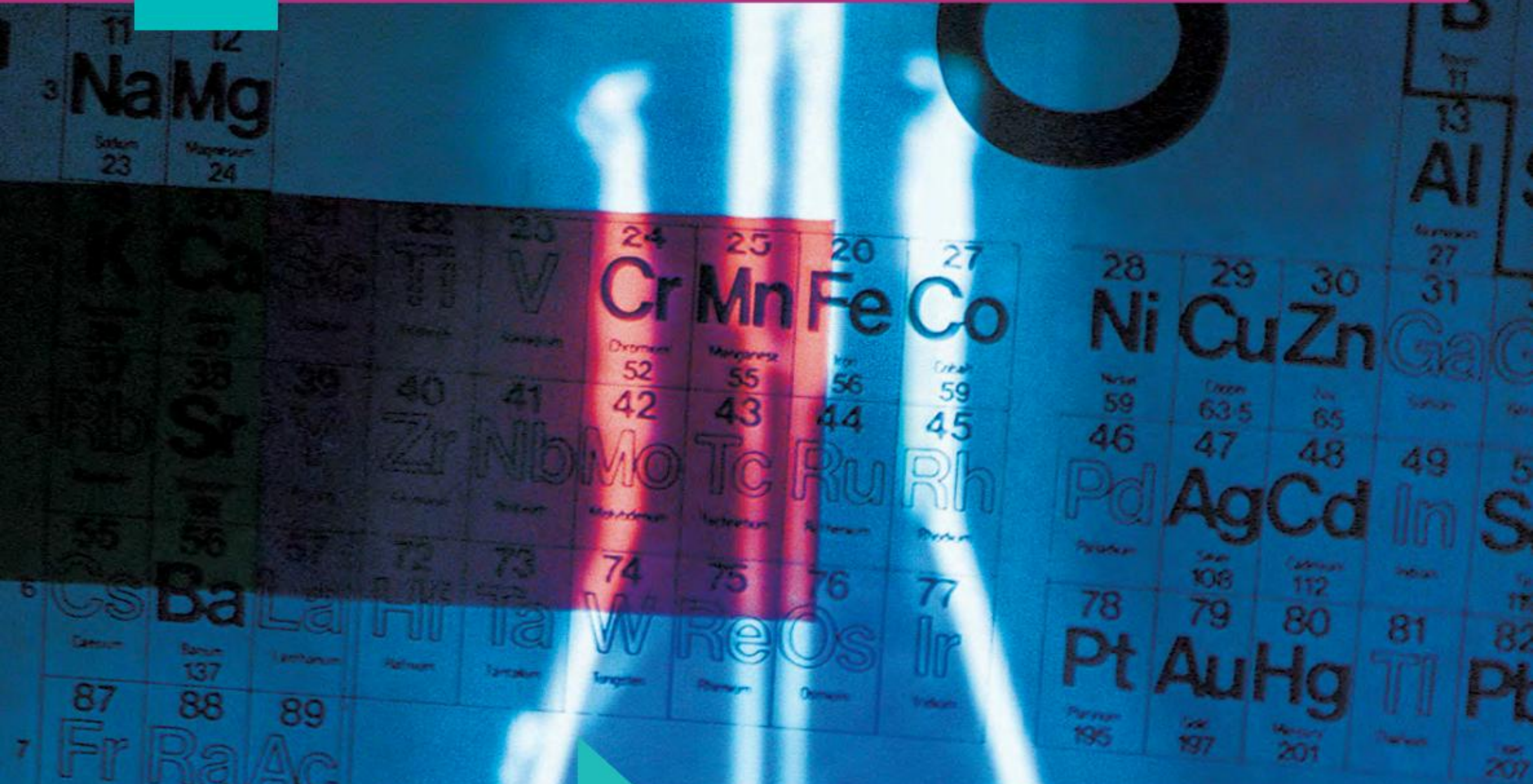
PLANT BREEDER

I am Dr Warwick Stiller, a plant breeder with CSIRO Plant Industry. My work involves developing new varieties of cotton that have higher yields, better disease resistance and higher fibre quality and use less water.

I use conventional breeding methods as well as genetically modified technologies. Some of the more interesting work is identifying useful traits in some of Australia's native cotton species and other wild species that could be transferred into the cotton varieties that we grow.

Being a plant breeder means that I get to make a real impact on farmers' livelihoods and the prosperity of rural Australia, as well as enjoying a diverse range of tasks from out in the field to the laboratory.

4 The periodic table



Have you ever wondered ...

- why the periodic table is important?
- why the periodic table has rows and columns?
- how scientists came up with its structure?
- how to predict what a substance will do in a chemical reaction?

After completing this chapter students should be able to:

- identify the atom as the smallest unit of an element and that it can be represented by a symbol
- distinguish between the atoms of common elements by comparing the numbers of protons, neutrons and electrons
- use atomic number to describe the arrangement of the periodic table
- describe how the properties of common elements are related to their position in the periodic table
- use the periodic table to predict the properties of common elements
- outline how creativity, logical reasoning and the scientific evidence available at the time contributed to the development of the periodic table L CCT N

ADDITIONAL

- describe how electrons are arranged in the energy levels of common elements
- investigate the order of activity of a range of metals
- conduct flame tests and explain the colours in terms of subatomic structure.

4.1 Atoms and elements

Atoms make up everything in the universe. They make up stars, rocks, water, T-shirts, butterflies and you. Like most things, atoms come in different 'varieties' or types. In chemistry, the different types of atoms are known as elements.

INQUIRY

science 4 fun

Element or not?

Can you make silver with an egg, water and a candle?

Collect this …

- 1 uncooked egg
- water
- candle
- clear glass bowl
- matches or lighter

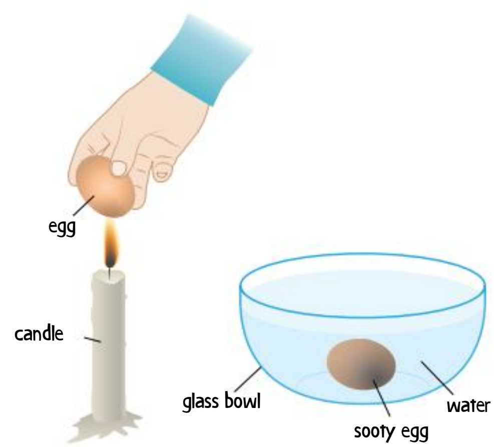
SAFETY

Be careful not to burn your fingers.

Tie back long hair.

Do this …

1. Fill the glass bowl with water and set aside.
2. Melt a little of the candle's base to form a small pool of wax.
3. Stand your candle in the molten wax and wait till it hardens and holds the candle upright. Light the wick.
4. Move your egg in and out of the top of the flame until all its surface is thickly covered in black soot.
5. Carefully slide your egg into the water.



Record this …

Describe what you see.

Explain why the shiny coating could not possibly be the element silver.

Atoms

Atoms are the particles that make up all the substances in the universe. Atoms are so small that you can't see them with normal microscopes. Only a powerful scanning tunnelling microscope (STM) allows them to be seen. A typical STM image is shown in Figure 4.1.1. Even an STM is unable to show the smaller protons, neutrons and electrons that make up atoms. Although these particles are 'invisible,' scientists have gathered evidence from which they have deduced that the particles exist and how they are arranged in the atom. This type of evidence is known as **indirect evidence** and does not involve direct observation of the particles themselves.

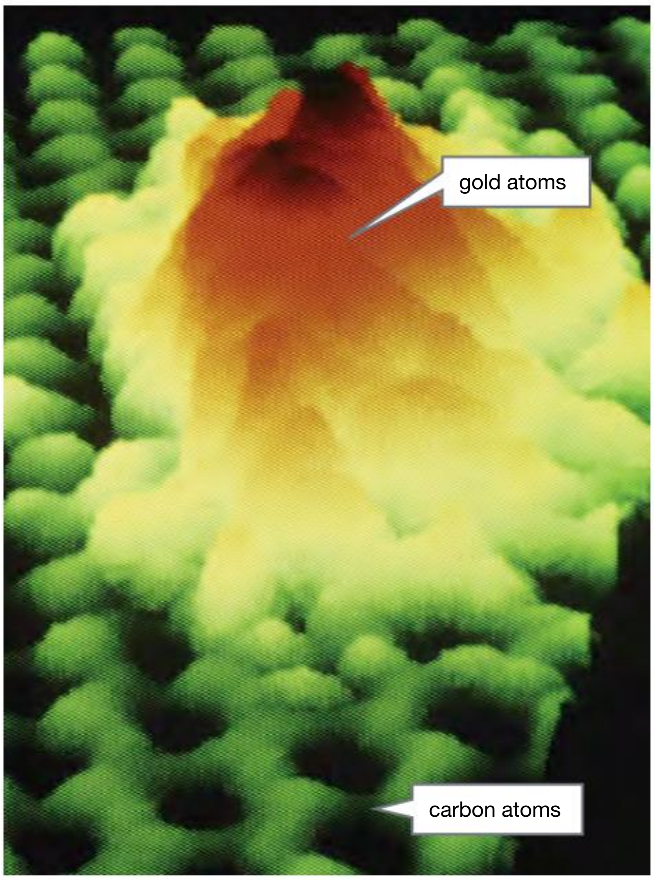


Figure 4.1.1 An STM image of some gold atoms (yellow and brown) on a graphite layer made up of carbon atoms (green)

The nucleus

At the centre of each atom is its **nucleus**, a tight, dense bundle of protons and neutrons. Neutrons are slightly heavier than protons and both are roughly 1800 times heavier than electrons. For this reason, almost all of an atom's mass is in its nucleus. Protons carry a positive charge (+) while neutrons are neutral, having no charge. The positive charges of all those protons in the nucleus give the nucleus a positive charge too.

Electrons

The electrons spin around in the space surrounding the nucleus. This is shown in Figure 4.1.2. Electrons are negatively charged (–) and therefore are attracted to the positive nucleus. This attraction keeps them from wandering too far from the nucleus but is not enough to pull them in completely.

Atoms are electrically neutral because the number of electrons is always the same as the number of protons.
That is:

Number of electrons in an atom = number of protons

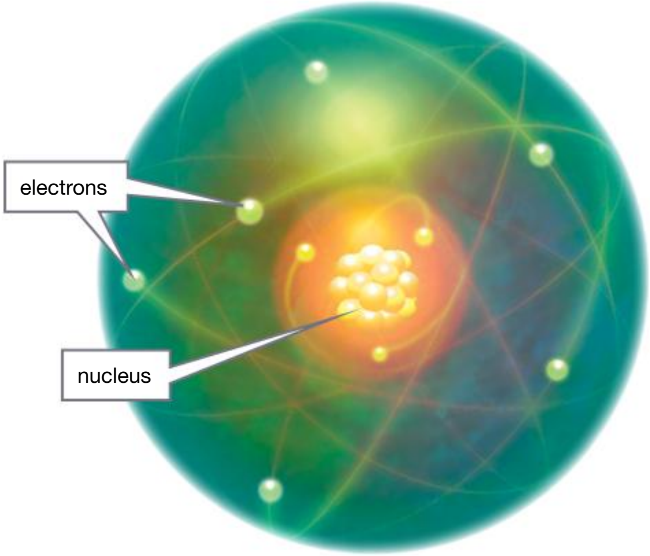


Figure 4.1.2 An atom has a heavy core called the nucleus. Around this are fast-moving electrons.

Elements

Elements can be thought of as the building blocks from which all substances are made. Atoms are the smallest unit of an element and each element is made up of atoms that are basically the same—the atoms have the same number of protons in their nuclei and therefore the same number of electrons spinning around them. The number of protons in the nucleus determines the element to which the atom belongs.

Currently there are 118 different elements. Twenty-six of these are not found naturally on Earth but are synthetic—they have been made in the laboratory.

The chemical formula of a compound tells you what elements make it up and in what proportions. For example, a molecule of water (H_2O) is made of two atoms of the element hydrogen and one atom of the element oxygen. The formula for the ionic lattice structure of common salt (sodium chloride, NaCl) indicates that there are equal numbers of ions of the element sodium and the element chlorine.

Using analogies

Models are used in science to explain difficult-to-understand concepts. Analogies are a type of model that compares something difficult with something that is encountered every day. For example, the heart is often compared to a pump. Likewise, atoms, elements and compounds can be compared to ice-cream. There are 118 different elements, so this analogy uses 118 different flavours of ice-cream to represent them. In this way, an ice-cream shop resembles a periodic table (Figure 4.1.3).

A single scoop of ice-cream represents an atom because it is the smallest amount of ice-cream you can get (Figure 4.1.4). However, most people don't buy a single scoop. Some will buy multiple scoops of the same flavour. This represents an element, where every atom is the same. Others will buy a number of scoops of different flavours. This represents a compound, made of atoms of different elements.

Figure 4.1.3 In this analogy, different elements can be thought of as different flavours of ice-cream.

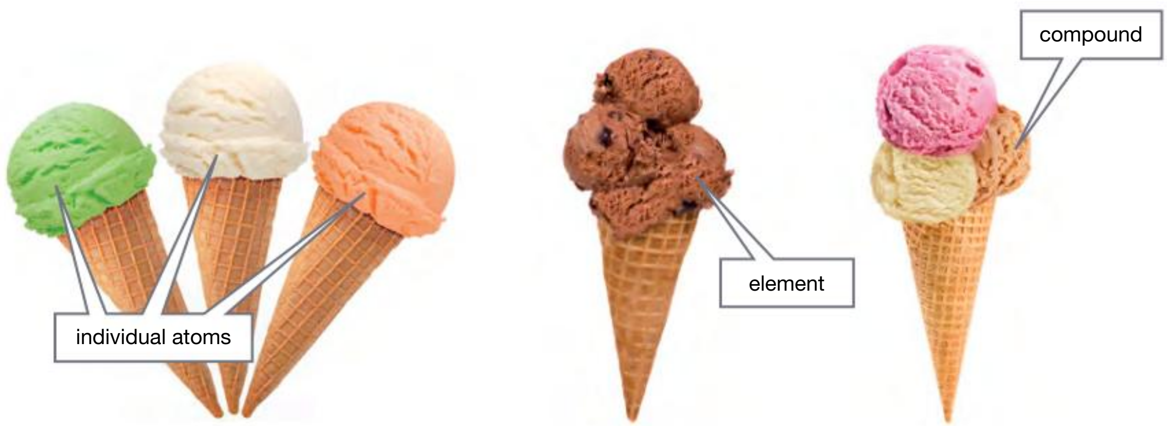


Figure 4.1.4 An element is made of the same type of atoms while a compound is made of different types.

Atomic number

The number of protons in the nucleus of an atom is known as its **atomic number**.

Atomic number = number of protons

Each element has a characteristic and identifying atomic number. For example, all carbon atoms have six protons and so all have an atomic number of 6. All oxygen atoms have eight protons (atomic number 8), and all uranium atoms have 92 protons (atomic number 92). This makes uranium atoms some of the heaviest known, and helps explain why they are unstable and radioactive (Figure 4.1.5). In contrast, a hydrogen atom has only a single proton in its nucleus. Its atomic number is 1, making hydrogen the smallest of all the atoms and the lightest of all the elements. This fact was used in early airships like the Zeppelin in Figure 4.1.6.

Figure 4.1.5 Uranium is the heaviest natural element. Its extreme mass makes its nuclei unstable. When these nuclei break apart, incredible amounts of energy are released, as is evident in this 1958 atomic bomb test.

Figure 4.1.6 Hydrogen is less dense than air and was used in the *Hindenburg* shown here. The hydrogen in the *Hindenburg* exploded on docking in 1937, destroying the airship.

Prac 1 p127 Prac 2 p128

Mass number

The total number of particles in the nucleus (protons + neutrons together) of an atom is called its **mass number**.

Mass number = number of protons + number of neutrons

An atom can be represented by using the symbol of the element it belongs to and its atomic number and mass number.

Isotopes

Atoms belonging to the same element always have the same numbers of protons in their nuclei and the same atomic number. However, they can have different numbers of neutrons. This gives the atoms different mass numbers. When this happens, the atoms are known as isotopes. **Isotopes** are atoms that:

- belong to the same element, with the same number of protons and the same atomic number
- have different numbers of neutrons, giving them different mass numbers.

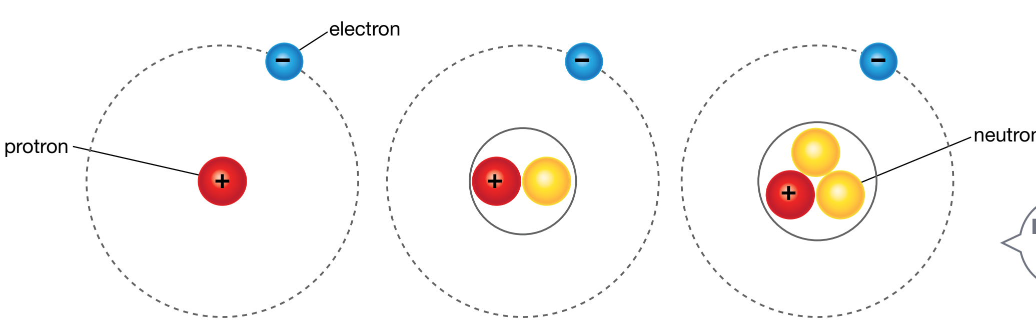
For example, hydrogen has three natural isotopes. You can see them in Figure 4.1.7.

Many elements have natural isotopes and all elements have synthetic isotopes made in the laboratory. As you can see from Table 4.1.1, one isotope is usually much more abundant (common) than the others.

Table 4.1.1 Isotope abundances

Element	Isotope	Abundance %	Protons	Neutrons
Hydrogen H	$^{1}_{1}H$	99.98	1	0
	$^{2}_{1}H$	0.02	1	1
	$^{3}_{1}H$ (radioactive)	Trace	1	2
Chlorine Cl	$^{35}_{17}Cl$	75.58	17	18
	$^{37}_{17}Cl$	24.22	17	20
Iron Fe	$^{55}_{26}Fe$	5.845	26	29
	$^{56}_{26}Fe$	91.754	26	30
	$^{57}_{26}Fe$	2.119	26	31
	$^{58}_{26}Fe$	0.282	26	32

GO TO Pearson science NSW 9 Unit 2.4



$^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$

Figure 4.1.7 Hydrogen has three isotopes. All isotopes of hydrogen have a single proton but different numbers of neutrons in their nuclei.

4.1 Unit review

Remembering

1 **List** the following in order from lightest to heaviest: atom, electron, proton, neutron.

2 **State** the electric charge of:
- **a** a proton
- **b** an electron
- **c** a neutron
- **d** a nucleus
- **e** an atom.

3 A particular atom has 8 protons, 8 electrons and 9 neutrons.
- **a** **State** its atomic number.
- **b** **State** its mass number.

Understanding

4 **Explain** how different flavours of ice-cream can be used to represent atoms, elements and compounds.

5 **Define** the following terms. L
- **a** STM
- **b** indirect evidence
- **c** atomic number
- **d** isotope

6 **Explain** why most of an atom's mass is due to its nucleus.

7
- **a** You are watching a replay of a Rugby League match on TV. You cannot see the sky but immediately deduce that it was a day match. **Describe** the indirect evidence that would lead you to this conclusion.
- **b** Another replay comes on and you know that this match was a night match despite not being able to see the sky or light towers. **Describe** the indirect evidence that now suggests it is night.

8 **State** or **calculate** the missing data for the atoms in the table below.

Atom	$^{107}_{47}Ag$	$^{29}_{14}Si$
Atomic number		
Mass number		
Number protons		
Number neutrons		
Number electrons		

9 **Explain** why:
- **a** $^{14}_{6}A$ and $^{14}_{7}B$ represent atoms of different elements
- **b** $^{16}_{8}C$ and $^{18}_{8}D$ represent isotopes of the same element.

Applying

10 Egg shells are made of calcium carbonate ($CaCO_3$) and soot is carbon. **Use** this information to **explain** why silver cannot have formed in the science4fun on page 122.

11 **Use** the information in Table 4.1.1 on page 125 to **state** the:
- **a** percentage abundance of the most common isotope of chlorine
- **b** atomic number of iron
- **c** mass number of the most common isotope of chlorine.

12 **Use** Table 4.1.1 on page 125 to **identify** what makes the most common isotope of hydrogen unusual.

Analysing

13 **Compare** a proton with a neutron by listing their similarities and differences.

Evaluating CCT

14 Below is a list of different atoms. Their element symbols have been replaced with the letters A, B, C, D and E.

$^{12}_{5}A$ $^{25}_{12}B$ $^{14}_{7}C$ $^{13}_{5}D$ $^{25}_{15}E$

- **a** **State** how many different elements are represented in the list.
- **b** From the list, **select** an atom that would be an isotope of atom A.
- **c** From the list, **select** two atoms that have the same mass number but are different elements.

Creating CCT

15 **Construct** the symbol for:
- **a** a sodium atom (chemical symbol Na) that has 11 protons, 12 neutrons and 11 electrons
- **b** a gold atom (symbol Au) with 79 protons, 79 electrons and 118 neutrons.

Inquiring

Curie, Mendeleev, Einstein, Rutherford, Roentgen and Nobel all have elements named after them. Research what important work these scientists did, write a few sentences on their achievements, state which elements were named after them and write their element symbols.

Present your findings as a series of paragraphs, one on each scientist.

4.1 Practical investigations

1 Investigating a metallic element

Purpose

To make crystals of the metallic element silver.

Materials

- 0.3 g silver nitrate (this could be pre-weighed)
- 0.5 g agar powder (this could be pre-weighed)
- 40 mL distilled or deionised water
- 1 cm × 4 cm clean zinc strip

- 250 mL beaker
- stirring rod
- hotplate or Bunsen burner, tripod, gauze mat and bench mat
- 100 mL measuring cylinder
- Petri dish
- stereomicroscope (optional)

Silver nitrate is poisonous and can irritate eyes and skin if it comes into contact. It stains skin, clothing and benchtops.

Do not taste or sniff. Wear safety glasses, gloves and protective clothing at all times.

Turn the Bunsen burner to yellow flame or off when not using it. Tie back long hair.

Wash your hands thoroughly after the prac.

Procedure

1. Fold a small piece of paper in two and then open it out.
2. Place the paper onto the electronic balance and measure out 0.5 g of agar onto it.
3. Use the measuring cylinder to measure out 40 mL of distilled or deionised water.
4. Pour the water into the beaker and sprinkle the agar into it as shown in step 1 of Figure 4.1.8.
5. Gently warm the beaker over the hotplate or Bunsen burner, stirring until all of the agar is dissolved.
6. Carefully remove the beaker from the hotplate or Bunsen burner and add 0.3 g of silver nitrate to the beaker. Stir until it is dissolved.
7. Pour the agar solution into a petri dish and gently place the zinc strip in the centre as shown in step 2 of Figure 4.1.8.
8. Place the lid on top of the Petri dish and allow the agar to cool in a dark place (perhaps inside a cupboard). The agar should set into a jelly.
9. Inspect the metal crystals that form over the next few days. If available, use a stereomicroscope for a better view.

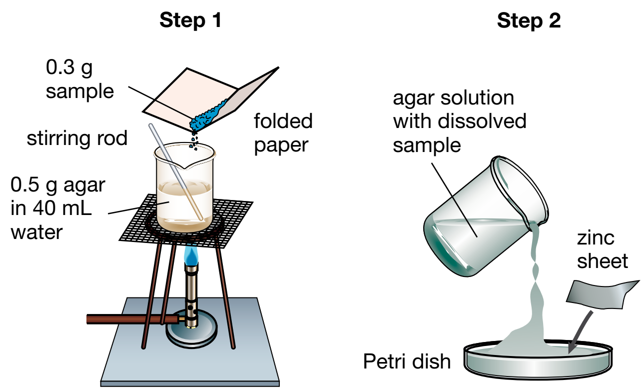


Figure 4.1.8 Making an agar plate

Results

1. Sketch or photograph the pattern produced by the crystals.
2. If you observed the crystals under the stereomicroscope, then draw the shape of an individual crystal.

Practical review

1. **Propose** a reason why the crystals were grown in agar and not a liquid.
2. **Describe** the colour of the agar after the silver nitrate dissolved in it.
3. **Use** your observations to **predict** what will happen if you handle silver nitrate with your bare hands.

2 Investigating a non-metallic element

Purpose

To determine how much oxygen is in air.

Materials

- non-soapy steel wool (cleaned first with methylated spirits, rinsed in water and dried)
- water

- large (50 mL) test-tube
- plastic container (such as a take-away food container)
- retort stand, bosshead and clamp
- marking pen
- 10 mL measuring cylinder
- access to a calculator

Procedure

1 Copy the table from the Results section into your workbook.

2 Add water to the plastic container and place it on the base of the retort stand.

3 Insert a 2–3 cm wad of steel wool in the bottom of the test-tube. Scrunch it up or add a little more so that it stays in place when inverted. (If the steel wool doesn't stick, then wet the inside of the bottom of the test tube.)

4 Wet the steel wool, then invert the test-tube and clamp so that it as shown in Figure 4.1.9. Make sure that the mouth of the test-tube is well under the surface of the water.

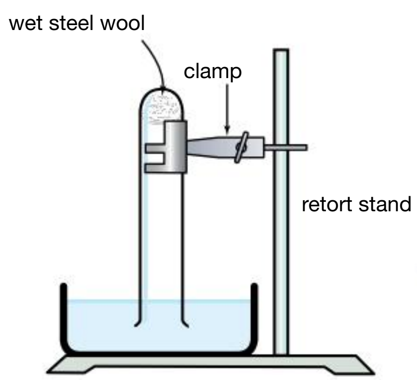


Figure 4.1.9

5 Mark where the water level is on the test-tube.

6 Leave the test-tube for at least 2 days. Mark the new water level in the test-tube.

7 Remove the test-tube from the clamp. Leave the steel wool in place and pour water into the test-tube until it reaches the line you marked at the end of the experiment. Empty the water into the measuring cylinder and record its volume in the results table (column 1).

8 Pour water into the test-tube until it reaches the line you marked at the start of the experiment. Pour it into an empty measuring cylinder and record its volume (column 2).

Results

1 Record the volumes in columns 1 and 2 of your table.

2 Gather the results from another four groups in your class.

Group	Column 1 Volume of air after 2 days (mL)	Column 2 Total volume of air at start (mL)	Column 3 Volume of air 'used up' (mL)	Column 4 Percentage of air 'used up'
1				
2				
3				
4				
5				
Average				

3 Calculate the amount of air 'used up' in the rusting of the steel wool. Calculate this volume by subtracting:

column 2 – column 1. Record this volume in column 3.

4 Calculate the percentage of air 'used up' in the experiment.

$$\% \text{ of air used up} = \frac{\text{column 3}}{\text{column 2}} \times 100$$ N

5 Calculate the average of the measurements of all the groups. N

Practical review

1 **Compare** the results obtained by the different groups.

2 **Identify** the errors in this experiment that will naturally contribute to some variation in the results.

3 **Explain** the advantages of taking multiple measurements in a practical activity.

4 a Air is about 21% oxygen. **Compare** this percentage with the percentage of air 'used up' in this experiment.

b **Assess** whether the two percentages should be the same or not.

c **Justify** your answer.

4.2 Arranging the elements

The periodic table is a list of all the elements, arranged in order of their atomic numbers. The table's structure allows you to predict the properties of a particular element and what its atoms are likely to do in a chemical reaction.

INQUIRY **science 4 fun**

Element bingo

Can bingo help you learn element symbols?

Collect this ...

- 1 bingo card from your teacher
- 1 pencil, pen or highlighter
- access to a periodic table

Do this ...

1. Your teacher will call out clues that will allow you to identify elements of the periodic table.
2. If you have the symbol of that element, then highlight or circle it.
3. When you have a complete row, column, diagonal or card, call out 'Bingo!'

Record this ...

Describe how this activity helps you learn the symbols of the elements.
Explain why this might occur.

The periodic table

The **periodic table** lists all of the known elements in order of increasing atomic number. You can see it in Figure 4.2.1 on page 130.

Every box within the table represents a different atomic number and therefore a different element. Each element also has its own characteristic symbol, such as Cl for chlorine and Ag for silver.

Hydrogen (element symbol H) contains atoms that have only one proton and so it has the atomic number 1. This makes hydrogen the first element of the periodic table. Ununoctium (symbol Uuo) is the last, with 118 protons (atomic number 118).

	Group 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period 1	1 **H** hydrogen																	2 **He** helium
Period 2	3 **Li** lithium	4 **Be** beryllium											5 **B** boron	6 **C** carbon	7 **N** nitrogen	8 **O** oxygen	9 **F** fluorine	10 **Ne** neon
Period 3	11 **Na** sodium	12 **Mg** magnesium											13 **Al** aluminium	14 **Si** silicon	15 **P** phosphorus	16 **S** sulfur	17 **Cl** chlorine	18 **Ar** argon
Period 4	19 **K** potassium	20 **Ca** calcium	21 **Sc** scandium	22 **Ti** titanium	23 **V** vanadium	24 **Cr** chromium	25 **Mn** manganese	26 **Fe** iron	27 **Co** cobalt	28 **Ni** nickel	29 **Cu** copper	30 **Zn** zinc	31 **Ga** gallium	32 **Ge** germanium	33 **As** arsenic	34 **Se** selenium	35 **Br** bromine	36 **Kr** krypton
Period 5	37 **Rb** rubidium	38 **Sr** strontium	39 **Y** yttrium	40 **Zr** zirconium	41 **Nb** niobium	42 **Mo** molybdenum	43 **Tc** technetium	44 **Ru** ruthenium	45 **Rh** rhodium	46 **Pd** palladium	47 **Ag** silver	48 **Cd** cadmium	49 **In** indium	50 **Sn** tin	51 **Sb** antimony	52 **Te** tellurium	53 **I** iodine	54 **Xe** xenon
Period 6	55 **Cs** caesium	56 **Ba** barium	57–71 lanthanides	72 **Hf** hafnium	73 **Ta** tantalum	74 **W** tungsten	75 **Re** rhenium	76 **Os** osmium	77 **Ir** iridium	78 **Pt** platinum	79 **Au** gold	80 **Hg** mercury	81 **Tl** thallium	82 **Pb** lead	83 **Bi** bismuth	84 **Po** polonium	85 **At** astatine	86 **Rn** radon
Period 7	87 **Fr** francium	88 **Ra** radium	89–103 actinides	104 **Rf** rutherfordium	105 **Db** dubnium	106 **Sg** seaborgium	107 **Bh** bohrium	108 **Hs** hassium	109 **Mt** meitnerium	110 **Ds** darmstadium	111 **Rg** roentgenium	112 **Cn** copernicium	113 **Uut** ununtrium	114 **Fl** flerovium	115 **Uup** ununpentium	116 **Lv** livermorium	117 **Uus** ununseptium	118 **Uuo** ununoctium

Lanthanides	57 **La** lanthanum	58 **Ce** cerium	59 **Pr** praseodymium	60 **Nd** neodymium	61 **Pm** promethium	62 **Sm** samarium	63 **Eu** europium	64 **Gd** gadolinium	65 **Tb** trebium	66 **Dy** dysprosium	67 **Ho** holmium	68 **Er** erbium	69 **Tm** thulium	70 **Yb** ytterbium	71 **Lu** lutetium
Actinides	89 **Ac** actinium	90 **Th** thorium	91 **Pa** protactinium	92 **U** uranium	93 **Np** neptunium	94 **Pu** plutonium	95 **Am** americium	96 **Cm** curium	97 **Bk** berkelium	98 **Cf** californium	99 **Es** einsteinium	100 **Fm** fremium	101 **Md** mendelevium	102 **No** nobelium	103 **Lr** lawrencium

atomic number — 13
symbol — **Al**
name — aluminium

KEY Non-metals | Metals | Metalloids

Figure 4.2.1 The periodic table is a list of all the known elements arranged in order of increasing atomic number.

Periods and groups

The periodic table lists the elements according to their atomic number but it also arranges them in rows and columns:

- The horizontal rows are called **periods**. They are numbered 1 to 7 and are shown in Figure 4.2.2.
- The vertical columns are called **groups**. Groups are numbered from 1 to 18. An older way of numbering uses the roman numerals I to VIII (Figure 4.2.3).

This arrangement of periods and groups gives each element a specific spot in the table. For example, oxygen (O) is in period 2, group 16. Chlorine (Cl) is in period 3, group 17 and potassium (K) is in period 4, group 1.

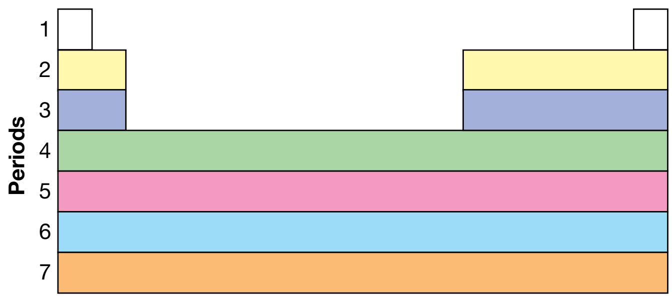


Figure 4.2.2 Periods are the horizontal rows of the periodic table.

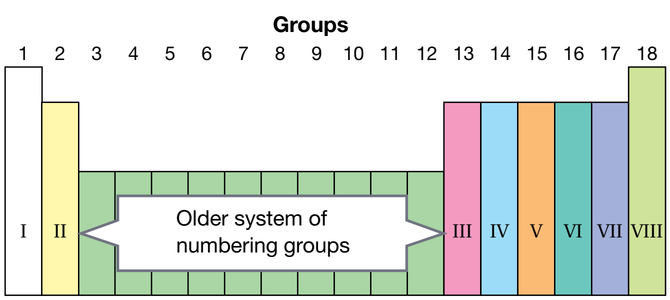


Figure 4.2.3 Groups are the vertical columns of the periodic table.

The arrangement of the periodic table into columns and rows places elements with similar physical and chemical properties in the same group. For example, beryllium, magnesium, calcium, strontium and barium display all the physical characteristics typical of metals. They react in much the same way as one another and form very similar compounds. For these reasons, they are all placed in group 2. Likewise, fluorine, chlorine, bromine and iodine act in a similar way in chemical reactions and so all are placed in group 17.

Hence, a group is a column in the periodic table but it can also be thought of as a set of elements that behave in very similar ways. This is useful as it allows you to predict what an element might do by looking at other elements in the same group. For example, sodium is in group 1 and burns brightly in air. Potassium is also in group 1, so it too can be expected to burn brightly in air. As Figure 4.2.4 shows, the combustion of sodium and potassium are very similar. Likewise sulfur, in group 16, can be expected to react in a very similar way to oxygen, which is also in group 16.

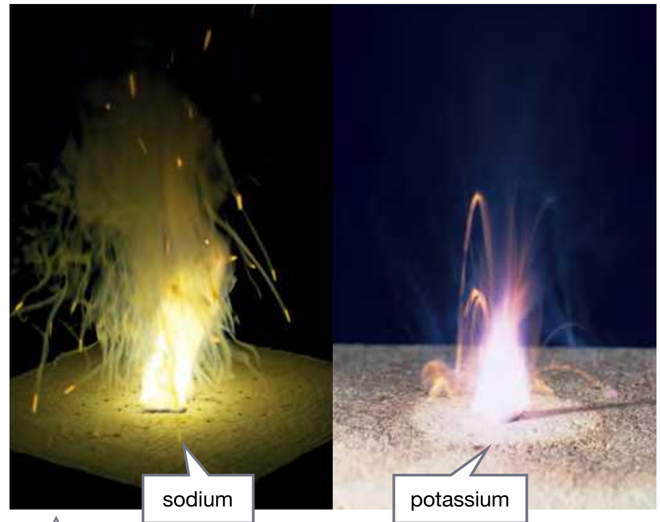


Figure 4.2.4 Sodium and potassium are both in group 1—both burn brightly in air.

GO TO Pearson science NSW 9 Unit 2.1

Special blocks

As Figure 4.2.5 shows, the periodic table also has three special blocks of elements known as the **transition elements**, **lanthanides** and **actinides**.

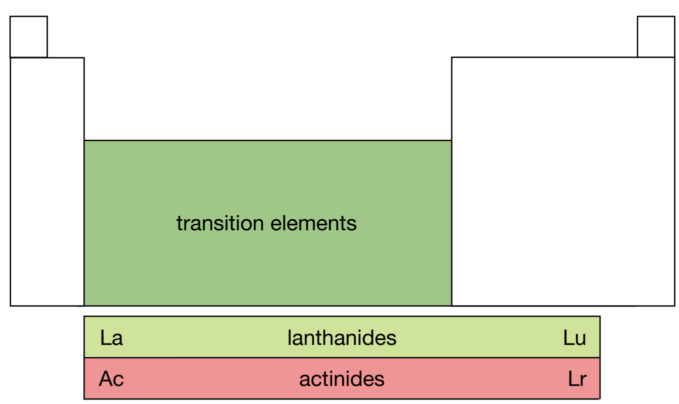


Figure 4.2.5 The transition elements, the lanthanides and actinides, are placed in special blocks.

Prac 1 p136
Prac 2 p137
4.1

Element symbols

The symbols of most elements use the first letter of their names or two 'logical' letters from them. This makes their symbols relatively easy to predict. Table 4.2.1 shows some of them.

However, a handful of metallic elements have symbols that seem illogical. This is because their symbols are based on their names in another language, usually Latin or Greek. These 'illogical' symbols are the ones you need to remember. Three of these elements are shown in Figure 4.2.6.

A few heavy, synthetic elements are so radioactive that they only exist for one-thousandth of a second or so. This makes confirmation of their existence extremely difficult. Until confirmation happens, they are given temporary symbols of three letters. You don't need to remember these (Figure 4.2.7).

Table 4.2.1 Examples of element symbols

	Name	Symbol
Uses first letter	Oxygen	O
	Fluorine	F
	Sulfur	S
Uses two 'logical' letters	Chlorine	Cl
	Magnesium	Mg
	Calcium	Ca
Based on their original Latin or Greek name	Sodium	Na
	Gold	Au
	Tin	Sn
Temporary	Ununoctium	Uuo

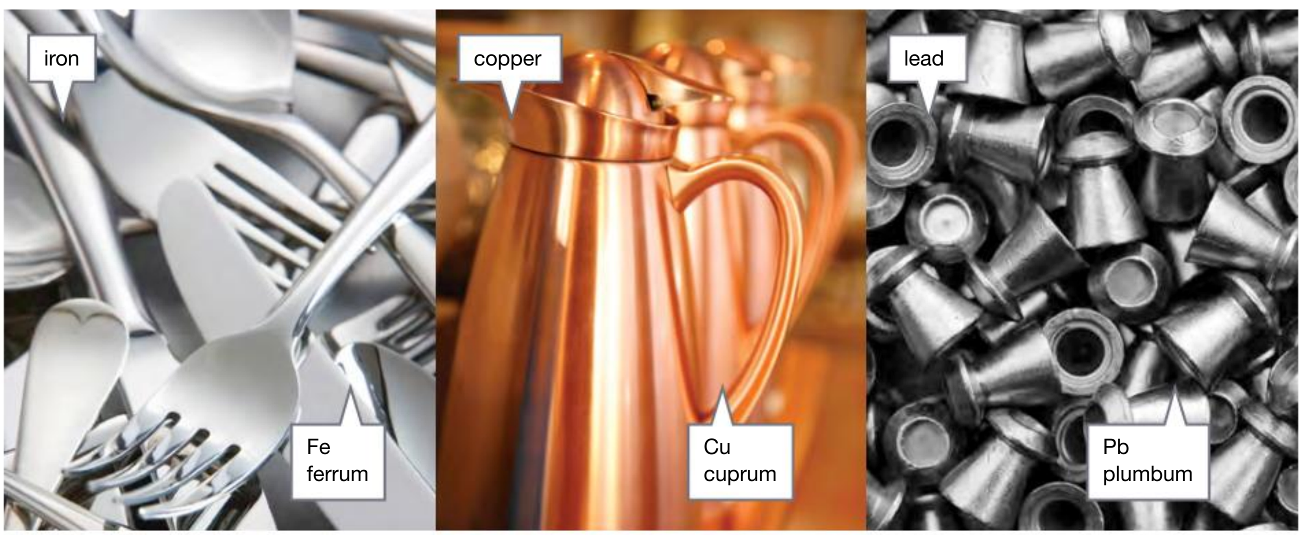


Figure 4.2.6 The symbols of iron (Fe), copper (Cu) and lead (Pb) are based on their respective Latin names *ferrum*, *cuprum* and *plumbum*.

Figure 4.2.7 In 1996, a particle accelerator like this one was used to discover an element with the atomic number 112. It was given the temporary name ununbium (Uub). In 2009, the existence of the element was finally confirmed. It was then given the name copernicium (Cn) after the famous astronomer Nicolaus Copernicus (1473–1543).

LEARNING ACROSS THE CURRICULUM

CRITICAL AND CREATIVE THINKING

DEVELOPMENT OF THE PERIODIC TABLE

The ancient Greek philosopher Aristotle thought that there were only four elements: earth, water, air and fire. Although scientists now know that these aren't elements, Aristotle's idea began a long search for what substances are made of. As scientific techniques advanced, so did the list of known elements. As more elements were discovered, scientists looked for ways to organise them.

Figure 4.2.8 John Dalton's table of elements and the symbols he gave them

Chemists had long known that certain elements behaved similarly to one another in chemical reactions and in their physical properties. This pattern provided a way of constructing the periodic table that is now used by all chemists worldwide.

THE FIRST TABLES

In 1789, the French chemist Antoine-Laurent de Lavoisier (1743–93) separated the known elements into metals, non-metals and 'earths'. However, his list of 33 elements also included light and a liquid called 'caloric' that was thought to carry heat from hot to cold bodies. Caloric is now known not to exist. Light does exist but is not an element. In 1808, the English chemist John Dalton (1766–1844) went further by giving each of the 36 known elements its own chemical symbol and organising them in order of their mass. You can see his symbols in Figure 4.2.8.

SciFile

Dalton's eyeballs

Dalton was colour-blind and suspected that it was because his eyes were filled with blue liquid! He instructed his doctor to dissect his eyes after death to determine if they were. No blue liquid was found but in 1995 the gene that leads to colour-blindness was isolated from his preserved eyes.

Fifty-five elements had been discovered by 1829. Some elements had very similar properties and seemed to be related. For example, chlorine, bromine and iodine (shown in Figure 4.2.9) reacted with other chemicals in a similar way. For this reason, the German chemist Johann Dobereiner (1780–1849) bunched them together into a family of three. Other related elements were also bunched into threes. Dobereiner called his bunches 'triads'. Lithium, sodium and potassium formed a triad, while calcium, strontium and barium formed another.

Figure 4.2.9 The properties of chlorine, bromine and iodine are so similar that Dobereiner placed them in the same triad.

In 1864, the English scientist John Newlands (1837–98) arranged the 60 known elements in order of their mass, forming a table of seven rows. Newland's rows were the equivalent of today's groups. This arrangement successfully placed many elements with similar properties together in the same row/group. However, the arrangement also placed some very different elements together. For example, the row/group that included the non-metals oxygen and sulfur also included the metals iron and gold! More confusingly, Newland's table sometimes had two elements in them and there were no 'blank' boxes for any element that might still be discovered.

SUCCESS

In 1869, the Russian chemist Dmitri Ivanovich Mendeleev (1834–1907) constructed a table of rows and columns like those of his favourite card game, called solitaire or patience. Each element had its own box. He placed the 63 elements known at the time horizontally according to their atomic masses and vertically according to their properties. He believed in the periodicity (repetition) of the properties of the elements and this arrangement placed elements with similar properties in the same columns. He then realised that some atomic masses were wrong and instead placed those elements where their resemblance to other elements suggested they should go. He also left gaps in his table for undiscovered elements and predicted what their properties might be. For example, he predicted that 'eka-silicon' would eventually be discovered. When isolated in 1886, eka-silicon's properties compared remarkably well with Mendeleev's predictions. Eka-silicon is now known as germanium. Table 4.2.2 compares its predicted and measured properties. Similarly, the properties he predicted for eka-aluminium, eka-boron and eka-manganese were close to those of gallium (isolated in 1875), scandium (1879) and technetium (1937) respectively.

Table 4.2.2 Comparing eka-silicon with germanium

Physical property	Eka-silicon: Mendeleev's predictions	Germanium: properties as measured
Colour	Grey	Grey-white
Atomic mass	72	72.61
Melting point (°C)	High	947
Density (g/cm^3)	5.5	5.35

A table similar to Mendeleev's was constructed in 1868–69 by the German chemist Lothar Meyer (1830–95).

OUR MODERN TABLE

Mendeleev and Meyer arranged the elements in order of increasing atomic mass. To construct his table in 1913, the English physicist Henry Moseley (1887–1915) used atomic numbers instead. An extended version of Moseley's table is still used today.

SciFile

An eccentric scientist!

Figure 4.2.10 shows Mendeleev's extravagant hair and beard, which he only trimmed once a year. Mendeleev (and his mother) hitch-hiked over 6000 km in 1848 to get to his first day of university in St Petersburg. While there, he spent some of his time perfecting the perfect vodka!

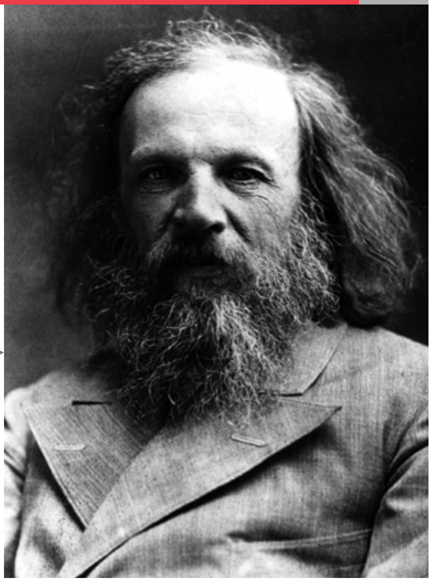


Figure 4.2.10 Dmitri Ivanovich Mendeleev constructed the first modern periodic table.

4.2

REVIEW

1 **Construct** a table or line graph showing how many elements were known in 1789, 1808, 1829, 1864, 1869 and 2014 (the year this book was published).

2 **Propose** reasons why Dalton's symbols would be difficult to use today.

3 **List** the elements that Dobereiner organised into three triads.

4 **Explain** why Newland's arrangement of the elements became known as the law of octaves.

5 Newland's table sometimes had two elements in the same box. **Explain** why this is now known to be impossible.

6 **Explain** why Mendeleev left gaps in his original table.

7 **Explain** how Moseley's periodic table differed from those of Mendeleev and Meyer.

4.2 Unit review

Remembering

1 **State** what determines the order of the elements of the periodic table.

2 **State** the names and symbols for ten elements that use as their symbols:
- **a** the first letter of their names (such as yttrium Y)
- **b** the first two letters of their names (such as francium Fr)
- **c** two other letters from their names (such as neptunium Np)
- **d** one or two letters that seem unrelated to their names (such as tungsten W).

3 **State** whether the following are true or false.
- **a** Periods are horizontal rows in the periodic table.
- **b** Groups are numbered 1 to 7.
- **c** Bromine (Br) is in period 17, group 4.
- **d** Magnesium (Mg) is in period 3, group 2.
- **e** Metals appear on the right of the periodic table and non-metals on the far-left.

4 For nitrogen, **state** its:
- **a** chemical symbol
- **b** atomic number
- **c** period
- **d** group number.

5 **List** five:
- **a** group 15 elements
- **b** period 2 elements
- **c** common transition elements
- **d** lanthanides
- **e** actinides.

6 **Name** two elements that could be expected to have similar properties to:
- **a** calcium (Ca)
- **b** sulfur (S)
- **c** argon (Ar).

Understanding

7 **Define** these terms. L
- **a** period
- **b** group

8 **Modify** the following list of elements arranging them in order from lightest to heaviest: B, He, Kr, As, S, U, Na, Ag.

9 **Explain** why two different elements cannot occupy the same box in the periodic table.

Applying

10 **Identify** the period and group to which these atoms would belong.
- **a** Ne
- **b** an atom with atomic number 13
- **c** an atom with 7 electrons

11 **Use** the periodic table to **determine** the number of electrons in an atom:
- **a** with eight protons
- **b** with 18 protons
- **c** with an atomic number of 3
- **d** with an atomic number of 19
- **e** in period 2, group 17
- **f** in period 3, group 2
- **g** of phosphorus
- **h** of potassium.

Analysing

12 **Compare** the elements H, Li and Na by listing the similarities and differences in:
- **a** the structure of their atoms
- **b** their placement in the periodic table.

Evaluating CCT

13 Games like Element Bingo on page 129 help you remember element symbols. **Propose** reasons why.

Creating CCT

14 **Construct** a way of remembering those element symbols that don't seem to match their names.

Inquiring

1 Research the lives, achievements and contributions to the development of the periodic table of Mendeleev, Lavoisier and Dalton.
Present your research as a short biography.

2 Find a version of Mendeleev's original periodic table and compare it with the one used today.
Present both tables as printouts, pasted into a Word document, with labels indicating their similarities and differences. ICT

3 Find alternative versions of the periodic table that are used today for different purposes.
Present each version as a printout, pasted into a Word document or screen dump. ICT

4.2 Practical investigations

1 Properties of elements

Purpose

To compare the properties of metals and non-metals.

Materials

- samples of sulfur, aluminium, carbon, silicon, tin, zinc, lead, magnesium, iron
- steel wool

- 3 or 4 test-tubes and rack
- power pack or battery (about 2 V)
- wires with alligator clips
- light globe
- rubber gloves

SAFETY

All these samples can irritate the skin and eyes and must be regarded as poisonous. Wear rubber gloves and safety glasses at all times. Do not taste or sniff any sample. Wash your hands thoroughly with soap and water after the prac.

Have your teacher check the circuit before you turn it on.

Procedure

1. Copy the table from the Results section into your workbook.
2. Use the periodic table in Figure 4.2.1 on page 130 to determine whether the element you are testing is a metal or a non-metal.
3. Record the appearance of each sample in a table as shown in the Results section.
4. Polish each sample with the steel wool. Record its appearance now.
5. Try and bend the sample. Record whether it bends or crumbles.
6. Place some of the sample in a test-tube with water. Record whether it floats or not and whether any change is obvious. For example, does it dissolve or react?
7. Use a circuit similar to the one in Figure 4.2.11 to test if the sample conducts electricity.

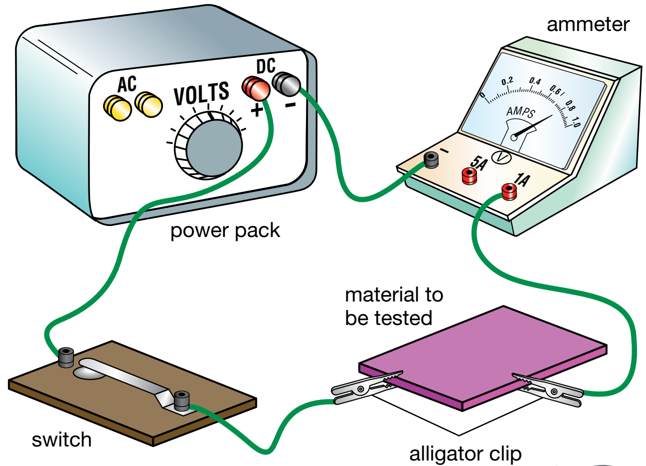


Figure 4.2.11

Results

Record all observations in your results table.

Element	Metal or non-metal	Appearance when polished	Bends or crumbles	Float or sinks	Action with water	Electrical conductivity

Practical review

1. Metals share certain physical properties. From your observations, **list** them.
2. **List** the properties that were common in all the non-metals you tested.

2 Card-game analogy

Purpose

To use cards as an analogy for the periodic table.

Materials

- printout of sheet that looks like Figure 4.2.12, provided by your teacher
- scissors
- access to paste or sticky tape

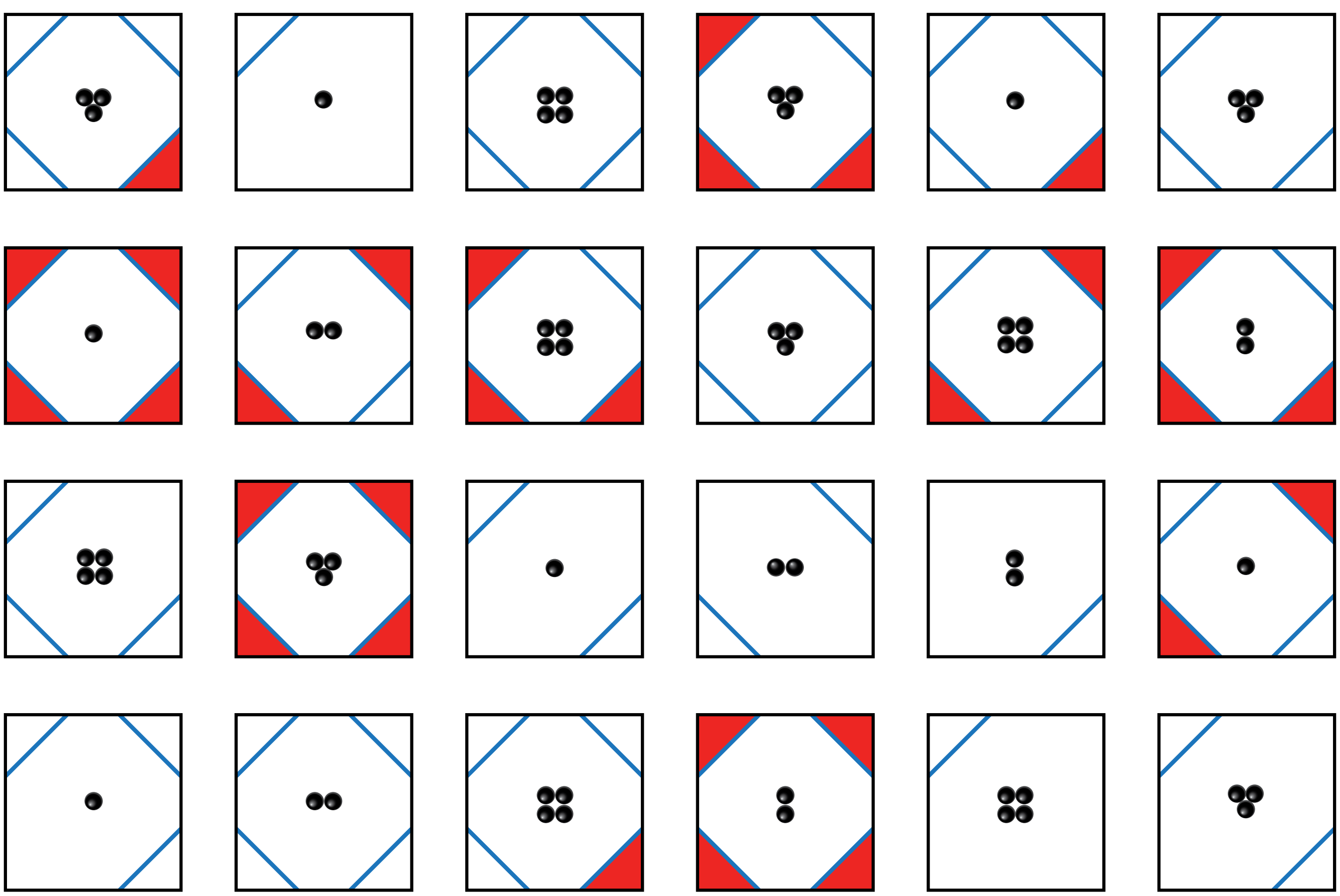
Procedure

1. Cut the sheet up to make 24 cards.
2. Look for similarities and patterns in the cards and arrange them logically into a table. Note that there may be some gaps.
3. Paste or tape your table into your workbook.

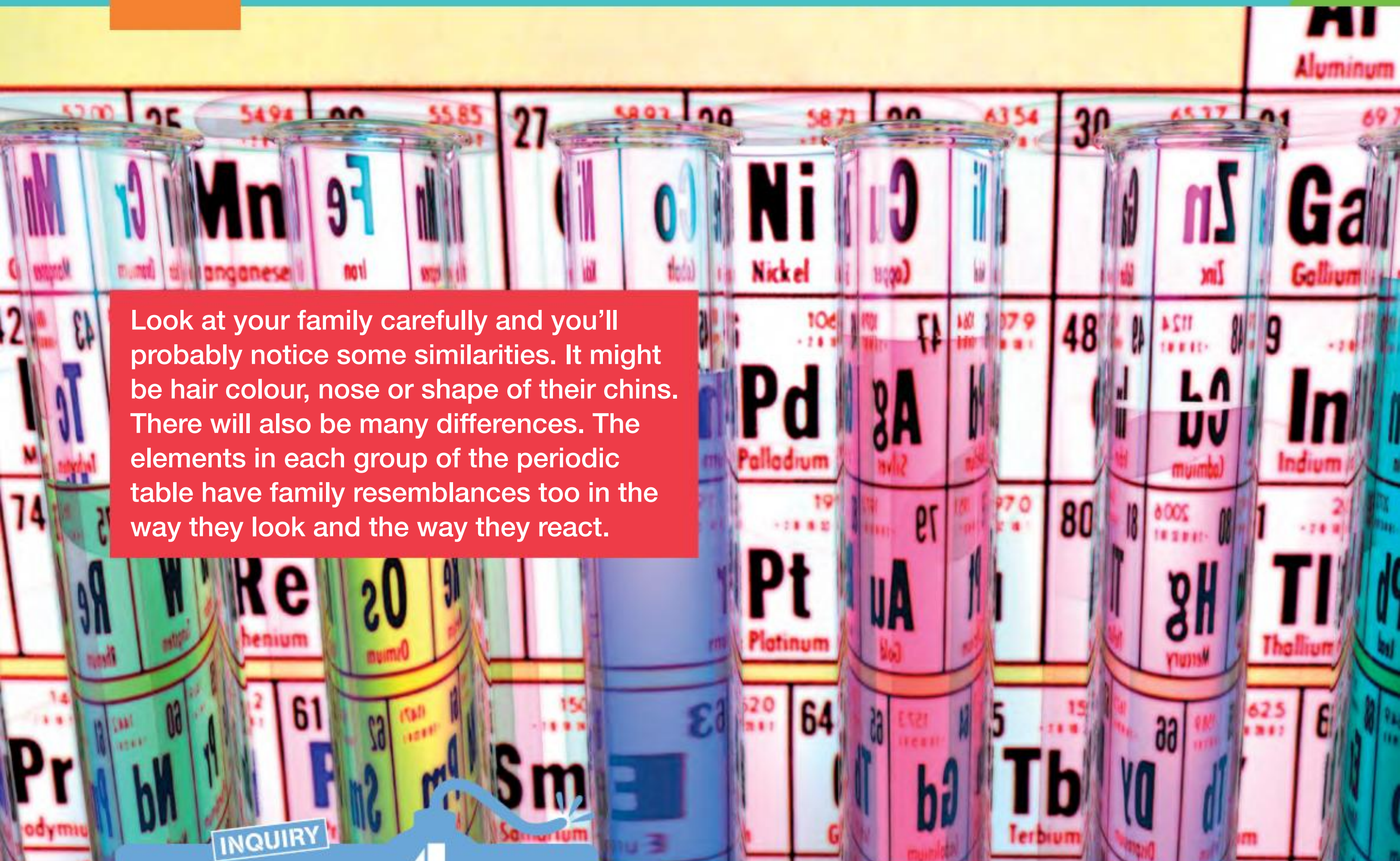
Practical review

1. **Compare** the table you constructed with those constructed by other students in the class.
2. a **State** how many cards seem to be 'missing' from your table.
   b **Construct** diagrams to show what you expect these cards to look like.
3. Mendeleev left gaps in his original periodic table for elements he believed had not yet been discovered.
   He then predicted their properties. **Use** the card analogy to **propose** how he did this.

Figure 4.2.12



4.3 Family groupings



Look at your family carefully and you'll probably notice some similarities. It might be hair colour, nose or shape of their chins. There will also be many differences. The elements in each group of the periodic table have family resemblances too in the way they look and the way they react.

INQUIRY

science 4 fun

A rough diamond

What does the structure of diamond look like?

YES

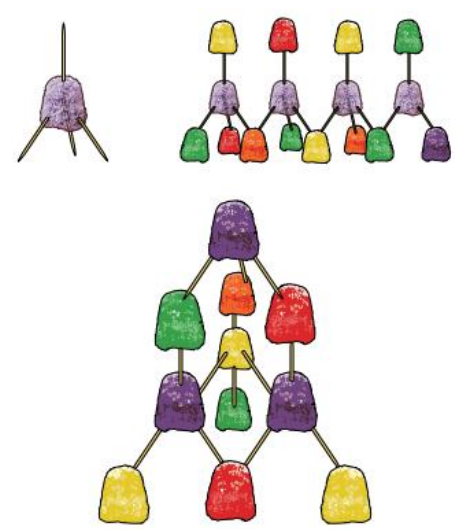
Collect this ...

- lollies such as fruit pastilles or raspberries
- toothpicks
- heavy book

SAFETY
Do not eat the lollies.

Do this ...

1. Insert four toothpicks into a lolly so that they form a tetrahedron or triangular pyramid like that shown on the right.
2. Attach more lollies and toothpicks until you have diamond!
3. Once built, place the book on top of your structure and push lightly down.



Record this ...

Describe how strong your structure was.
Explain why you think this happened.

Similar but different

Each group in the periodic table contains a set of elements that have similar physical and chemical properties. The elements are not identical but resemble one another by sharing similar characteristics. In this way, they are like a family. Some groups even have family names, shown in Figure 4.3.1. For example, group 18 is known as the noble or inert gases. All elements in this group are gases that do not react with substances or are extremely reluctant to do so. This lack of reactivity makes them extremely useful in advertising signs such as the one shown in Figure 4.3.2.

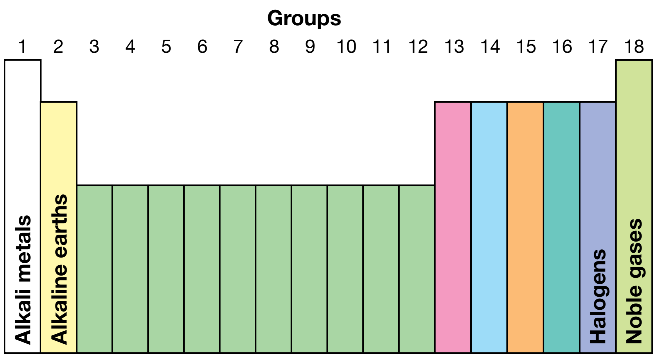


Figure 4.3.1 Elements in the same group share similar physical and chemical properties. For this reason, each group can be considered to be a 'family' of elements.

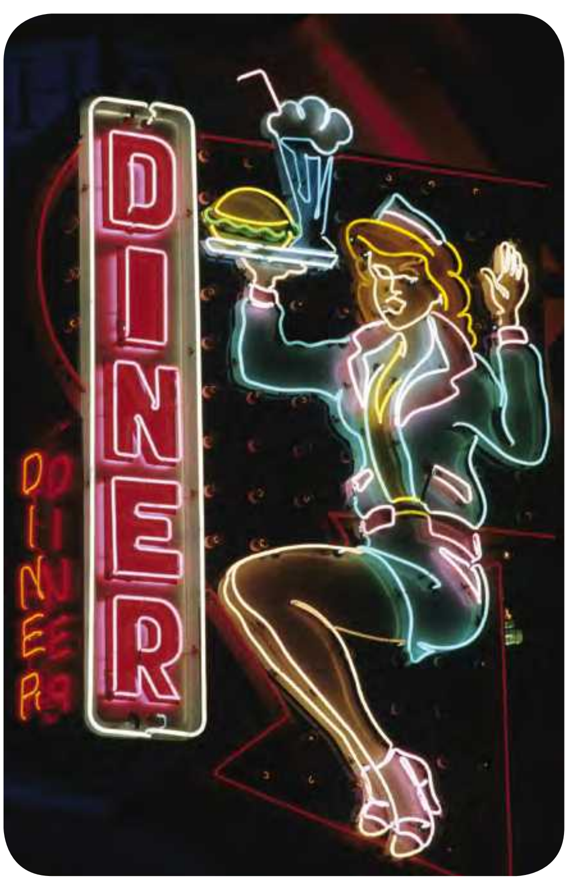


Figure 4.3.2 Bright red-orange advertising signs often contain the noble gas neon. Other noble gases give different colours.

Group 1—the alkali metals

The group 1 elements shown in Figure 4.3.3 are known as the **alkali metals**. All the alkali metals:

- form +1 ions
- are far too reactive to be found naturally in their pure forms
- have typical metallic properties
- display similar extreme chemical behaviour.

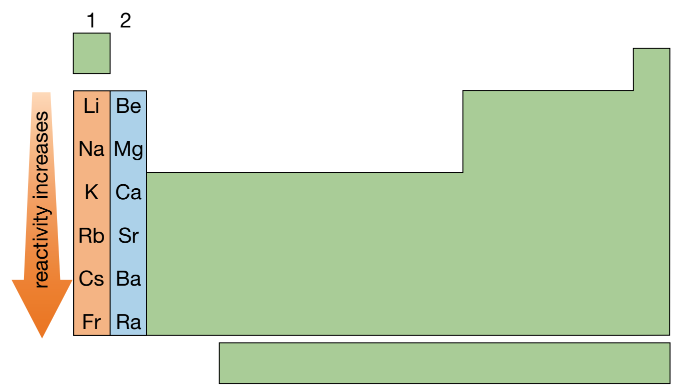


Figure 4.3.3 The alkali metals are group 1 and the alkaline earths are group 2.

Lithium, sodium and potassium are less dense than water, allowing them to float on it. These three elements are so soft that they can be cut with a knife.They all react with chlorine gas (and the other group 17 elements) and produce similar white salts. For example, lithium reacts with chlorine gas to form lithium chloride. This can be written as the balanced formula equation:

$$2Li + Cl_2 \rightarrow 2LiCl$$

From this equation, you can predict the equations for the other alkali metals and the group 17 elements. Some of these equations are:

$$2Na + Cl_2 \rightarrow 2NaCl$$

$$2K + Br_2 \rightarrow 2KBr$$

$$2Li + F_2 \rightarrow 2LiF$$

All alkali metals react violently with water, producing an alkaline or basic solution and hydrogen gas, which sometimes ignites due to the heat produced. This is what has happened in Figure 4.3.4 on page 140. For sodium, the balanced formula equation is:

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

The other alkali metals will do much the same:

$$2Li + 2H_2O \rightarrow 2LiOH + H_2$$

$$2K + 2H_2O \rightarrow 2KOH + H_2$$

4.3

Figure 4.3.4 An accident in which sodium was accidentally dropped into water. Reactions of this type become even more violent as you move down group 1.

Group 2—the alkaline earths

The group 2 elements are known as the **alkaline earths** or alkaline earth metals. The alkaline earths are all metals and all act in a similar (but slightly less reactive) way to group 1 elements. When they do react, the alkaline earths form ions with a charge of +2.

Table 4.3.1 compares the melting and boiling points of the alkali metals and the alkaline earths.

Table 4.3.1 Comparison of properties of groups 1 and 2

	Group 1 element	Melting point (°C)	Boiling point (°C)	Group 2 element	Melting point (°C)	Boiling point (°C)
Period 2	Li	181	1342	Be	1278	2970
Period 3	Na	98	883	Mg	649	1107
Period 4	K	63	760	Ca	839	1484
Period 5	Rb	39	686	Sr	769	1384
Period 6				Ba	725	1640

SKILL BUILDER

Predicting chemical equations

Elements of the same group tend to react in very similar ways and so a balanced chemical equation for one element can be used to predict the reactions for other elements in the group. For example, the balanced formula equation for the reaction of fluorine with hydrogen sulfide is:

$$F_2 + H_2S \rightarrow S + 2HF$$

Fluorine is a group 17 element, so the other group 17 elements will react in similar ways. It can be expected that their balanced formula equations will be similar too. Hence, you can predict that their reactions will most likely be:

$$Cl_2 + H_2S \rightarrow S + 2HCl$$

$$Br_2 + H_2S \rightarrow S + 2HBr$$

$$I_2 + H_2S \rightarrow S + 2HI$$

Prac 1 p145

ADDITIONAL

Trends in chemical activity of metals

Atoms get progressively larger as you move down any group from period 1 to period 7 in the periodic table. For example, the smallest atoms in group 1 belong to hydrogen in period 1. Lithium is also in group 1 but it is in period 2. Hence the atoms of lithium are larger than the atoms of hydrogen. Sodium atoms are larger than lithium atoms, potassium atoms are larger than sodium atoms and so on down the group. The largest atoms in group 1 belong to francium in period 7.

This increase in size down the group causes metals to become less stable and more likely to react with other substances. Metal atoms have a weak hold on their outer electrons. This hold weakens even further as atoms get larger and the outer electrons are further from the nucleus they spin around. The weaker this hold, the more unstable and reactive a metal atom will be. Lithium has the smallest atoms of all the alkali metals and so holds its outer electrons more strongly than any of the other metals in the group. This makes lithium relatively stable and unreactive. For example, lithium metal only fizzes when put into water.

Sodium atoms are a little bigger and can react explosively with moisture in the air. Reactions with moisture become even more violent as you move down group 1. To avoid this happening accidentally, alkali metals are usually stored in paraffin oil to keep them moisture-free.

ADDITIONAL

Group 14

The elements of group 14 display a wide range of properties (Figure 4.3.5). The group begins with the non-metal carbon, moves through the metalloids silicon and germanium and finishes with the metallic elements tin and lead.

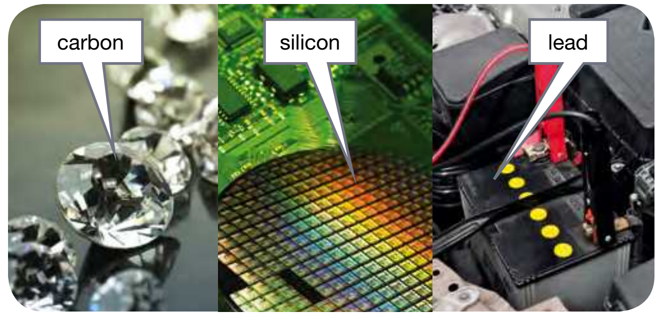


Figure 4.3.5 Diamond is carbon. Electronic circuit chips are made of silicon. The plates of car batteries are lead. Carbon, silicon and lead are all group 14 elements.

Pure carbon exists in several different forms or **allotropes**, the most common being amorphous carbon (charcoal), diamond, graphite and buckyballs. The molecular structures of the four allotropes of carbon are all different.

Carbon is also in molecules in every living thing on Earth, and anything that was once living such as wood. Carbon has the ability to form an amazing range of molecules. Substances that have carbon skeletons are known as **organic** substances and their molecules are **organic molecules**. Organic molecules make up all living things, fossil fuels and polymers (plastics) (Figure 4.3.6).

4.4 4.5

Silicon is found as silicon dioxide and metal silicates. Together they make up 75% of Earth's crust—sand, clay, asbestos and quartz contain silicon as do many gemstones. You can see one such gemstone in Figure 4.3.7 on page 142. Silicon also is the major component of glass.

Figure 4.3.6 There are more compounds of carbon than any other element on Earth. Organic compounds form the basis for all life on Earth, all fossil fuels and most plastics.

Mendeleev predicted the existence of germanium 15 years before its discovery, naming it eka-silicon. Germanium is used as the catalyst in fluorescent lights and its oxides are used in the production of lenses for optical instruments such as microscopes. Both silicon and germanium are semiconductors and are widely used in electronic components.

Tin and lead are metals and have characteristic metallic properties. They are malleable (able to be bent), ductile (able to be stretched into wires), lustrous (shiny when polished) and electrical and thermal conductors.

Figure 4.3.7 Silicon dioxide is the main component of many precious and semiprecious gemstones such as this amethyst.

Group 17—the halogens

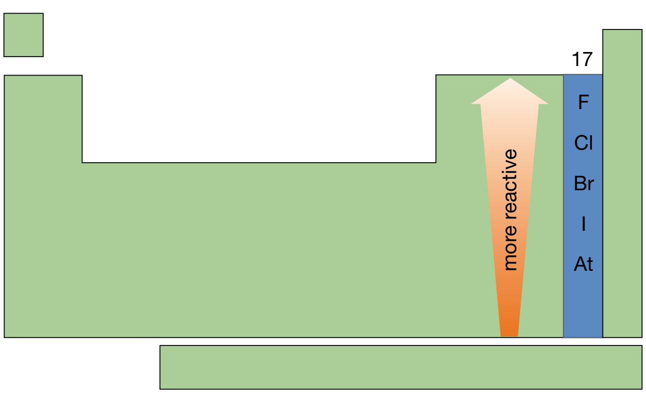


Figure 4.3.8 The halogens

The group 17 elements shown in Figure 4.3.8 are known as the **halogens**. Atoms of halogens:

- form ions with a charge of –1
- are not found in nature in their pure form but are found in various types of salts, including sea salt
- get bigger and become less reactive as you move down the group
- all form molecules that are made up of two atoms (F_2, Cl_2, Br_2 and I_2). You can see this in Figure 4.3.9
- have coloured and poisonous vapours.

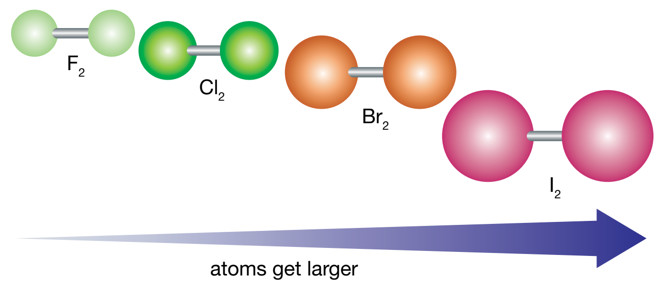


Figure 4.3.9 Although the halogens have similarities, their different sizes result in some differences in their properties.

All of the halogens convert hydrogen sulfide (H_2S, known as 'rotten egg' gas) into sulfur (S). These reactions also form very similar gases composed of hydrogen and the halogen, such as hydrogen chloride. These reactions can be written as balanced formula equations:

$$F_2 + H_2S \rightarrow S + 2HF$$

$$Cl_2 + H_2S \rightarrow S + 2HCl$$

As Figure 4.3.10 shows, they also react in a similar way with iron.

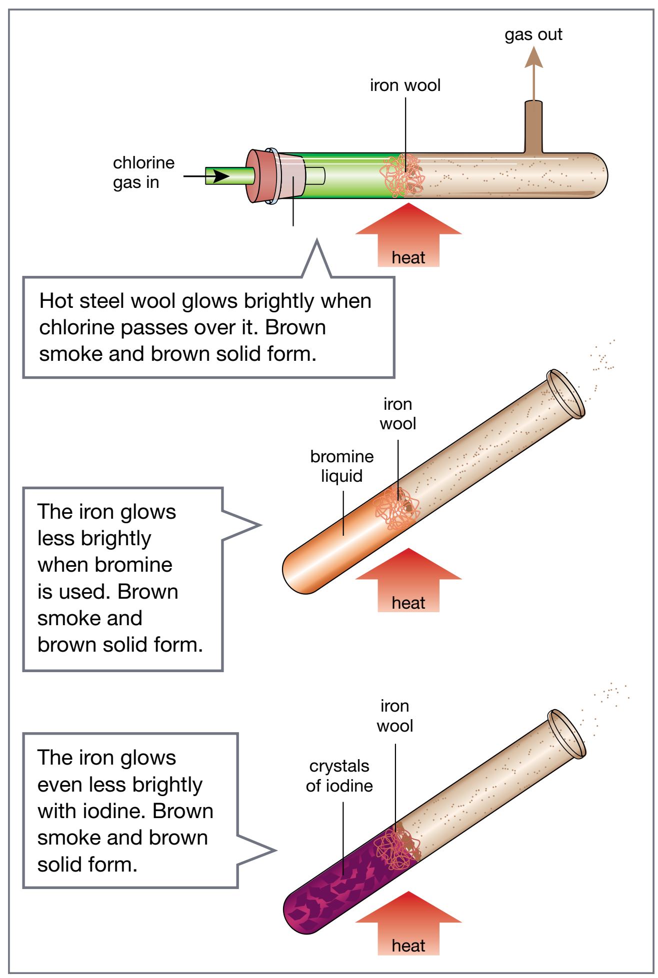


Figure 4.3.10 Each of the halogens reacts with iron in a very similar way, forming very similar products.

Prac 2 p146

Group 18—the noble gases

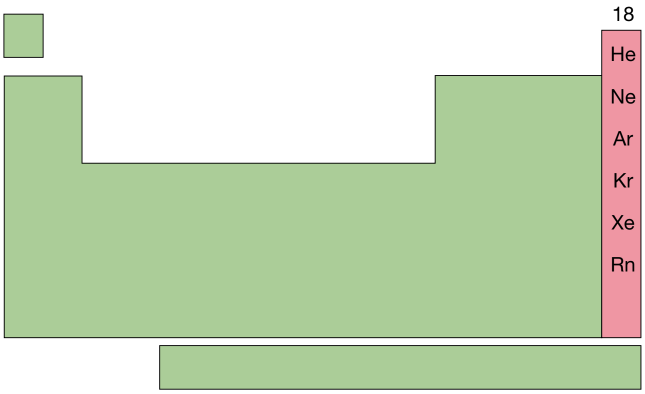


Figure 4.3.11 The noble or inert gases

The **noble gases** of group 18 are also known as the **inert gases**. They are shown in Figure 4.3.11. All are colourless and occur naturally in the atmosphere. Distillation is used to separate them from liquid air. They are incredibly stable and react only under rare or extreme circumstances. Helium has a density much less than that of air. This is why helium balloons float up into the air. This and its lack of reactivity make helium the ideal gas for party balloons and for airships (unlike the alternative hydrogen which is explosive). As you move down group 18, the other noble gases get progressively denser. This makes their balloons get heavier. This is shown in Figure 4.3.12.

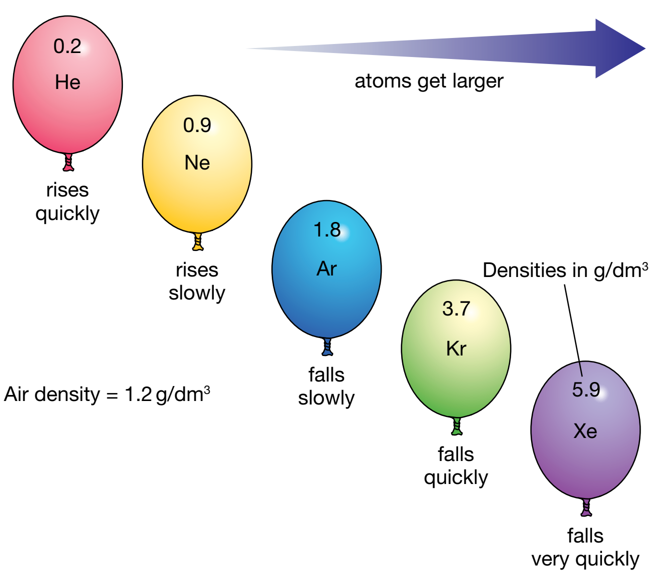


Figure 4.3.12 The atoms of noble gases get bigger and heavier as you move down the group. This makes them denser and less likely to float in air.

The transition metals

The transition elements (groups 3–12) are all metals and include many of our most useful, colourful and valuable ones such as iron, copper, zinc, gold and silver. Their salts and solutions are also colourful—some are shown in Figure 4.3.13. The transition metals have very similar properties. For example, they all tend to be relatively hard with high melting points. Likewise, the period 4 metals iron, cobalt and nickel are all magnetic.

Figure 4.3.13 These solutions of transition metals show how colourful transition metals can be.

Squeaky voices

SciFile

Your voice goes high and squeaky when you breathe in helium from a party balloon. Your vocal cords vibrate more quickly in helium because it is lighter than air, making the pitch go higher. Don't try this, though. People have died from breathing in gases such as helium.

Scandium, agent Sc-46!

SciFile

The East German secret police (the Stasi) regularly sprayed opponents of the government (dissidents) with the radioactive transition element scandium, $^{46}_{21}Sc$. The unknowing dissidents were then traced with a Geiger counter strapped under the armpits of Stasi agents. Vibrations alerted the agent that their trace was nearby. The Stasi also used radioactive silver bullets that could be safely shot into the tyres of cars they wanted to track.

4.3 Unit review

Remembering

1 **State** the group number of the following families of elements.
- **a** alkali metals
- **b** alkaline earths
- **c** halogens
- **d** noble gases

2 **Name** an element that has similar properties to:
- **a** potassium (K)
- **b** calcium (Ca)
- **c** oxygen (O).

3 **Name** three allotropes of carbon.

4 **State** the chemical formulas for molecules of fluorine and molecules of chlorine.

5 **Name** the separation method that is used to separate noble gases from air.

Applying

6 **Use** the structure shown in the science4fun activity on page 138 to **explain** why diamond is so strong.

7 Radon is a radioactive gas.
- **a** **State** the period and group number for radon.
- **b** **List** five other elements that radon could be expected to be similar to.
- **c** **Describe** what would most likely happen to a balloon filled with radon.
- **d** **Identify** the most likely density of radon gas from the following numbers: 0.1, 1.2, 5.0, 10.0 g/dm^3.

8 **Use** family resemblances and the balanced formula equations given in this unit to **predict** the reactions of:
- **a** sodium (Na) with water (H_2O)
- **b** rubidium (Rb) with water (H_2O)
- **c** lithium (Li) with iodine (I_2)
- **d** sodium (Na) with bromine (Br_2).

9 **Use** family resemblances to **identify** the chemical formulas missing from each of the following balanced formula equations.
- **a** $2Na + F_2 \rightarrow 2...$
- **b** $2Cs + 2... \rightarrow 2CsOH + H_2$

Analysing

10 **Analyse** the melting and boiling points in Table 4.3.1 on page 140. **Describe** what happens to them as you move:
- **a** down group 1 and group 2
- **b** across any period from group 1 to group 2.

Evaluating CCT

11 **a** **Define** what the term *organic* means chemically. L

b In 2013, seven companies were instructed to remove labels saying that their bottled water was organic. **Assess** whether water can be organic.

12 Tin acts like a non-metal at temperatures below 13°C. In 1913 Captain Robert Scott and two fellow explorers froze to death in Antarctica after they ran out of heating fuel that was stored in tins. **Use** the properties of metals and non-metals to **propose** reasons why they unexpectedly ran out.

Creating CCT

13 The melting and boiling points for each of the halogens are shown below.
- **a** **Identify** which halogens would be solid, liquid or gas at the following temperatures. N
  - **i** 20°C
  - **ii** 100°C
  - **iii** −199°C
  - **iv** 150°C
- **b** **Use** a spreadsheet or graph paper to **construct** accurate line graphs of the: N
  - **i** melting point versus period number
  - **ii** boiling point versus period number.

Period number	Group 17 element	Melting point (°C)	Boiling point (°C)
2	Fluorine F	–220	–188
3	Chlorine Cl	–101	–35
4	Bromine Br	–7	59
5	Iodine I	114	185

Inquiring

1 Research the uses for the alkali metals, alkaline earths, halogens and/or noble gases.

Construct a table to summarise your findings.

2 Some metals such as lead and mercury are known as cumulative poisons. Research what this means, the symptoms of cumulative poisoning and how you might come into contact with these metals.

Present your findings as a poster or digital presentation. ICT

4.3 Practical investigations

1 The alkaline earths

Purpose

To investigate the reactivity of group 2, the alkaline earth elements.

Materials

- distilled or de-ionised water
- 1 × 5 cm strip of magnesium
- phenolphthalein solution
- small sample of calcium

- 2 test-tubes and rack
- 1 rubber stopper with hole and glass tubing
- 1 rubber stopper with no hole
- 250 mL beaker
- Bunsen burner, tripod, bench mat and matches
- steel wool or emery paper
- tweezers

SAFETY

Do not handle calcium metal with your bare hands because it reacts with moisture.

Wear safety glasses at all times.

Procedure

Part A

1. Clean the magnesium strip with steel wool or emery paper and then form it into a coil.
2. Place the coil in a test-tube and cover it with distilled water.
3. Watch *very* carefully over the next 5 minutes. Look for bubbles.
4. If nothing happens, heat the test-tube gently over a yellow flame (Figure 4.3.14).
5. When finished, add 1 drop of phenolphthalein to the solution. Record the colour.

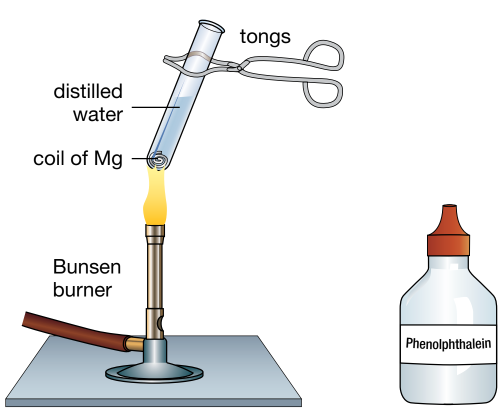


Figure 4.3.14

Part B

1. Put about 5 cm of distilled water into the other test-tube.
2. Using tweezers, add a piece of calcium. Immediately stopper the test-tube with the single-holed rubber stopper and collect any gas generated as shown in Figure 4.3.15.
3. Once the inverted test-tube is filled with gas, remove and stopper it.
4. Light a match, remove the stopper and place the match near the opening of the test-tube filled with gas. Record what happens and use the following guide to identify the gas.
   - If the match pops, then the gas is hydrogen.
   - If the match goes out, then the gas is carbon dioxide.
   - If the match flares up, then the gas is oxygen.
5. Add one drop of phenolphthalein to the test-tube that contained the water and calcium. Record the colour.

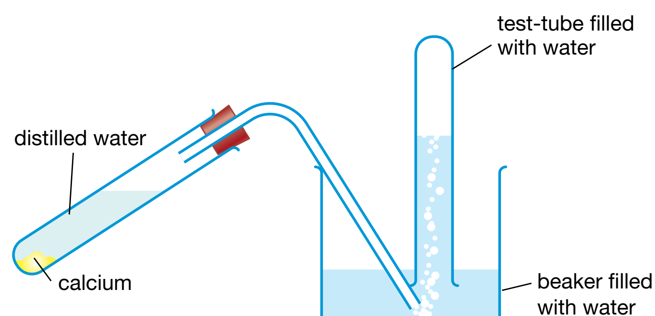


Figure 4.3.15

Practical review

1. From your observation, **state** whether magnesium or calcium is more reactive.
2. **Describe** what happens to reactivity as you move down group 2.
3. Group 1 metals are more reactive than group 2 metals. **Propose** a reason why reactions of group 1 metals are rarely performed in class except as teacher demonstrations.

2 Halogen precipitates

Precipitates are insoluble solids that sometimes form when solutions are mixed.

Purpose

To compare the precipitates formed when lead combines with different halogens.

Materials

- dropping bottles of solutions of
  lead nitrate,
  potassium fluoride (KF),
  potassium chloride (KCl),
  potassium bromide (KBr) and
  potassium iodide (KI)
- disposable gloves
- white tile or spotting tray (tray with small indents)
- marker pen

SAFETY

Lead is toxic. Do not get any of its compounds on you.

Wear disposable gloves and safety glasses at all times.

Wash your hands well after the activity.

Procedure

1. Put your disposable gloves and safety glasses on.
2. Place 3 drops of potassium fluoride solution in one indent of the spotting tray or on one corner of the white tile.
3. Use the marker pen to label this sample with KF.
4. In the each of the other indents or corners, place 3 drops of potassium chloride, potassium bromide or potassium iodide solutions. Label them KCl, KBr or KI respectively.
5. Add 3 drops of lead nitrate to each of the samples as shown in Figure 4.3.16. Record your observations.

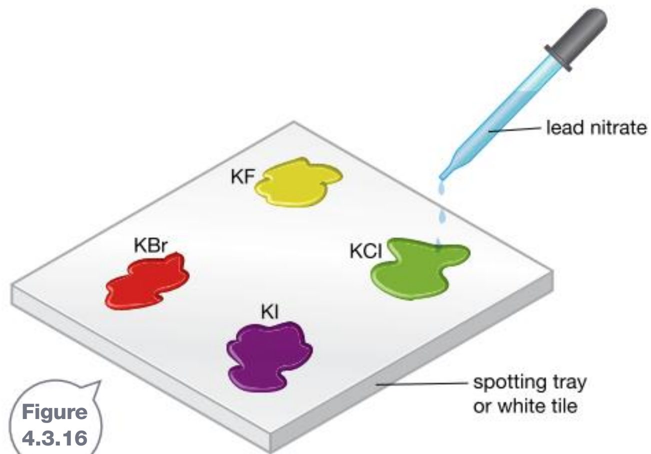


Figure 4.3.16

Results

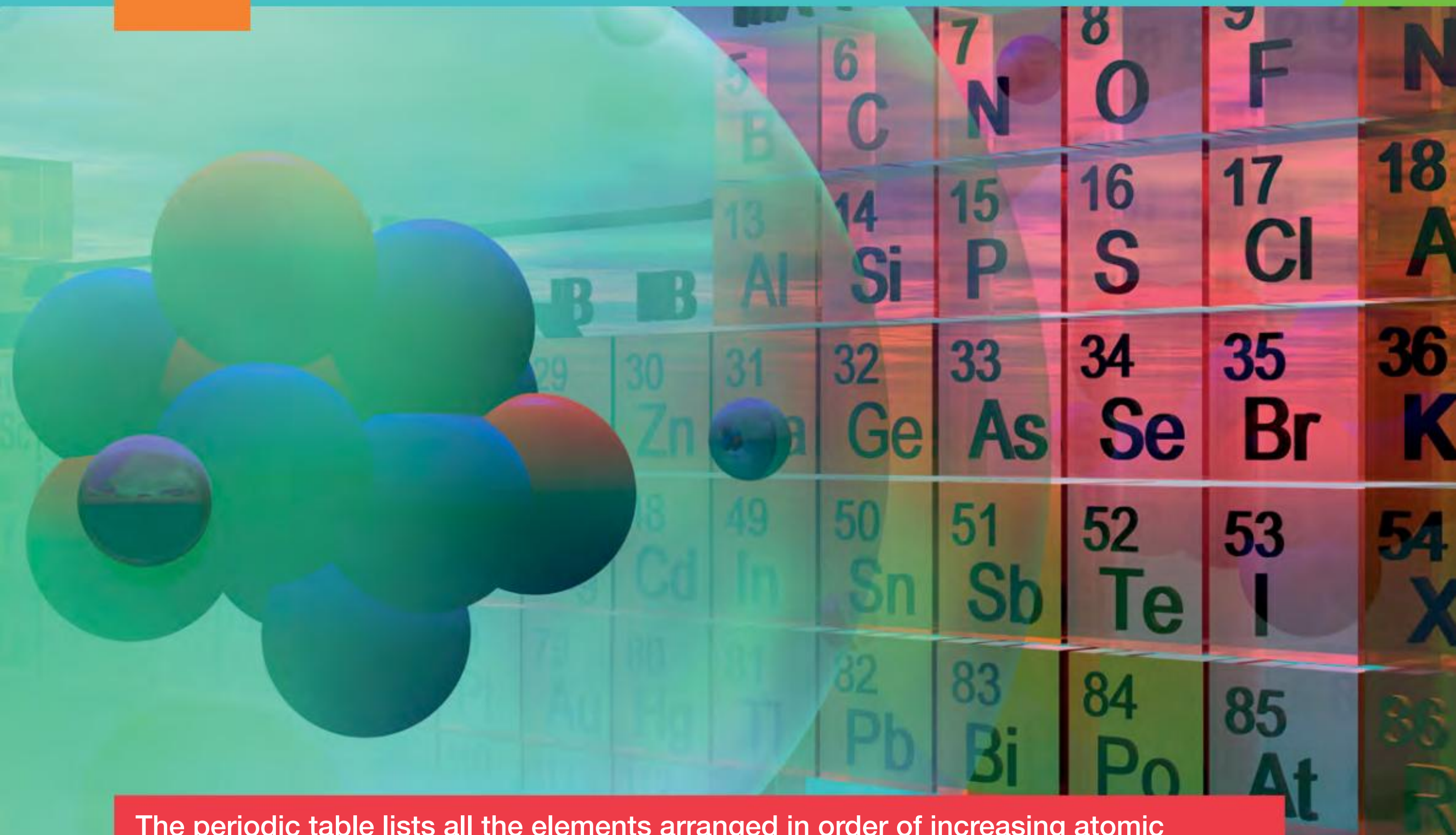
Construct a table to display your observations.

Practical review

1. The solid formed was a precipitate. **Describe** what a precipitate is.
2. The precipitates formed were lead fluoride, lead chloride, lead bromide and lead iodide. **Compare t**he precipitates formed by listing their similarities and differences.
3. **Describe** the changes in the colour of the precipitates as you moved down group 17 from fluorine to iodine.

ADDITIONAL

4.4 Electrons and the periodic table



The periodic table lists all the elements arranged in order of increasing atomic number. Hence the table is arranged in order of increasing number of protons in the nuclei. However, it is the electrons that determine which period and group an element is placed in. This is because electrons determine all the reactions that an atom takes part in and the numbers of each atom in any compound formed.

INQUIRY

science 4 fun

Glow-in-the-dark drink

Tonic water contains the fluorescent chemical quinine. Can you get it to glow in the dark?

Collect this …

- tonic water
- clear drinking glass
- torch (even better a UV light or 'dark light')

Do this …

1. Find a place that you can make very dark.
2. Pour tonic water into the drinking glass.
3. Turn on your torch or 'dark light' then turn off any other light in the room.
4. Shine the 'dark light' on the glass or point your torch at it from different directions.

Record this …

Describe what you observed.
Explain why you think this happened.

The role of electrons

Chemical reactions can occur when atoms bump into one another. As they bump, they trade or share electrons. In the process, they form bonds and join to form compounds. The electrons most likely to be affected by all this bumping are those furthest from the nucleus. Protons and neutrons are at the centre of the atom and so are 'safe' from interference. They never take part in a chemical reaction.

Hence, the way an atom behaves in a chemical reaction depends on what it does with its electrons, particularly its outermost electrons. The groups of the periodic table depend on chemical properties and so groups also depend on how the electrons are arranged within the atom.

SciFile

Radioactive toast?

Be glad that cooking toast involves only shifting electrons around in a series of chemical reactions! If reactions like these involved the nucleus then you would end up with radioactive toast or it would be exploding like an atomic bomb!

Electron shells

Electrons don't just spin anywhere—they spin around the nucleus in regions known as **electron shells** or **energy levels**. The first electron shell is the closest to the nucleus and so the attraction between the nucleus and first-shell electrons is the strongest. This is the lowest energy level for electrons. Electrons in the outermost shell have the highest energy.

The first shell is relatively small and can only hold a maximum of two electrons. The next electron shell is a little further out and so is a little bigger. It can hold eight electrons. The next two shells are bigger again and so are capable of holding even more electrons. The maximum number of electrons that a shell can hold is given by the formula $2n^2$, where n is the number of the shell. This is shown in Table 4.4.1.

Table 4.4.1 Maximum number of electrons held in each shell

Shell	Maximum number of electrons (= $2n^2$)
$n = 1$ (innermost)	2
$n = 2$	8
$n = 3$	18
$n = 4$	32

Electron configuration

Electrons are attracted to the nucleus and this attraction is strongest close to the nucleus. Hence, electrons fill the first shell, then the second shell and so on. When filled in this way, the atom is in its lowest energy state. This is called its **ground state**.

Electron configuration shows how the electrons are arranged in the shells of an atom when it is in its ground state. For example, a sodium atom has 11 electrons. Its electron configuration is 2,8,1. Two electrons are in shell 1, eight are in shell 2 and the remaining electron is in shell 3. Shell 4 is empty. You can see this arrangement in Figure 4.4.1.

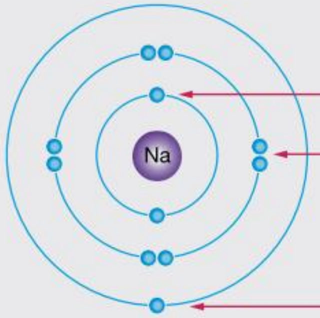


Figure 4.4.1 Sodium's electrons are arranged in its shells according to the electron configuration of 2,8,1. Note that electrons pair up once there are four of them in a shell.

WORKED EXAMPLE
Determining electron configuration

Problem

Determine the electron configuration for a chlorine atom.

Solution

The periodic table tells you that the atomic number for chlorine (Cl) is 17. Hence a chlorine atom has 17 protons and 17 electrons. The first shell ($n = 1$) can only hold two electrons while the second shell ($n = 2$) holds eight. Hence, ten electrons are held in the first two shells. The remaining seven electrons must go into the third shell ($n = 3$). This gives chlorine the configuration 2,8,7.

Practice

Determine the electron configurations of atoms of:

a oxygen
b argon
c magnesium.

4.6

Excited electrons

Sometimes outer-shell electrons jump from one shell to another. This requires energy that usually comes from a flame, light or spark. When electrons jump to a higher energy level, they are referred to as being **excited**. As these excited electrons return back to their ground state, their excess energy is released as light. The process is summarised in Figure 4.4.2.

Different elements release different amounts of energy and so each emits light of a different colour. This occurs because different elements have different numbers of protons in their nuclei. This means that outer-shell electrons are held more tightly in some elements than in others. As a result the energy levels and the jumps between them are different too. As Figure 4.4.3 shows, these differences provide a way of identifying elements.

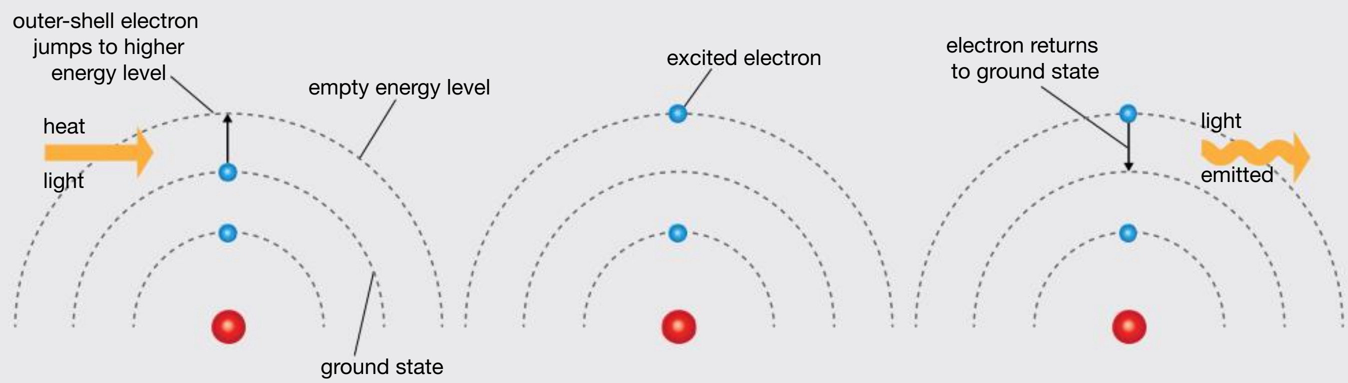


Figure 4.4.2 Energy from a flame or light can cause outer-shell electrons to become excited and to jump from one energy level to another. Light is emitted when the electrons return to their ground state.

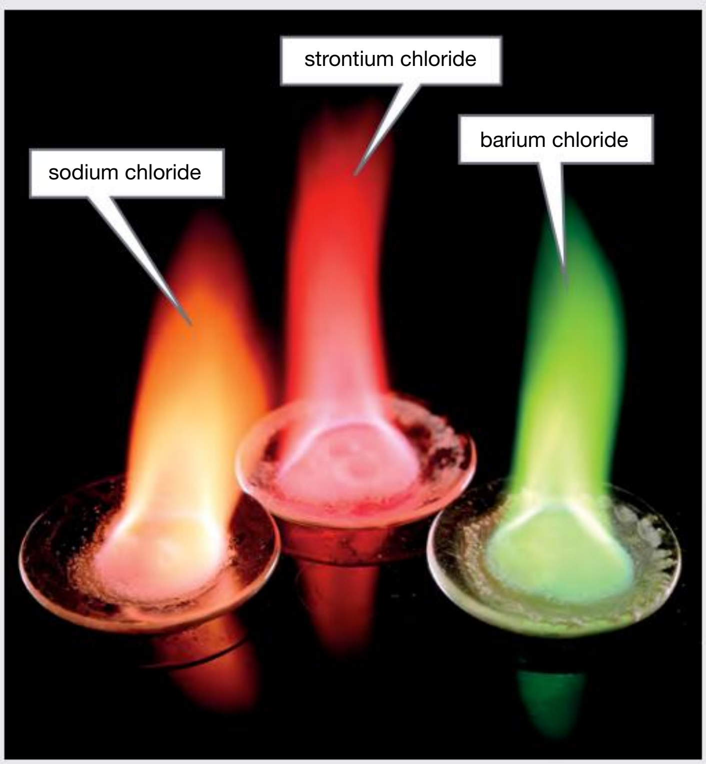


Figure 4.4.3 Each sample emits a characteristic colour when the electrons drop back to their ground state.

SciFile

Fireworks

The explosive heat of fireworks excites electrons in the atoms to jump from one shell to another. As the electrons return to their ground state, energy is released as light. Different metallic elements release different amounts of energy so each give the fireworks a different colour.

Prac 1 p153

Sometimes, this process releases light that didn't seem to be there before. For example, some chemicals absorb invisible ultraviolet (UV) light, exciting electrons within them. As they return to their ground state, these electrons emit light of a different frequency which is visible, usually as a strange blue-white colour. For example, chemicals are added to washing powders and toothpaste to make clothes and teeth appear 'whiter than white'. These chemicals **fluoresce**—they absorb UV light and re-emit it as blue-white light. You can see it happening in Figure 4.4.4.

Figure 4.4.4 This woman's teeth are fluorescing, as are specks of washing powder left on her clothing.

A quantum jump

SciFile

The term *quantum jump* is often used in everyday language to describe a big step up in something like technology. For example, the technology used in smartphones might be said to be a quantum jump above the technology used in older mobile phones, which is a quantum jump above landline telephones. In contrast, a quantum jump in science is extremely small and very precise—it is the exact energy required by an electron to jump from one energy level to another in an atom.

The periodic table

The discovery of electrons by English scientist J.J.Thomson in 1897 and the discovery of electron configuration in about 1920 eventually led to the periodic table being arranged according to the way electrons were arranged in their shells. Amazingly, this version was identical to the earlier table based on physical and chemical properties! This led scientists to realise that chemistry was largely about electrons and how they behave (particularly the outer-shell electrons).

The period and group in which an element is placed is determined by the electron configuration of its atoms:

- The period number of an element is the same as the number of shells occupied by its electrons. So atoms of elements in period 2 have two occupied shells and atoms of elements in period 7 have seven occupied shells.
- The last digit of the group number is usually the number of electrons in the outer shell. So atoms of elements in group 2 have 2 electrons in the outer shell and atoms of elements in group 18 have eight.

SKILL BUILDER

Placing elements in periods and groups

The electron configuration tells you the period and the group of an element. For example:

- Sodium (element symbol Na) has 11 electrons and an electron configuration of 2,8,1. This configuration shows that sodium atoms have three occupied shells, with one electron in their outer shell. For these reasons, sodium is placed in period 3, group 1 (group I).
- Nitrogen (N) has an electron configuration of 2,5. It has two occupied shells and five outer-shell electrons. It is therefore placed in period 2, group 15 (group V).
- Fluorine (F) has an electron configuration of 2,7, so it is placed in period 2, group 17 (group VII).

The connection between electron configuration of the first 18 elements and their position in the periodic table is clear in Table 4.4.2.

Table 4.4.2 Electron configuration of the first 18 elements

Period	Group 1 I	2 II	13 III	14 IV	15 V	16 VI	17 VII	18 VIII
1	H 1							He 2
2	Li 2,1	Be 2,2	B 2,3	C 2,4	N 2,5	O 2,6	F 2,7	Ne 2,8
3	Na 2,8,1	Mg 2,8,2	Al 2,8,3	Si 2,8,4	P 2,8,5	S 2,8,6	Cl 2,8,7	Ar 2,8,8

An older way of numbering groups was to use Roman numerals. This is shown in Table 4.4.2 and in Figure 4.2.3 on page 131. Using this method, the number of electrons in the outer shell is equivalent to the group number. Hence, atoms of elements group III have 3 electrons in their outer shell and atoms of elements in group VII have 7.

SciFile

The odd one out!

These balloons contain helium atoms. Each helium atom has two electrons occupying a single shell. Helium *should* be in group 2 but is placed in group 18 because of its properties, which are far more like those of group 18 elements than group 2 elements.

WORKED EXAMPLE
Placing elements in periods and groups

Problem 1

Magnesium atoms have 12 electrons arranged in the electron configuration 2,8,2. Determine the period and group for Mg.

Solution

The configuration 2,8,2 tells us that Mg uses three shells and has two electrons in its outer shell. Hence Mg is in period 3, group 2 (group II).

Problem 2

The element sulfur is in period 3, group 16 (group VI). Determine the electron configuration for S.

Solution

Sulfur is in period 3 so its atoms use three shells. Group 16 (group VI) indicates that its atoms have six electrons in their outer shells. Hence the electron configuration of S is 2,8,6.

Practice

1 Aluminium atoms have 13 electrons arranged in an electron configuration 2,8,3. **Determine** the period and group for Al.

2 The element phosphorus is in period 3, group 15. **Determine** the electron configuration for P.

Family groupings

The elements of any particular group in the periodic table all have the same number of outer-shell electrons. For this reason, elements in the same group tend to form ions of the same charge. These ionic charges can be seen in Figure 4.4.5. When elements in the same group form molecules, the number of outer-shell electrons involved is the same and so the number of bonds forming the molecule is the same too.

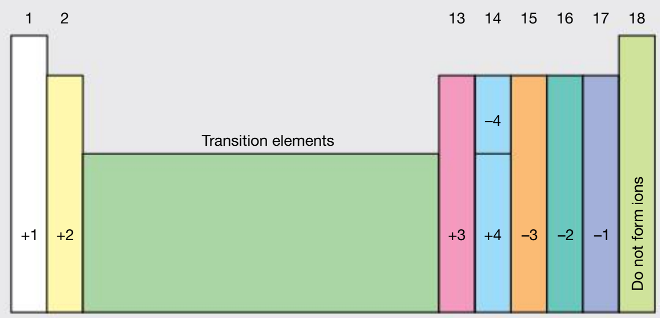


Figure 4.4.5 The group number of an element can be used to predict the charges of any ion formed.

For example, every element in group 2 (group II) is a solid metal. When these elements bond with a non-metal, each forms an ion carrying a charge of +2. For this reason, they all form similar ionic compounds with chlorine, with the same 1:2 ratio of metal to chlorine. This is shown in their formulas: $MgCl_2$, $CaCl_2$, $SrCl_2$ and $BaCl_2$. Likewise, the elements of group 17 (group VII) form the same number of bonds and therefore form similar molecules, such as HF, HCl, HBr and HI.

However, the elements in each group are not the same. This is because every new period represents a new shell being added to the atom. Therefore, the outer electrons are a little further out from the nucleus and held less tightly. Hence, a gradual change in physical and chemical properties is observed as you move down through the atoms in each group.

For example, the alkali metals of group 1 (group I) have a single electron in their outer shells. In chemical reactions, they lose this electron to form positive ions with a charge of +1. As you move down group 1, this electron is easier to remove, making it easier to form ions. This causes the alkali metals to become progressively more reactive. A similar pattern is shown by the alkaline earths of group 2 (group II). Their two outer-shell electrons become easier to remove, so they are more likely to form ions of charge +2.

ADDITIONAL

4.4 Unit review

Remembering

1 **State** the maximum number of electrons that can fit in each of the first four electron shells.

2 **State** how many shells are occupied in atoms of elements in period 4.

3 **State** how many electrons are in the outer shell of atoms of elements in:
- a group 1
- b group 13
- c group V
- d group VIII.

4 **State** how many electrons are in an atom that has an electron configuration of 2,8,8.

5 **State** the charges of the ions formed by the atoms of:
- a group 1
- b group 2.

Understanding

6 **Define** these terms. L
- a electron configuration
- b excited electrons
- c fluoresce

7 **Outline** how the electron configuration of an element determines its position in the periodic table.

8 The quinine in tonic water shines a strange blue-white colour when lit with UV light. **Explain** what is happening here.

9 a On the basis of its electron configuration, helium (He) could be placed in group 2. **Explain** why.
- b **Explain** why helium is normally placed in group 18 instead.

10 **Explain** why atoms in the same group have similar properties.

11 **Explain** why the metals of group 1 and group 2 progressively get more reactive as you move down the groups.

Applying

12 **Use** the formula $2n^2$ to **calculate** the maximum number of electrons held by shell 5 ($n = 5$).

13 **Demonstrate** how to write electron configurations by writing them for the following atoms.
- a lithium (with 3 electrons)
- b carbon (with 6 electrons)
- c sodium (with 11 electrons)
- d chlorine (with 17 electrons)

14 The electron configurations of different elements are given below. **Identify** the period in which and group they should be placed.
- a 2,3
- b 2,8,7
- c 2,8,8,2
- d 2,8,18,6
- e 2,8,18,8,2

15 **Use** the periodic table to **identify** the elements whose electron configurations are listed in question 14.

16 **Use** the periodic table to help you **predict** the electron configuration for:
- a silicon (Si)
- b helium (He)
- c nitrogen (N)
- d magnesium (Mg).

17 **Use** the periodic table to **determine** the electron configuration of an atom in:
- a period 2, group 16
- b period 3, group 18.

Analysing

18 **Distinguish** between the everyday use and the scientific use of the term *quantum jump*. L

Evaluating CCT

19 Figure 4.4.3 on page 149 shows three different samples burning with different colours.
- a **Determine** whether the colour is coming from the metallic element in each sample (sodium, strontium, barium) or the non-metallic element (chloride, the ionic form of the element chlorine).
- b **Justify** your choice.

Creating CCT

20 **Construct** simple diagrams showing how the electrons are arranged in shells for the atoms listed in question 13.

Inquiring

Within the shells are subshells named s, p, d and f. They explain the existence of transition elements, lanthanides and actinides. Find diagrams of what these subshells look like.

Present your diagrams as a labelled printout or sketch.

ADDITIONAL

4.4 Practical investigation

1 Firework colours

Purpose

To observe the colours that metal salts produce when heated.

Materials

- wooden icy-pole sticks soaked overnight in distilled water or de-ionised water and solutions of barium chloride, copper chloride, potassium chloride, sodium chloride and strontium chloride
- Bunsen burner, bench mat and matches
- tongs
- spectroscope (optional)

SAFETY

Turn the Bunsen burner to the yellow flame or off when not using it.

Tie long hair back.

Do not allow the icy-pole stick to catch fire.

Do not point the spectroscope directly at the Sun.

Procedure

1. Use tongs to hold the icy-pole stick soaked in water in the hottest part of a blue Bunsen flame. Hold it there for a few seconds only and remove it before it can catch fire.
2. Observe what colour the stick gives to the flame and record the colour in a table like that shown in the Results section.
3. Repeat steps 1 and 2 for the other sticks.

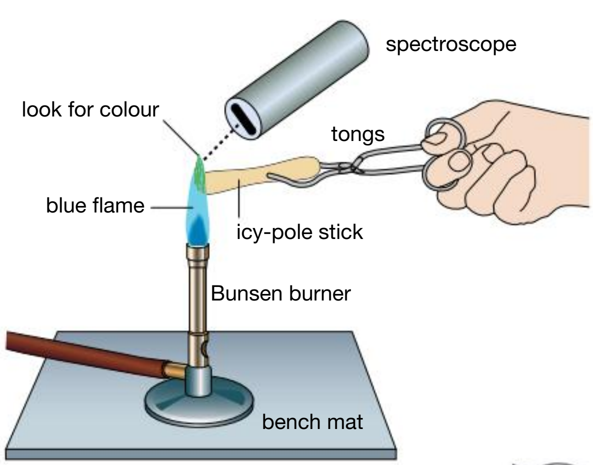


Figure 4.4.6

Extension

4. Point a spectroscope towards a bright portion of the sky (not the Sun). Sketch the spectrum you see.
5. Observe each of the coloured flames through the spectroscope (Figure 4.4.6). Record what you see.

Results

Copy the following table into your workbook. List all the solutions you tested.

Solution tested	Formula	Colour of flame	Metallic element in solution	Non-metallic element in solution
Distilled water	H_2O		None	H, O
Barium chloride	$BaCl_2$		Ba	Cl, H, O

Practical review

1. Modern fireworks include metal salts to colour them. **Identify** which of the metal salts would make a firework:
   a. red
   b. green
   c. blue-green.
2. Firework colours come from electrons changing energy levels. Heat gives electrons energy to jump from one energy level to another. **Describe** where they get this energy from.
3. When the electrons jumped back to their original shells, they released all that energy. **State** the evidence that energy is released.
4. **Identify** the purpose of the stick soaked in water only.
5. **Explain** why distilled water or de-ionised water was used rather than tap water.
6. The non-metallic element did not add colour to the flame. **Outline** the evidence that supports this statement.

4 Chapter review

Remembering

1 **State** how many different elements are currently known.

2 **Name** the following elements.
- a F
- b Ca
- c Na
- d Pb

3 **List** the symbols for the group 18 elements.

Understanding

4 **State** the group numbers for the following element 'families':
- a halogens
- b alkaline earths
- c noble gases
- d alkali metals

5 **State** an alternative name for the noble gases. L

6 **Define** the following terms. L
- a element
- b atomic number
- c allotrope
- d organic molecule

7 **State** or **calculate** the number of protons, neutrons and electrons that are in these atoms.
- a $^{13}_{6}C$
- b $^{130}_{56}Ba$
- c $^{232}_{92}U$

8 **Explain** how isotopes can belong to the same element, despite having different numbers of neutrons.

Applying

9 **Identify** the following metals.
- a the only metal that is a liquid at 25°C
- b those in period 3
- c those in group 14

10 **Identify** a non-metallic element that:
- a is in group 15
- b is in period 2
- c has similar properties to chlorine.

11 Carbon is a group 14 element that forms a compound CH_4. **Use** this information to **predict** the formula of compounds formed from hydrogen and the other four elements of group IV.
- a silicon
- b germanium
- c tin
- d lead

12 The equation $Cl_2 + H_2S \rightarrow S + 2HCl$ shows chlorine reacting with hydrogen sulfide.

Use this reaction to **predict** the balanced formula equation for the reaction of hydrogen sulfide (H_2S) with the following halogens.
- a bromine (Br_2)
- b iodine (I_2)

Analysing

13 **Compare** protons, neutrons and electrons.

14 **Compare** atomic number with mass number.

15 **Compare** the three isotopes of hydrogen $^{1}_{1}H$, $^{2}_{1}H$ and $^{3}_{1}H$.

16 **Contrast** atom $^{14}_{6}C$ with atom $^{28}_{14}Si$.

Evaluating CCT

17 **Propose** a meaning for the term *subatomic particle*. L

18 Plumbing pipes were once made of lead. **Use** the symbols of the periodic table to **propose** where the words 'plumber' and 'plumbing' came from. L

19 a **Determine** whether you can or cannot answer the questions on page 121 at the start of this chapter.
- b **Use** this to **assess** how well you understand the material presented in this chapter.

Creating CCT

20 **Construct** the symbol showing an atom of the element sodium which has 11 protons, 12 neutrons and 11 electrons.

21 **Construct** a simple outline of the periodic table, labelling the direction the groups and periods go, the important 'family' groups and the important other blocks.

22 **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter.

row	period
group	column
mass number	atomic number
protons	electrons
neutrons	periodic table

4.7

Thinking scientifically

The periodic table below will assist you in answering these questions.

Q1 State which of the following is the correct symbol for sodium. CCT

A So **B** Sm
C Na **D** NA

Q2 State which of the following statements is incorrect. CCT

A Chlorine is in period 3.
B Chlorine is in group 17.
C Chlorine has the atomic number 17.
D Chlorine would react in a similar way to Al, Si, P and S.

Q3 The atoms get bigger as you move down any group. Use this information, to identify the statement below that is *definitely* true. CCT

A Helium is the biggest of all the group 18 elements.
B A sulfur atom is bigger than an oxygen atom.
C A sulfur atom is bigger than a phosphorus atom.
D A sodium atom is bigger than a potassium atom.

Q4 Non-metallic atoms in the same group of the periodic table tend to form similar molecules. Carbon and chlorine form the molecule CCl_4. Use this information and the periodic table to identify which of the following molecules could not occur. CCT

A CN_4 **B** CBr_4
C CF_4 **D** $SiCl_4$

Q5 Atoms in the same group of the periodic table tend to react in a very similar way to each other. The reaction between lithium and chlorine is: CCT

$$2Li + Cl_2 \rightarrow 2LiCl$$

Use this information and the periodic table to identify which of the following reactions could not occur.

A $2Mg + Cl_2 \rightarrow 2MgCl$
B $2Na + Cl_2 \rightarrow 2NaCl$
C $2Na + Br_2 \rightarrow 2NaBr$
D $2K + I_2 \rightarrow 2KI$

Group

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period 1	1 H hydrogen																	2 He helium
Period 2	3 Li lithium	4 Be beryllium											5 B boron	6 C carbon	7 N nitrogen	8 O oxygen	9 F fluorine	10 Ne neon
Period 3	11 Na sodium	12 Mg magnesium											13 Al aluminium	14 Si silicon	15 P phosphorus	16 S sulfur	17 Cl chlorine	18 Ar argon
Period 4	19 K potassium	20 Ca calcium	21 Sc scandium	22 Ti titanium	23 V vanadium	24 Cr chromium	25 Mn manganese	26 Fe iron	27 Co cobalt	28 Ni nickel	29 Cu copper	30 Zn zinc	31 Ga gallium	32 Ge germanium	33 As arsenic	34 Se selenium	35 Br bromine	36 Kr krypton
Period 5	37 Rb rubidium	38 Sr strontium	39 Y yttrium	40 Zr zirconium	41 Nb niobium	42 Mo molybdenum	43 Tc technetium	44 Ru ruthenium	45 Rh rhodium	46 Pd palladium	47 Ag silver	48 Cd cadmium	49 In indium	50 Sn tin	51 Sb antimony	52 Te tellurium	53 I iodine	54 Xe xenon
Period 6	55 Cs caesium	56 Ba barium	57–71 lanthanides	72 Hf hafnium	73 Ta tantalum	74 W tungsten	75 Re rhenium	76 Os osmium	77 Ir iridium	78 Pt platinum	79 Au gold	80 Hg mercury	81 Tl thallium	82 Pb lead	83 Bi bismuth	84 Po polonium	85 At astatine	86 Rn radon
Period 7	87 Fr francium	88 Ra radium	89–103 actinides	104 Rf rutherfordium	105 Db dubnium	106 Sg seaborgium	107 Bh bohrium	108 Hs hassium	109 Mt meitnerium	110 Ds darmstadium	111 Rg roentgenium	112 Cn copernicium	113 Uut ununtrium	114 Fl flerovium	115 Uup ununpentium	116 Lv livermorium	117 Uus ununseptium	118 Uuo ununoctium

Lanthanides	57 La lanthanum	58 Ce cerium	59 Pr praseodymium	60 Nd neodymium	61 Pm promethium	62 Sm samarium	63 Eu europium	64 Gd gadolinium	65 Tb trebium	66 Dy dysprosium	67 Ho holmium	68 Er erbium	69 Tm thulium	70 Yb ytterbium	71 Lu lutetium
Actinides	89 Ac actinium	90 Th thorium	91 Pa protactinium	92 U uranium	93 Np neptunium	94 Pu plutonium	95 Am americium	96 Cm curium	97 Bk berkelium	98 Cf californium	99 Es einsteinium	100 Fm fremium	101 Md mendelevium	102 No nobelium	103 Lr lawrencium

Glossary

Unit 4.1

Atomic number: the number of protons in an atom

Atoms: the particles that make up all materials; the smallest part of an element that can take part in a chemical reaction

Element: a substance composed of atoms with the same atomic number; 118 are known to exist

Indirect evidence: evidence that does not involve direct observation

Isotopes: atoms of the same element with different numbers of neutrons

Mass number: the number of particles in the nucleus (protons + neutrons)

Nucleus: heavy core at the centre of the atom, made of protons and neutrons

Unit 4.2

Actinides: a special block of metallic elements with atomic numbers 89–103

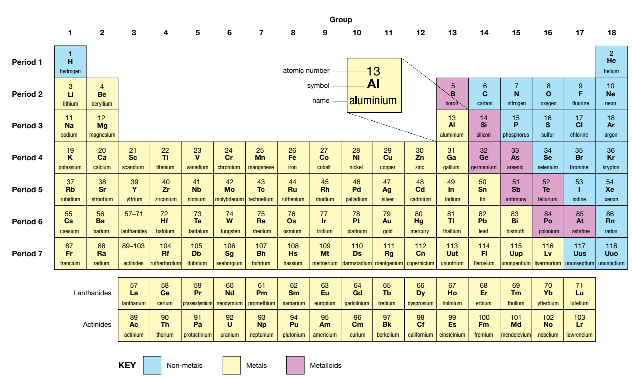
Groups: vertical columns of the periodic table

Lanthanides: a special block of metallic elements with atomic numbers 57–71

Periodic table: a list of all the known elements, arranged in order of increasing atomic number

Periods: horizontal rows of the periodic table

Periodic table



Transition elements: a special block of metallic elements covering elements in groups 3–12

Unit 4.3

Alkali metals: group 1 elements

Alkaline earths: group 2 elements; also known as alkaline earth metals

Allotropes: forms of the same element that have different molecular structures and therefore different properties

Allotropes

Halogens: group 17 elements

Noble gases: also known as inert gases, group 18 elements known for their stability (lack of reactivity)

Noble gases

Inert gases: another name for the noble gases of group 18

Organic: compound that is or was part of a living thing; contains carbon

Organic molecules: molecules that have a skeleton of carbon atoms

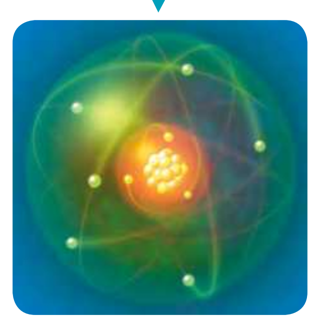
Unit 4.4

Electron configuration: arrangement of electrons in electron shells

Electron shells: also known as energy levels; the regions surrounding the nucleus where electrons may be found

Energy levels: also known as electron shells; the regions surrounding the nucleus where electrons may be found

Electron shells



Excited: electrons that have jumped to a higher energy level

Fluoresce: absorbing UV light and re-emitting light that is visible

Ground state: the lowest energy arrangement of an atom's electrons in energy levels (shells)

5 Chemical reactions

Have you ever wondered...

- what puts the fizz in soft drinks?
- why you feel hot after exercise?
- why some people get heartburn?

After completing this chapter students should be able to:

- classify chemical reactions as exothermic or endothermic
- construct word equations for a range of chemical reactions L
- deduce that new substances are formed during chemical reactions by rearranging atoms rather than creating or destroying them
- investigate a range of types of chemical reactions including combustion, corrosion, decomposition, the reactions of acids, neutralisation and precipitation
- identify respiration as an important chemical reaction that occurs in living systems
- compare combustion and respiration as chemical reactions that release energy but occur at different rates
- describe the effects of factors such as temperature and catalysts on the rate of chemical reactions
- analyse how social and ethical considerations can influence decisions about scientific research into new materials CCT EU L S
- describe examples to show where advances in science significantly affect people's lives CCT L WE

ADDITIONAL

- investigate the order of activity of a range of metals
- balance a range of chemical equations
- research ways that are used to restore and prevent corrosion of submerged objects.

5.1 Energy in chemical reactions

One of the most important and useful features of chemical reactions is that many can produce large amounts of energy. The energy from chemical reactions powers the modern world, with more than 80% of our energy needs coming from the burning of fossil fuels. You also use the energy from chemical reactions on a more domestic level. Whenever you light a birthday candle, cook food, start a car or breathe, you are using energy from chemical reactions. Even your smartphone is powered by the chemical reactions taking place in its battery.

INQUIRY science 4 fun

Acrobatic flame

Can a flame travel along candle fumes?

YES

Collect this ...

- candle
- box of matches

Do this ...

1 Light the candle and let it burn for a couple of minutes.
2 Strike another match and then blow out the candle.
3 Put the flame of the lit match into the fumes coming from the unlit candle.
4 The candle should reignite as if by magic. See how far you can get the flame to jump.

SAFETY

Be very careful when using matches and candles. Be careful to blow matches out and rinse with water to make sure they are out before disposing of them.

Record this ...

Describe what you saw.
Explain why you think this happened.

Chemical equations

A chemical equation describes what happens in a chemical reaction. The general structure of a chemical equation is:

reactants → products

where the arrow (→) means rearrange to form.

Word equations

Replacing the **reactants** and **products** with the chemical name of each substance gives a **word equation**. For example, when calcium carbonate ($CaCO_3$) reacts with sulfuric acid (H_2SO_4), it produces calcium sulfate ($CaSO_4$), water (H_2O) and carbon dioxide gas (CO_2). In this reaction, you have:

Reactants = calcium carbonate, sulfuric acid

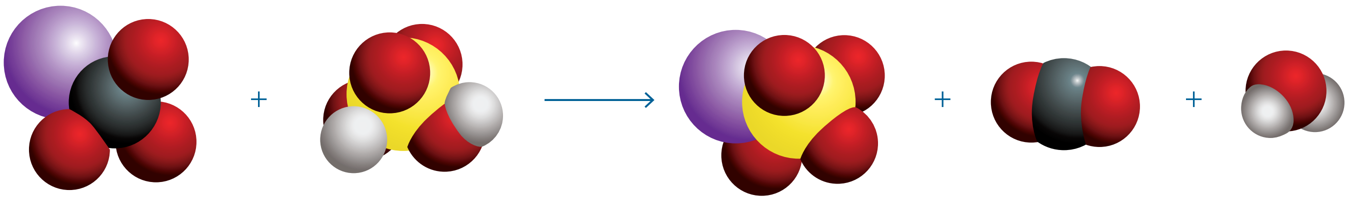
Products = calcium sulfate, water, carbon dioxide gas

So the general form of an equation:

reactants → products

becomes the word equation:

calcium carbonate + sulfuric acid → calcium sulfate + carbon dioxide gas + water



calcium carbonate + sulfuric acid → calcium sulfate + carbon dioxide + water

$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + CO_2 + H_2O$

Figure 5.1.1 The atoms from the calcium carbonate combine with the atoms from the sulfuric acid to produce calcium sulfate, carbon dioxide and water.

Balanced formula equations

Chemists can write the equation much more effectively by replacing the chemical names with their chemical formulas. The chemical equation for the reaction between calcium carbonate and sulfuric acid then becomes:

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + CO_2 + H_2O$$

This type of chemical equation is known as a **formula equation**. Figure 5.1.1 shows how the reactants in the above equation rearrange to form the products.

A chemical reaction doesn't create or destroy atoms. Instead, a chemical reaction simply rearranges the atoms. As a result, the number of atoms of each element in the reaction needs to be balanced. This means that the number of atoms of each element in the reactants must equal the number of atoms of each element in the products. When this happens, a formula equation is referred to as being **balanced**. For example, the equation for the reaction between calcium carbonate and sulfuric acid is balanced because the numbers of calcium, carbon, sulfur, hydrogen and oxygen atoms are the same on both sides.

GO TO Unit 5.4

Exothermic and endothermic reactions

One way to classify chemical reactions depends on whether they release or absorb energy. Chemical reactions that release energy in the form of heat or light are referred to as **exothermic**. Exothermic reactions include flames, explosions and fireworks.

For example, octane (C_8H_{18}) in petrol explodes releasing energy as heat and a flash of light. The word equation for this reaction is:

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

and its balanced formula equation is:

$$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O + \text{energy}$$

The chemical reactions in glow sticks and glow-worms are also exothermic because they produce light. However, not all exothermic reactions are as impressive as these—some may just feel warm to the touch.

Chemical reactions that absorb energy are called **endothermic**. Endothermic reactions usually feel cold because they absorb the heat energy from your skin and the surroundings. Chemical ice packs use an endothermic reaction between ammonium chloride and water to make the pack icy cold without refrigeration. A chemical ice pack is shown in Figure 5.1.2.

Prac 1 p164

Figure 5.1.2 Sports people often use chemical ice packs to soothe injuries. When the endothermic chemical reaction starts, the pack suddenly cools.

SciFile

An alluring glow

Many animals such as glow-worms use exothermic chemical reactions that produce light to attract a mate or food. This is called bioluminescence. An example of bioluminescence is the deep sea anglerfish. This fish has a long, bioluminescent antenna that attracts smaller fish while it waits in the darkness to attack.

Reactions with oxygen

Reactions that have oxygen as one of the reactants tend to be exothermic. The fire in Figure 5.1.3 needs oxygen to burn and is an obvious example of an exothermic reaction. Other exothermic reactions involving oxygen are less obvious. These include reactions such as respiration and corrosion.

Figure 5.1.3 Fires needs oxygen—they are examples of exothermic combustion reactions.

GO TO Pearson science NSW 9 Unit 2.1

Combustion reactions

Combustion describes any chemical reaction in which a substance burns in oxygen gas to produce light and heat. Therefore, all combustion reactions can also be classified as exothermic reactions.

Combustion reactions are some of our most important and useful reactions. Lighting a match, burning gas on a stove top, igniting fuel in a car engine and burning coal in a power station are all examples of combustion. All of these chemical reactions involve oxygen gas and all produce heat and light. Some processes then convert that energy into other forms such as electrical energy.

For example, some spacecraft use hydrogen fuel cells for their propulsion. These fuel cells release energy because of a combustion reaction. In this reaction, hydrogen gas (H_2) combusts explosively with oxygen gas (O_2) to produce water vapour (H_2O). Its chemical equations are:

hydrogen gas + oxygen gas → water vapour

$$2H_2 + O_2 \rightarrow 2H_2O$$

Very reactive metals such as sodium and magnesium can also combust in oxygen. When magnesium is burnt, it combines with the oxygen in the air to produce magnesium oxide. The equations for this reaction are:

magnesium + oxygen → magnesium oxide

$$2Mg + O_2 \rightarrow 2MgO$$

This reaction is extremely exothermic and produces large amounts of heat and bright light as shown in Figure 5.1.4.

5.1

Figure 5.1.4 As powdered magnesium burns in this Bunsen burner, a spectacular white light is produced.

Hydrocarbons are substances that are made of only hydrogen and carbon atoms. They can be a gas such as natural gas or methane (CH_4), a liquid like the octane in petrol (C_8H_{18}) or a solid like candle wax ($C_{20}H_{42}$), as shown in Figure 5.1.5. In the case of a candle, the flame continuously heats the wax to form a liquid and vapour that act as fuels for the flame.

Figure 5.1.5 Hydrocarbons come in solid, liquid and gaseous forms. Most make excellent fuels.

Hydrocarbons make excellent fuels because they burn in oxygen to produce large amounts of energy. The combustion of hydrocarbons produces carbon dioxide and water. For example, the combustion of butane (C_4H_{10}) used as lighter fluid has the chemical equations:

butane + oxygen → carbon dioxide + water

$$2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$$

The chemical reaction changes when the supply of oxygen is limited. In limited oxygen, the combustion of butane proceeds as two reactions, producing a mix of poisonous carbon monoxide and sooty carbon:

$$\text{butane} + \text{oxygen} \rightarrow \text{carbon monoxide} + \text{water}$$
$$2C_4H_{10} + 9O_2 \rightarrow 8CO + 10H_2O$$

$$\text{butane} + \text{oxygen} \rightarrow \text{carbon} + \text{water}$$
$$2C_4H_{10} + 5O_2 \rightarrow 8C + 10H_2O$$

Combustion in a limited oxygen supply is known as **incomplete combustion**.

Respiration

Respiration is a chemical reaction that goes on inside the cells of all living things. It involves the combination of glucose ($C_6H_{12}O_6$) with oxygen to produce carbon dioxide and water:

$$\text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}$$
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

The energy produced by respiration is used by the organism to live, move and grow. Respiration is slow compared with combustion, so it doesn't produce explosive amounts of heat or light. However, it is fast enough to keep your body warm. You get hot when exercising because of respiration. As you require more energy when exercising, you respire more and so you produce more heat.

GO TO Pearson science NSW 9 Unit 2.3

Corrosion

Most metals will combine with oxygen gas in the air to form metal oxides. This process is known as **corrosion**. The general word equation for corrosion reactions with oxygen is:

$$\text{metal} + \text{oxygen} \rightarrow \text{metal oxide}$$

The most common example of corrosion is the rusting of iron and its alloy, steel. In this process, iron metal combines with oxygen gas and moisture in the air to produce rust, hydrated iron(III) oxide.

$$\text{iron} + \text{oxygen gas} + \text{water} \rightarrow \text{hydrated iron(III) oxide}$$
$$4Fe + 3O_2 + 2H_2O \rightarrow 2Fe_2O_3{\cdot}H_2O$$

This reaction is usually written more simply as:

$$\text{iron} + \text{oxygen gas} \rightarrow \text{iron(III) oxide}$$
$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$

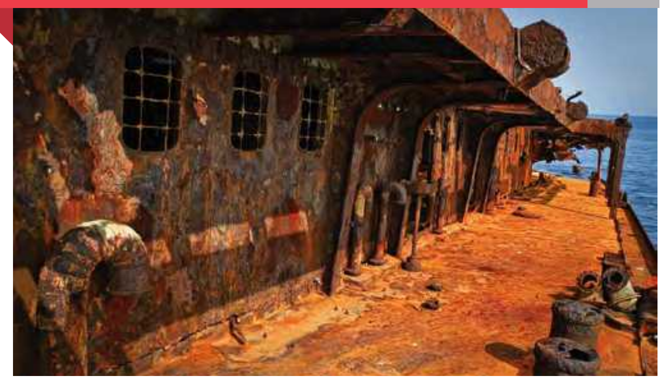
Corrosion and the combustion of metals are very similar chemical reactions. Both reactions involve the combination of metals with oxygen to form metal oxides and both are exothermic. The difference is that corrosion occurs much more slowly than combustion. So although the combustion of metals produces spectacular amounts of heat and light, corrosion produces heat so slowly that it is almost unnoticeable.

Prac 2 p165
Prac 3 p166

SciFile

The cost of rusting

Rusting is an example of an unwanted and very destructive chemical reaction. Although iron is cheap to make, the CSIRO estimates that corrosion costs Australia $13 billion each year.



ADDITIONAL

The activity series

Whether or not a metal corrodes or combusts depends on how easily the metal reacts with oxygen. How easily a metal reacts with other substances such as oxygen, water and acids is a chemical property known as a metal's **reactivity**. Chemists order metals from most reactive to least reactive on a list called the **activity series**. You can see it in Table 5.1.1. At the top of the table are highly reactive metals like potassium and sodium and at the bottom are metals that do not react much at all, such as silver and gold.

Table 5.1.1 Activity series for common metals

	Metal
more reactive ↑	Potassium (K)
	Sodium (Na)
	Calcium (Ca)
	Magnesium (Mg)
	Aluminium (Al)
	Zinc (Zn)
	Iron (Fe)
	Nickel (Ni)
	Tin (Sn)
	Lead (Pb)
	Copper (Cu)
	Silver (Ag)
↓ less reactive	Gold (Au)

Very reactive metals such a potassium, sodium, calcium and magnesium corrode very quickly in air. They can even react explosively when in contact with water. Metals from aluminium to silver will corrode when exposed to air but will not combust. Gold, however, does not even corrode, which is why it can be found naturally in the environment as gold nuggets.

GO TO Unit 4.3

ADDITIONAL

LEARNING ACROSS THE CURRICULUM

SUSTAINABILITY

BIOFUELS

As the world's fossil fuel resources start to run out, scientists around the world are looking for alternative fuels and resources. Biofuels may be the answer.

Figure 5.1.6 Most biofuels come from crops and so they are a form of renewable energy that can help replace fossil fuels.

Biofuels are a type of fuel that promises to be a renewable resource. The biofuel can be manufactured by fermenting the sugars in crops such as sugar cane, potato and corn (maize). The fermentation process uses microorganisms such as yeast to convert the sugars into ethanol according to the reaction:

$$\text{glucose} \rightarrow \text{ethanol} + \text{carbon dioxide}$$

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

Ethanol is the alcohol found in alcoholic drinks. It is also found in different petrol blends around the world. For example, in Australia fuel labelled E10 contains 10% ethanol, the maximum amount allowed by the government to be added. In Brazil, the only fuel available is E25 (25% ethanol/75% petrol), while E85 (85% ethanol/15% petrol) is sometimes available in Europe and USA. Biodiesel (Figure 5.1.7) is a biofuel made from plant- or animal-based fatty acids blended with 'normal' diesel fuel.

Figure 5.1.7 This is one of a new generation of vehicles that use biofuels.

The current world production of biofuels is more than 100 billion litres per year and is increasing rapidly. Most of this production comes from corn in the USA and sugar cane in Brazil. Biofuels provide a renewal alternative to fossil fuels and could make up 25% of the fuels used across the world for transportation. However, biofuels are unlikely to ever be our only source of fuels, as it would require huge areas of land to grow the raw materials required to supply all of our fuel needs.

The rapid increase in the demand for biofuels has brought with it problems. Crops and farmlands that would once have been used for food are now being used for the production of biofuels. This means that there is less food available and so the price of food increases.

REVIEW

1 **List** three crops that can be used to produce biofuels.

2 **Recall** the chemical name of the biofuel produced by fermentation.

3 **Explain** how biofuels can affect the price of food.

4 **Explain** why biofuels are unlikely to be our only fuel source in the future.

5.1 Unit review

Remembering

1 **Recall** the general name given to the chemicals that combine to form the products of a chemical reaction.

2 **Recall** one example of an exothermic reaction and one example of an endothermic reaction.

3 **List** the reactants and products involved in respiration.

4 **Recall** the following reactions by writing their word and formula equations.
- a combustion of magnesium to form magnesium oxide
- b combustion of butane
- c respiration
- d the reaction of iron with oxygen and water to produce rust (iron(III) oxide).

Understanding

5 **Describe** what happens to the atoms of the reactants during a chemical reaction.

6 **Explain** why oxygen is written as O_2 in chemical equations rather than just O.

7 a **Explain** what is meant by a balanced chemical equation.
- b **Explain** why a chemical equation needs to be balanced.

8 a **Explain** why respiration is considered to be an exothermic reaction.
- b **Explain** why doing a lot of exercise makes you feel hot.

Applying

9 **Use** word equations to **describe** the following chemical reactions:
- a $2C + O_2 \rightarrow 2CO$
- b $H_2 + Cl_2 \rightarrow 2HCl$
- c $HCl + NaOH \rightarrow NaCl + H_2O$

Analysing

10 **Contrast** exothermic reactions with endothermic reactions.

11 **Classify** the following reactions as exothermic or endothermic.
- a Octane in petrol burns in air.
- b A chemical cold pack is broken to place on an ijury to reduce swelling.

Evaluating CCT

12 **Evaluate** ways in which combustion is important in our everyday lives.

13 When most metals react with oxygen gas in the air it is called corrosion. However, when magnesium is burnt in air to form magnesium oxide, it is called combustion. **Evaluate** why.

14 Fabrics fade because sunlight causes a chemical reaction to take place. This reaction is most likely to be endothermic. **Propose** a reason why.

15 A candle can be relit using its vapour trail. **Propose** a reason why.

Creating CCT

16 **Construct** a Venn diagram to **compare** combustion, respiration and corrosion.

17 The following reactions all have oxygen gas as one of their reactants. **Construct** word equations to describe these reactions.
- a Carbon is burnt in oxygen gas at high temperature to form carbon dioxide.
- b Carbon dioxide and water vapour form when propane gas is burnt.
- c Yeasts consume glucose and oxygen to form carbon dioxide and water.
- d Zinc metal is exposed to air and forms zinc oxide.
- e Methane gas (natural gas) is burnt on a gas stove top to boil water.

Inquiring

ADDITIONAL

1 Choose two metals from the activity series table on page 161—one from the top four in the list and one of the others. Investigate how these two metals are extracted from their ores into their pure form.

Present your research as a series of labelled diagrams to demonstrate the processes.

2 Research methods that are used to restore and prevent corrosion of submerged objects.

Present your findings as a case study of two submerged objects for which used different methods are used. Use the activity series in your answer.

ADDITIONAL

5.1 Practical investigations

1 Exothermic and endothermic reactions

Purpose

To observe exothermic and endothermic reactions.

Materials

- ammonium chloride
- hydrochloric acid (1 M)
- sodium hydroxide (1 M)

distilled water

- 4 × 100 mL beakers
- spatula
- thermometer
- glass stirring rod

SAFETY

Sodium hydroxide and hydrochloric acids are corrosive, so wear safety glasses and rubber gloves at all times.

Procedure

1. In your workbook construct a table similar to the one in the Results section.
2. Use the spatula to put ammonium chloride into one of the beakers. Fill the beaker to approximately the 10 mL level.
3. Fill the second beaker to around the 20 mL mark with water. Measure the temperature of the water and record your measurement in the Results table.
4. Pour the water into the ammonium chloride. Mix thoroughly with the glass stirring rod and then measure the temperature of the mixture. Record the temperature in your table.
5. Wash the stirring rod and thermometer and let the thermometer return to room temperature.
6. Fill the third beaker with about 20 mL of the sodium hydroxide solution. Measure the temperature of the solution and record it in the Results table.
7. Fill the fourth beaker to around the 20 mL mark with hydrochloric acid.
8. Pour the acid into the sodium hydroxide solution. Use the glass stirring rod to mix the two solutions together and then measure the temperature again.

Results

Record all observations and measurements in your results table.

Reaction	Observations	Starting temp. (°C)	Final temp. (°C)
Ammonium chloride + water			
Sodium hydroxide + hydrochloric acid			

Practical review

1. **Identify** which chemical reaction is exothermic and which is endothermic.
2. **Describe** what is happening in terms of the particles and energy in both reactions.
3. a **Evaluate** which reaction you think caused the biggest change in energy to its surroundings.
   b **Justify** your answer.

2 Corrosion as an exothermic reaction

Corrosion of iron and steel normally occurs very slowly because the iron(III) oxide (rust) forms a layer that partially protects the metal underneath. Rusting only continues into the deeper layers when this rust flakes off. However, acetic acid (vinegar) strips away the iron(III) oxide and exposes the metal underneath. This allows the corrosion reaction to proceed continuously.

Purpose

To demonstrate that corrosion is an exothermic reaction.

SAFETY

Acetic acid will sting if it gets into your eyes or an open cut, so wear safety glasses and rubber gloves at all times.

Hypothesis

What do you think will happen when steel wool is placed in vinegar—will it react and will its reaction be exothermic or endothermic? Before you go any further with this investigation write a hypothesis in your workbook.

Materials

- steel wool
- acetic acid (vinegar)

- 2 × 500 mL beakers
- tongs
- thermometer (preferably digital or with fine graduations)
- rubber gloves

Procedure

1. Construct a table like the one in the Results section in your workbook.
2. Place enough steel wool into one of the beakers to fill about one-third of the beaker.
3. Soak the steel wool in vinegar for about 1 minute.
4. Remove the steel wool from the vinegar with the tongs. Squeeze our any excess vinegar and place the steel wool in the unused beaker.
5. Insert the thermometer into the steel wool and record the temperature every minute in your results table until the temperature stops changing.
6. Once the reaction has finished, look closely at the steel wool and record your observations in your workbook.

Results

1. Record all measurements in your results table.
2. Use graph paper or plotting software to plot the results in your table. ICT

	1	2	3	4	5
Time (min)					
Temperature (°C)					

Practical review

1. a **Construct** a conclusion for your experiment.
   b **Assess** whether your hypothesis was supported or not.
2. **Describe** the shape of your graph.
3. **Explain** the role of the acetic acid in this experiment.
4. **Explain** why you can measure the temperature change in this experiment but you can't feel heat being produced by a rusting shipwreck.

3 Rust prevention

Purpose

To investigate the conditions under which rusting occurs.

Hypothesis

What effect to you think distilled water, salt water and the presence of magnesium will have on the corrosion of iron nails—will it increase the amount of corrosion, reduce it or have no effect? Before you go any further with this investigation, write a hypothesis in your workbook.

Materials

- 4 iron nails (not galvanised)
- salt water (sodium chloride solution)
- 5 cm magnesium ribbon
- 4 large test-tubes
- test-tube rack

Procedure

1. Place a nail in each of three of your four test-tubes.
2. Wrap the magnesium ribbon around the fourth nail and place it in the remaining test-tube.
3. Add salt water (sodium chloride solution) to three of the test-tubes, as shown in Figure 5.1.8, so that each nail is almost entirely submerged.

Results

1. Construct a table like the one below in your workbook.
2. Use it to record your observations after 3 or 4 days. Draw diagrams to show any corrosion on either the iron nails or the magnesium.

	Observations
Nail + air	
Nail + distilled water	
Nail + salt water	
Nail + salt water + magnesium	

Practical review

1. a **Construct** a conclusion for your investigation.
   b **Assess** whether your hypothesis was supported or not.
2. **Recall** the word and formula equations for rusting.
3. **Identify** which variables seemed to:
   a increase the amount of rust produced
   b reduce rusting.
4. **Use** your results to **explain** why iron structures such as car bodies rust faster in coastal areas than inland.
5. **Propose** a reason why it might be a good idea to attach magnesium metal to the hull of a ship or steel pier.

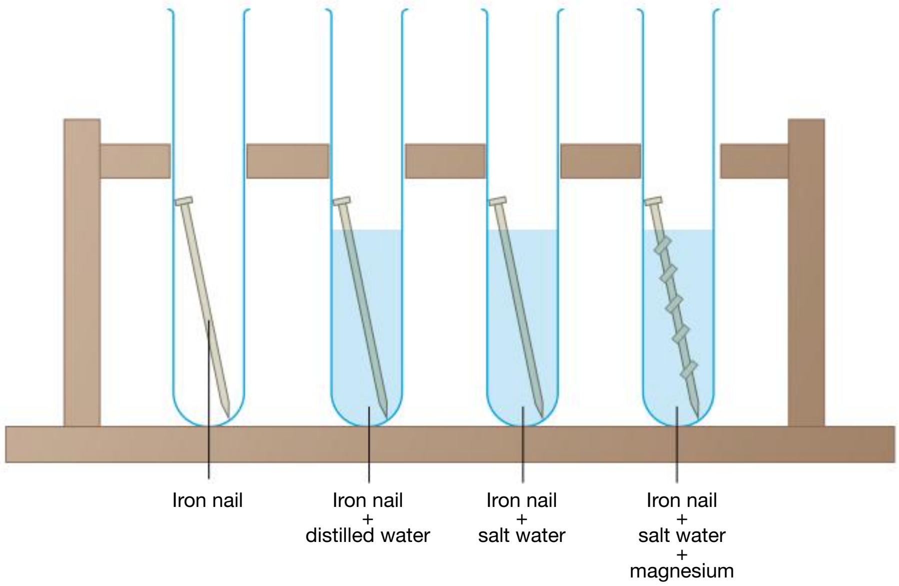
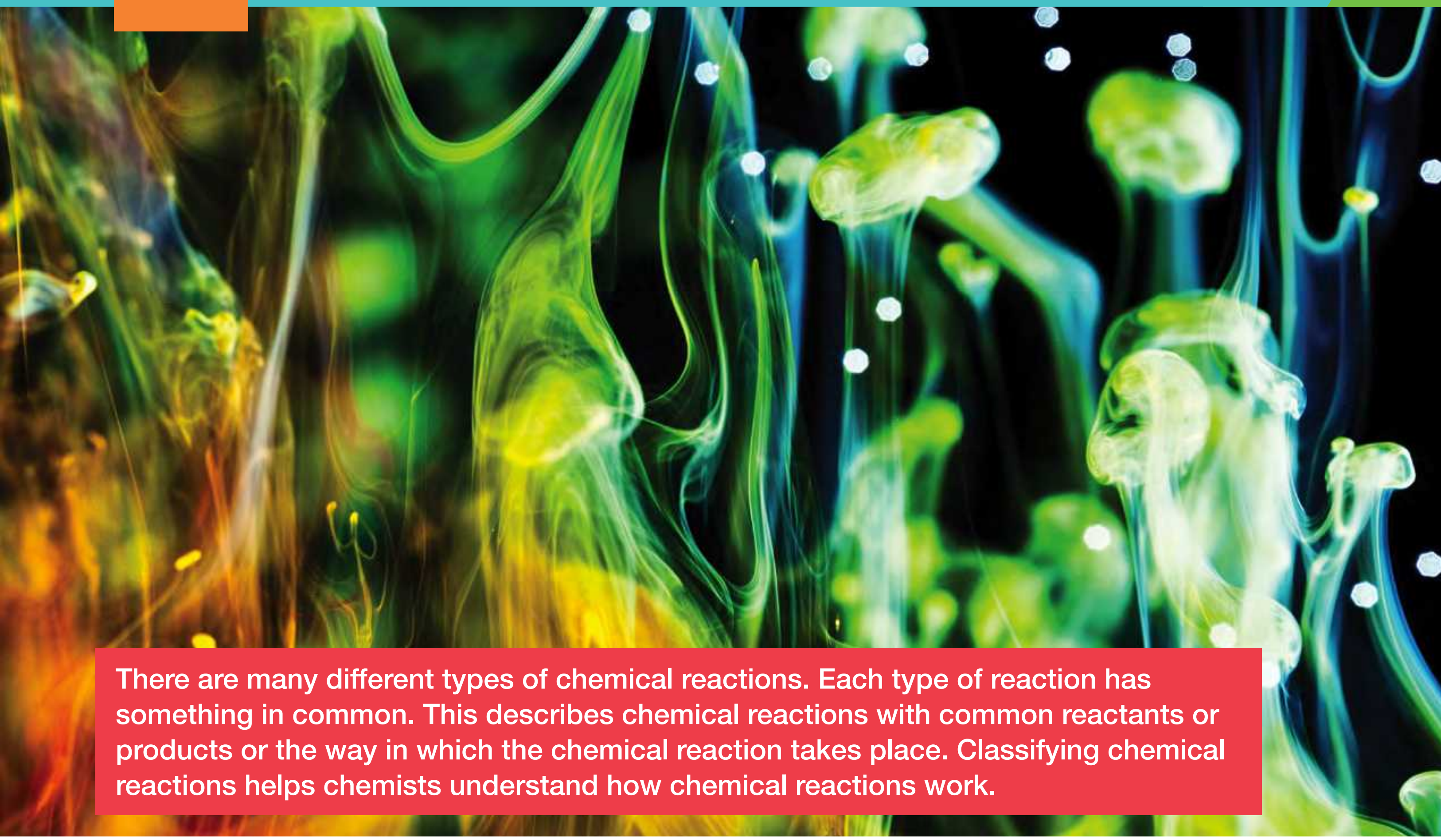


Figure 5.1.8

5.2 Classifying chemical reactions



There are many different types of chemical reactions. Each type of reaction has something in common. This describes chemical reactions with common reactants or products or the way in which the chemical reaction takes place. Classifying chemical reactions helps chemists understand how chemical reactions work.

INQUIRY science 4 fun

Raisin lava lamp

Can you use a chemical reaction to make a lava lamp?

YES

Collect this …

- clear fizzy drink such as lemonade or tonic water
- raisins
- clear glass or bottle

Do this …

1. Pour the lemonade into the clear glass or bottle.
2. Add several raisins.

Record this …

Describe what you saw.

Explain why you think this happened.

Decomposition reactions

Some chemical reactions are classified by how the reactants form the products. For example, when a single reactant breaks apart to form several products, the reactant is said to decompose. This type of chemical reaction is known as a **decomposition reaction** and has the general equation:

$$XY \rightarrow X + Y$$

An everyday example of a decomposition reaction is the chemical reaction that puts the fizz in soft drinks like the one shown in Figure 5.2.1 on page 168. Soft drinks contain dissolved carbonic acid (H_2CO_3). When carbonic acid decomposes, it forms water (H_2O) and bubbles of carbon dioxide gas (CO_2). The carbon dioxide gas formed by this reaction remains dissolved in the soft drink until the lid is removed.

The chemical equations for the decomposition of carbonic acid are:

$$\text{carbonic acid} \rightarrow \text{water} + \text{carbon dioxide}$$

$$H_2CO_3 \rightarrow H_2O + CO_2$$

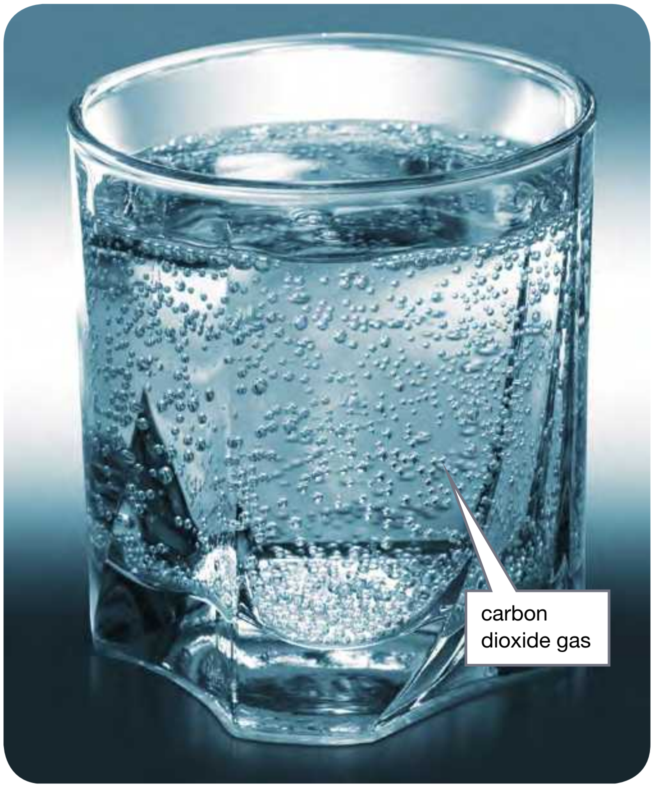


Figure 5.2.1 The decomposition reaction of carbonic acid gives carbonated water its fizz.

Thermal decomposition

Some substances will only decompose when heated. This is known as thermal decomposition. Metal carbonates and metal hydrogen carbonates both undergo thermal decomposition when heated. For example, when sodium hydrogen carbonate is heated above 50°C, it decomposes to form sodium carbonate, carbon dioxide and water. The equations for this reaction are:

sodium hydrogen carbonate → sodium carbonate + carbon dioxide + water

$$2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$$

Thermal decomposition of sodium azide (NaN_3) is a chemical reaction that saves lives every day by inflating vehicle airbags like the one in Figure 5.2.2. When sodium azide is heated, it decomposes into sodium metal and nitrogen gas. The equations for this reaction are:

sodium azide → sodium + nitrogen gas

$$2NaN_3 \rightarrow 2Na + 3N_2$$

Just 100 grams of sodium azide can produce around 56 litres of nitrogen gas in under 0.03 seconds. This reaction rapidly inflates the airbag in the event of a collision.

Prac 1
p176

Combination reactions

Combination reactions occur when two reactants combine to form a single product. The general equation for a combination reaction can be written as:

$$X + Y \rightarrow XY$$

Combination reactions are important in industry. For example, a combination reaction is used to create hydrochloric acid for industry and laboratories. First, hydrogen gas (H_2) and chlorine gas (Cl_2) are combined to form hydrogen chloride gas (HCl) in large chemical plants like the one in Figure 5.2.3.

The equations for the combination of hydrogen and chlorine are:

hydrogen gas + chlorine gas → hydrogen chloride gas

$$H_2 + Cl_2 \rightarrow 2HCl$$

The hydrogen chloride gas that is produced is then bubbled through de-ionised water to produce hydrochloric acid.

Precipitation reactions

Occasionally when two clear solutions are mixed together, they react to form an insoluble solid. The solid is said to precipitate (fall) out of the solution. These types of reactions are known as **precipitation reactions**. For example, the scale that builds up in kettles, taps and pipes is solid calcium carbonate ($CaCO_3$) that has precipitated out of the tap water. As shown in Figure 5.2.4, most precipitates quickly fall to the bottom of the container.

Precipitation reactions and solubility

Figure 5.2.2 The decomposition of sodium azide (NaN_3) saves lives every day.

Figure 5.2.3 Hydrochloric acid is manufactured at chemical plants using a combination reaction between hydrogen gas and chlorine gas.

Figure 5.2.4 Precipitation reactions occur when two aqueous solutions react to produce an insoluble solid.

A precipitation reaction occurs when two **soluble** reactants combine to form an **insoluble** product known as the **precipitate**.

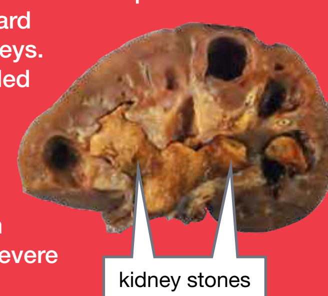
A substance is said to be soluble if it dissolves. For example, sugar is soluble in water. When a soluble substance is dissolved in water, the particles that make up the substance are spread thinly throughout the solution. The particles are so small and so thinly distributed that they cannot be seen with the naked eye. As a result, the solution appears transparent clear, not cloudy or murky.

In precipitation reactions, particles from two soluble compounds mix together and some stick together to form an insoluble solid. The solid precipitates out of the solution, making it murky. Usually, the solution then clears as the precipitate settles on the bottom.

SciFile

Painful precipitates

Your body is full of dissolved compounds. However, sometimes these compounds precipitate out as hard deposits in the kidneys. These deposits, called kidney stones, are extremely painful. Usually kidney stones will pass out of the body with urine. However, in severe cases, the stones may have to be removed surgically or shattered by intense soundwaves.



Ionic compounds

Most precipitation reactions happen because solutions of different **ionic compounds** have been mixed.

Ionic compounds (Figure 5.2.5) are substances made up of a crystal lattice of positive **ions** (**cations**) and negative ions (**anions**).

Figure 5.2.5 Ionic compounds are normally hard and brittle and come in a wide variety of colours.

The cations that make up the crystal lattice are atoms (or groups of atoms) that have lost electrons and therefore have a positive charge. Anions are atoms (or groups of atoms) that have gained electrons and therefore have a negative charge. Table 5.2.1 lists common cations and anions.

When ionic compounds dissolve, the cations and the anions break away from the crystal lattice and spread evenly throughout the solvent. For example when sodium chloride (NaCl) dissolves in water, the sodium cations (Na^+) and chloride anions (Cl^-) are dispersed throughout the liquid as shown in Figure 5.2.6.

Naming ionic compounds

The name of an ionic compound is simply the name of the cation followed by the name of the anion. For example, barium sulfate ($BaSO_4$) is made up of the barium cation (Ba^{2+}) and the sulfate anion (SO_4^{2-}). In the cases where an atom can form more than one type of ion (such as copper(I), Cu^+, and copper(II), Cu^{2+}), a roman numeral is included in the name of the compound. For example, copper(I) hydroxide ($CuOH$) or copper(II) sulfate ($CuSO_4$). The Roman numeral indicates the charge on the cation.

Ionic compounds have no overall charge—they are always charge neutral. Hence the total charge on the cations balances the total charge on the anions. For example, sodium oxide is made up of sodium ions (Na^+) each with a charge of +1 and oxide ions (O^{2-}) each with a charge of –2. Therefore, the

Table 5.2.1 Common cations and anions

		Chemical name	Symbol
Cations	Lost 1 electron	Hydrogen ion	H^+
		Lithium ion	Li^+
		Sodium ion	Na^+
		Potassium ion	K^+
		Ammonium ion	NH_4^+
		Copper(I) ion	Cu^+
	Lost 2 electrons	Calcium ion	Ca^{2+}
		Magnesium ion	Mg^{2+}
		Barium ion	Ba^{2+}
		Copper(II) ion	Cu^{2+}
		Iron(II) ion	Fe^{2+}
	Lost 3 electrons	Iron(III) ion	Fe^{3+}
		Aluminium ion	Al^{3+}
Anions	Gained 1 electron	Fluoride	F^-
		Chloride	Cl^-
		Bromide	Br^-
		Iodide	I^-
		Hydroxide	OH^-
		Nitrate	NO_3^-
		Hydrogen carbonate	HCO_3^-
	Gained 2 electrons	Oxide	O^{2-}
		Sulfide	S^{2-}
		Sulfate	SO_4^{2-}
		Carbonate	CO_3^{2-}
	Gained 3 electrons	Nitride	N^{3-}
		Phosphate	PO_4^{3-}

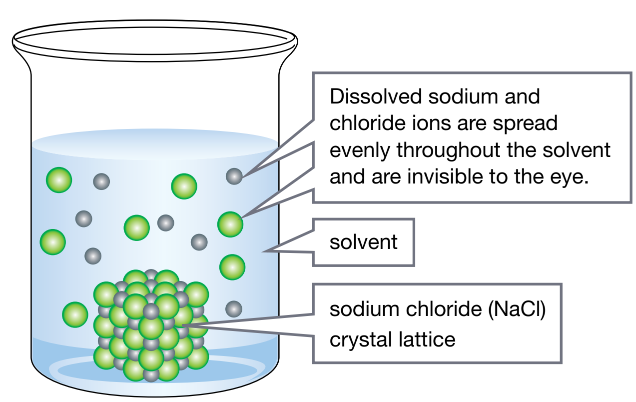


Figure 5.2.6 When sodium chloride dissolves, the lattice breaks apart and the ions distribute through the solution.

chemical formula for sodium oxide is Na_2O. This formula indicates that there need to be two sodium ions for every oxide ion in the crystal lattice to balance the charge.

Polyatomic ions are ions with more than one atom. Examples are NH_4^+ and SO_4^{2-}. The chemical symbol of these ions is put inside brackets when more than one is needed for a balanced formula. For example, the chemical formula for calcium hydroxide is $Ca(OH)_2$. This indicates that there are two hydroxide ions (OH^-) to balance the charge of each calcium ion (Ca^{2+}).

Predicting precipitation reactions

Scientists use the solubility rules in Table 5.2.2 to predict if a precipitation reaction will occur when two ionic solutions are mixed.

Table 5.2.2 Solubility rules

Negative ions (anions)	Positive ions (cations)	Solubility of compounds
Acetate, CH_3COO^-	All	Soluble
All	Li^+, Na^+, K^+, Rb^+, NH_4^+	Soluble
Chloride, Cl^- Bromide, Br^- Iodide, I^-	Ag^+, Pb^{2+}, Hg^{2+}, Cu^+	Low solubility
	All others	Soluble
Hydroxide, OH^-	Li^+, Na^+, K^+, Rb^+, NH_4^+, Sr^{2+}, Ba^{2+}	Soluble
	All others	Low solubility
Nitrate, NO_3^-	All	Soluble
Phosphate, PO_4^{3-} Carbonate, CO_3^{2-}	Li^+, Na^+, K^+, Rb^+, NH_4^+	Soluble
	All others	Low solubility
Sulfate, SO_4^{2-}	Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+}	Low solubility
	All others	Soluble
Sulfide, S^{2-}	Li^+, Na^+, K^+, Rb^+, NH_4^+, Be^{2+}, Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}	Soluble
	All others	Low solubility

Using the solubility rules, you can predict what will happen when two ionic solutions are mixed. For example, consider what happens when a potassium chloride solution is mixed with a solution of silver nitrate.

The solubility rules state that all potassium ionic compounds are soluble and therefore potassium chloride (KCl) is soluble. The rules also state that all nitrates are soluble. Therefore, silver nitrate ($AgNO_3$) must be soluble. Together, these solutions can combine to create potassium nitrate (KNO_3) and silver chloride (AgCl). Potassium nitrate (KNO_3) must be soluble because all potassium ionic compounds and all nitrates are soluble. However, the solubility rules show that silver chloride is only slightly soluble in water and so it will precipitate out of the solution as a solid.

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Figure 5.2.7 shows this happening. The chemical equations for this precipitation reaction are:

potassium chloride solution + silver nitrate solution → potassium nitrate solution + silver chloride solid

$$KCl + AgNO_3 \rightarrow KNO_3 + AgCl$$

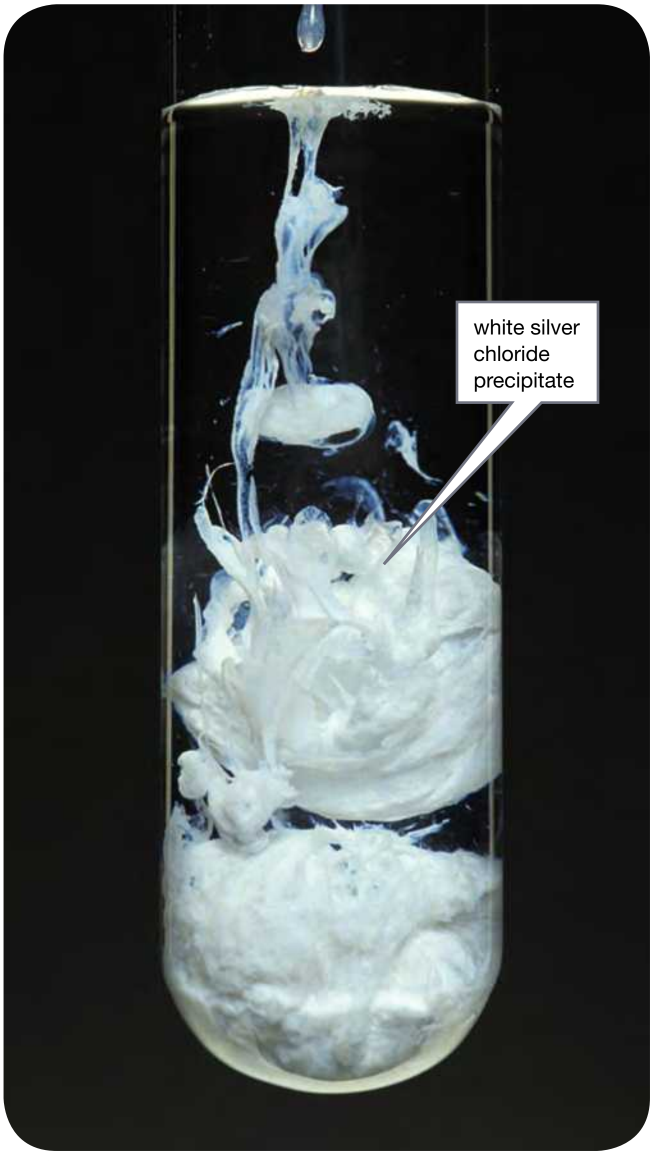


Figure 5.2.7 Silver chloride precipitates out as a white solid when potassium chloride is mixed with silver nitrate.

SKILL BUILDER

Predicting precipitation reactions

It is possible to predict the outcome of mixing two solutions by considering the solubility of all the possible combinations of cations and anions. Consider a mixture of solutions of magnesium sulfate ($MgSO_4$) and barium nitrate ($Ba(NO_3)_2$).

Step 1: Swap the cations and anions of the reactants to get the possible products.

Product 1 = Magnesium nitrate ($Mg(NO_3)_2$)

Product 2 = Barium sulfate ($BaSO_4$)

Step 2: Check the solubility of the possible products in Table 5.2.2.

Product 1 = Magnesium nitrate is soluble because all nitrates are soluble.

Product 2 = Barium sulfate is insoluble because all sulfates are soluble except Ba^{2+}, Ca^{2+}, Sr^{2+}, Pb^{2+}.

Step 3: Write the chemical equation for the reaction showing that barium sulfate is a solid precipitate.

barium nitrate solution	+	magnesium sulfate solution	→	barium sulfate solid	+	magnesium nitrate solution
$Ba(NO_3)_2$	+	$MgSO_4$	→	$BaSO_4$	+	$Mg(NO_3)_2$

WORKED EXAMPLE
Predicting precipitation reactions

Problem

Solutions of aluminium chloride ($AlCl_3$) and sodium hydroxide (NaOH) are mixed. Predict what will happen by writing a word equation.

Solution

Step 1: Swap the anions in the reactants to see what the possible products are.

Product 1: NaCl

Product 2: $Al(OH)_3$

Step 2: Use the solubility table to check the solubility of the products.

Product 1: All sodium compounds are soluble so NaCl must be soluble

Product 2: Only a few hydroxide compounds are soluble and $Al(OH)_3$ is not one of them, so it should precipitate out of the solution.

Step 3: Write out the word equation indicating $Al(OH)_3$ as the solid precipitate

aluminium chloride solution	+	magnesium sulfate solution	→	aluminium hydroxide solid	+	sodium chloride solution

Practice

The following solutions are mixed. **Predict** what will happen by writing word equations.

1 potassium sulfate (K_2SO_4) and calcium nitrate ($Ca(NO_3)_2$)

2 copper(I) nitrate ($CuNO_3$) and sodium hydroxide (NaOH)

3 ammonium sulfide ($(NH_4)_2S$) and zinc chloride ($ZnCl_2$)

4 sodium bromide (NaBr) and ammonium hydroxide (NH_4OH)

Reactions with acids

Another method of classifying chemical reactions is based on the type of reactants used in the chemical reactions. Acids are a common type of reactant used throughout industry and in the home. There are several types of chemical reactions that use acids, including neutralisation reactions, acid–metal reactions and acid–carbonate reactions.

GO TO Pearson science NSW 9 Unit 2.2

Neutralisation reactions

Neutralisation reactions occur when an acid reacts with a base. An **acid** is any substance that releases hydrogen ions (H^+) when dissolved in water. Acids have a pH of less than 7 and can be highly corrosive.

For example, sulfuric acid (H_2SO_4), hydrochloric acid (HCl) and nitric acid (HNO_3) are strong acids that can cause severe chemical burns to living tissue and eat through metals. Other acids are weaker and are often present in the foods you eat. Examples are acetic acid or ethanoic acid (CH_3COOH) found in vinegar, lactic acid ($C_3H_6O_3$) found in sour milk and citric acid ($C_6H_8O_7$) found in citrus fruits like the ones shown in Figure 5.2.8.

Figure 5.2.8 Not all acids are highly corrosive. The citric acid found in these citrus fruits is edible. You still wouldn't want to get it in your eye though!

Bases can be considered to be the opposite of acids. A **base** is a substance that produces hydroxide (OH^-) ions when dissolved in water. The solution formed is referred to as being alkaline. Bases and alkaline solutions have a pH greater than 7 and can be just as dangerous as acids. However, bases are instead referred to as being **caustic**. Sodium hydroxide (NaOH) is commonly referred to a caustic soda. It is an example of a highly corrosive base. However, there are also mild forms of bases that are safe to use around the home. These bases are commonly used as cleaning products and include household ammonia, soap and toothpaste (Figure 5.2.9).

Figure 5.2.9 Everyday cleaning products that you find in the home are often bases, such as toothpaste, soap and drain cleaner.

When an acid and a base are mixed together they can neutralise each other. This is because the hydrogen ions (H^+) from the acid combine with the hydroxide ions (OH^-) from the base to form water (H_2O). Water is **neutral**. It has a pH of 7 and is neither acidic nor basic. The ions that the acid and base leave behind form a salt in the solution. The general equation for a neutralisation reaction is:

acid + base → salt + water

The term *salt* does not always refer to common table salt, sodium chloride (NaCl). Rather, the term *salt* has a very specific scientific definition. To chemists, **salt** refers to ionic compounds that are produced through a chemical reaction with an acid. For example, sulfuric acid (H_2SO_4) is neutralised by magnesium hydroxide ($Mg(OH)_2$). Its chemical equations can be written as:

sulfuric acid + magnesium hydroxide → magnesium sulfate + water

$$H_2SO_4 + Mg(OH)_2 \rightarrow MgSO_4 + 2H_2O$$

The hydrogen ions (H^+) from the sulfuric acid combine with the hydroxide ions (OH^-) in the magnesium hydroxide to form water molecules. This leaves behind magnesium (Mg^{2+}) and sulfate (SO_4^{2-}) ions that form a magnesium sulfate solution. In this case, magnesium sulfate is the salt.

Heartburn is caused by an excess of acid in the stomach. It can be controlled by a neutralisation reaction. Antacids are essentially bases in solid or liquid form that neutralise the excess acid. This is why they relieve heartburn.

SciFile

Houston we have a problem!

A neutralisation reaction saved the lives of the astronauts on the *Apollo 13* space mission. In the last stages of their mission, the crew members were faced with a serious build up of carbon dioxide gas that would have suffocated them. They managed to use lithium hydroxide, a base, to neutralise the carbon dioxide and keep the air breathable.

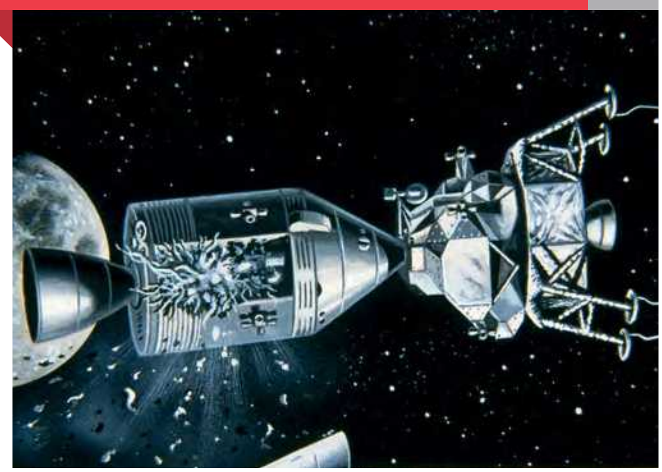


Figure 5.2.10 An artist's impression of the explosion that crippled *Apollo 13* on its way to the Moon in 1970.

Acids and metals

Acids react with metals to produce a salt and hydrogen gas. The general equation for this type of reaction is:

acid + metal → salt + hydrogen

For example, the reaction between hydrochloric acid (HCl) and magnesium metal (Mg) produces large amounts of hydrogen gas (H_2). The balanced chemical equation for this reaction is:

hydrochloric acid + magnesium → magnesium chloride + hydrogen gas

$$2HCl + Mg \rightarrow MgCl_2 + H_2$$

ADDITIONAL

Acids and metal reactivity

Most metals will react with acids, but some react more than others as shown in Figure 5.2.11. Very reactive metals such as sodium (Na), potassium (K) and calcium (Ca) react violently. Others such as lead (Pb) require hot and highly concentrated acids before a reaction will occur. Gold (Au) does not usually react with acids.

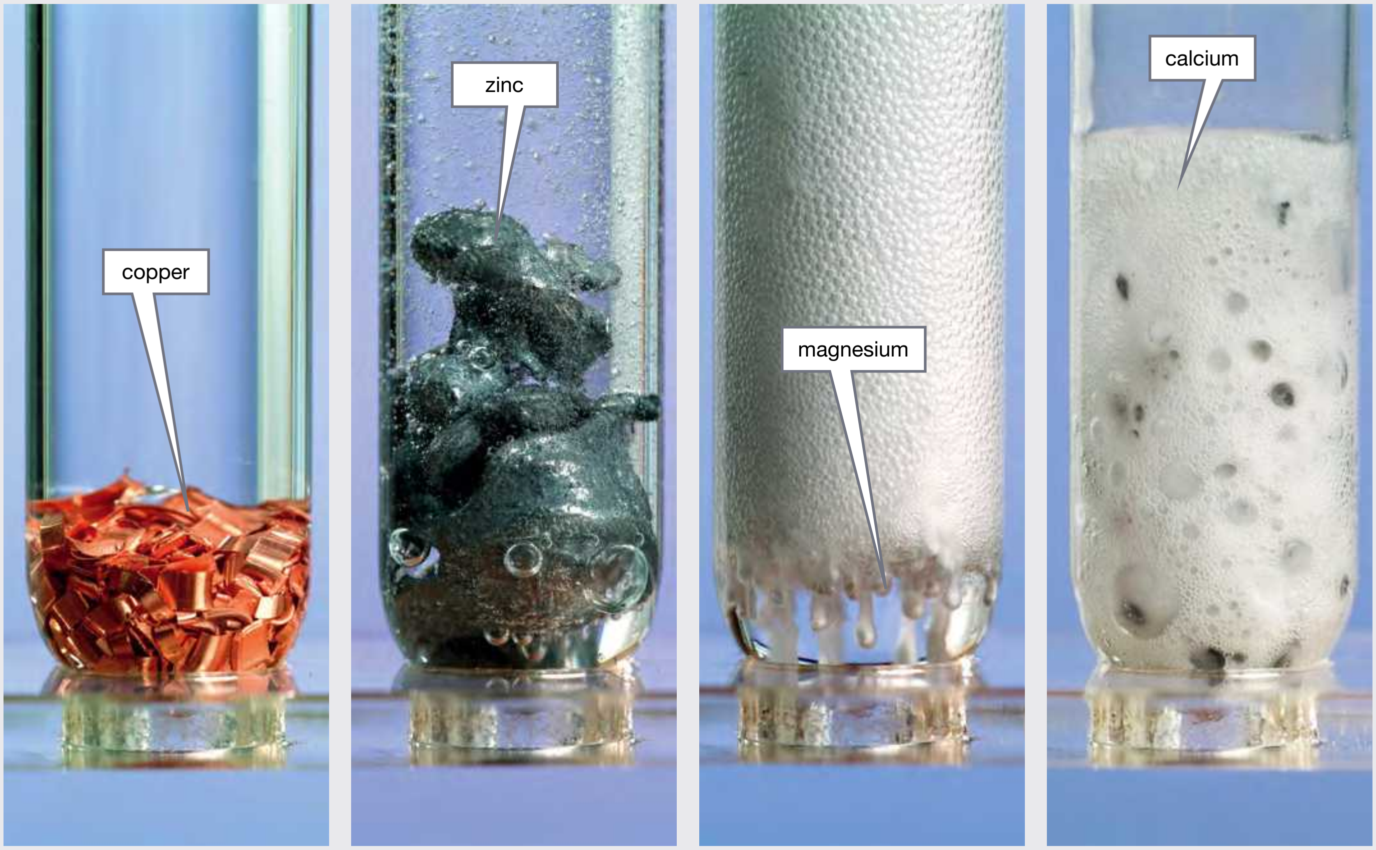


Figure 5.2.11 Copper, zinc, magnesium and calcium all react with acid to varying degrees. Copper hardly reacts at all, but calcium reacts violently.

ADDITIONAL

Acids and carbonates

Acids react with carbonates to produce salt, water and carbon dioxide gas. The general word equations for these reactions are:

acid + carbonate salt + water + carbon dioxide

For example, when sulfuric acid (H_2SO_4) reacts with calcium carbonate ($CaCO_3$) to produce calcium sulfate ($CaSO_4$), water (H_2O) and carbon dioxide (CO_2). The balanced equation for this reaction is:

sulfuric acid + calcium carbonate → calcium sulfate + water + carbon dioxide

$$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + H_2O + CO_2$$

Acid–carbonate reactions are better for cleaning up acid spills than a neutralisation reaction or acid-metal reactions. To neutralise a concentrated acid you need a concentrated base, which is just as dangerous as the concentrated acid. Using an acid-metal reaction would clean up the acid but produce large amounts of hydrogen gas, which is highly explosive. In contrast, carbonates are relatively harmless but can completely neutralise concentrated acids without producing flammable gases.

5.2 5.3

5.2 Unit review

Remembering

1 **List** two examples of decomposition reactions and two examples of precipitation reactions.

2 **Recall** the following reactions by writing their word and formula equations:
  a Sulfuric acid (H_2SO_4) is neutralised by magnesium hydroxide ($Mg(OH)_2$).
  b Hydrochloric acid (HCl) reacts with magnesium metal (Mg).
  c A solution of aluminium chloride ($AlCl_3$) reacts with a solution of magnesium sulfate ($MgSO_4$) to form a precipitate.

3 **List** the names and symbols of three polyatomic ions.

4 **State** whether nitrates are normally soluble or insoluble.

5 **List** the products formed when an acid and a base neutralise each other.

6 **List** the products formed when:
  a an acid reacts with a carbonate
  b an acid reacts with a metal.

Understanding

7 **Explain** why combination and decomposition reactions can be considered the reverse of each other.

8 **Describe** the changes that are normally seen during a precipitation reaction.

9 **Describe** everyday examples of neutralisation.

Applying

10 **Apply** rules for chemical formula writing to write the formula for the ionic compound calcium chloride.

11 **Use** Table 5.2.1 on page 170 to **name** the following ionic compounds.
  a NaBr   b K_2S
  c BaO   d Na_3N
  e NH_4Cl f LiOH
  g Ag_2CO_3 h $ZnSO_4$

12 **Identify** the salt produced by each of these reactions.
  a nitric acid + strontium hydroxide
  b sulfuric acid + copper carbonate
  c hydrochloric acid + silver oxide
  d nitric acid + magnesium hydrogen carbonate

13 **Use** word equations to **describe** these chemical reactions:
  a $2Mg + O_2 \rightarrow 2MgO$
  b $KOH + HCl \rightarrow KCl + H_2O$
  c $H_2SO_4 + MgCO_3 \rightarrow MgSO_4 + CO_2 + H_2O$
  d $2HNO_3 + 2Na \rightarrow 2NaNO_3 + H_2$

14 **Use** Table 5.2.2 on page 171 to **predict** the precipitate formed when these solutions are mixed.
  a silver nitrate and sodium chloride
  b mercury(II) nitrate and potassium iodide
  c calcium nitrate and lithium carbonate
  d barium nitrate and sodium sulfate

Analysing

15 **Classify** the following reactions as combination or decomposition reactions.
  a $2KClO_3 \rightarrow 2KCl + 3O_2$ b $2H_2O_2 \rightarrow O_2 + 2H_2O$
  c $Fe + S \rightarrow FeS$ d $2H_2 + O_2 \rightarrow 2H_2O$

16 **Classify** the following reactions as neutralisation or precipitation reactions.
  a $HNO_3 + KOH \rightarrow KNO_3 + H_2O$
  b $BaCl_2 + (NH_4)_2SO_4 \rightarrow BaSO_4 + 2NH_4Cl$
  c $3NaOH + Al(NO_3)_3 \rightarrow 3NaNO_3 + Al(OH)_3$

Creating CCT

17 **Construct** a table to **summarise** the different reaction types in this unit.

18 **Construct** word equations from the following reactions:
  a When heated, copper(II) carbonate decomposes to form copper(II) oxide and carbon dioxide.
  b A neutralisation reaction takes place between hydrochloric acid and sodium hydroxide.
  c The metal magnesium reacts with nitric acid.
  d Sulfuric acid reacts with calcium carbonate.

Inquiring

Research the 18th century chemists Carl Wilhelm Scheele, Joseph Priestley and Antoine-Laurent Lavoisier. Find:

- a brief description of their lives
- an outline of their important scientific discoveries
- why the decomposition of mercury oxide (HgO) was an important part of their work.

Present your findings as a PowerPoint presentation with one slide per scientist. ICT

5.2 Practical investigations

1 Heating metal carbonates

Calcium hydroxide ($Ca(OH)_2$) is slightly soluble in water. When it mixes it forms a solution called limewater. Limewater turns milky in the presence of carbon dioxide.

Purpose

To investigate the effect of heat on metal carbonates.

Hypothesis

What do you think will happen to copper(II) carbonate when it is heated? Before you go any further with this investigation, write a hypothesis in your workbook.

Materials

- limewater (calcium hydroxide solution $Ca(OH)_2$)
- 5 g copper(II) carbonate
- 2 large test-tubes
- stopper for test-tube with a delivery tube
- 2 retort stands
- 2 bossheads and clamps
- Bunsen burner and mat
- spatula
- rubber gloves

SAFETY

Wear safety glasses. Do not stop heating the copper carbonate for more than about 10 seconds (while the delivery tube is in the limewater) or the limewater will be sucked back into the hot test-tube with copper carbonate and it will shatter. One team member must watch this during the heating. Copper(II) carbonate is an irritant, so avoid contact with eyes, skin and mouth.

Wear safety glasses and rubber gloves at all times. Wash your hands thoroughly after the prac.

Procedure

1. Use the spatula to put about 5 g (or about 2 cm depth) of copper(II) carbonate ($CuCO_3$) in one of the test-tubes.
2. Fit the test-tube with the stopper and delivery tube.
3. Use the bosshead and clamp to secure the test-tube on an upward angle with the delivery tube pointing down as shown in Figure 5.2.12.
4. Half-fill the second test-tube with limewater and clamp it to the retort stand so that the delivery tube just dips into the limewater.
5. Use the Bunsen burner to heat the copper carbonate gently at first and then more strongly.
6. Record your observations but remove the delivery tube from the limewater as soon as the heating is stopped to prevent limewater rising up the delivery tube.

Practical review

1. **Assess** if a chemical reaction has taken place.
2. **Propose** whether the mass of the substance left in the test-tube after heating would be greater or less than the mass of copper carbonate put into the test-tube originally.
3. When carbon dioxide is bubbled through limewater, it reacts to form solid calcium carbonate and water.
   a. **Classify** this reaction as a decomposition, combination, precipitation or neutralisation reaction.
   b. **Construct** a word equation to **describe** the reaction between carbon dioxide and limewater.
4. a. **Construct** a conclusion for your investigation.
   b. **Assess** whether your hypothesis was supported or not.

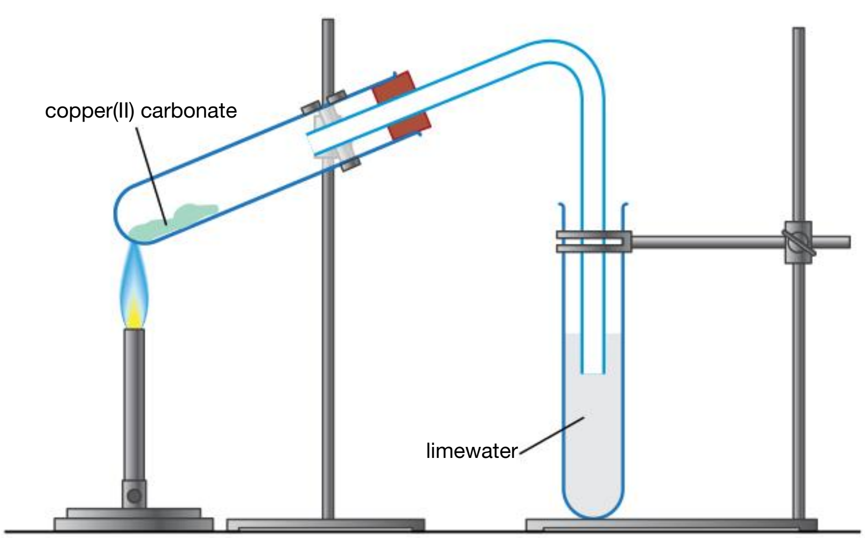


Figure 5.2.12

2 Precipitation reactions

Purpose

To predict and then test particular precipitation reactions.

Materials

- 0.1 M solutions of silver nitrate, sodium carbonate, sodium hydroxide, barium nitrate and copper sulfate (all in 'dropper' bottles)
- 10 small test-tubes and test-tube rack
- gloves

SAFETY

The chemicals used in this investigation are toxic so in all cases avoid contact with skin, eyes, nose and mouth. Silver nitrate causes stains so avoid contact with skin and clothing. Wear rubber gloves, safety glasses and protective clothing. Sodium hydroxide is toxic and corrosive. Copper(II) sulfate is toxic. Barium nitrate is toxic and an irritant. Solutions from this experiment must not be washed down the sink. They should be placed in a clearly marked waste bottle.

Wear gloves and safety glasses at all times.

Procedure

1 Construct a table like the one below. You need 11 rows to record 10 tests.

2 In your table, enter all possible combinations of two of the test solutions.

3 Using Table 5.2.2 on page 171, predict what should happen in each tube and write your prediction in the table.

4 For your first pair of solutions, place 10 drops of solution A in a test-tube, and then add 10 drops of solution B to the same test-tube. Place the tube in a test-tube rack and allow it to rest.

5 Repeat step 4 for each pair of solutions.

Results

Record all observations in your results table.

Practical review

1 **Analyse** the solubility rules in Table 5.2.2 on page 171 to **deduce** what has precipitated from each solution.

2 **Construct** word equations to **describe** what is happening in each case where a reaction occurred.

Solution A	Solution B	Prediction of precipitation (yes/no)	Observations before mixing	Observations after mixing	Name of precipitate (if any)
Silver nitrate	Sodium carbonate				

STUDENT DESIGN

3 Identifying unknown solutions

Purpose

To determine the contents of three unlabelled solutions.

Materials

- three unknown solutions labelled A, B C as prepared by teacher or lab technician
- other materials and equipment as selected by students

SAFETY

A risk assessment is required for this investigation.
Some chemicals used in this experiment are toxic so wear gloves and safety glasses to avoid contact with your skin and eyes.
Refer to the MSDS of all chemicals when constructing your risk assessment.

Procedure

1 Use the solubility rules in Table 5.2.2 on page 171 to design an experiment that can determine the contents of three unlabelled solutions of sodium chloride, barium nitrate or potassium nitrate.

2 Brainstorm in your group and come up with several different ways to investigate the problem. Select the best procedure and write it in your workbook. Include your prediction of what you expect to observe and how this will prove what is in each unlabelled solution.

3 Before you start any practical work, assess all risks associated with your procedure. Refer to the MSDS of all the chemicals you use. Construct a risk assessment that outlines the risks and any precautions you need to take to minimise them. Show your teacher your procedure and risk assessment. If your teacher approves, then collect all the required materials and start work.

Practical review

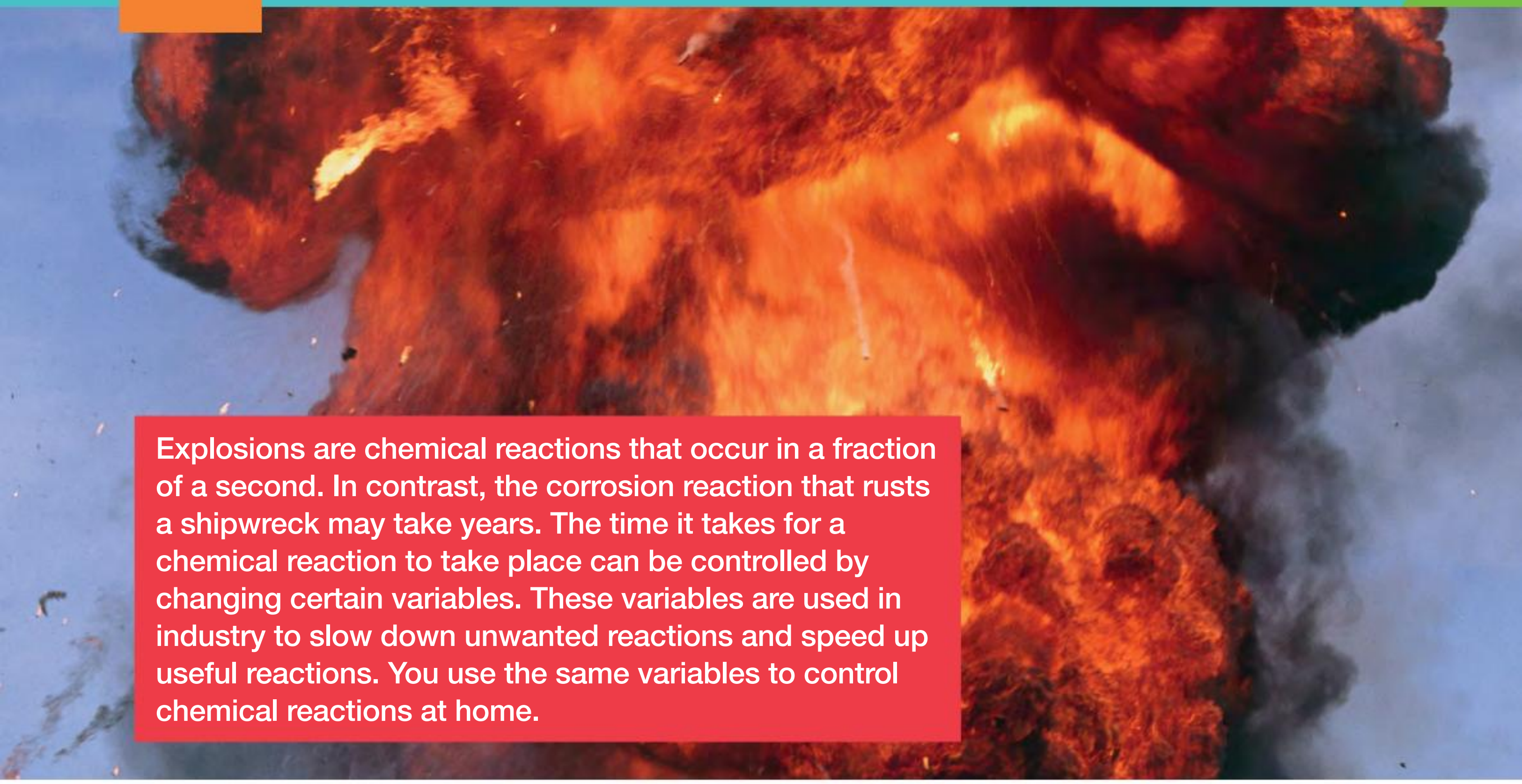
1 **State** the type of reactions that you observed.

2 **Construct** word equations for each of the reactions you observed.

3 **Use** Table 5.2.2 on page 171 to **explain** why determining the contents of unlabelled solutions containing sodium nitrate, barium nitrate or potassium nitrate would be much more difficult.

4 **Evaluate** your procedure. Pick two other prac groups and **evaluate** their procedures too, identifying their strengths and weaknesses.

5.3 Rates of chemical reactions



Explosions are chemical reactions that occur in a fraction of a second. In contrast, the corrosion reaction that rusts a shipwreck may take years. The time it takes for a chemical reaction to take place can be controlled by changing certain variables. These variables are used in industry to slow down unwanted reactions and speed up useful reactions. You use the same variables to control chemical reactions at home.

Fast and slow chemical reactions

The speed at which a chemical reaction proceeds is known as the **rate of reaction**. Some chemical reactions that proceed quickly are explosions and combustion reactions, such as the combustion of natural gas in a Bunsen burner and the welding shown in Figure 5.3.1. These reactions are said to have a fast rate of reaction. Chemical reactions that proceed slowly are said to have a slow rate of reaction. Rusting, ripening and the fermentation of grapes to produce wine are examples (Figure 5.3.2) .

Figure 5.3.1 Welders use the rapid combustion of acetylene to produce the extremely hot flame required to weld and cut metals.

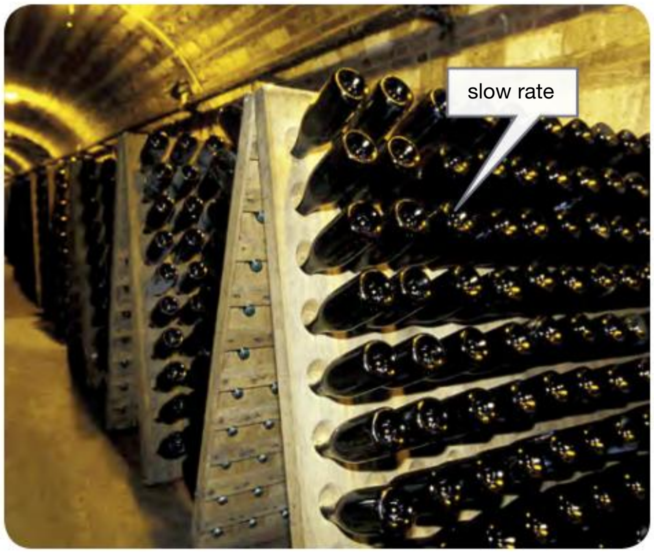


Figure 5.3.2 The slow chemical reactions that ferment wine and give it its flavour mean that it can take years before the wine is ready to drink.

Controlling the rate of chemical reactions

The rate of almost every reaction can be increased or decreased. For example, when you run a race you start to breathe harder and your heart pumps faster to speed up the rate of respiration. The rate of respiration slows down when you're calm and relaxed. Animals that hibernate reduce their respiration rate to extremely low levels. This allows them to use up very little of their body's fat reserves during winter. In spring, food is more plentiful and so they increase their rate of respiration, returning it to normal.

Factors that affect the rate of reaction are:

- temperature
- concentration of the reactants
- surface area (if the reactants are in lumps or fine powder)
- agitation (mixing and stirring)
- catalysts (chemical helpers).

By changing these variables, scientists can control how fast or slow a chemical reaction proceeds.

Temperature

Increasing the temperature will normally increase the rate of a chemical reaction. This occurs for two reasons:

- Increasing the temperature increases the speed of the particles in liquids and gases. As a result, particles collide more frequently, so more chemical reactions occur in a shorter amount of time.
- Increasing the temperature gives the particles more energy. So, when the molecules collide, they hit harder. Chemical bonds are more likely to break and the atoms in the reactants can rearrange more easily to form products.

When you bake a batch of biscuits, you place it in the oven to increase the rate of chemical reactions that convert your dough into biscuits. However, you can't increase the temperature too much or the rate of reaction will be so fast that the biscuits will burn on the outside before they are cooked all the way through. This is what has happened in Figure 5.3.3.

Sometimes you may want to slow the rate of reaction by lowering the temperature. When you place a carton of milk in the fridge, it slows the rate of the chemical reaction that turns milk sour. Similarly, fruit farmers will transport their produce in refrigerated trucks to stop the fruit ripening before it gets to market.

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Figure 5.3.3 Biscuits must be baked at the right temperature. When the temperature is too high, the reaction is so fast that they burn before they are cooked inside.

Putting life on hold

SciFile

Through the process of in-vitro fertilisation (IVF), human egg cells can be fertilised and frozen for later use. Freezing the eggs stops the chemical reactions that cause the embryo to develop. Today, one in 33 births in Australia is the result of IVF. That's almost one in every classroom.

Figure 5.3.4 Human eggs in test-tubes and frozen in liquid nitrogen

Concentration

The term **concentration** refers to the amount of a particular substance present in a particular volume of liquid or gas. For example, if you put 20 teaspoons of sugar in a litre of water, then the concentration of sugar is high. The solution is concentrated. However, if you put 1 teaspoon of sugar in a litre of water, then the concentration of sugar is low. The solution is dilute. Figure 5.3.5 compares concentrated and dilute solutions.

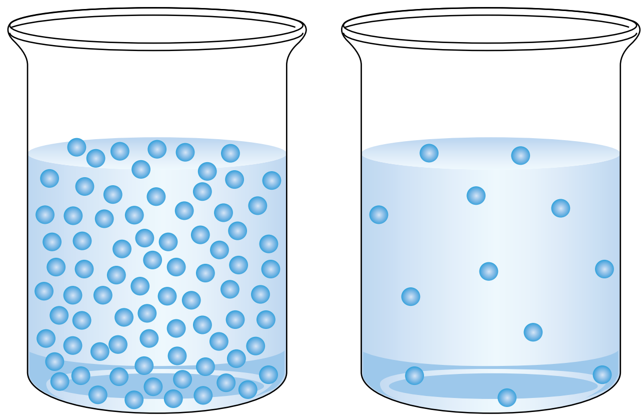

Figure 5.3.5 A concentrated solution has a large number of sugar molecules in a beaker of water. A dilute solution has very few sugar molecules in the same volume.

Increasing the concentration of the reactants will increase the rate of reaction. This is because the particles are more likely to collide and react when there are more of them. Collisions between particles are necessary for the reactants to rearrange to form the products.

Increasing the concentration of reactants is a very common way of increasing the rate of reaction. You concentrate the reactants whenever you turn up the gas knob on a heater or stove like the one in Figure 5.3.6, add more wood to a fire, add more sugar to a breadmaker or drink 20 mL instead of 10 mL of antacid to relieve heartburn.

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Figure 5.3.6 When you increase the flow of gas on a gas stove, you increase the concentration of reactants to produce a bigger flame and more heat.

It is also common to reduce the concentration of reactants in order to slow the rate of some reactions. When you place food in a zip-lock bag or air-tight container, you are limiting the supply and concentration of oxygen. This slows down the rate at which the food can go off or become stale. A similar principle is used to protect some iron structures from rusting. Iron is often painted to limit the amount of oxygen that can react with the surface to form iron(III) oxide (rust).

Agitation

Stirring reactants can also increase the rate of reaction. Stirring is known scientifically as **agitation**. Agitation ensures that the reactants are kept in contact. It does this by removing build-up of products around the reactants. For example, if a solid piece of calcium carbonate is dropped into the bottom of a beaker of hydrochloric acid, it will react with the acid to produce calcium chloride, water and carbon dioxide gas. The equations for this reaction are:

$$\text{calcium carbonate} + \text{hydrochloric acid} \rightarrow \text{calcium chloride} + \text{water} + \text{carbon dioxide}$$

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$$

Although the carbon dioxide bubbles off as a gas, the other products—calcium chloride and water—build up around the calcium carbonate as shown in Figure 5.3.7. The products surround the calcium carbonate, making it more difficult for the hydrochloric acid to come into contact with the calcium carbonate. Agitating the reaction flushes the products away from the calcium carbonate, and allows the hydrochloric acid to attack the surface of the calcium carbonate once more. Magnetic stirrers are used in the laboratory to constantly agitate reactions and ensure the maximum rate of reaction. You can see one in action in Figure 5.3.8 on page 182.

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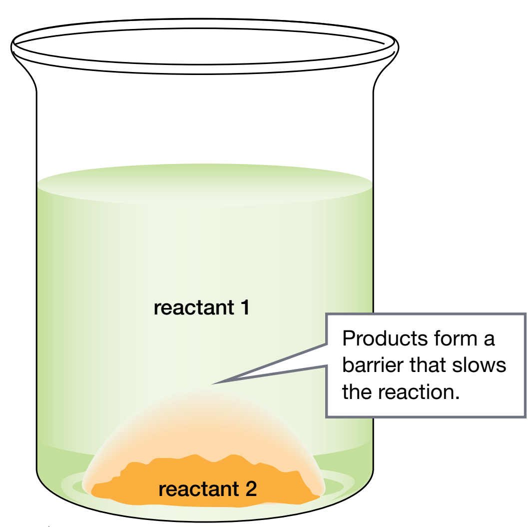


Figure 5.3.7 When a solid reacts with a liquid, the products build up around the solid, slowing down the rate of reaction. Agitation removes the build-up of products to maximise the rate of reaction.

Figure 5.3.8

In the laboratory, chemists use magnetic stirrers to constantly agitate and ensure a maximum rate of reaction.

Surface area of reactants

The rate of reaction between calcium carbonate and hydrochloric acid can be increased further if the calcium carbonate is crushed into a powder rather than used as one solid piece. If the calcium carbonate is placed in the acid as a single, solid lump, then the hydrochloric acid can only react with the outside of the lump. This is shown in Figure 5.3.9. However, if the lump is broken down into smaller pieces, then particles inside the lump are exposed and can react with the acid. This means more particles are reacting at the same time, so the reaction is faster. Cutting up or crushing solid reactants into smaller pieces creates a much larger surface in contact between the reactants.

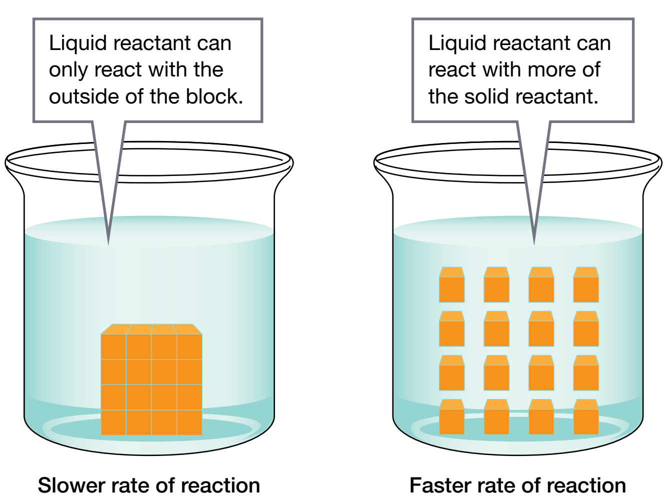


Figure 5.3.9

When a solid reactant is divided into smaller pieces, more of the solid is exposed to the liquid reactant and the rate of reaction is increased.

Having reactants with a large surface area is important in the delivery of medicines into your body. Capsules contain powdered medicines. When the capsule breaks apart in your stomach, the powdered medicine can be absorbed into your bloodstream more quickly than if the medicine was a solid tablet.

Prac 4 p190
5.4

Catalysts

Catalysts are chemicals that speed up chemical reactions but are not consumed (used up) during the reaction. They can be considered 'chemical helpers' that help the reactants to form the products. Catalysts can do this in two ways:

- they reduce the amount of energy that is required to convert the reactants into products
- they make it easier for reactant molecules to collide and form products.

For example, a catalytic converter in a car exhaust system uses platinum metal as a catalyst. This helps convert the poisonous gas carbon monoxide (CO) into the less toxic carbon dioxide (CO_2). Normally, carbon monoxide and oxygen would not react fast enough to form carbon dioxide (Figure 5.3.10). However, in a catalytic converter the carbon monoxide and oxygen molecules both stick to the platinum catalyst and move around on its surface. When they finally collide, the platinum helps the reactant molecules to rearrange and form carbon dioxide, which then leaves the surface of the platinum and is flushed out via the exhaust. Catalytic converters also remove some dangerous nitrogen oxides.

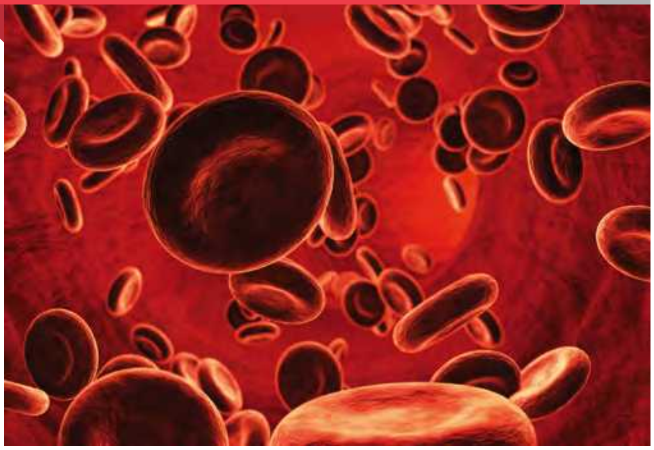
Figure 5.3.10

Catalytic converters in car exhaust systems prevent toxic chemicals from being released into the environment.

Carbon monoxide poisoning

SciFile

Carbon monoxide is a colourless, odourless gas that is produced when hydrocarbons are burnt in a limited supply of oxygen. Haemoglobin is the molecule in red blood cells that transports oxygen around your body. However, carbon monoxide binds to haemoglobin more strongly than oxygen does. This leaves no space for the oxygen, so your cells quickly become starved of oxygen and die.



Enzymes

Enzymes are biological catalysts. Enzymes are natural molecules that hold reactant molecules together until they rearrange to form products. Many enzymes are at work in your body right now. One of the first processes of digestion uses an enzyme called amylase, which is found in your saliva (Figure 5.3.11). Similar enzymes are secreted (released) by your pancreas and small intestine. Amylase is responsible for breaking down the starches in complex carbohydrates, such as in breads and potatoes, into simple sugars for easy absorption into the body.

Figure 5.3.11 Saliva uses the enzyme amylase to break down starches into simple sugars.

Some enzymes are particularly good at cutting long molecules into smaller pieces. You can observe this at home by putting kiwi fruit or fresh pineapple in jelly. The enzymes from the fruit cut the long jelly molecules into smaller pieces, preventing the jelly from setting. In a similar way, some cells use enzymes to attack and cut up the genetic material in viruses. This stops the virus from working and helps protect the cell from infection. Biologists have since used similar enzymes to cut DNA into smaller pieces and isolate specific genes.

5.5 5.6

GO TO Unit 1.4

INQUIRY science 4 fun

Jellied enzymes

How do the enzymes in pineapple affect jelly?

YES

Collect this …

- jelly powder
- water
- fresh pineapple
- apple
- banana
- 4 small containers to set the jelly in
- kettle
- access to a refrigerator

Do this …

1. Cut up the fruit into small pieces, about 1–2 cm cubes.
2. Dissolve the jelly in hot water according to the instructions on the packet.
3. Divide the jelly mix evenly between the four small containers.
4. Allow the jelly to cool in the fridge for a few hours, but not set. Place the pineapple in one container of jelly, the apple in the second and the banana in the third. Don't put any fruit in the fourth.
5. Place the containers in the refrigerator and wait for them to set.

Record this …

Describe what you observed.
Explain why you think this happened.

ADDITIONAL

LEARNING ACROSS THE CURRICULUM

ETHICAL UNDERSTANDING

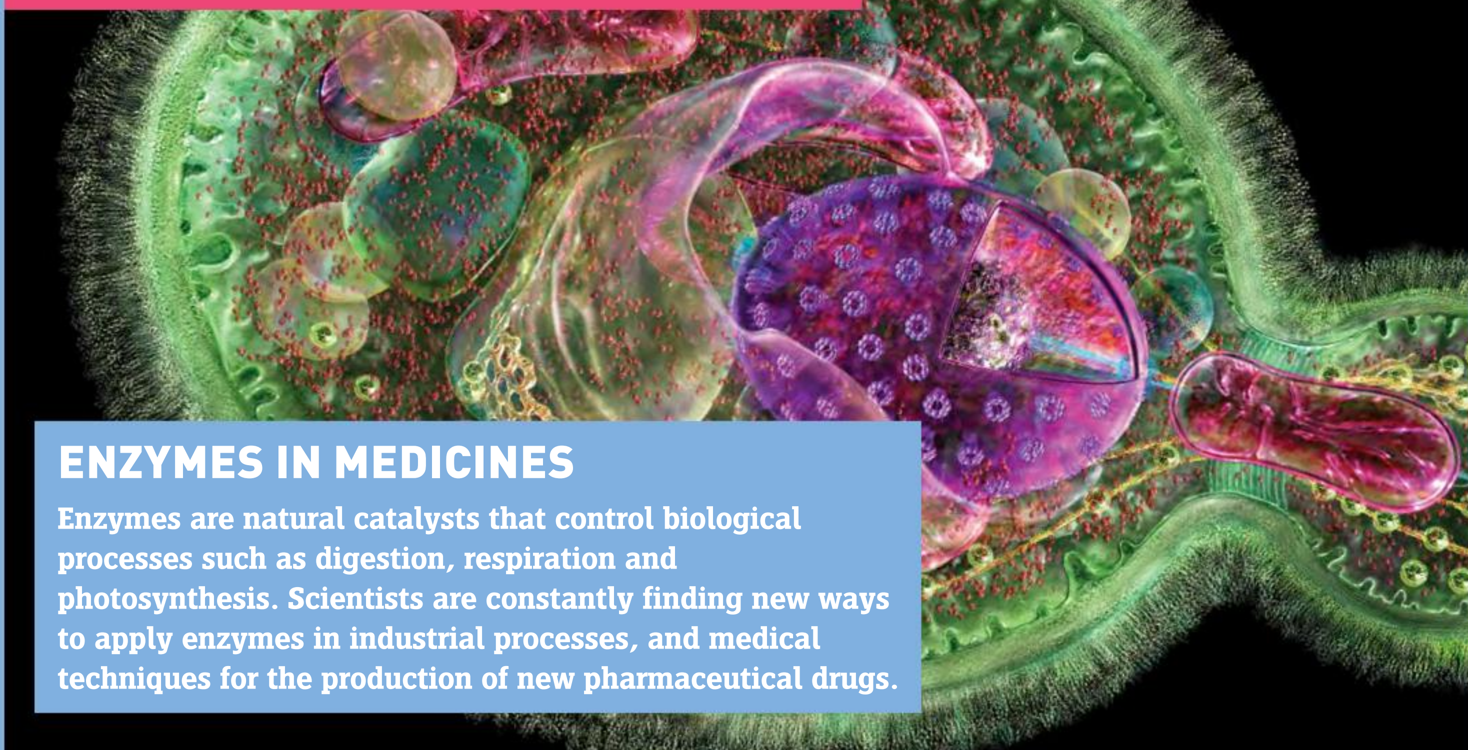


Figure 5.3.12 Enzymes found in cells like this yeast cell can help in the production of new pharmaceuticals.

ENZYMES IN MEDICINES

Enzymes are natural catalysts that control biological processes such as digestion, respiration and photosynthesis. Scientists are constantly finding new ways to apply enzymes in industrial processes, and medical techniques for the production of new pharmaceutical drugs.

PHARMACEUTICALS

The field of medicine has also benefited greatly from deeper scientific understanding of enzymes. One of the most revolutionary discoveries has been the synthesis of penicillin—the world's most widely used antibiotic. This discovery has saved countless lives.

The process for producing penicillin involves the use of two different enzymes to combine three different chemicals into the wonder drug. These enzymes occur naturally in the *Penicillium* fungi, in which the drug was first discovered by Scottish scientist Alexander Fleming (1881–1955) in 1928.

More recently, enzymes have been used to treat various conditions such as cancers and blood clots. In 1987, the first enzyme-based drug was approved for human use. The drug contained a 'clot-buster' enzyme that was able to treat heart attacks caused by blockages in the arteries. Since then, many other enzyme-based treatments have been approved. These treatments normally involve enzyme replacement therapies. However, enzymes have also been used in the treatment of leukaemia, to alleviate the side effects of chemotherapy, and to clear the airways of those with cystic fibrosis.

GO TO Unit 1.3

Figure 5.3.13 In 1945, Howard Florey won Australia's second ever Nobel Prize for his work.

SciFile

Howard Florey

Although Fleming discovered penicillin, he had no idea how to produce it in large quantities. A method of mass production of penicillin became vital once World War II broke out in 1939. Australian scientist Howard Florey (1898–1968) and his colleagues Ernest Chaim and Norman Heatley eventually found a way of making sufficient quantities of the drug. For this they received a Nobel Prize in 1945.

GENETIC ENGINEERING

Enzymes are used in genetic engineering to create new breeds of plants and animals. Enzymes are used to cut genes from the DNA of one organism and to insert the genes into the DNA of a different organism. For example, the gene from a pest-resistant cotton plant may be inserted into a wheat plant to create a new type of wheat that is also resistant to pests (Figure 5.3.14).

This type of technology is commonly used in agriculture to develop crops that survive harsher environments and produce more food. However, there is much ethical debate about the use of genetic engineering in agriculture and medicine.

Figure 5.3.14 Scientists use genetic engineering to produce crops that can survive in harsher environments and resist pests.

People have different ideas about how the technology should be used. Today genetic-screening technology is currently being used to screen embryos for genetic diseases. This gives the parents the opportunity to terminate the pregnancy if they feel that the child would not have a good quality of life. It could also be used to eliminate these diseases from society. However, the same technology can be used to screen for other things—will the child be a boy or a girl, have blue eyes or brown eyes or will it be athletic? This raises the moral issue of when is it acceptable to abort embryos based on their genetics. If it is reasonable to destroy an embryo with a serious illness but it is not reasonable to destroy the embryo based on the sex of the child, then where is the moral line between these two extremes?

The concept of genetic engineering takes the debate to another level. Through genetic engineering, parents could actively choose the features that they would like their child to have—they could create a designer baby. Some might argue that by designing your child to have a higher intelligence or greater athletic ability you are giving your child the best chance at a good life. Others would argue that choosing genetic traits is going too far, and that parents should not have the right to specify the genetics of their child. It also has social implications. Only the richest people will be able to afford this technology so will that create a genetic gap between the rich and the poor?

GO TO Unit 1.4

REVIEW

1 **Recall** the name of the Australian scientist who won the Nobel Prize in 1945 and the discovery for which he won it.

2 **Explain** how enzymes are used in genetic engineering.

3 a **Evaluate** whether the following uses of genetic engineering are ethical.

  i Creating fruit trees that grow faster and produce more fruit

  ii Creating chickens that grow faster and produce more meat

  iii Identifying genetic diseases in an unborn child

  iv Producing bioluminescent mice (Figure 5.3.15).

  b **Justify** your response in each case.

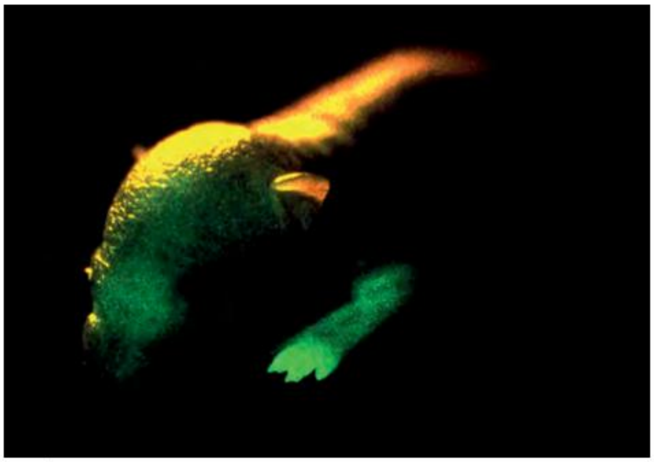


Figure 5.3.15 This baby mouse has been genetically modified to glow. A gene from a naturally bioluminescent jellyfish was inserted into the egg from which the mouse developed. Research like this has caused much debate as to its advantages and disadvantages.

5.3 Unit review

Remembering

1 **List** three examples each of fast and slow reactions.

2 **State** the five ways that the rate of reaction can be controlled.

3 **State** the name given to chemicals that speed up a chemical reaction but are not used up during the chemical reaction.

Understanding

4 **Define** the term *rate of reaction*. L

5 **Explain** why you need to choose the right temperature when baking a cake.

6 Scientists use magnetic stirrers to maximise the rate of reaction. **Explain** how continually stirring the reaction helps to make it go faster.

7 **Explain** how a catalyst increases the rate of reaction.

8 **Explain** why particles must collide before they can react.

9 **Explain** why the jelly in the science4fun on page 183 is less likely to set when fruit is added.

Applying

10 a **Identify** two examples of reactions at home that you speed up.

b **Identify** two examples of reactions at home that you slow down.

c For each case, **describe** what you do to change the rate.

11 To remove a stain faster, Jenny applies more stain remover. **Identify** which of the methods of increasing the rate of reaction Jenny is using.

12 The advice on headache tablet boxes is that adults can take two, but a child should only take one. **Identify** a factor affecting reaction rate that is relevant to this advice.

Analysing

13 **Discuss** two other examples where the word *rate* is used in everyday life. Assess what this word means in each context.

14 **Compare** a catalyst with an enzyme.

15 Increasing agitation and increasing the surface area of reactants increase the rate of a reaction. **Compare** these two methods.

Evaluating CCT

16 a **Propose** the effect of the following changes on a wood fire heater.

i The wood is chopped into smaller pieces.

ii The vent is closed so that less air can get in.

b **Justify** your predictions.

17 Athletes use altitude training to increase their numbers of red blood cells and hence the concentration of oxygen in their bloodstream. **Propose** how this might help them during a race.

Creating CCT

18 **Construct** a labelled diagram showing how a higher concentration of hydrochloric acid increases the rate at which the acid reacts with a block of calcium carbonate.

Inquiring

1 Investigate the term metabolism. Find:

- what is meant by metabolic rate
- how can you change your metabolic rate
- how your metabolic rate changes as you get older
- how metabolism differs in endothermic (warm-blooded) and ectothermic (cold-blooded) animals.

Present your finding as a PowerPoint or Prezi presentation. ICT

2 Research different enzymes that assist digestion.

Present your research as a poster of the human digestive system. Indicate on the poster where you will find the different types of enzymes and their role in digestion.

5.3 Practical investigations

1 Temperature and reaction rate

Purpose
To determine how temperature affects a glow stick.

Hypothesis
How do you think changing the temperature will affect the light produced by a glow stick—do you think it will glow brighter/duller or for longer/shorter than before? Before you go any further with this investigation, write a hypothesis in your workbook.

Materials
- iced water
- hot water
- 2 glow sticks
- 2 beakers

Procedure
1 Start the glow sticks glowing and darken the room as much as possible.

2 Place one glow stick in a beaker of iced water and one in a beaker of hot tap water as shown in Figure 5.3.16.

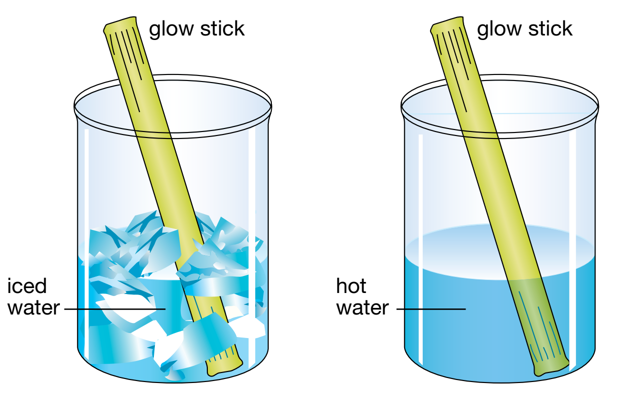


Figure 5.3.16

Results
Record your observations.

Practical review
1 **State** what evidence there is that a chemical reaction is taking place inside the glow sticks.

2 **State** what changing the temperature has done to the rate of reaction. **Justify** your answer based on your observations.

3 Glow sticks work by a chemical reaction between hydrogen peroxide and a chemical called an ester. A product of this reaction then causes a dye to emit light. **Explain** how temperature may be affecting the reaction.

4 Figure 5.3.16 shows the equipment used in this prac in three dimensions (3D). **Construct** a scientific diagram that shows it in two dimensions (2D).

5 a **Construct** a conclusion for your investigation.
b **Assess** whether your hypothesis was supported or not.

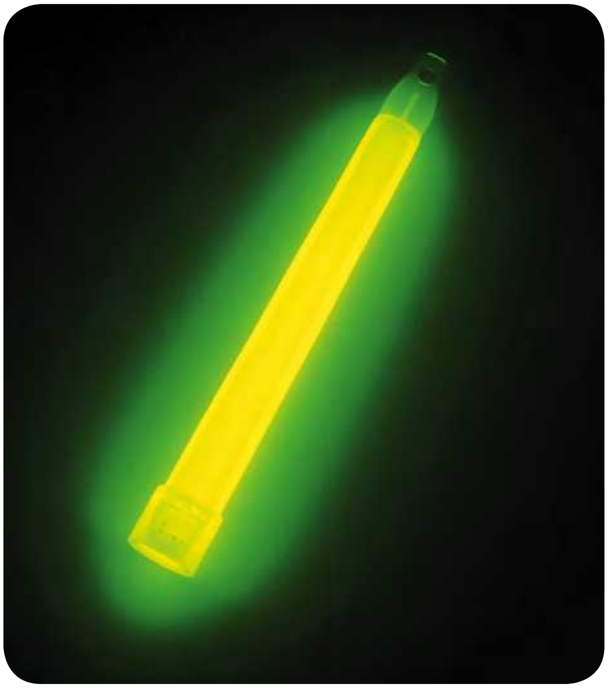


Figure 5.3.17 A glow stick emitting light

5.3 Practical investigations

2 Concentration and reaction rate

Purpose

To examine how concentration affects the rate of a reaction.

Hypothesis

What effect do you think changing the concentration of hydrochloric acid will have on how it reacts with marble chips (a form of calcium carbonate)—will it increase or decrease the rate of reaction? Before you go any further with this investigation, write a hypothesis in your workbook.

Materials

- marble chips
- 20 mL of 0.5 M hydrochloric acid in a small beaker
- 20 mL of 2 M hydrochloric acid in a small beaker

- 3 large test-tubes
- rubber stopper with flexible delivery tube
- pneumatic trough, large beaker or large deep tray
- retort stand with test-tube clamp
- timer
- ruler
- water
- rubber gloves

SAFETY

Hydrochloric acid is toxic and corrosive so avoid contact with skin, eyes, nose and mouth. Wear safety glasses, rubber gloves and protective clothing at all times.

Procedure

1. Copy the table in the Results section into your workbook.
2. Place a few marble chips in two of the large test-tubes. Make sure the amount of marble is the same in each test-tube.
3. Set up the rest of the apparatus as shown in Figure 5.3.18. Fill the tray with water, fill the large test-tube with water and place it horizontally in the tray then invert the test-tube. Make sure the mouth of the test-tube remains submerged and then clamp the test-tube in place as shown.
4. Carefully pour 20 mL of 0.5 M hydrochloric acid into one of the test-tubes containing marble chips then immediately connect it to the rubber stopper and hose.
5. Start the timer and let the reaction run for 5 minutes.

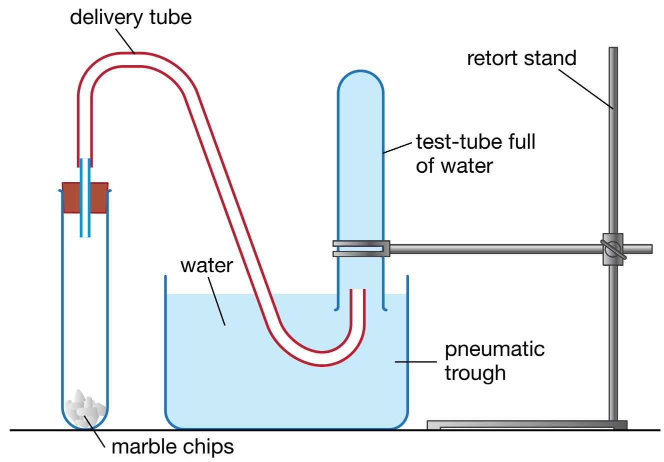


Figure 5.3.18

6. Record how much water was displaced in the inverted test-tube, in your results table.
7. Set up the apparatus again so that the inverted test-tube is filled with water.
8. Repeat steps 3–5 using 2 M hydrochloric acid.

Results

Record all measurements in your results table.

Acid	Displaced water (cm)
0.5 M hydrochloric acid	
2 M hydrochloric acid	

Practical review

1. Marble chips are a form of calcium carbonate. When they react with hydrochloric acid, they produce calcium chloride, carbon dioxide and water. **Construct** a word equation for this reaction.
2. **Compare** the rate of reactions for the 0.5 M and 2 M hydrochloric acid.
3. **Explain** your observations.
4. **Discuss** other factors that should be kept constant during this experiment to ensure that only the concentration of the acid affects the rate of reaction.
5. a **Construct** a conclusion for your investigation.
   b **Assess** whether your hypothesis was supported or not.

3 Agitation and reaction rate

Purpose

To determine the effect of stirring on the rate of a reaction.

Hypothesis

What effect do you think stirring will have on how quickly hydrochloric acid reacts with calcium carbonate—will it increase or decrease the rate? Before you go any further with this investigation, write a hypothesis in your workbook.

Materials

- 2 × 5 mm pieces of calcium carbonate
- 1 M hydrochloric acid
- 2 × 250 mL beakers
- stirring rod
- stopwatch
- rubber gloves

SAFETY

Hydrochloric acid is toxic and corrosive so avoid contact with skin, eyes, nose and mouth. Wear safety glasses, rubber gloves and protective clothing at all times.

Procedure

1. Fill both beakers with 50 mL of hydrochloric acid.
2. Place one piece of calcium carbonate into each beaker of acid at the same time.
3. Start the stopwatch.
4. Stir one beaker with the stirring rod continuously while leaving the other standing.
5. Record the time that both pieces of calcium carbonate finish reacting, in the table in the Results section.

Results

Copy and complete the following table.

Reaction	Time for reaction to complete
Still reaction	
Agitated reaction	

Practical review

1. **State** what indicates that a chemical reaction is taking place.
2. **Discuss** anything you observed that suggested one chemical reaction was going faster than the other.
3. **Identify** which reaction was faster. **Justify** your choice.
4. a **Construct** a conclusion for your investigation.
   b **Assess** whether your hypothesis was supported or not.

5.3 Practical investigations

STUDENT DESIGN

4 Surface area and reaction rate

Purpose
To determine the effect of changing the surface area on the rate of reaction.

Hypothesis
What effect do you think changing the surface area will have on the rate of the reaction between hydrochloric acid and calcium carbonate—will the rate increase or decrease? Before you go any further with this investigation, write a hypothesis in your workbook.

Materials
- calcium carbonate lumps
- 1 M hydrochloric acid

- beakers
- timers
- rulers
- marking pens
- chalk

SAFETY
A risk assessment is required for this investigation. Refer to the MSDS of all chemicals when constructing your risk assessment.

Procedure
1. Design an investigation that will test how surface area effects the rate of reaction.
2. Brainstorm in your group and come up with several different ways to investigate the problem. Select the best procedure and write it in your workbook. Draw a diagram of how you intend to proceed and construct a list of the data you will collect.
3. Before you start any practical work, assess all risks associated with your procedure. If using chemicals, then refer to their MSDS. Construct a risk assessment that outlines these risks and precautions you need to take to minimise them. Show your teacher your procedure and risk assessment. If your teacher approves, then collect all the required materials and start work.

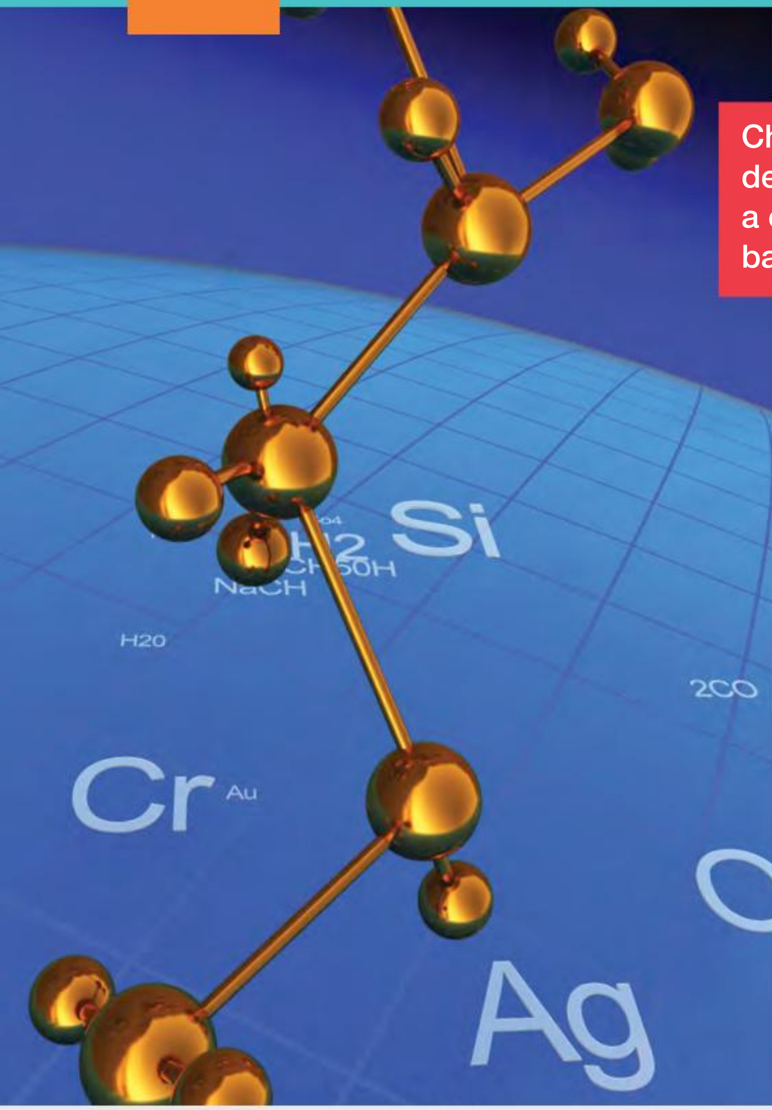
Hints
To design your experiment you should consider the following.
- How will you measure the rate of reaction?
- What one factor will you change in each of your samples?
- What factors will you control (keep the same) for each sample?

Results
Present your data in a suitable way and answer the discussion questions.

Practical review
1. **Describe** any pattern or patterns you found in the data.
2. **Summarise** the relationship between surface area and rate of reaction.
3. **Explain** the relationship between surface area and rate of reaction.
4. a **Construct** a conclusion for your investigation.
   b **Assess** whether your hypothesis was supported or not.
5. **Evaluate** your procedure. Pick two other prac groups and **evaluate** their procedures too, identifying their strengths and weaknesses.

ADDITIONAL

5.4 Balancing chemical equations



Chemists have developed their own way of describing and explaining what happens during a chemical reaction. They do this by writing balanced chemical equations.

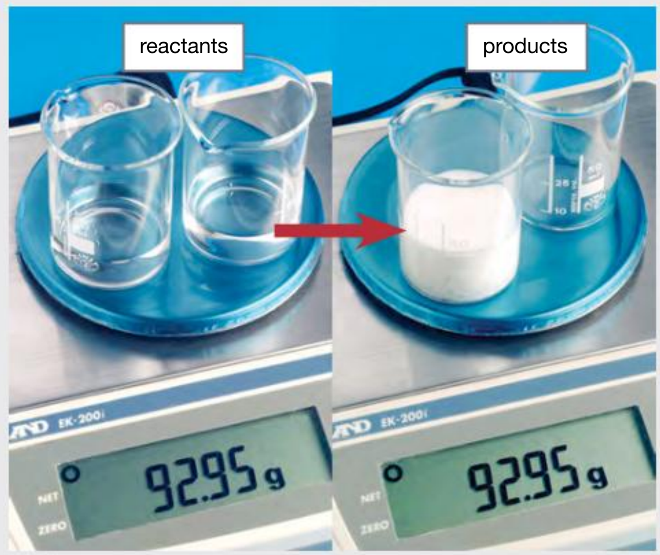


Figure 5.4.1 The total mass of these beakers does not change despite a chemical reaction having taken place. The law of conservation of mass says that the total mass of the reactants and the total mass of the products must be the same.

Law of conservation of mass

The **law of conservation of mass** states that:

During a chemical reaction, atoms cannot be created or destroyed.

In other words, the atoms in the reactants can only rearrange to form the products. This law also means that the mass of the reactants must equal the mass of the products—mass is conserved (doesn't change) in a chemical reaction. You can see this conservation of mass in Figure 5.4.1.

Chemists need to ensure that the chemical equations they write obey the law of conservation of mass. They do this by ensuring that the number of atoms of each element in the products is exactly equal to the number in the reactants. When the numbers of atoms of each element on both sides are equal, the chemical equation is said to be balanced.

Balanced chemical equations

Calcium carbonate ($CaCO_3$) and sulfuric acid (H_2SO_4) react to form calcium sulfate ($CaSO_4$), carbon dioxide gas (CO_2) and water (H_2O). This can be shown as a word equation:

calcium carbonate + sulfuric acid → calcium sulfate + carbon dioxide gas + water

Replacing the chemical names with their chemical formulas produces this formula equation:

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + CO_2 + H_2O$$

The formula equation for the reaction of calcium carbonate with sulfuric acid is balanced—it has the same number of atoms of each element on both sides of the equation. You can easily check this by counting the number of atoms in the reactants and products:

Reactants = 1 × Ca, 1 × C, 7 × O, 2 × H, 1 × S

Products = 1 × Ca, 1 × C, 7 × O, 2 × H, 1 × S

However, not all formula equations automatically balance like this one. For example, when hydrogen gas reacts with oxygen gas, the product is water. The word and formula equations for this reaction are:

hydrogen gas + oxygen gas → water

$$H_2 + O_2 \rightarrow H_2O$$

Counting the number of atoms on both sides of the equation shows that the equation is not balanced:

Reactants = 2 × H, 2 × O

Products = 2 × H, 1 × O

This means that if one molecule of hydrogen reacts with one molecule of oxygen, then an oxygen atom is left over. The equation is unbalanced. This is shown in Figure 5.4.2.

However, if two hydrogen molecules react with one oxygen molecule, then the atoms can rearrange to produce two complete molecules of water. This is shown in Figure 5.4.3. Chemists represent this reaction as the balanced formula equation:

$$2H_2 + O_2 \rightarrow 2H_2O$$

Placing a 2 in front of the chemical formula for hydrogen gas and water indicates that the reaction uses two hydrogen molecules and produces two water molecules.
Re-counting the number of atoms in the reactants and products shows that this equation is now balanced:

Reactants = 4 × H, 2 × O

Products = 4 × H, 2 × O

SciFile

Big burners

The fuel tanks that supply fuel to lift space rockets into orbit do not use petrol. Some use oxygen and hydrogen that react explosively to produce large amounts of energy. This creates the enormous plume of exhaust gases that exit from the rocket motors.

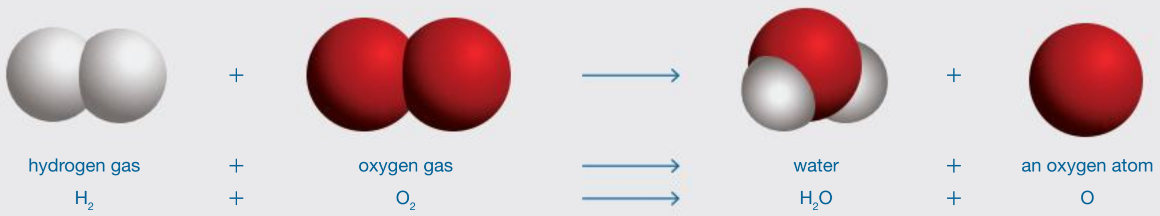


Figure 5.4.2 A single hydrogen molecule will not react with a single oxygen molecule because there would be an extra oxygen atom left over.

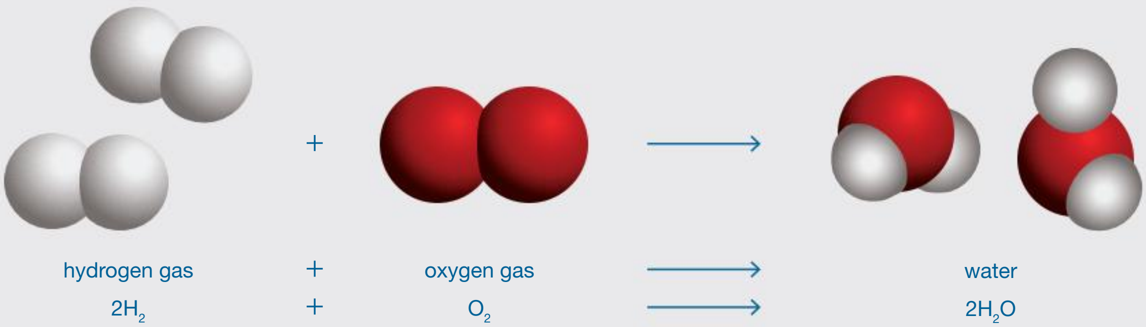


Figure 5.4.3 It takes two hydrogen molecules for each oxygen molecule, and this produces two water molecules.

Consider another chemical reaction in which calcium metal (Ca) reacts with oxygen gas (O_2) to produce solid calcium oxide (CaO). The reactants in this reaction are calcium and oxygen gas. The only product is calcium oxide. Therefore, the general equation:

$$\text{reactants} \rightarrow \text{products}$$

becomes the word equation:

$$\text{calcium} + \text{oxygen gas} \rightarrow \text{calcium oxide}$$

Replacing the chemical names with their formulas gives the formula equation:

$$Ca + O_2 \rightarrow CaO$$

Checking the atoms of each element on both sides shows that the equation is unbalanced:

Reactants $= 1 \times Ca, 2 \times O$

Products $= 1 \times Ca, 1 \times O$

However, it will be balanced if two calcium atoms react with one oxygen molecule to produce two formula units of CaO. So the final balanced equation can be written as:

$$2Ca + O_2 \rightarrow 2CaO$$

SciFile: In the limelight

Solid calcium oxide (CaO) is also known as lime or quicklime. When it is heated to 2500°C it begins to glow with an extremely bright light. For this reason, it was used in theatres for lighting before the invention of the electric light and is the origin of the term 'in the limelight'.

Figure 5.4.4 Lime or quicklime burns brightly.

SKILL BUILDER: Balancing equations

Balancing chemical equations can be tricky, but if you follow some simple steps you should arrive at the right answer. Let's look at the reaction between potassium carbonate (K_2CO_3) and nitric acid (HNO_3), which produces potassium nitrate (KNO_3), water (H_2O) and carbon dioxide (CO_2).

1. Write the word equation.

   potassium carbonate + nitric acid → potassium nitrate + water + carbon dioxide

2. Write the unbalanced equation by replacing the chemical names with the chemical formula.

   $K_2CO_3 + HNO_3 \rightarrow KNO_3 + H_2O + CO_2$

3. Balance each element one by one.

   Potassium (K): There are two on the left and only one on the right, so put a 2 in front of the potassium nitrate (KNO_3). This is sensible because you cannot destroy atoms—if you start with two, you must end up with two.

   $K_2CO_3 + HNO_3 \rightarrow 2KNO_3 + H_2O + CO_2$

   Carbon (C): There is one on the left and one on the right, so you don't need to change these.

   Oxygen (O): There are six on the left (three from the K_2CO_3 and three from the HNO_3). However, there are nine on the right:

   - 1 from the H_2O
   - 2 from the CO_2
   - 6 from the $2KNO_3$

   Putting a 2 in front of the HNO_3 solves the problem:

   $K_2CO_3 + 2HNO_3 \rightarrow 2KNO_3 + H_2O + CO_2$

   Now everything balances. (Note that, when trying to balance by adding numbers, this adds multiple lots of everything in the chemical formula. For example, adding a 2 in front of the K_2CO_3 would also balance the oxygen atoms but it would unbalance the potassium and carbon atoms.)

   Hydrogen (H): There are now two on the left and two on the right, so this balances.

   Nitrogen (N): There are now two on the left and two on the right, so this balances.

4. Double-check the numbers of atoms on both sides of the equation.

   Reactants $= 2 \times K, 1 \times C, 9 \times O, 2 \times H, 2 \times N$

   Products $= 2 \times K, 1 \times C, 9 \times O, 2 \times H, 2 \times N$

   The equation is now balanced.

WORKED EXAMPLE
Balancing equations

Problem 1

Construct a balanced chemical equation for the combustion of propane (C_3H_8) in oxygen (O_2) to produce carbon dioxide (CO_2) and water (H_2O).

Solution

Step 1: Write the word equation.

propane + oxygen → carbon dioxide + water

Step 2: Replace the chemical names with their chemical formulas to get the formula equation.

$$C_3H_8 + O_2 \rightarrow CO_2 + H_2O$$

Step 3: Balance the number of carbon atoms. There are three in the reactants so multiply the CO_2 by 3 to have three in the products.

$$C_3H_8 + O_2 \rightarrow 3CO_2 + H_2O$$

Step 4: Balance the number of hydrogen atoms. There are eight in the reactants so multiply the H_2O by four to have eight in the products.

$$C_3H_8 + O_2 \rightarrow 3CO_2 + 4H_2O$$

Step 5: Balance the number of oxygen atoms. There are 10 in the products (six from the $3CO_2$ and four from the $4H_2O$) so multiply the O_2 by 5 to have 10 in the reactants.

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

Step 6: Double check that the number of atoms is the same on both sides of the equation.

Reactants = 3 × C, 8 × H, 10 × O

Products = 3 × C, 8 × H, 10 × O

The equation is balanced.

Problem 2

Construct a balanced chemical equation for the corrosion of aluminium (Al) in oxygen gas to form aluminium oxide (Al_2O_3).

Solution

Step 1: Write the word equation.

aluminium + oxygen gas → aluminium oxide

Step 2: Replace the chemical names with their chemical formulas to get the formula equation.

$$Al + O_2 \rightarrow Al_2O_3$$

Step 3: Balance the number of aluminium atoms. There are two in the products so multiply the Al in the reactants by 2 to get two.

$$2Al + O_2 \rightarrow Al_2O_3$$

Step 4: Balance the number of oxygen atoms. There are three in the products so multiply the O_2 in the reactants by 1.5 to get three.

$$2Al + 1.5O_2 \rightarrow Al_2O_3$$

Step 5: Check that the number of atoms is the same on both sides of the equation.

Reactants = 2 × Al, 3 × O

Products = 2 × Al, 3 × O

The equation is balanced. However, 1.5 oxygen molecules makes no sense.

Step 6: Multiply everything by 2.

$$4Al + 3O_2 \rightarrow 2Al_2O_3$$

Step 7: Double-check that the equation is still balanced.

Reactants = 4 × Al, 6 × O

Products = 4 × Al, 6 × O

The equation is balanced.

Practice

N

Construct a balanced formula equation for the following reactions.

1 Methane (CH_4) burns in oxygen gas (O_2) to produce carbon dioxide (CO_2) and water vapour (H_2O).

2 Calcium carbonate ($CaCO_3$) dissolves in hydrochloric acid (HCl) forming a solution of calcium chloride ($CaCl_2$), carbon dioxide (CO_2) and water (H_2O).

Prac 1 p196

Prac 2 p197

5.7

5.4 Unit review

Remembering

1 **State** the general name given to the chemicals that:
- a take part in a chemical reaction
- b are produced by a chemical reaction.

2 **State** what → means in chemical equations.

3 **State** the law of conservation of mass.

4 **Recall** the chemical formula for each of these substances.
- a carbon dioxide
- b sulfuric acid
- c hydrogen gas
- d potassium carbonate
- e calcium

Understanding

5 **Explain** how the law of conservation of mass applies to chemical equations.

6 Consider the formula $2CH_4$ and **explain** what the numbers 2 and 4 mean.

Applying

7 **Use** word equations to **describe** the following reactions.
- a When copper is added to dilute nitric acid, copper nitrate, nitrogen monoxide and water are formed.
- b When sulfuric acid is poured onto solid sodium carbonate, bubbles of carbon dioxide are produced, as well as water and sodium sulfate in solution.
- c Magnesium burns easily in oxygen gas, producing magnesium oxide.
- d When sodium metal is placed in water, it reacts to produce sodium hydroxide and hydrogen gas.

8 **Identify** the equation that is *not* balanced. N
- A $4Al + 3O_2 \rightarrow 2Al_2O_3$
- B $Mg + 2HCl \rightarrow MgCl_2 + H_2$
- C $2Zn + O_2 \rightarrow 2ZnO$
- D $C_5H_{12} + 8O_2 \rightarrow CO_2 + 6H_2O$

Analysing

9 **Analyse** the following equations and **modify** them to make them balanced. N
- a $P_4 + O_2 \rightarrow P_2O_5$
- b $KClO_3 \rightarrow KCl + O_2$
- c $BaO + HNO_3 \rightarrow Ba(NO_3)_2 + H_2O$
- d $Pb_3O_4 \rightarrow PbO + O_2$
- e $Pb(NO_3)_2 \rightarrow PbO + NO_2 + O_2$

Evaluating CCT

10 Jessica heated some blue copper(II) nitrate crystals ($Cu(NO_3)_2$) in a test-tube. She noticed that brown nitrogen dioxide gas (NO_2) was produced. When a glowing splint was held at the top of the test-tube, it relit, proving that oxygen gas (O_2) was also produced. A fine black solid, copper(II) oxide (CuO), was left in the test-tube.
- a **Determine** the reactants and products of the reaction.
- b **Deduce** the word equation for this reaction.
- c **Deduce** the formula equation for this reaction.
- d **Modify** the formula reaction in part c to balance it.

11 David added dilute hydrochloric acid to solid calcium carbonate in a beaker. When he weighed the beaker after the bubbling had stopped, he noticed a reduction in mass. **Propose** why his results did not appear to agree with the law of conservation of mass.

Creating CCT

12 Photosynthesis is a series of reactions that eventually makes glucose ($C_6H_{12}O_6$). The reaction can be summarised as:

carbon dioxide + water → glucose + oxygen gas

Construct a balanced formula equation for photosynthesis.

13 Juan burns different masses of magnesium metal (Mg) with oxygen (O_2) to form magnesium oxide (MgO). He measures the mass of the reactants and product before and after, as shown in the table.

Mass of magnesium reacting (g)	Mass of oxygen reacting (g)	Mass of magnesium oxide produced (g)
2.00	0.70	2.70
3.00	1.04	4.04
4.00	1.39	5.39

- a **Construct** a word equation for this reaction.
- b **Construct** a balanced chemical equation.
- c **Explain** how the above results demonstrate the law of conservation of mass.

Inquiring

Research Dalton's atomic model to discover his five key ideas describing atoms, elements, compounds and chemical reactions.

Present your research as a table or poster illustrating each of the components of the model.

ADDITIONAL

5.4 Practical investigations

1 Reactions with modelling clay

Purpose

To simulate the conservation of mass in chemical reactions using modelling clay models.

Materials

- 3 different colours of modelling clay
- atomic model kit

Procedure

1 Use the atomic model kit to make models of methane (CH_4), oxygen (O_2) and ethane (C_2H_6).

2 Use the modelling clay to create models of the three molecules. Your models should be spheres stuck together to simulate chemical bonds.

3 Without adding, subtracting or splitting any modelling clay atoms, try to simulate how the atoms rearrange according to the unbalanced chemical reaction for burning methane in air:

methane + oxygen gas → carbon dioxide + water

$CH_4 + O_2 \rightarrow CO_2 + H_2O$

4 Construct one methane molecule and two oxygen molecules and simulate the balanced chemical reaction:

methane + oxygen gas → carbon dioxide + water

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

5 Perform the same simulation for the combustion of ethane (C_2H_6) in oxygen by first simulating the unbalanced equation:

ethane + oxygen gas → carbon dioxide + water

$C_2H_6 + O_2 \rightarrow CO_2 + H_2O$

6 Simulate the balanced equation with the plasticine models:

ethane + oxygen gas → carbon dioxide + water

$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$

Practical review

1 **Describe** what happened when you tried to simulate the unbalanced reactions, listing any excess atoms and those you did not have enough of.

2 **Explain** how a balanced equation gives an accurate description of what is going on during a chemical reaction.

2 Conservation of mass

Purpose

To investigate conservation of mass in a chemical reaction.

Hypothesis

What do you think will happen to the total mass of substances before and after a precipitation reaction—will the masses be the same or different? Before you go any further with this investigation, write a hypothesis in your workbook.

Materials

- 20 mL barium nitrate ($BaNO_3$) solution
- 20 mL of sodium sulfate ($NaSO_4$) solution
- 2 × 50 mL beakers
- access to an electronic balance

SAFETY

Barium nitrate solution is toxic, so avoid contact with eyes, skin and mouth. Wear safety glasses, protective clothing and gloves.

Procedure

1. Copy the table in the Results section into your workbook.
2. Pour approximately 20 mL of barium nitrate into one beaker and approximately 20 mL of sodium sulfate into the other.
3. Measure the weight of each beaker and record your results in your results table.
4. Pour the barium nitrate in beaker 1 into beaker 2.
5. Remeasure the weight of each beaker and record your results.

Results

Calculate the total mass before and after the reaction and add these to your table.

	Beaker 1	Beaker 2	Total
Mass before reaction (g)			
Mass after reaction (g)			

Practical review

1. **Describe** what happened when the two solutions were mixed.
2. The products of this reaction are solid barium sulfate and a sodium nitrate solution. From this information, **construct** a word equation and balanced formula equation for this reaction.
3. **Assess** whether your results agree with the law of conservation of mass. **Explain** your assessment.
4. a **Construct** a conclusion for your investigation.
   b **Assess** whether your hypothesis was supported or not.

5 Chapter review

Remembering

1 **List** five different types of chemical reaction.

2 **Name** the gas given off when calcium carbonate undergoes thermal decomposition.

3 **List** five ways in which the speed of a chemical reaction can be controlled.

Understanding

4 **Define** the term *rate of reaction*. L

5 **Explain** why burning of magnesium metal is considered to be combustion but rusting of iron is considered to be corrosion.

6 **Describe** what happens during a neutralisation reaction. L

7 **Discuss** why it is useful to classify reactions into different types.

8 **Predict** the products of the following reactions
- a Hydrochloric acid (HCl) reacts with sodium hydroxide (NaOH)
- b Nitric acid (HNO_3) reacts with magnesium metal (Mg)
- c Sulfuric acid (H_2SO_4) reacts with sodium carbonate (Na_2CO_3)

Applying

9 Calcium forms the ion Ca^{2+} and chlorine forms the chloride ion, Cl^-. **Identify** the correct ionic formula for calcium chloride.
- A CaCl
- B Ca_2Cl
- C $CaCl_2$
- D Ca_2Cl

10 a **Identify** types of ionic compounds that are almost always soluble.
- b **List** any exceptions.

11 **Identify** two reactions that should be slowed down and how they are slowed down.

12 **Use** word equations to **describe** the following reactions.
- a A container of hydrogen peroxide is sitting in the sun. Bubbles of oxygen gas and hydrogen gas are forming in the bottle.
- b When lithium hydrogen carbonate is heated, carbon dioxide and water vapour is released. Only lithium carbonate remains behind.
- c A solid white precipitate of barium sulfate is produced when sodium sulfate is mixed with a barium chloride solution.
- d Hydrogen gas bubbles off when nitric acid is poured on some copper. After the reaction, all that remained was a solution of copper nitrate.

Analysing

13 **Classify** each of the following reactions as decomposition, combustion or precipitation.
- a barium nitrate solution + sodium sulfate solution → barium sulfate solid + sodium nitrate solution
- b Magnesium carbonate is heated to produce magnesium oxide and carbon dioxide.
- c methane + oxygen → carbon dioxide + water

Evaluating CCT

14 Karen is observing a reaction in a test-tube and notices condensation on the outside of the test-tube.
- a **Evaluate** whether the reaction is likely to be an exothermic or endothermic reaction.
- b **Justify** your answer.

15 Refer to the solubility rules in Table 5.2.2 on page 171. **Assess** which of the following substances would be soluble in water.
- a $BaSO_4$
- b $LiNO_3$
- c $CaCO_3$
- d $MgCl_2$

16 Hydrogen peroxide breaks up slowly by itself to form oxygen and water. When some manganese(IV) oxide (MnO_2) is added to it, there is a sudden increase in the production of oxygen gas. However, none of the manganese(IV) oxide seems to be used up in the reaction. **Propose** why the manganese(IV) oxide has this effect.

17 a **Determine** whether you can or cannot answer the questions on page 157 at the start of this chapter.
- b **Use** this to **assess** how well you understand the material presented in this chapter.

Creating CCT

18 **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter.

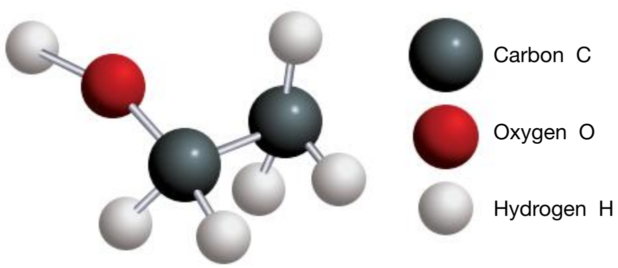
acid/base	catalyst
chemical reaction	combustion
neutralisation	oxygen gas
precipitation	rate
temperature	ions

5.8

Thinking scientifically

Q1 Scientists use molecular formulas as short-hand notation for describing the structure of molecules. The formulas can be used to communicate which types of atom are in the molecule and how many of each type there are. For example, the chemical formula for water, H_2O, says that in every water molecule there are two hydrogen atoms and one oxygen atom. CCT

Shown here is a molecule of the compound ethanol. Which of the following molecular formulas best describes this molecule?



A C_2H_4O
B C_2H_5O
C C_2H_6O
D $C_2H_4O_2$

Q2 The law of conservation of mass states that during a chemical reaction, atoms cannot be created or destroyed. From this law, it follows that during a chemical reaction, the total mass of the reactants and products: CCT

A always increases
B always decreases
C may increase or decrease
D always stays the same.

Q3 The term *solubility* is used to describe how well a compound dissolves. A compound that dissolves well is referred to as soluble, while a compound that does not dissolve is referred to as insoluble. Scientists use solubility tables like the one in the next column to predict whether a compound will be soluble or insoluble in water. CCT

Type of compound	Solubility	Exceptions
Nitrates NO_3^-	Soluble	None
Chlorides Cl^- Bromides Br^- Iodide I^-	Soluble	Ag^+, Hg^+, Pb^{2+}
Sulfates SO_4^{2-}	Soluble	Ca^{2+}, Ba^{2+}, Pb^{2+}, Ag^+
Carbonates CO_3^{2-}	Insoluble	Li^+, Na^+, K^+, NH_3^+
Phosphates PO_4^{3-}	Insoluble	Li^+, Na^+, K^+, NH_3^+

Use this solubility table to determine which of the following compounds is insoluble.

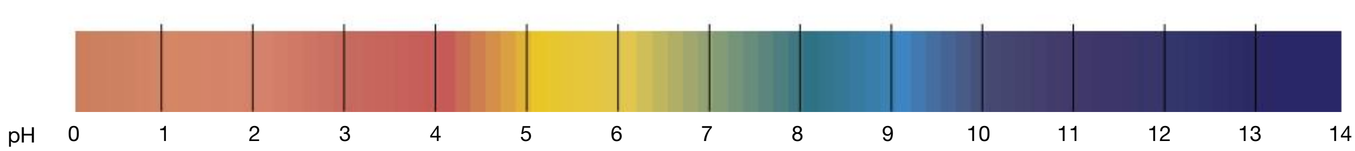
A $NaNO_3$
B $MgCl_2$
C K_2CO_3
D $PbSO_4$

Q4 Scientists use the pH scale (shown below) to measure the concentration of acids and bases and alkaline solutions. The pH scale ranges from 0 to 14. Substances with a pH less than 7 are acidic, and substances with a pH greater than 7 are basic/alkaline. CCT

The pH of a substance can be measured by an indicator. An indicator is a chemical that changes colour depending on the pH. Indicators change colour because they react with the acid or base. Universal indicator is made up of a combination of several of these chemicals so that it changes colour many times as the pH changes from 0 to 14. Below is a chart that shows the colour of universal indicator over the full pH range.

Lemon juice has pH 2.3. It is most likely to turn universal indicator:

A red-orange
B yellow
C yellow-green
D green.



Thinking scientifically

Q5 Michelle performed five experiments to see how different factors influence how quickly hydrochloric acid reacts with blackboard chalk. CCT

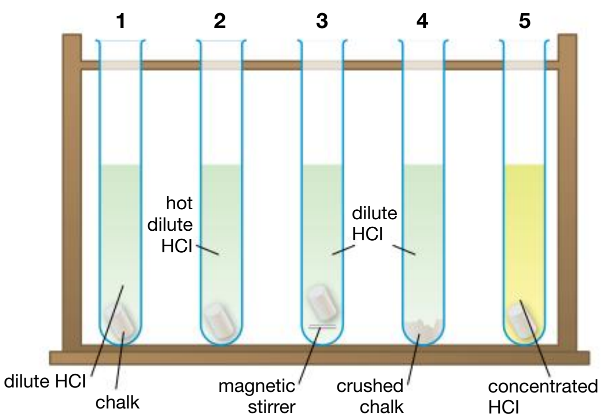
Experiment 1: 1 cm of chalk in dilute hydrochloric acid at room temperature

Experiment 2: 1 cm of chalk in dilute hydrochloric acid heated to 80°C

Experiment 3: 1 cm of chalk in dilute hydrochloric acid with a magnetic stirrer

Experiment 4: 1 cm of chalk crushed and put in dilute hydrochloric acid

Experiment 5: 1 cm of chalk in concentrated hydrochloric acid



In each case, Michelle collected and measured the volume of carbon dioxide gas (CO_2) produced in 5 minutes. Her results are tabulated below.

Experiment	Volume of CO_2 produced (mL)
1	5
2	10
3	30
4	50
5	10

From her data, Michelle can conclude that:

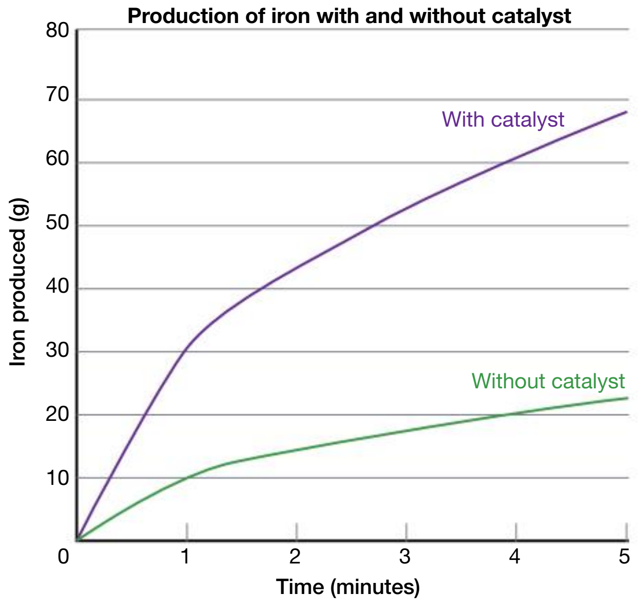
A increasing the temperature had no affect on the rate of reaction

B increasing the concentration of the acid increased the rate of reaction more than stirring the reaction

C stirring increased the rate of reaction the most

D crushing the chalk increased the rate of reaction the most.

Q6 Wasim is developing a new chemical reaction for converting iron ore into iron metal. He wants to determine how adding a catalyst changes the rate of reaction. To do this, Wasim measures the amount of iron metal produced by the chemical reaction every minute for the first 5 minutes. He has plotted the results in the graph below. CCT



From his graph, Wasim can conclude that the catalyst:

A has no effect on the rate of reaction

B halves the rate of reaction

C doubles the rate of reaction

D triples the rate of reaction.

Glossary

Unit 5.1

Activity series: a table that orders metals from most reactive to least reactive

Balanced: describes a chemical equation that has the same number of atoms of each element on both sides of the equation

Chemical equation: a short-hand notation that scientists use to communicate what happens during a chemical reaction

Corrosion: a chemical reaction in which a metal reacts with oxygen to produce a metal oxide but does not produce significant amounts of heat and light

Combustion

Combustion: a chemical reaction in which a substance burns in oxygen gas to produce light and heat

Endothermic: describes a physical or chemical process that absorbs energy in the form of heat and light

Exothermic: describes a physical or chemical process that produces energy in the form of heat and light

Formula equation: a chemical equation in which the reactants and products are identified by their chemical formulas

Hydrocarbons: all substances made up of just hydrogen and carbon atoms; hydrocarbons are commonly used as fuels

Incomplete combustion: combustion that occurs in a limited supply of oxygen

Product: a substance produced by a chemical reaction

Reactant: the initial substance of a chemical reaction

Reactivity: the property of a substance that describes how easily it undergoes chemical reaction, usually with common substances such as oxygen, water and acids

Respiration: an exothermic chemical reaction that takes place in the cells of living things. It is the reaction between sugar and oxygen to produce carbon dioxide and water. The energy produced by the reaction is used by the organism to live, move and grow

Word equation: a chemical equation in which the reactants and products are identified by their chemical names

Unit 5.2

Acid: a substance that produces hydrogen ions (H^+) when dissolved in water

Alkaline: describes the solution made when a base is dissolved

Anion: a negatively charged ion

Base: a substance that produces hydroxide ions (OH^-) when dissolved in water

Cation: a positively charged ion

Caustic: the term given to corrosive bases

Combination reaction: occurs when two reactants combine to form a single product

Decomposition reaction: a chemical reaction in which one reactant breaks apart into two or more products

Neutral: neither acidic or basic

Insoluble: does not dissolve

Precipitation reaction

Ion: an atom that has gained or lost electrons to become electrically charged

Ionic compound: a substance made up of positive and negative ions

Polyatomic: having many atoms

Precipitate: the insoluble product of a precipitation reaction

Precipitation reaction: when two clear solutions react to produce an insoluble solid

Salt: ionic compounds formed by the chemical reaction of an acid with another element or compound.

Soluble: able to dissolve

Unit 5.3

Agitation

Agitation: stirring

Catalyst: a chemical that helps to speed up a chemical reaction but is not used up during the reaction

Concentration: the amount of a chemical in a certain volume of water

Enzyme: a natural occurring catalyst

Rate of reaction: how fast a chemical reaction proceeds

Unit 5.4

Law of conservation of mass: the law that states that atoms cannot be created or destroyed during a chemical reaction

6 Global systems

Have you ever wondered...

- what happens to dead plants and animals in nature?
- why the weather is not the same every year?
- how climate and weather are different?
- why Australia gets droughts and floods
- why there is so much concern about burning fossil fuels?
- why some people are worried about climate change?

After completing this chapter students should be able to:

- outline how matter such as nitrogen is cycled through ecosystems
- outline how global systems rely on interactions involving the biosphere, lithosphere, hydrosphere and atmosphere
- describe impacts of natural events on Earth's spheres, including earthquakes, volcanoes and cyclones CCT L
- evaluate scientific evidence of some current issues affecting society that are the result of human activity on global systems CCT EU PSC S
- discuss the reasons different groups in society may use or weight criteria differently or evaluate claims, explanations or predictions in making decisions about contemporary issues involving interactions of Earth's spheres CCT EU PSC

ADDITIONAL

- examine factors that drive deep ocean currents and their role in regulating climate and their effect on marine life
- research evidence relating global warming to changes in weather patterns, including El Niño and La Niña CCT S
- research how computer modelling has improved knowledge and predictability of phenomena such as climate change ICT
- discuss the development and implications of international agreements such as the 1997 Kyoto Protocol and the 2009 United Nations Climate Change Conference. EU S

6.1 Earth's spheres

Natural events such as earthquakes, volcanic eruptions and tropical cyclones influence Earth's atmosphere, landforms and oceans in different ways. More subtle changes are happening as nitrogen, carbon and water are recycled, forming different compounds at different times.

The biosphere

The **biosphere** includes all parts of the Earth's surface and atmosphere where living things exist. It is the sum of all Earth's ecosystems. The biosphere is where other spheres of the planet interact:

- The land (**lithosphere**) interacts with the water (**hydrosphere**).
- The land interacts with the air (**atmosphere**).
- Living things interact with the land, water and air.

Natural changes

Major natural events such as earthquakes, volcanic eruptions and tropical cyclones have shaped Earth. These natural events influence the atmosphere, lithosphere and hydrosphere. They also cause the different spheres to interact in different ways.

Earthquakes

Depending on their severity, earthquakes may cause parts of the lithosphere to move apart, move together, rise or subside (drop). This movement may cause large cracks to appear or land to increase in height. The movement may cause landslides or mudslides. Landslides and mudslides tear down forests and any other vegetation in their path. The destruction of ecosystems causes the habitats of many animals to be lost.

During the Christchurch earthquakes of 2011, the shaking of the ground caused liquefaction. **Liquefaction** occurs when saturated, sandy soils lose their structure and behave as a liquid. The process is illustrated in Figure 6.1.1.

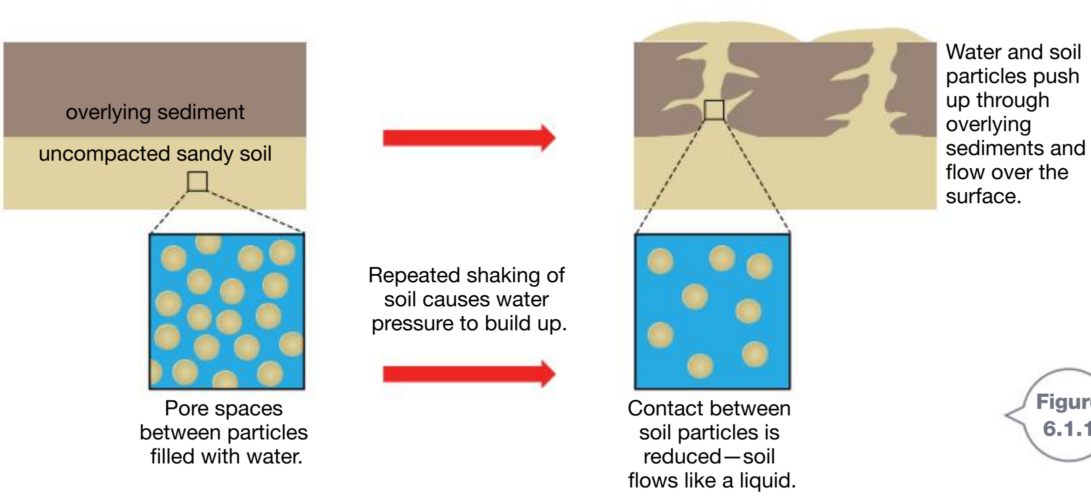


Figure 6.1.1 The pressure of an earthquake can cause saturated soil to behave as a liquid, which can push through to the surface and flow over it.

In saturated soils, water fills the pores (spaces) between the particles. When an earthquake compresses the soil, it puts the water in it under pressure. This pressure can squeeze the water out from between the soil particles. Large quantities of water and soil particles bubble up through the layers and flow over the surface like a liquid. When the shaking from the earthquake stops, pressure is released and the soil becomes solid again. Anything caught in the liquid is trapped when the soil solidifies once more. This is what has happened to the car in Figure 6.1.2.

Earthquakes have little effect on the atmosphere. However, they can have significant effects on the hydrosphere. Earthquakes out to sea may cause tsunamis, such as those that inundated (flooded) parts of South-East Asia on Boxing Day in 2004 and Japan in 2011. Earthquakes on land can:

- change the course of rivers
- cause landslides and rock falls that block rivers creating new lakes
- destroy dams, releasing large amounts of water in a huge flood down the valley.

Volcanic eruptions

Volcanic eruptions change the atmosphere in ways that have both short- and long-term effects.

Volcanic eruptions that send large ash clouds up into the atmosphere can produce very heavy rain and spectacular lightning, as seen in Figure 6.1.3. The rain occurs because the ash particles allow water vapour to condense around them and form rain droplets. The probable cause of the lightning is the collision of ash and air particles that become charged and are then forced apart. Some areas of the atmosphere become negatively charged while others areas become positively charged. When the difference in charge and the voltage it creates becomes high enough, a flow of electric charge occurs. That flow is seen as lightning.

Figure 6.1.2 When the shaking of the earthquake stops, pressure on the liquefied soil is released and the soil becomes solid again.

In the longer term, clouds of ash in the atmosphere from a volcanic eruption reduce the amount of sunlight reaching the surface of Earth. This has a cooling effect in subsequent years. The April 1815 eruption of Mt Tambora (Indonesia) ejected 160 km^3 of rock fragments into the atmosphere. In the northern hemisphere 1816 became known as the 'year without summer', when colder than average temperatures led to crop failures and the death of livestock.

A similar effect followed the 1883 eruption of Krakatau (Indonesia). In the following year the average global temperature fell by 1.2°C and did not return to normal for five years. The explosion of Krakatau sent large amounts of sulfur dioxide (SO_2) into the atmosphere. This later reacted with water in the atmosphere and came back down as acid rain (sulfurous acid H_2SO_3).

GO TO Pearson science NSW 9 Unit 2.2

Figure 6.1.3 Rapidly rising ash clouds from a volcano lead to spectacular lightning displays.

Explosive volcanic eruptions such as Krakatau cause mountains and islands to disappear. Volcanoes can also create mountains and islands. The islands of Hawaii are formed by a build up of lava, as are the island chains of Indonesia, the Galapagos Islands and Japan. In 1963 sailors saw a plume of smoke and ash rising from the sea off Iceland. It was evidence of an undersea volcanic eruption. The next day the build up of lava broke the surface and was visible as a new island. You can see it in Figure 6.1.4.

GO TO Pearson science NSW 9 Unit 9.3

Figure 6.1.4 The new island that appeared of the coast of Iceland was named Surtsey, after the Norse god of fire. It is 500 metres in length with a height of 45 metres.

Lava from volcanic eruptions burns the plants and animals in its path. The new land formed by the lava is too hot for any living thing to survive and it may be many years before the lava is cool enough for seeds and spores to start germinating.

Toxic gases and ash produced by volcanoes suffocate animals and can smother plants, making their survival unlikely.

Tropical cyclones

Tropical cyclones are caused by intense low pressure atmospheric systems that develop in the warm tropics when the sea surface temperature is above 26.5°C. Evaporation above the warm water causes clouds to form, and the low air pressure causes the clouds to spiral upwards forming very large, very high clouds. These spirals can become very destructive. Tropical cyclones produce very heavy rain and wind speeds of 63 km/h to more than 200 km/h. Figure 6.1.5 illustrates the mass of spiralling cloud associated with a cyclone.

Figure 6.1.5 A satellite view of the spiralling clouds of a tropical cyclone. The dark area in the centre is the eye of the cyclone.

Heavy rainfall associated with tropical cyclones continues after the tropical cyclone has moved inland and decayed. The rain causes rivers to flood and the effects extend far beyond the area of the cyclone. For example, the Murray–Darling River system and Cooper Creek begin in Queensland but flow through other states. Rainfall from a tropical cyclone in Queensland flows down these rivers causing floods in regions hundreds of kilometres away.

Storm surges are also associated with tropical cyclones. The wind and low pressure increase the tide level of the sea by 2 to 5 metres. When this surge crosses the coast at the same time as a high tide, low-lying coastal areas such as those in Figure 6.1.6 may be flooded by salt water.

Figure 6.1.6 Storm surges carry salt water on to areas that are normally dry land. They can cause significant erosion.

The torrential rain and floods resulting from tropical cyclones cause erosion of the land and waterways. Sediment carried in the river causes the river mouth to become blocked with silt.

Cyclones uproot trees destroying the habitats for anything that lives on or in them. Animals and plants are washed into flooded rivers.

Recycling in nature

The natural recycling of water and elements such as carbon and nitrogen is a very important interaction between Earth's spheres. Natural recycling enables natural ecosystems to be sustainable (self-renewing). An example is the wetland shown in Figure 6.1.7. **Sustainable ecosystems** are ecosystems that are diverse and provide for the needs of the organisms that live there.

Figure 6.1.7 Wetland ecosystems are important parts of the biosphere. A large variety of organisms live in wetlands or use them as a resource during migration. Many wetlands hold flood waters, removing silt from them before the water flows out to the oceans.

Nitrogen cycle

The **nitrogen cycle** is an important natural cycle for living things, because nitrogen is an important element in proteins. A summary of the nitrogen cycle is shown in Figure 6.1.8.

Air is 78% nitrogen, but most living things cannot use nitrogen when it is in the form of a gas. Plants use nitrogen compounds from the soil. Animals are consumers that obtain their nitrogen by eating plants or other animals.

Some bacteria, such as decomposers and **nitrogen-fixing bacteria**, make nitrogen available to other living things. They do this by converting it into ammonia and then nitrates that plants can use. Other bacteria, known as **denitrifying bacteria**, convert nitrates back into gaseous nitrogen (N_2). This is then released back into the atmosphere.

GO TO Pearson science NSW 9 Unit 8.2

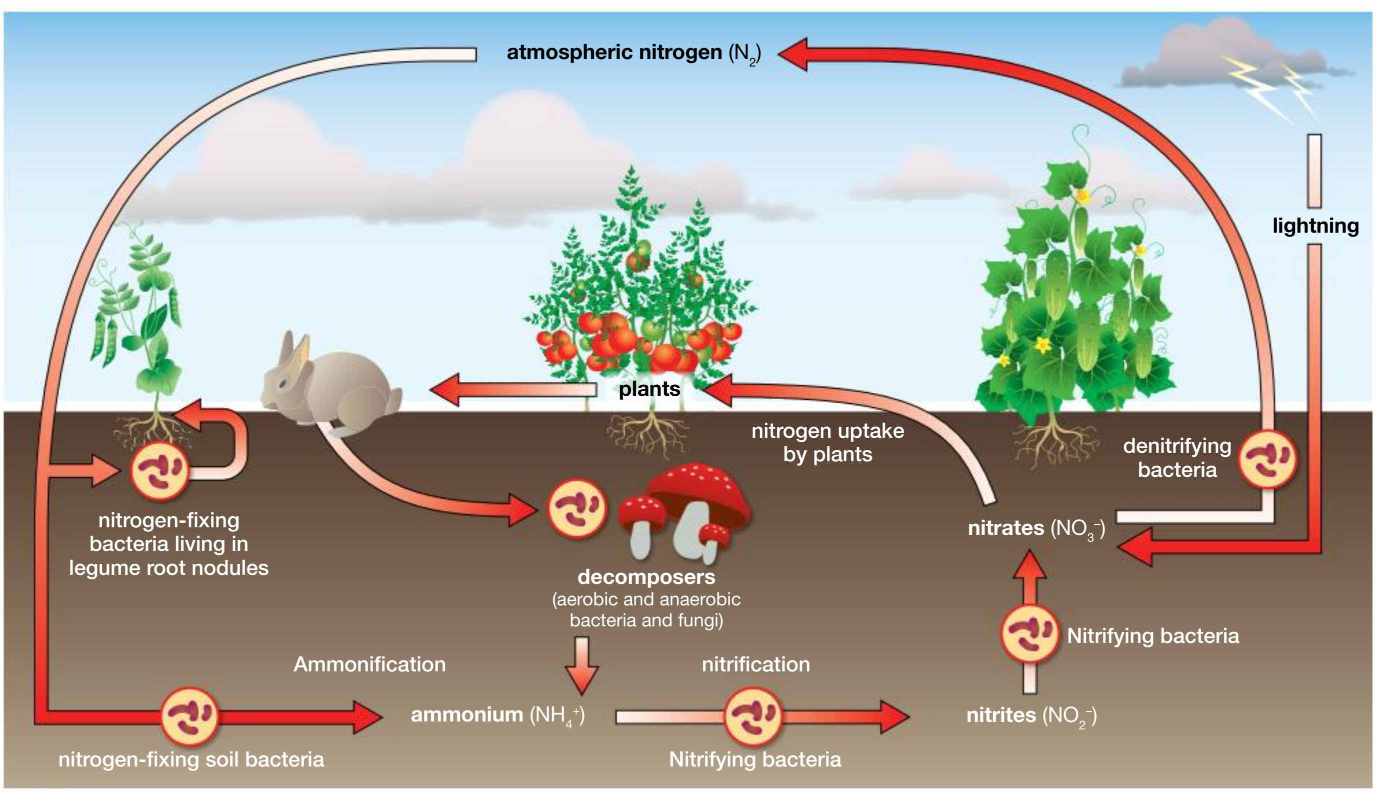


Figure 6.1.8 The nitrogen cycle shows how important different groups of bacteria are in the recycling process. Sometimes the work done by one group of bacteria is undone by another group.

Carbon cycle

The **carbon cycle** is essential for life on Earth. Carbon is found in all living things, and in their dead bodies and wastes. It is part of the carbohydrates, fats, proteins, vitamins and DNA found in cells, tissues and organs. Carbon is also found in the atmosphere as carbon dioxide (CO_2) gas.

Carbon dioxide is used in **photosynthesis** when plants combine it with the hydrogen from water to form glucose. Photosynthesis can be summarised in the following chemical equations:

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{chlorophyll}]{\text{sunlight}} \text{glucose} + \text{oxygen gas}$$

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

Animals and other consumer organisms obtain the carbon they need from the food they eat. However, there is not an endless supply of carbon. Carbon is recycled through the soil, through living things and the atmosphere in the carbon cycle. This is shown in Figure 6.1.9.

As part of this cycle, the process of photosynthesis in green plants incorporates carbon into living things. **Respiration** releases carbon back into the atmosphere and hydrosphere as carbon dioxide, where it becomes available for photosynthesis.

Respiration is described using the chemical equations:

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

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

GO TO Pearson science NSW 9 Unit 2.3

Organisms release carbon into the soil in wastes such as faeces, urine and fallen leaves. These wastes are used as food by decomposer organisms. As the decomposer organisms respire, carbon is released as carbon dioxide back into the atmosphere, water and soil.

Fossils are the preserved remains of once-living organisms. **Fossil fuels** such as coal and oil contain the carbon of plants and animals that died and were preserved millions of years ago. Burning fossil fuels releases carbon that has been unavailable to the carbon cycle for millions of years. Burning wood releases carbon stored for hundreds or maybe even a thousand years. When plenty of oxygen is available, the carbon released into the atmosphere from burning fossil fuels and wood is in the form of carbon dioxide. If oxygen is limited, then the carbon is released as carbon particles (soot) and carbon monoxide gas (CO) instead.

Earth's largest and oldest long-term store of carbon is calcium carbonate ($CaCO_3$). This chemical is found in limestone, a sedimentary rock usually made from the shells of molluscs and other marine organisms.

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6.1

GO TO Unit 2.1

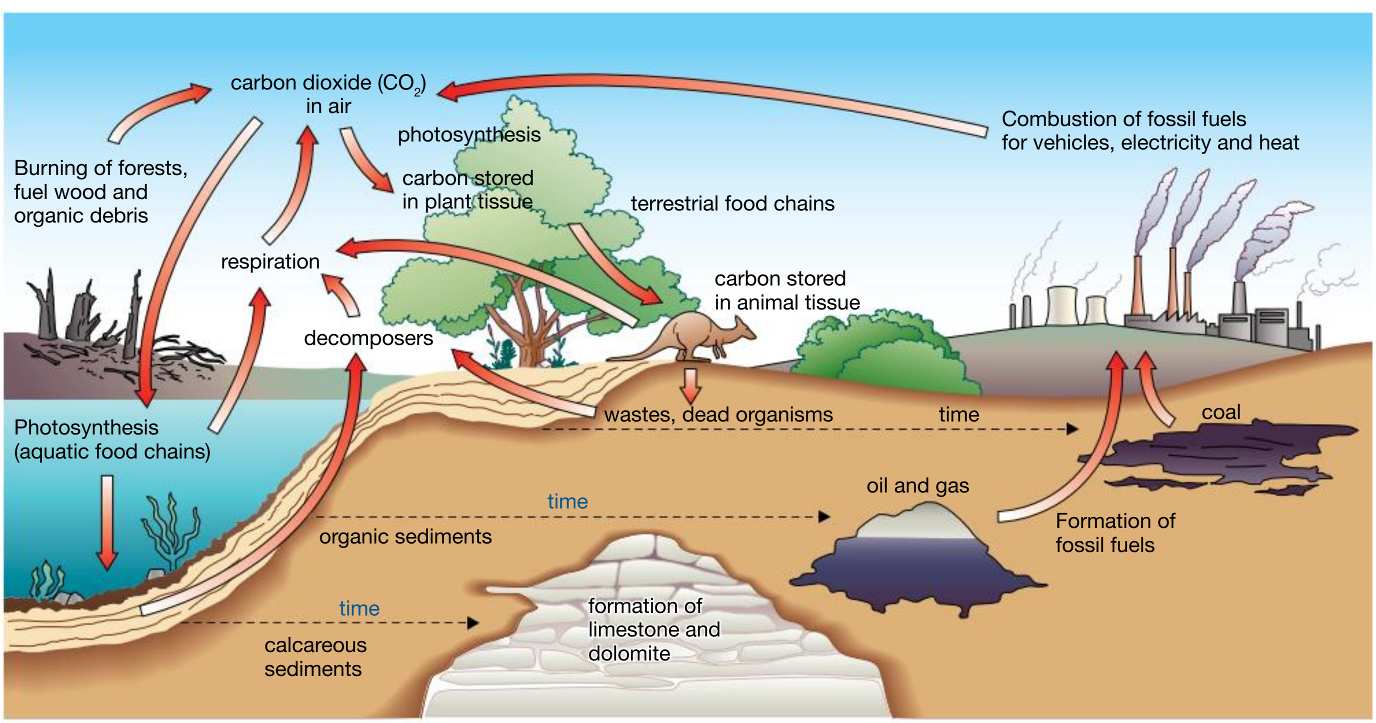


Figure 6.1.9 The carbon cycle moves carbon between the living and non-living parts of ecosystems.

INQUIRY

science 4 fun

Natural recycling

What happens to the leaves and fruit that fall off trees?

YES

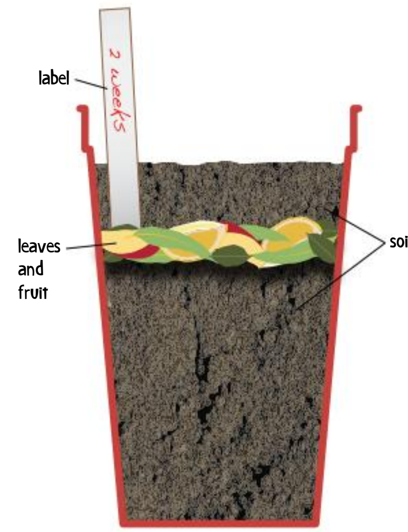
Collect this …

- natural materials such as leaves and fruit
- garden soil
- 4 flower pots (an area of the garden could be used instead of pots)
- icy-pole sticks as labels

SAFETY
Wash your hands thoroughly after working with soil.
Do not inhale dust.

Do this …

1. Divide the materials collected into four identical groups.
2. Fill the four flower pots three-quarters full with garden soil. Alternatively, mark out four small plots in the garden and scrape away about 4 cm of soil.
3. Photograph the fruit and leaves.
4. Place one set of materials in each of the pots and cover them with 4 cm of soil.
5. Label the pots (or plots) ‘1 week’, ‘2 weeks’, ‘3 weeks’, ‘4 weeks’.
6. Ensure that the soil remains moist but not waterlogged.
7. At the end of the relevant time period, clear off the top 4 cm of soil.
8. Photograph the materials to record any changes.



Record this …

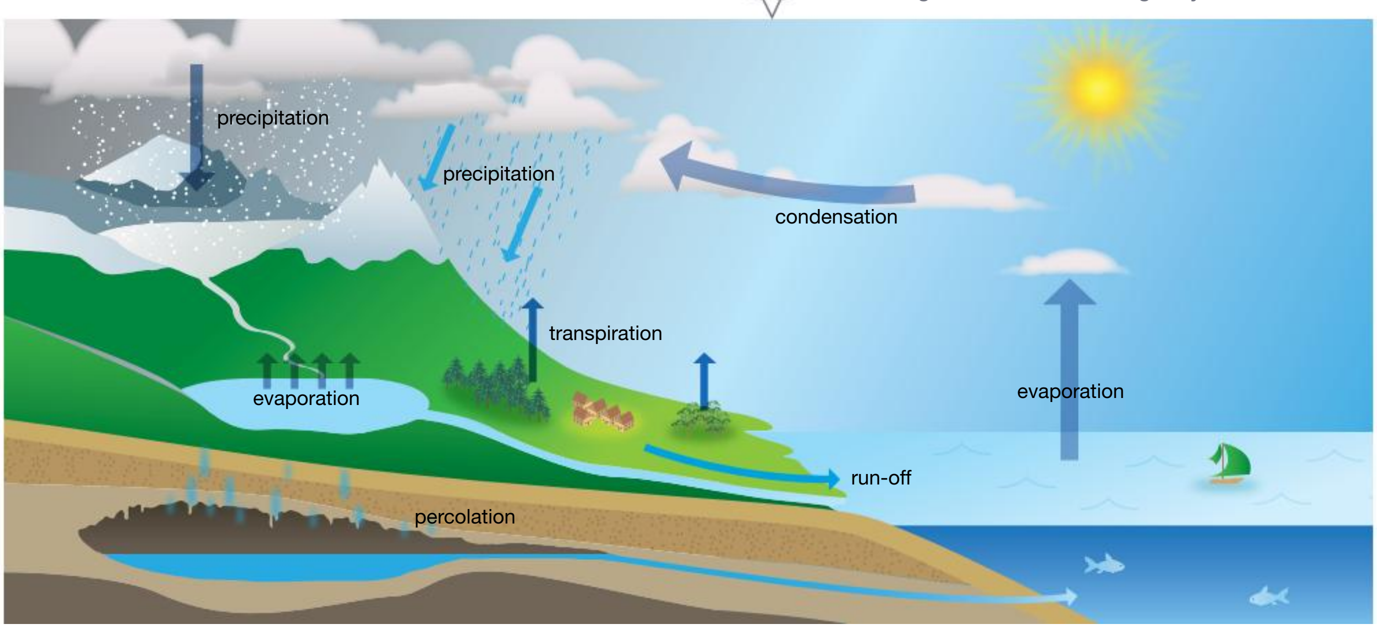
Describe what happened.
Explain why you think this happened.

The water cycle

Water is one of the most precious resources on Earth and is an essential part of all living things.

The water on Earth is recycled continuously in the water cycle. Energy from the Sun causes water to evaporate from moist surfaces such as oceans, soil, plants and animals. The largest amount of water vapour comes from the oceans because they are the largest bodies of water on Earth. The water cycle is summarised in Figure 6.1.10.

Figure 6.1.10 The water cycle describes the endless cycle of water evaporating from Earth’s surface, condensing to form clouds, falling as rain, and the run-off returning it to the oceans it originally came from.



6.1 Unit review

Remembering

1 a **Name** two spheres of the Earth that are affected by:
 i earthquakes
 ii volcanic eruptions.
 b **List** two ways each of these spheres is affected.

2 **Name** the process that takes carbon into food chains.

3 a **Name** the compound in which carbon is found in the atmosphere.
 b **State** its chemical formula.

Understanding

4 **Describe** these Earth's spheres:
 a biosphere
 b lithosphere
 c hydrosphere
 d atmosphere

5 **Define** these terms.
 a sustainable ecosystem
 b fossil fuels

6 a Carbon is a major part of all living things. **Explain** how the carbon gets into living things.
 b **Explain** what the carbon is used for in the bodies of living things.

7 **Explain** how decomposers return carbon to the atmosphere.

8 **Explain** how nitrogen from the air is made available to plants.

9 **Explain** where the carbon in coal and oil came from.

10 a **Explain** what is meant by *long-term stores*.
 b **Name** two long-term stores of carbon.
 c **Explain** why these stores of carbon are considered to be long-term stores.

11 **Explain** why plants can suffer from a lack of nitrogen despite being surrounded by air that is 78% nitrogen.

12 **Explain** what is meant by the cartoon in Figure 6.1.11.

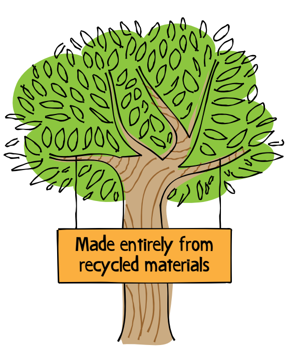


Figure 6.1.11

Applying

13 **Identify** the following chemicals:
 a SO_2
 b $CaCO_3$
 c $C_6H_{12}O_6$
 d H_2SO_3

14 Leaves and fruit eventually 'disappear' in investigations like that in the science4fun on page 208.
 a **Explain** what really happens to them.
 b **Identify** the organisms that cause them to 'disappear'.

15 **Use** a diagram to **demonstrate** how the carbon cycle would change in an area if a forest was replaced by an urban development.

Analysing

16 Nitrogen-fixing bacteria and denitrifying bacteria are both part of the nitrogen cycle. **Contrast** the parts they play.

17 Figure 6.1.12 is a graph of the effect of volcanic ash and other particulate matter in the atmosphere on world temperatures.
 a **Analyse** the graph and **identify** the years in which major volcanic eruptions are most likely to have taken place.
 b **Describe** the features of the graph that you used to make your decision in part **a**.

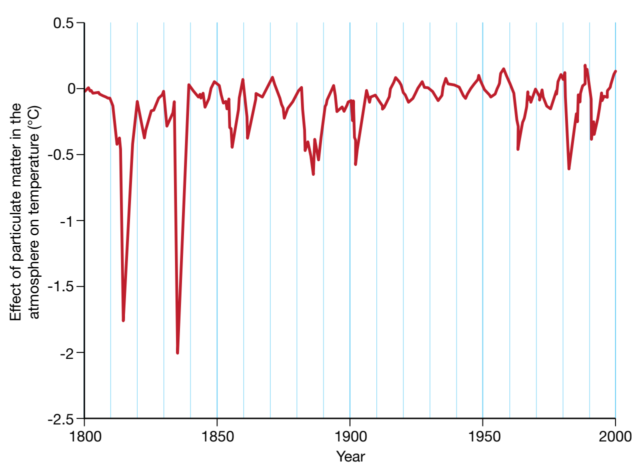


Figure 6.1.12 Effect of particulate matter in the atmosphere on world temperatures

6.1 Unit review

Evaluating CCT

18 Mt Tambora erupted in 1815, Krakatau erupted in 1883 and Mt St Helens erupted in 1981.

a **Use** the graph in Figure 6.1.12 on page 209 to **propose** which of these eruptions ejected the largest amount of ash into the atmosphere.

b **Justify** your response.

Figure 6.1.13 The 1883 eruption of Krakatau destroyed the island. Volcanic activity is rebuilding it.

19 **Propose** reasons why tropical cyclones develop only in the summer months and only in the northern parts of Australia.

20 Grass grows well when it is provided with nitrogen-rich fertiliser. **Deduce** the reason why grass that has been provided with plenty of water appears to grow better after a thunderstorm.

21 During extended periods of dry weather many gullies are dry. When significant rain falls, water flows through these gullies. However, after the rain has stopped, water often remains in these gullies and continues to flow for some time.

a **Deduce** where this water comes from.

b **Use** a diagram to help you **justify** your answer to part **a**.

Creating CCT

22 **Use** information about the processes involved in the nitrogen, carbon and water cycles shown in this unit to **construct** a diagram to show how oxygen cycles in the environment.

Inquiring

1 Research tropical cyclones. Find:

- whether the winds travel clockwise or anticlockwise around the eye
- whether the winds spiral into the eye of a cyclone or out of the eye
- the wind speeds and damage that can be expected from different categories of cyclone
- the highest category of tropical cyclone in Australia
- the names of five cyclones that have hit Australia in the last ten years and the towns that were affected
- the differences (if any) between a cyclone, a hurricane and a typhoon.

Present your findings in digital form. ICT

2 Investigate the research scientists are undertaking into environmental contamination of soil and/or water.

Find:

- what is causing the contamination
- any effect the contamination is having on the cycling of matter
- strategies suggested to overcome the problem.

3 Phosphorus is another element that cycles through ecosystems. Research:

- how plants and animals use phosphorus
- the cycling of phosphorus through ecosystems
- how the phosphorus cycle compares with the cycling of carbon
- why fertilisers contain phosphorus.

Present your results as an illustrated fact sheet for gardeners.

4 Coal mining is a major industry in NSW. Research any impacts that coal mining has on the environment, particularly on Earth's four spheres (atmosphere, hydrosphere, lithosphere and biosphere).

Present your findings as an environmental impact report.

5 Research the eruption of either Mt Tambora or Krakatau.

- Construct a timeline of the events leading up to the eruption (such as earthquakes and smaller eruptions) and during the eruption.
- Describe the effects of the eruption on the biosphere.
- Identify which of Earth's spheres were influenced by each effect.

Present your findings as a digital slideshow. ICT

6.1 Practical investigations

1 Carbon cycle game

Purpose

To simulate the carbon cycle.

Materials

- 5 containers labelled 'Plant', 'Animal', 'Decomposer', 'Soil', 'Air'
- 4 or 5 cards for each container, as described in step 1 of the procedure

Procedure

1 As a class, construct the following 20 cards for the game.

Plant
Eaten by animal → animal
Plant waste → decomposer
Plant death → decomposer
Respiration → air
STAY in plant (2 cards)

Animal
Animal waste → decomposer
Animal death → decomposer
STAY in animal (2 cards)

Decomposer
Carbon compounds in wastes → air
STAY in decomposer (2 cards)

Soil
STAY as carbon compounds (2 cards)
STAY as fossil fuel

Air
Photosynthesis → plants
STAY in air (3 cards)

Place the cards in the relevant labelled containers.

2 Copy Figure 6.1.14 into your workbook. This simplified version of the carbon cycle should take up half a page.

3 To play the game, set up five stations around the room. Label them 'Plant', 'Animal', 'Decomposer', 'Soil', and 'Air'. Place the relevant cards at each station.

4 Start at any one of the stations and record the name of the station.

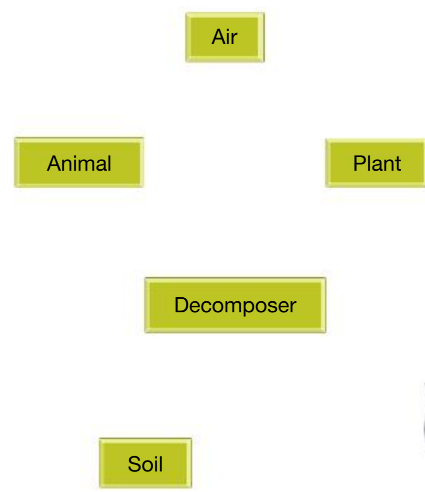


Figure 6.1.14

5 Take a card from the container, read the card and return it to the container. Mix the cards around before the next student takes a card. For all cards except those that say 'STAY', record what it said and move to the next station. If you pick a 'STAY' card, record 'stay', put the card back in the pack, then go to the back of the queue at the station before you pick your second card.

6 You should have a record of the card you picked each time at each stop.

7 The game is complete when you have made 15 visits to stations.

Results

1 On your diagram of the carbon cycle, record the pathway that you took through the cycle. Use arrows to show the direction you moved.

2 Draw a square around any part of the cycle where you had to 'stay'. There should be a separate square for each 'stay' card.

Practical review

1 a **Compare** the carbon cycle you have constructed with Figure 6.1.9 on page 207.

b **Propose** reasons for any differences.

2 **Identify** the areas where carbon did not move quickly on to another part of the cycle.

3 **Identify** the parts of the cycle where carbon moved rapidly on to the next stage.

4 **Discuss** the aspects of the carbon cycle that you understand better as a result of taking part in the simulation.

6.2 Natural influences on climate

Weather and climate are caused by interactions between Earth's spheres. Weather is a common topic of conversation. More recently climate and climate change are regularly in the news. These topics have led to heated debate.

Weather and climate

Tropical cyclones, tornadoes and heatwaves are extreme weather patterns. **Weather** describes the state of the atmosphere in terms of temperature, wind, cloud cover and precipitation. Weather is created by interactions between the hydrosphere (all the water on Earth), the lithosphere (Earth's land masses) and the atmosphere (the layers of gases surrounding the planet). Weather changes from day to day and sometimes there are extreme events.

Climate is the long-term averages of weather conditions. Climate is described by data (such as temperature, rainfall and wind speeds) that uses averages calculated from 30 years of weather records. This data includes extreme events such as cyclones and drought. To understand **climate change**, you first have to understand what influences climate and the particular factors that affect Australia's climate.

Influences on climate

The Sun is the ultimate source of energy for most living things. It also keeps the planet warm enough to support life. Energy from the Sun is therefore a major influence on climate. However, other factors also influence the world's climate.

Surface of the Earth

Characteristics of Earth's surface determine how much of the energy from the Sun is reflected back into space. This is shown in Figure 6.2.1. Clouds and the ice of the Arctic and Antarctic reflect most of the energy coming in from the Sun. Ice reflects about 84% of this energy compared with the dark green forests, which reflect about 14%. If all Earth was covered in forests, a lot more of the Sun's energy would be absorbed and Earth would be warmer than it is today.

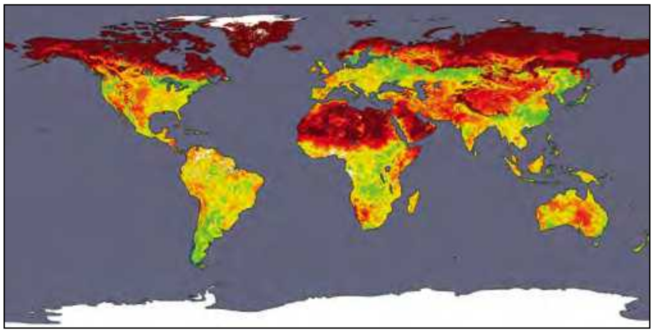


Figure 6.2.1 The white and red areas indicate more reflection of the Sun's rays. In the green and yellow areas, more of the energy from the Sun is absorbed.

Gases in the atmosphere

The energy that comes from the Sun is short-wave radiation. It is absorbed by clouds and the Earth's surface and radiated back out into space as long-wave radiation (heat). Nitrogen and oxygen are the gases that make up most of Earth's atmosphere, and they have no effect on the radiation coming in from the Sun or on the radiation going back out into space.

However, the same is not true for a number of other gases in the atmosphere. Water vapour, carbon dioxide, methane, nitrous oxide and ozone all allow the incoming short-wave solar radiation to pass through. They absorb the out-going long-wave radiation (heat) and they re-emit the heat in all directions. Some is radiated back to Earth's surface.

GO TO Pearson science NSW 9 Unit 4.1

These gases have the effect of trapping heat close to the surface, keeping Earth warmer than it would be if these gases were not present. These gases are known as **greenhouse gases** and the effect they have on warming Earth is known as the **greenhouse effect**. Figure 6.2.2 shows what happens in a greenhouse. Greenhouses (or glasshouses) heat up because the short-wave solar radiation can pass through glass into the greenhouse, where it is absorbed by the air, soil and objects in the greenhouse. The heat that is re-radiated is long-wave radiation and cannot pass through glass. It causes the temperature inside the greenhouse to increase. Figure 6.2.3 illustrates the effect of greenhouse gases on Earth's atmosphere. Without the protection of the atmosphere, the days would be hotter and the nights colder. Without the greenhouse effect, Earth's average temperature would be about –18°C rather than 15°C. This would affect weather conditions, plant growth and animal survival.

Prac 1 p219

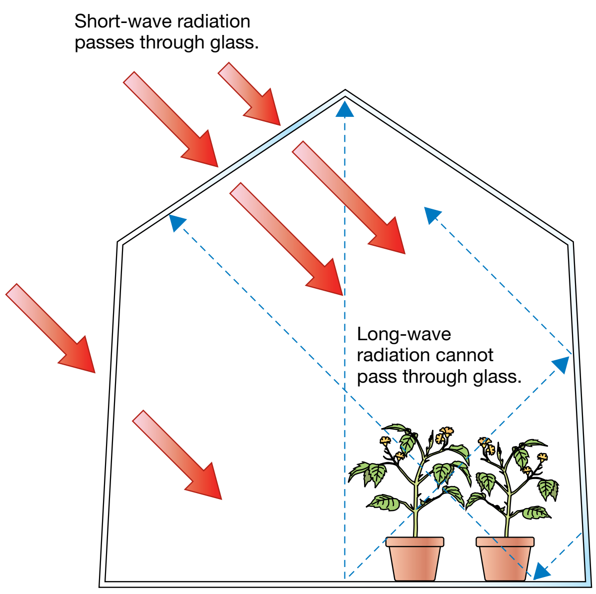


Figure 6.2.2 How a greenhouse heats up

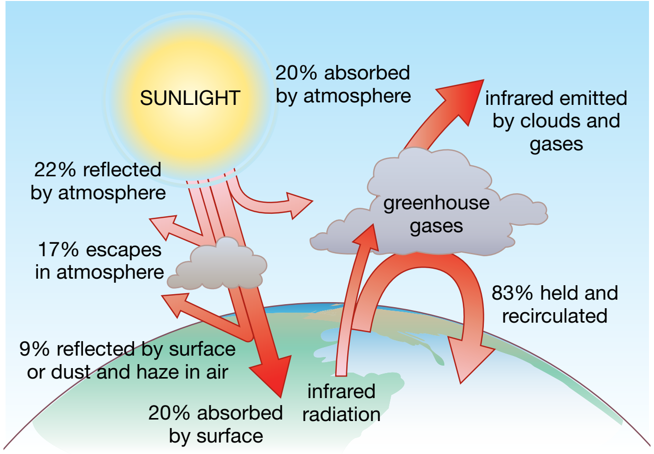


Figure 6.2.3 The effect of greenhouse gases on Earth's atmosphere

Orientation of the Earth

Earth is roughly spherical. It orbits the Sun and rotates on its own tilted axis. Figure 6.2.4 demonstrates how the tilt of the axis and Earth's movement around the Sun cause the seasons. If the tilt of Earth was different, then the characteristics of the seasons would also be different.

As Earth rotates, the atmosphere and the waters of the oceans are dragged around with it. This movement influences the circulation of the air and water on a global scale. However, the major factor influencing circulation of water in the oceans is temperature.

Differences in the temperature of the oceans in different parts of the world have a major impact on Australia's climate.

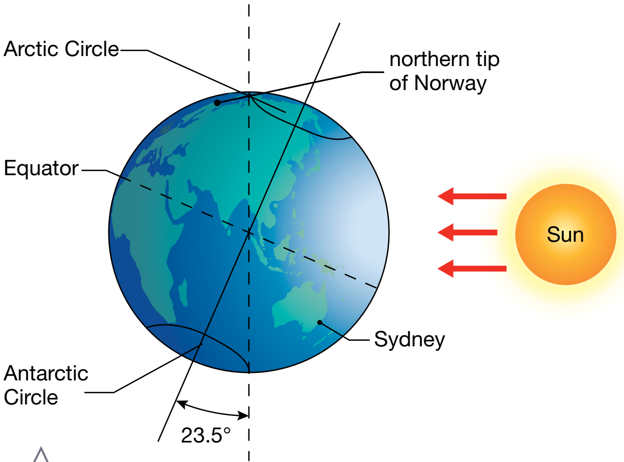


Figure 6.2.4 The diagram shows the northern summer. Radiation from the Sun is reaching a larger proportion of the northern hemisphere than the southern hemisphere.

ADDITIONAL

Ocean currents

Ocean currents are continuous movements of ocean water. They can flow for great distances and cause water to circulate continuously around the whole of the Earth. This circulation plays an important part in determining the climate of many of Earth's regions.

Currents can be at the surface or deep in the ocean. The main causes of currents are:

- wind
- temperature
- variations in salinity (salt levels)
- the rotation of Earth on its own axis
- the gravitational pull of the Sun and Moon.

Surface currents

The surface currents of Earth are caused by wind. Wind pushes the surface water along until it reaches land. Then the water has to flow left or right or sometimes downwards. In the major ocean basins, the currents form the circular patterns shown in Figure 6.2.5. These circular patterns, called **gyres**, flow in a clockwise direction in the northern hemisphere and anticlockwise in the southern hemisphere. The circular pattern of gyres is caused by the rotation of Earth.

Deep currents

Deep currents begin at the poles, where extremely cold water is found. They flow through the ocean, carrying very cold water along the bottom.

Prac 2 p220

Currents and climate

Surface currents and deeper currents interact. Water cycles from deep currents to surface currents, and then back to the deep again, forming the **thermohaline circulation** (*thermo* means temperature, *haline* means salt). The thermohaline circulation is very slow, taking about 1600 years to complete just one circuit! Scientists commonly call the thermohaline circulation the **global conveyor belt**. It is shown in Figure 6.2.6.

The global conveyor belt is important because it distributes heat around the globe and so affects the climates of Earth.

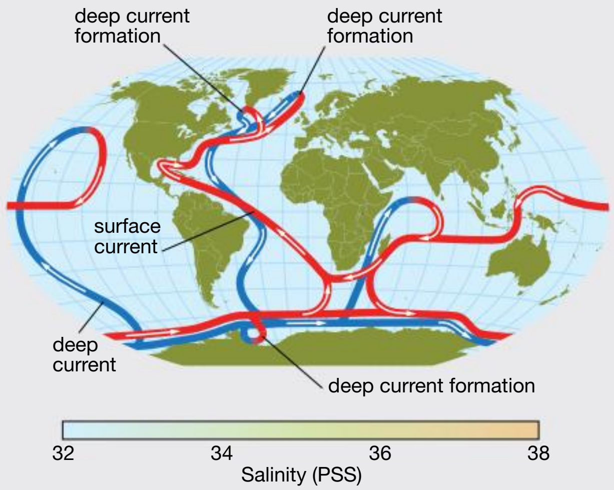


Figure 6.2.6 The global conveyor belt of interconnected ocean currents distributes heat around the Earth and affects its climates.

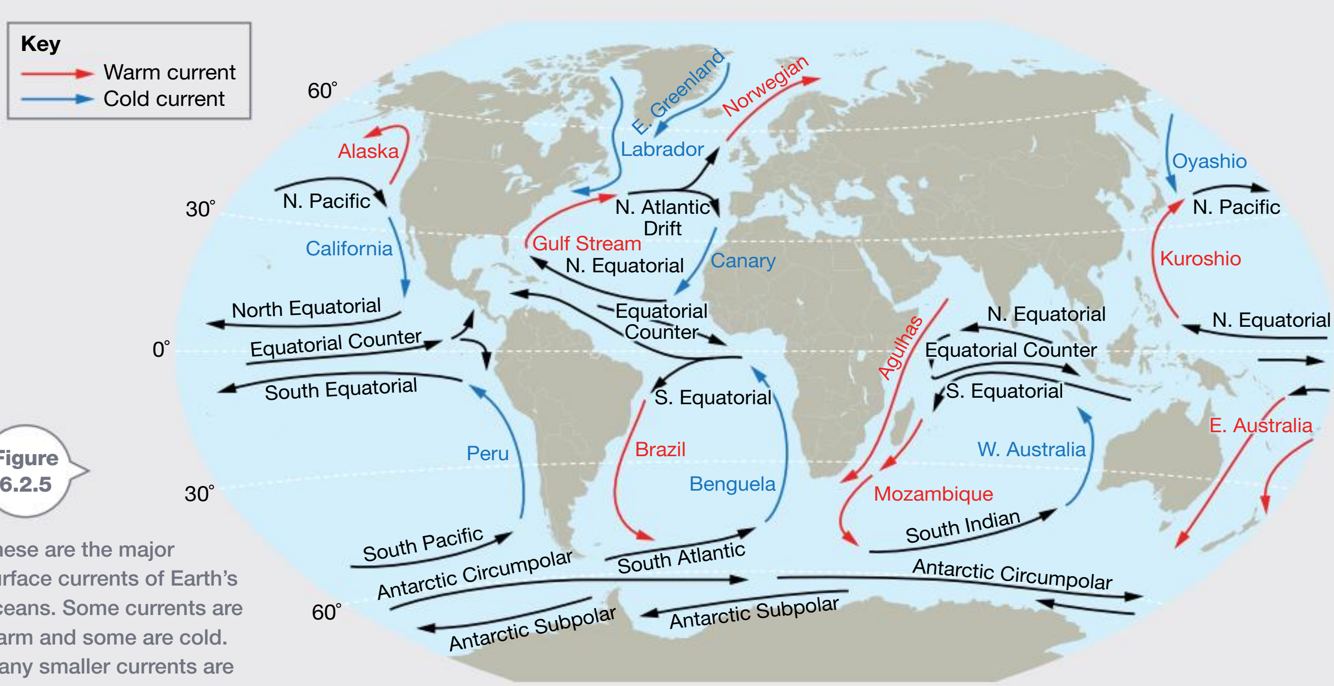


Figure 6.2.5 These are the major surface currents of Earth's oceans. Some currents are warm and some are cold. Many smaller currents are not shown on this map.

INQUIRY
science 4 fun

Spinning oceans

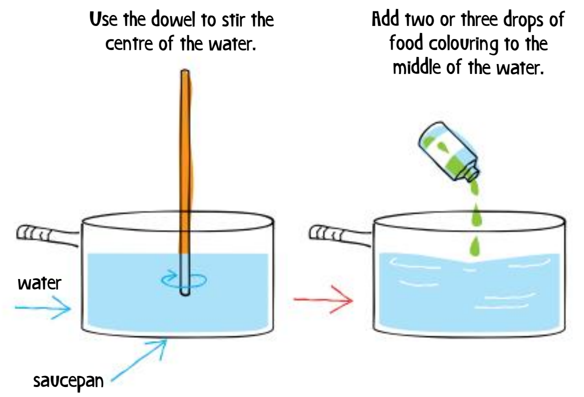
Does the spinning of the Earth really drag the water with it?

Collect this …

- water
- food colouring
- large circular container such as a saucepan or baking bowl
- wooden dowel for stirring

Do this …

1. Fill the container with water.
2. Stir the water in the centre only until a good current is achieved (see diagram). Stop stirring.
3. Add two or three drops of food colouring into the centre of the container.



4. Observe the way the food colouring spreads through the water.

Record this …

Describe what happened.
Explain why this happened.

The Gulf Stream

The Gulf Stream is part of the global conveyor belt. It is a current that makes western Europe much warmer in winter than any other region at the same latitude. For example, although cold, the United Kingdom and Norway are much warmer than Greenland and Canada. A computer-enhanced image of the Gulf Stream is shown in Figure 6.2.7. The Gulf Stream flows from the warm Caribbean Sea carrying heat across the North Atlantic Ocean towards Europe. The Gulf Stream feeds into the North Atlantic Drift and the Norwegian currents and into the Labrador and Greenland seas. Very cold Arctic winds then cool the water of the Gulf Stream, increasing its density. The denser water sinks, pushing away the water below it and creating a deep current. This cold deep current flows all the way south to Antarctica.

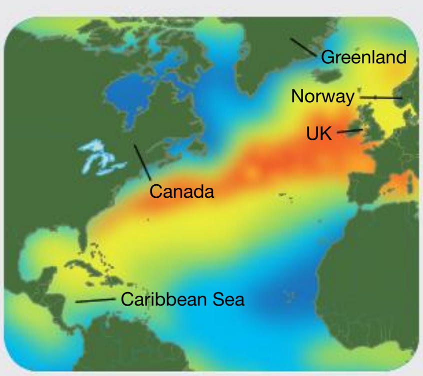


Figure 6.2.7 The Gulf Stream is a warm ocean current. In this image orange indicates the warmest water. Blue is coldest.

6.2 6.3

ADDITIONAL

Changing climate

There is evidence that Australia's climate in the past was very different from that experienced today. More than 62 million years ago, the land mass that became Australia was still joined to the ancient supercontinent Gondwana.

Then Australia experienced a warmer and wetter climate. As you can see in Figure 6.2.8, there have been many cycles of cooling and warming in Earth's history. About 2.5 million years ago, an ice sheet covered Tasmania and southern Australia. Cycles of warming and cooling followed. Then about 20 000 years ago, the current period of warming began.

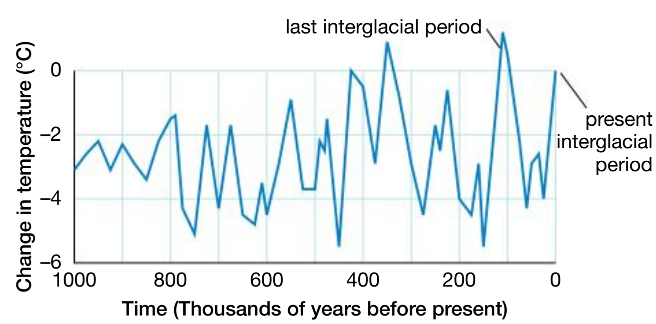


Figure 6.2.8 In the history of Earth, there have been many periods of glaciation when conditions were cooler and ice covered large areas. These periods of glaciation varied in length and intensity. Between the glaciations were interglacial periods when the world's climate was warmer.

As an ice age approaches, the ice caps at the north and south poles expand and the amount of liquid water on Earth decreases. Sea levels fall, exposing additional land on the coasts. Figure 6.2.9 shows where there were land bridges during the last ice age. At that time it would have been possible to walk from mainland Australia to Tasmania and the island of New Guinea.

Figure 6.2.9 During cooler periods, the amount of ice on Earth's surface increases. Water is held in the ice caps and ocean levels fall, exposing more land.

Global warming

Interglacials are periods between glaciations—they are periods of **global warming** in which the average world temperature increases. During interglacials, ice caps melt and this causes the sea level to rise and coastal lands to flood. Evidence for the rise and fall of sea level can be seen in the patterns of sediments and fossils in coastal rocks.

Reasons for the past warming and cooling of Earth are not understood completely. Therefore, it is challenging to fully assess the contribution that human actions are making to the present period of global warming. The data in Figure 6.2.10 show that the current period of global warming started 20 000 years ago when humans were just about to emerge from the Stone Age.

SciFile

Return of the ice

Approximately every 100 000 years, Earth's climate warms up. These interglacial periods are temporary. They last approximately 15 000–20 000 years, and then an ice age returns. It has been over 18 000 years since the last ice age.

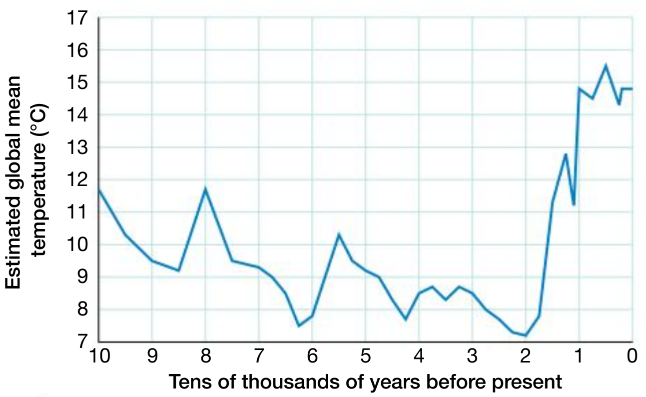


Figure 6.2.10 The current period of global warming started long before the Industrial Revolution (1750–1850). Therefore, it cannot be blamed entirely on human actions and increased production of greenhouse gases.

Evidence for climate change

Evidence for past changes in climate has come from a variety of sources.

Glaciers

Glaciers are indicators of climate change, advancing when the climate cools and retreating when the climate warms.

As glaciers move, they grind against the rocks on the sides and floor of the valley through which they flow. The rocks on the side of the valley are deeply scored by broken rocks being dragged along the sides and base of the glacier. When the glacier retreats, the scoring of the rocks becomes visible. The pile of grey rock at the front of the glacier in Figure 6.2.11 is a moraine. This is the debris the glacier was carrying. It was left behind as the glacier retreated.

Figure 6.2.11 The black material in the front of the glacier is the debris that has been dropped as the glacier retreated.

Ice cores

On some glaciers and ice sheets, sufficient snow falls each year to form recognisable annual layers. Scientists take cores like the one in Figure 6.2.12, from ice sheets in places such as Antarctica. By analysing the physical and chemical properties of ice cores, they collect data about temperatures and the composition of the air from hundreds of thousands of years ago. This information shows links between temperature and variations in the global sea level. It also reveals that the amount of carbon dioxide in the atmosphere has varied in the past.

Figure 6.2.12 The bands seen in this core represent ice of different ages and composition.

In early 2010, scientists studying Antarctic ice cores discovered a strong link between the amount of snow that falls in eastern Antarctica and drought in south-west Western Australia. Ice cores reveal that in the last 30–40 years, eastern Antarctica has experienced higher than average snowfalls. During this time, winter rainfall in south-west Western Australia has decreased by 15%. This is shown in Figure 6.2.13.

The reduced rainfall is thought to be caused by climate change modifying the path followed by the Antarctic Circumpolar Current seen in Figure 6.2.14. This current circulates round Antarctica and usually sends moist warm air up to Western Australia. A change in the pattern is causing the warm moist air to be directed to Antarctica where snowfall is the result. Cold, dry air directed towards Australia results in reduced rainfall.

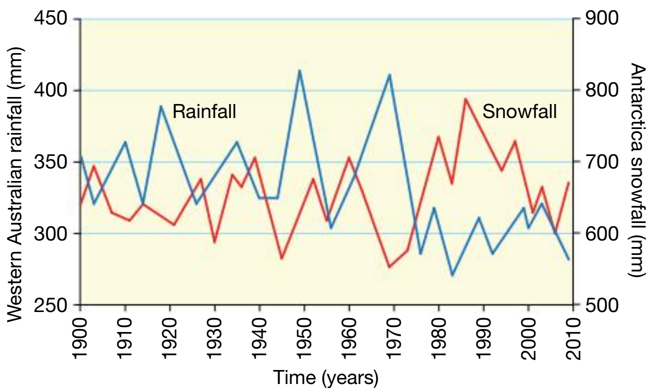


Figure 6.2.13 The relationship between snowfall in eastern Antarctica and rainfall in south-west Western Australia

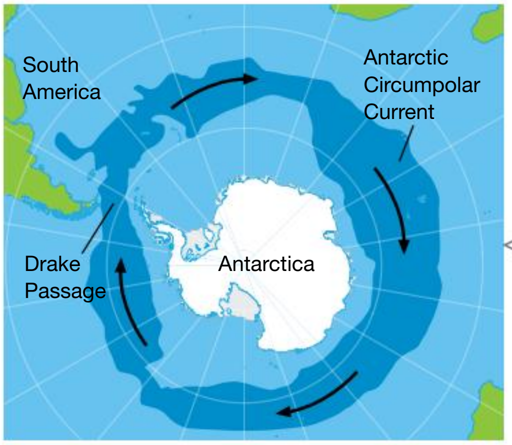


Figure 6.2.14 The path of the Antarctic Circumpolar Current

SciFile

Strong current

As the Antarctic Circumpolar Current passes through the Drake Passage (between Antarctica and South America) it carries about 134 million cubic metres of water per second. This is like all the water in Sydney Harbour passing you in 3 seconds!

Pollen analysis

Pollen decays very slowly and often becomes fossilised. Fossil pollen indicates the species growing in the area when the sediments that created the fossils were laid down. Changes in the types of pollen found indicate changes in vegetation and climate.

Sea level change

The worldwide distribution of sedimentary rocks and the types of fossils found in them are indicators of changes in sea level in the past. For example, sedimentary rocks in central Australia contain fossils of sea creatures.

GO TO Pearson science NSW 9 Unit 4.1

6.2 Unit review

Remembering

1 **State** the increase in average temperature in Australia in the past 50 years.

2 **List** three factors that affect the world's climate.

3 **Name** three main greenhouse gases.

4 **State** the major influence on the world's climate.

Understanding

5 **Describe** how climate differs from weather.

6 a **Define** the term *interglacial*. L

b **Outline** the relationship between interglacials and global warming.

7 **Describe** how glaciers can indicate whether the climate is cooling or warming.

8 **Explain** how it was possible to walk to Tasmania from Victoria during the last ice age.

9 **Predict** what will happen in the science4fun on page 215.

Applying

10 **Use** diagrams to **demonstrate** how the greenhouse effect influences conditions on Earth.

Evaluating CCT

11 **Propose** what would happen to the seasons of the year if Earth's axis changed its orientation to:

a vertical (no angle)

b an angle of 40 degrees.

12 **Propose** the changes that would occur on Earth if carbon dioxide, methane and other greenhouse gases were removed from the atmosphere.

13 The occurrence of sedimentary rock with marine fossils at a height of 500 metres above sea level is used as evidence of a different sea level in the past.

a **Justify** the use of this as evidence of higher sea levels in the past.

b **Propose** whether the climate at that time was warmer or cooler than at present, and justify your answer.

Creating CCT

14 **Construct** a concept map of the different types of evidence used to indicate climate change.

Inquiring

1 Compare Australia 300 million years ago with the continent as it is today. Research:

- aspects of the climate, such as temperature, humidity and rainfall
- vegetation—the type and distribution
- the conditions required for the development of coal deposits.

Present your findings as a digital presentation that explains why there is so much coal currently in NSW. ICT

ADDITIONAL

2 Research the Southern Oscillation Index (SOI) and its extremes of El Niño and La Niña. Find:

- a description of the SOI
- a graph of the SOI over recent years
- how differences in sea temperatures cause La Niña and El Niño
- how La Niña and El Niño affect Australia's weather patterns
- how computer modelling is used to make predictions about La Niña and El Niño.

Present your research as an illustrated presentation that demonstrates the effect of the Southern Oscillation on Australia's climate now and in a possible future with global warming. CCT S

3 It has been known for a long time that fish stocks along the east coast of Australia increase and decrease depending on whether the coast is experiencing drought or higher-than-normal rains. Similarly, the number of fish caught off Chile and Peru in the eastern Pacific Ocean changes with drought and rain. More recently, these changes have been linked to the occurrence of El Niño or La Niña. Research:

- how El Niño and La Niña affect deep ocean currents
- how these currents affect marine life in the Pacific Ocean, particularly along its western and eastern shores
- what happens to the marine life along the Australian coast and the coast of Chile and Peru during El Niño
- what happens to the marine life along both coasts during La Niña.

Present your findings as a series of annotated maps and diagrams.

ADDITIONAL

6.2 Practical investigations

1 Greenhouse effect

Purpose
To investigate the greenhouse effect.

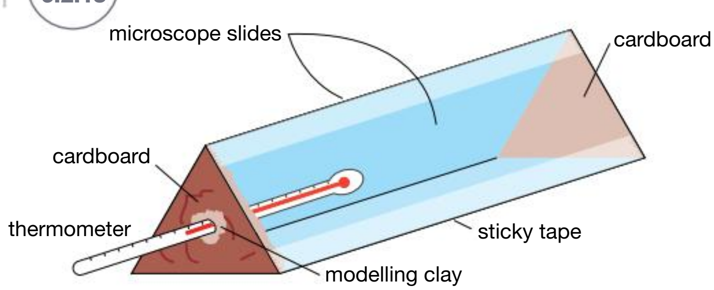
Hypothesis
Which do you think will get hotter—the thermometer outside the 'greenhouse' or the one inside? Before you go any further with this investigation, write a hypothesis in your workbook.

Materials
- block of wood
- modelling clay
- 2 thermometers (or temperature probes and datalogging equipment)
- 3 microscope slides
- sticky tape
- 2 triangular pieces of cardboard to fit the ends of the 'greenhouse'

SAFETY
Take care when handling glass microscope slides.

Procedure
1 Construct a table in your workbook like the one shown in the Results section.
2 Create a hole in one of the pieces of cardboard, just large enough for the thermometer to pass through. Use the modelling clay to hold the thermometer in place. It needs to be a good seal, to stop air escaping.
3 Construct the model greenhouse as shown in Figure 6.2.15.

Figure 6.2.15



4 Place the 'greenhouse' outside in a sunny position.
5 Place the second thermometer on the block of wood next to the greenhouse. Ensure that the bulb of the thermometer is suspended in the air.
6 Record the temperature on the two thermometers at the beginning of the experiment.
7 Record the temperatures every 2 minutes for 14 minutes.

Results
1 Record all measurements in your results table.

Time (minutes)	Temperature (°C)	
	Greenhouse	Air
0		
2		
4		

2 Construct two line graphs on the same set of axes to display the temperatures.

Practical review
1 **Explain** why the second thermometer recording air temperature was used.
2 **Compare** the temperature patterns inside and outside the greenhouse.
3 **Deduce** the effect of your model greenhouse on the air inside it.
4 **Discuss** any other factors that could have affected the temperature.
5 **Explain** what has happened in this model of the greenhouse effect.
6 a **Construct** a conclusion for your investigation.
  b **Assess** whether your hypothesis was supported or not.
7 **Compare** the model in this prac to the global greenhouse effect.

2 Ocean currents

Purpose

To demonstrate ocean currents.

Hypothesis

What do you think will happen to cold water mixed into hot water—will it float on the surface of the warmer water, sink to the bottom or spread out evenly? Before you go any further with this investigation, write a hypothesis in your workbook.

Materials

- 400 mL warm tap water
- 50 mL ice-cold water (no ice)
- food colouring
- medium-sized, flat rectangular plastic container
- 250 mL beaker
- teaspoon

SAFETY
Take care with hot water.

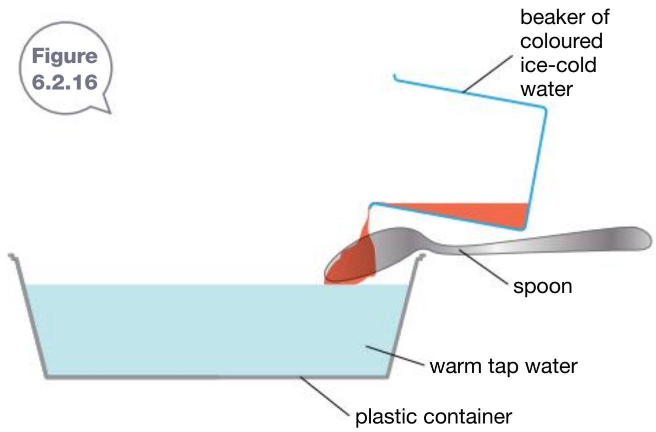
Procedure

1. Place the plastic container flat on the bench.
2. Three-quarters fill the container with warm water.
3. Allow the water to become completely still.
4. Add a few drops of food colouring to the ice-cold water in the beaker.
5. Add the ice-cold water to one end of the container by carefully pouring it over the back of the teaspoon, as shown in Figure 6.2.16. This will minimise the disturbance to the warm water in the container.
6. Without touching the container, observe the container from the side.

Extension

7. If datalogging equipment is available, try recording the differences in temperature between the water at the surface and bottom of the container.
8. Design an investigation to demonstrate what would happen if hot water (such as a warm current) met a body of cold water.

Figure 6.2.16



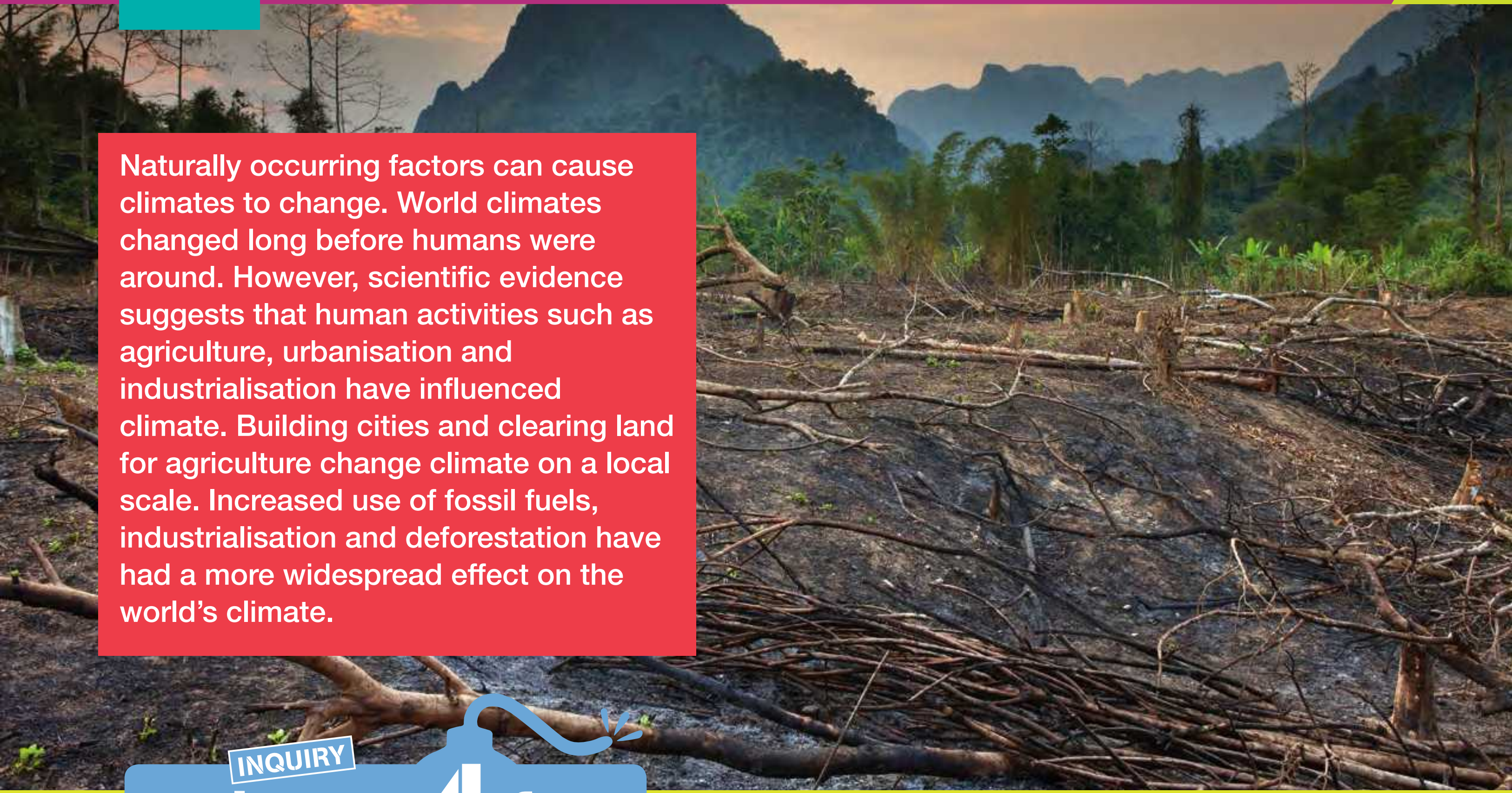
Results

Record the movement of the coloured water over the next 5 minutes using the video function of a digital camera or mobile phone.

Practical review

1. **Describe** the movement of the coloured water.
2. **Explain** why the coloured water moved in this way.
3. **Explain** how this situation could arise in an ocean.
4. **Discuss** the relationship between this demonstration and the development of ocean currents
5. a **Construct** a conclusion for your investigation.
   b **Assess** whether your hypothesis was supported or not.
6. **Predict** what would happen if the water you poured into the container was warmer than the water in the container.

6.3 Human influence on climate



Naturally occurring factors can cause climates to change. World climates changed long before humans were around. However, scientific evidence suggests that human activities such as agriculture, urbanisation and industrialisation have influenced climate. Building cities and clearing land for agriculture change climate on a local scale. Increased use of fossil fuels, industrialisation and deforestation have had a more widespread effect on the world's climate.

INQUIRY science 4 fun

Melting icebergs

YES

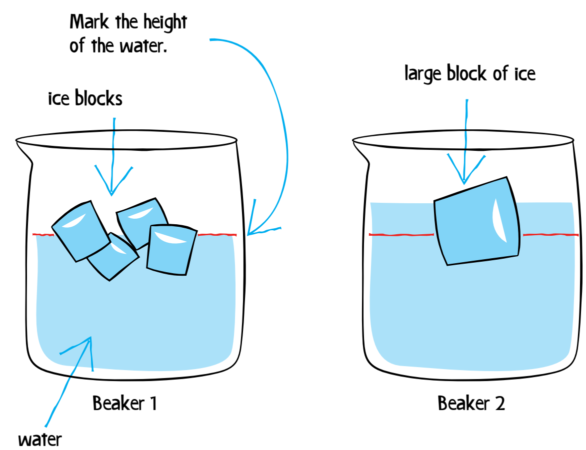
What effect do melting icebergs and glaciers have on sea levels?

Collect this …

- 2 glasses or jars of equal size and large enough to contain 300 mL of water each
- 4–6 small ice blocks that have been made using 100 mL of water
- large block of ice made from 100 mL of water
- yoghurt container or similar in which to create the block of ice
- measuring jug
- 400 mL water

Do this …

1. Place the small ice blocks in one of the empty glasses and half fill it with water. Mark the water level on the side, as shown in the diagram. This beaker represents the ocean in which icebergs are floating.
2. Pour water into the second glass until it is at the same level as in glass 1. Mark the water level on the side. This glass represents the ocean into which a glacier is flowing.
3. Place the large block of ice into glass 2. The ice block represents a large chunk of ice that has broken off a glacier in Antarctica.



4. When all the ice has melted, mark the new water levels on both glasses.

Record this …

Describe what happened.

Explain whether icebergs or the melting glaciers will contribute most to sea level rises.

Is Earth warming?

All indications are that Earth is in a period of warming. According to the World Meteorological Organization (WMO), the decade (2000–09) was the warmest on record. This is shown in Figure 6.3.1.

The Intergovernmental Panel on Climate Change (IPCC) conducted a comprehensive review of the scientific evidence for climate change. In 2007, the IPCC reported:

- increases in global average air and ocean temperatures
- rising global average sea level (Figure 6.3.2)
- widespread melting of snow and ice (Figure 6.3.3).

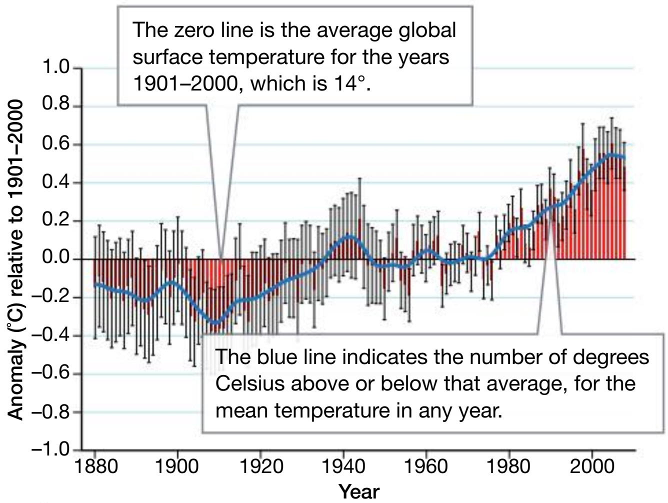


Figure 6.3.1 This graph shows that Earth is warming. For example, in 2000 the temperature was 0.4°C above the long-term average. In 2009, it was 0.44°C above the long-term average of 14°C.

Figure 6.3.2 The islands of Tuvalu (in the Pacific Ocean) are between 1 metre and 4.5 metres above sea level. Tuvalu will experience severe flooding if there is a significant rise in sea level.

Figure 6.3.3 A scientific study of more than 100 000 glaciers worldwide has found that most glaciers are shrinking.

The enhanced greenhouse effect

Many scientists believe that human activities are having a significant effect on the rate and intensity of global warming, and that this is influencing climate change. However, measurement of climate variables on a worldwide scale has been occurring for little more than a century. Many of the trends that drive climate change occur over periods much longer than this—hundreds of thousands of years. Therefore it is difficult to identify the exact effect of changes caused by humans.

The IPCC report suggested that global warming is partly due to natural processes but is also caused by the **enhanced greenhouse effect**. The enhanced greenhouse effect is an increase in the natural greenhouse effect caused by human activity.

The major cause of the enhanced greenhouse effect is an increase in carbon dioxide, methane and nitrous oxide concentrations in the atmosphere.

Scientists have created computer models to try to forecast the effects of global warming on Earth's climate. Not all the computer models agree in specific details. However, there is agreement that if greenhouse gases continue to be produced at the same rate as in the year 2000, then there will be a 0.1°C increase in temperature per decade. What actually happens will depend on the actual carbon dioxide emissions that occur. As can be seen from Figure 6.3.4, Australia's emissions already exceed our 2000 levels.

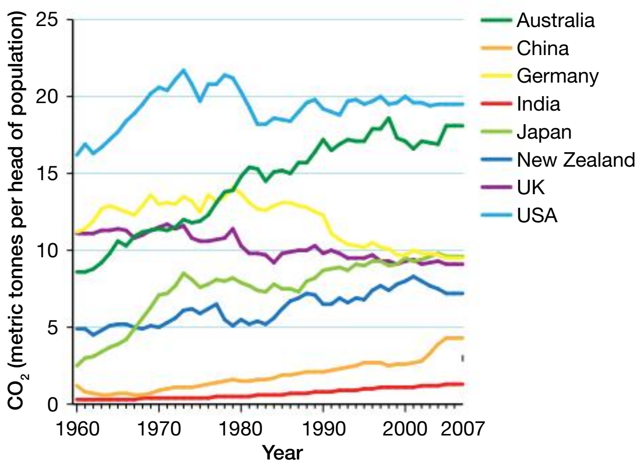


Figure 6.3.4 Australia's carbon dioxide emissions have risen since 2000. Other developed nations have reduced or stabilised their emissions per head of population.

Carbon dioxide in the atmosphere

Of all the carbon dioxide produced on Earth, 95% would be emitted whether humans were present or not. The largest source is natural decay of organic material in forests and grasslands. However, the carbon dioxide produced by natural means is balanced by natural carbon sinks—these are places and events that remove carbon dioxide from the atmosphere.

In 1957, measurement of carbon dioxide began at the Mauna Loa Observatory, Hawaii (USA). Before that evidence of carbon dioxide levels in the atmosphere came from ice cores collected in Antarctica. Figure 6.3.5 shows this data on atmospheric carbon dioxide over the last thousand years.

The concentration of carbon dioxide in the atmosphere has increased from 280 parts per million (ppm) before the Industrial Revolution to 391 ppm in 2010. Compare this with an increase of only 20 ppm in the 8000 years before industrialisation.

Coal and gas are both major carbon sinks. Since the Industrial Revolution, humans have been extracting and burning coal and gas as a primary energy source, releasing carbon dioxide into the atmosphere.

In Australia most of the energy used in homes and by industry is produced by coal-fired power stations. Figure 6.3.6 shows the output of carbon dioxide in Australia per head of population compared with other nations.

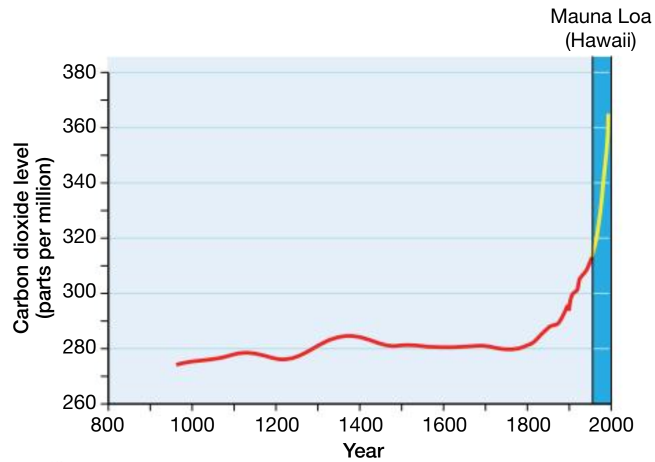


Figure 6.3.5 The rapid increase in the concentration of atmospheric carbon dioxide coincides with the Industrial Revolution, which began around 1750.

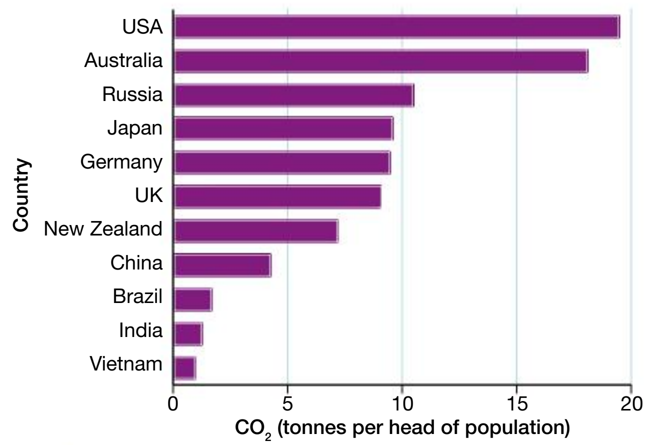


Figure 6.3.6 In 2007, Americans produced more carbon dioxide per head of population than any other nation—Australians are not far behind.

6.4

India and China produce only a small amount of carbon dioxide per person when compared with Australia. However, when the population of these countries is taken into account, the picture is different. Table 6.3.1 compares the populations of these four countries.

Table 6.3.1 Comparing the populations of four countries

Country	Population (millions)	Total CO_2 output (millions of tonnes)
Australia	22.3	400
United States	307.0	5990
India	1140.0	1140
China	1325.0	5300

Methane

Methane (CH_4) is able to trap more than 20 times the heat of carbon dioxide. It is formed from the breakdown of organic matter. Methane is produced in the stomachs of cows and sheep as bacteria digest the cellulose in the grass the animals eat (Figure 6.3.7). Rice paddies, garbage tips, coal mines and natural gas fields also release methane. The concentration of methane in the atmosphere in 2010 was 18.5 ppm, which is more than double the level before the Industrial Revolution.

Figure 6.3.7 Digestion of plant material releases methane. Livestock produce 11% of Australia's methane emissions.

SciFile

Gas emissions

About 90% of New Zealand's methane emissions are produced as animals such as cows and sheep burp and fart. The 45 million sheep and 10 million cattle in New Zealand make for a lot of methane!

On Earth, there are areas near the poles where the temperature in layers of soil or rock beneath the surface never rises above freezing point. These layers are known as **permafrost**. Vast areas of the Arctic are boggy wetlands of permafrost where the remains of plants and animals decompose, producing methane. Permafrost traps the methane (Figure 6.3.8). However, rising temperatures in the Arctic causes the boggy soils to melt and release the trapped methane. Estimates suggest that Arctic soils store billions of tonnes of methane.

Increased methane emissions may cause the temperature to rise further, melting more ice and releasing more methane in a process known as positive feedback.

Figure 6.3.8 Bubbles of methane are trapped in the ice of the permafrost. Between 2003 and 2007, methane emissions from the Arctic increased by 31%.

Nitrous oxide

Nitrous oxide (N_2O) is capable of trapping 300 times more heat than carbon dioxide. Its concentration in the atmosphere in 2010 was 3.19 ppm—this is about 18% higher than before the Industrial Revolution. Nitrous oxide is produced in car exhausts and through many industrial processes, as well as the burning of forests and the use of nitrogenous (nitrogen-based) fertilisers.

Loss of ice

During winter, the amount of ice in the Antarctic doubles to cover an area of about 19 million square kilometres. That is an area about three times the size of Australia. Scientists are currently gathering information that seems to suggest that the extent and thickness of the ice has an effect on climate.

Areas of the globe covered in ice reflect more of the Sun's rays and have a cooling effect on Earth. Any reduction in the area of Antarctic ice would reduce this cooling effect.

When it covers the ocean water, ice acts as a blanket. The amount of heat that moves from the ocean to the atmosphere is reduced. Less ice means that more heat will be added to the atmosphere.

Ice is fresh water. As salt water freezes, the salt remains in the ocean. The salinity increases and therefore the density of the water also increases. The dense water sinks, moving into the deep currents that circle Earth. Changes to the amount of Antarctic ice entering them could cause changes in the deep currents and the global climate.

Prac 1 p228

Carbon dioxide absorption

Water at the surface of the oceans absorbs carbon dioxide from the atmosphere. As the cold dense water of the Antarctic Ocean sinks, the carbon dioxide is carried with it. This has the effect of pumping carbon dioxide out of the atmosphere. Without this process, any build-up of carbon dioxide in the atmosphere would be faster.

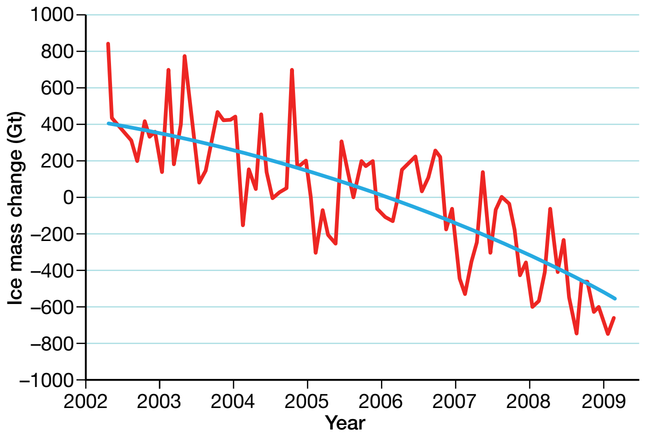


Figure 6.3.9 The amount of Antarctic ice varies throughout the year (thicker in winter, thinner in summer) and from year to year. The general trend for 2002–09 is that the mass of Antarctic ice is decreasing.

Shrinking Antarctica

Scientists are investigating whether or not the Antarctic ice is melting. Satellites are used to measure the total mass of ice on Antarctica. Figure 6.3.9 represents the results collected so far. The results indicate that Antarctica is losing ice and that the rate of loss is increasing.

Different things are happening in different parts of the continent of Antarctica. Under the ice of east Antarctica is a land mass about the size of Australia. In this part of the continent, there is a little loss of ice at the edges and an accumulation of snow in the interior. Therefore, there is not much change.

West Antarctica is more like a series of islands so a lot of the ice is sitting in water. Here the sea ice surrounding the islands is retreating. Loss of sea ice allows the glaciers to flow more rapidly, sending large amounts of ice into the ocean.

In February 2010, an iceberg 78 km long and 39 km wide broke off the tongue of the Mertz Glacier in East Antarctica. The tongue of the glacier was hit by an iceberg known as 'B9B' which is 97 kilometres long. Some scientists are concerned that this event may affect wildlife in the area. You can see this collision in Figure 6.3.10.

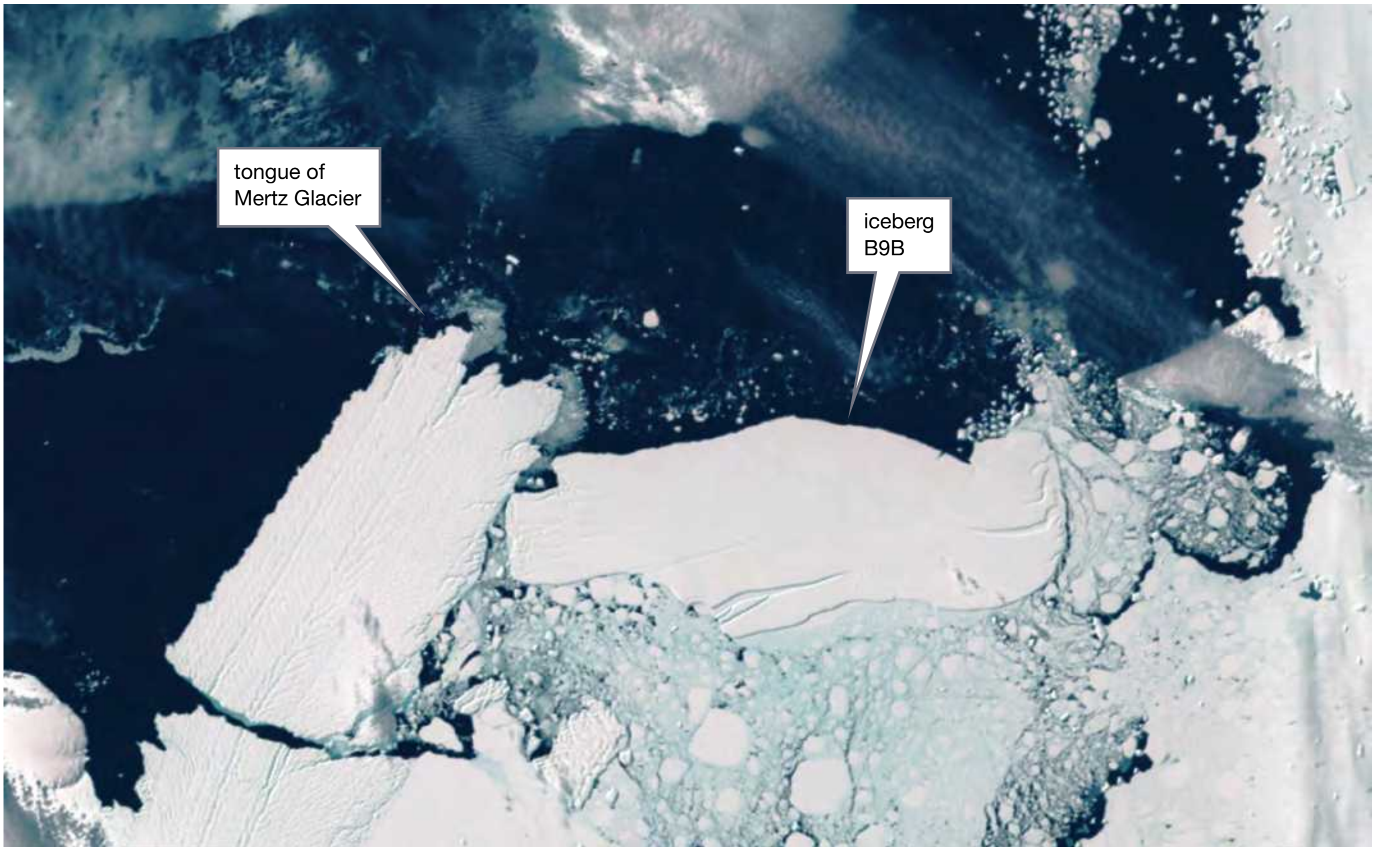


Figure 6.3.10 The tongue of the Mertz Glacier broke off when it was hit by Iceberg B9B.

Prac 2 p229
Prac 3 p229

LEARNING ACROSS THE CURRICULUM

SUSTAINABILITY

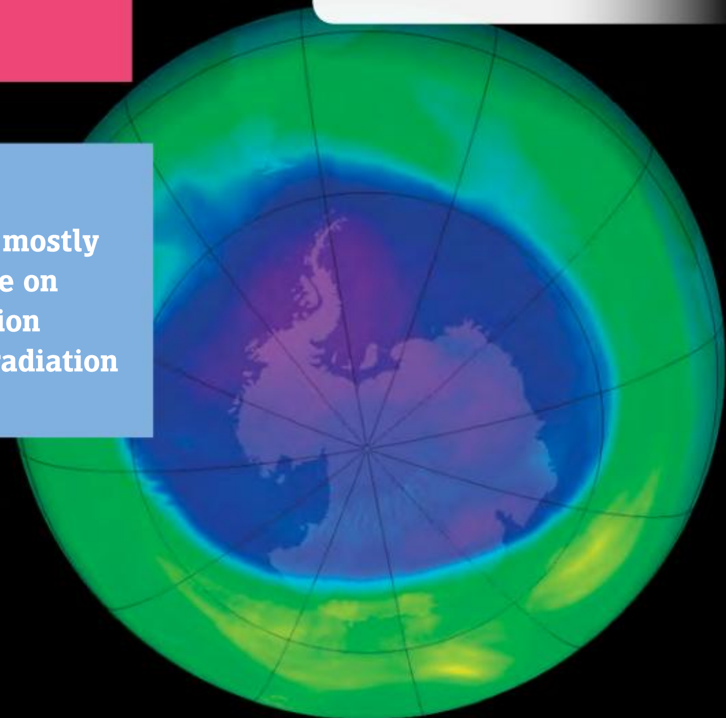


Figure 6.3.11 The hole in the ozone layer over Antarctica (shown in purple)

OZONE

Ozone (O_3) occurs naturally in the atmosphere, mostly in the stratosphere. It is vitally important to life on Earth because it absorbs ultraviolet (UV) radiation emitted by the Sun. Too much exposure to UV radiation can cause skin cancers and eye disease.

Dobson Units

The 'thickness' of the ozone layer is measured in Dobson Units (DU). Ozone is spread throughout the stratosphere, so the term *thickness* is misleading. If all the ozone in the world could be concentrated into a pure layer at ground level, it would be 5 mm thick or 500 DU.

A value of less than 220 DU is considered a 'hole'.

The concentration of ozone in the atmosphere varies throughout the year and around the world. Measurements over Antarctica show that the values are lowest during September to October, when daylight returns after the long dark winter. In November, prevailing winds carry ozone-rich air from other regions and repair the hole. But lower ozone levels still remain over Australia and New Zealand (Figure 6.3.11).

Chlorofluorocarbons

An increase in the rate of ozone destruction was linked to the release into the atmosphere of manufactured compounds such as chlorofluorocarbons (CFCs). CFCs were developed in the 1920s and were soon used as coolants in refrigerators and air conditioners. By the late 1940s CFCs were widely used as the propellants in spray cans. They were used to make the bubbles in foam packaging and were included in industrial cleaners. CFCs are very stable compounds until they are exposed to high levels of UV radiation, such as those found high in the atmosphere. Then CFCs break down to release chlorine, which destroys ozone. Chlorine is most effective at breaking down ozone at the end of the southern winter. This destruction led to the 'hole' observed each spring.

When the destructive power of CFCs was recognised in the 1970s, the use of CFCs was banned in the United States, Canada and Norway. However, it took until 1985 and the identification of a hole in the ozone layer over Antarctica, to convince the rest of the world that there was a serious problem. In 1987, 196 countries agreed to stop producing CFCs. This treaty (known as The Montreal Protocol) demonstrates the contribution that science can make to environmental protection agreements. Scientists predict that the ozone layer will recover to its pre-1980 concentrations by the middle of the 21st century.

REVIEW

1 **State** the chemical formula for ozone.
2 **Describe** the importance of ozone to living things.
3 **Name** the manufactured chemical that can damage the ozone layer.
4 **Describe** the natural annual cycle of change in the ozone layer.
5 **Explain** what is meant by *a hole in the ozone layer*.
6 Is layer a good explanation of the distribution of ozone in the atmosphere? **Explain** your answer.
7 **Explain** what the Montreal Protocol was and what it achieved.

6.3 Unit review

Remembering

1 **Name** two factors that influence world climate.

2 **Name** two aspects of climate that have been measured and have increased since the Industrial Revolution.

3 **Name** three gases found in the atmosphere that are responsible for the greenhouse effect.

Understanding

4 **Explain** why melting icebergs will not affect sea levels but melting glaciers will.

5 **Explain** the term *carbon sink*.

6 **Explain** why nitrous oxide became more important as a greenhouse gas in the second half of the 1900s.

7 a **List** the sources of methane in the atmosphere.
b **Describe** the human actions that are increasing methane levels in the atmosphere, and explain how the increase is brought about.

8 **Explain** why there is so much concern about the increase in carbon dioxide in the atmosphere.

9 **Explain** how the amount of ice in polar regions can influence climate.

Applying

10 a **Calculate** the annual output of carbon dioxide in Australia, the United States, India and China from the data presented in Figure 6.3.6 and Table 6.3.1 on page 223. N
b **Identify** the country that is the highest emitter of carbon dioxide, then rank the others in order of decreasing production.

Analysing

11 **Compare** global warming and climate change.

12 a **Compare** carbon dioxide, methane and nitrous oxide as greenhouse gases.
b **Explain** why the focus of concern about greenhouse gases is on carbon dioxide, not on methane and nitrous oxide.

Evaluating CCT

13 **Propose** reasons for why the data in Figure 6.3.6 on page 223 are presented as carbon dioxide emissions per head of population, rather than for the total population.

14 It is over 100 years since people were made aware of the potential global warming effect of carbon dioxide. **Propose** reasons why people did not act earlier to reduce carbon dioxide emissions.

Creating CCT

15 **Construct** a consequences wheel for global warming. Use Figure 6.3.12 as a guide to the layout. In the centre, write 'global warming'. In the next layer record the immediate consequences of global warming such as a rise in average world temperature. In the second layer add the consequences of these changes.

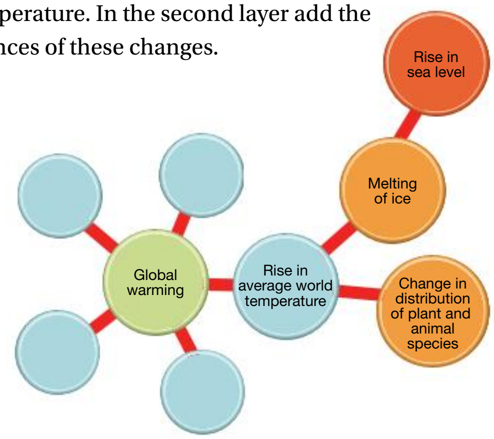


Figure 6.3.12

Inquiring

1 There are different viewpoints and opinions about the degree to which human activity is responsible for climate change. Find:

- how computer modelling has been used to predict the effects of climate change
- some of the outcomes of the different models
- some different viewpoints on climate change
- the arguments used in support of these viewpoints and assess their scientific accuracy.

Present your information as a speech you could use in a debate.

2 Research energy sources that are used as alternatives to fossil fuels. Find:

- their efficiencies as energy sources
- their impacts on the environment when first accessing the energy source and then when using it
- a comparison of the long-term availability of these energy sources.

Present your findings as an information sheet that consumers could use when making decisions about the energy sources they will use.

6.3 Practical investigations

1 Freezing and density

Purpose

To investigate the effect of freezing on the density of salt water.

Hypothesis

What do you think will happen when the cold salt water is added to the container of water? Before you go any further with this investigation, write a hypothesis in your workbook.

Materials

- 6 L water
- 60 g salt (sodium chloride)
- food colouring
- 6 L container (such as a bucket or watering can)
- 2 large transparent containers (pneumatic trough, pie dish or aquarium)
- 2 L container that can be placed in the freezer
- 1 L plastic container
- access to a fridge and freezer
- stirrer

Procedure

1. Mix 6 L of water with 60 g of salt and stir until all the salt is dissolved.
2. Add 2 L of the salt solution to each of the large transparent containers. Place the containers in the fridge.
3. Add a few drops of food colouring to the remaining 2 L of salt solution.
4. Pour the coloured salt solution into the 2 L container and place in the freezer.
5. Leave the coloured salt solution in the freezer until two-thirds of it is frozen.
6. Pour the liquid that has not frozen from step 5 into the 1 L container and place it in the fridge.
7. Save the ice from the coloured salt solution and allow it to thaw in the fridge. Add a few more drops of colouring if there is not an obvious tint to the water.
8. When the coloured solution and thawed ice are at the same temperature as the solution in the large containers, remove all containers from the fridge.
9. Allow the water in the large containers to settle.
10. Gently pour the coloured salty water in a slow steady stream into one end of one of the large containers as shown in Figure 6.3.13. Observe where the coloured water goes. Record your observations in your workbook.
11. Using the same technique as step 10, gently pour the thawed ice water in a slow steady stream into one end of the other large container. Observe where the coloured water goes. Record your observations in your notebook.

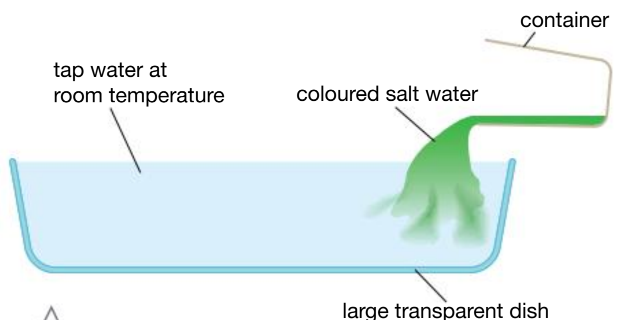


Figure 6.3.13

Practical review

1. **Describe** the behaviour of the coloured salt water when it was poured into the large container.
2. **Describe** the behaviour of the coloured water that came from thawing the ice when it was poured into the large container.
3. **Compare** the ways in which the solution and water from the ice behaved.
4. **Propose** why the two solutions behaved in this way.
5. **Explain** how this experiment is relevant to the effect of polar ice on the Arctic or Antarctic Oceans.
6. a **Construct** a conclusion for your investigation.
   b **Assess** whether or not your hypothesis was supported.

STUDENT DESIGN

2 Carbon dioxide and air temperature

Purpose

To investigate the effect of carbon dioxide on air temperature.

SAFETY

A risk assessment is required for this investigation.

Materials

- as selected by students

Procedure

1. Design an experiment that investigates the effect of carbon dioxide on air temperature.
2. Brainstorm in your group and come up with several different ways to investigate the problem. Select the best procedure and write it in your workbook. Draw a diagram of how you intend to proceed.
3. Before you start any practical work, assess all risks associated with your procedure. For all chemicals (including carbon dioxide) refer to their MSDS. Construct a risk assessment that outlines these risks and the precautions you need to take to minimise them.
4. Show your teacher your procedure and your risk assessment. If your teacher approves, then collect all the required materials and start work.

Hints

You will need to decide on:

- the source of carbon dioxide to be used in your experiment
- what is going to be measured and how it will be measured.

Practical review

1. **Construct** a conclusion for your investigation.
2. **Evaluate** your procedure. Pick two other prac groups and **evaluate** their procedures too, identifying their strengths and weaknesses.

STUDENT DESIGN

3 Water temperature and survival

Purpose

To investigate the effect of rising temperature on the survival of aquatic life.

SAFETY

A risk assessment is required for this investigation.

Materials

- as selected by students

Procedure

1. Design an experiment that investigates the effect of temperature on the survival of aquatic life.
2. Brainstorm in your group and come up with several different ways to investigate the problem. Select the best procedure and write it in your workbook.
3. Before you start any practical work, assess all risks associated with your procedure. For all chemicals (including carbon dioxide) refer to their MSDS. Construct a risk assessment that outlines these risks and the precautions you need to take to minimise them.
4. Show your teacher your procedure and your risk assessment. If your teacher approves, then collect all the required materials and start work.

Hints

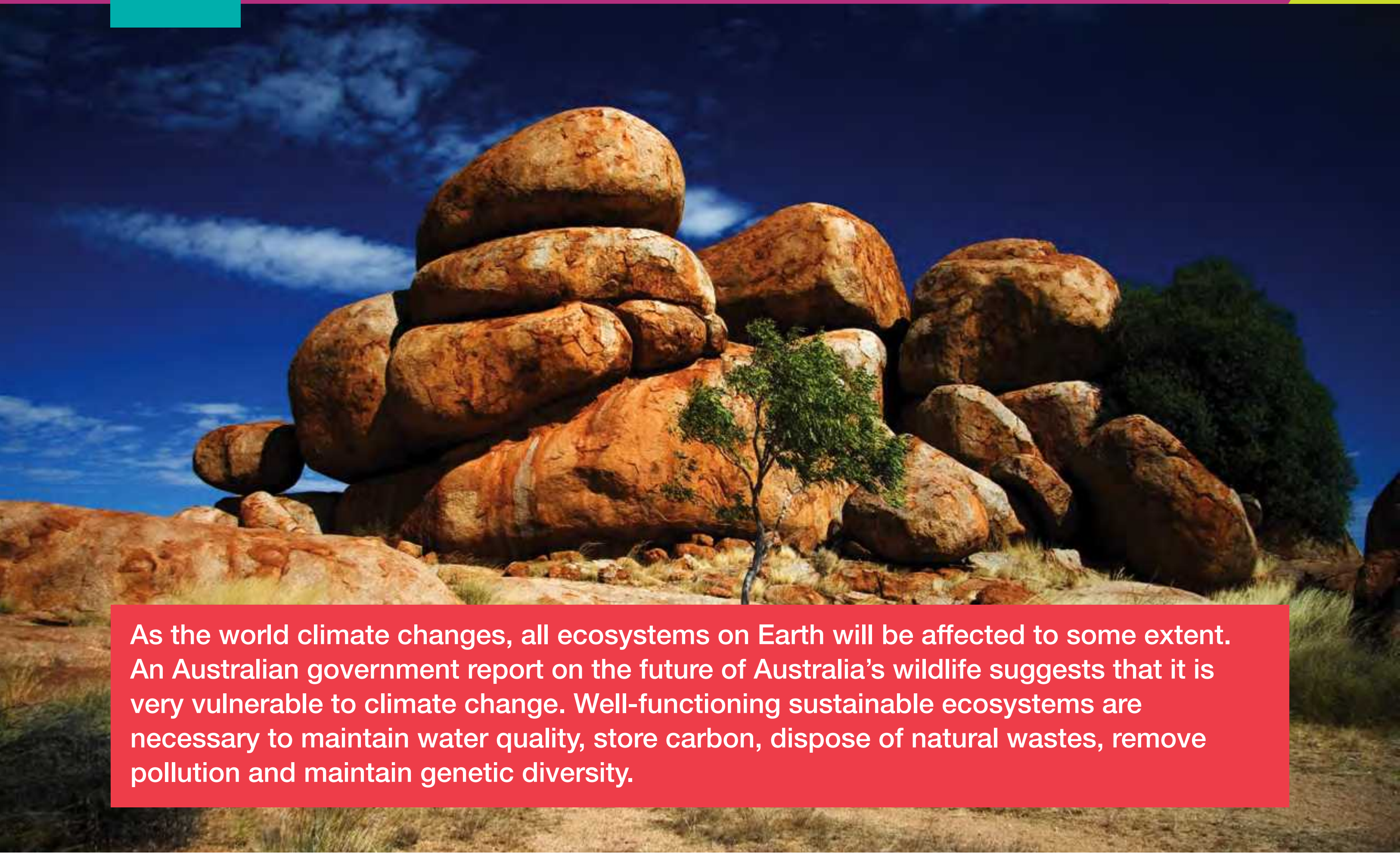
You will need to decide on:

- whether you are going to use sea water or fresh water
- the temperatures you are going to use—you could use 2°C increments from the 'normal' temperature of the water source
- the living things you are going to use in the experiment
- what you are going to measure and how it will be measured.

Practical review

1. **Construct** a conclusion for your investigation.
2. **Evaluate** your procedure. Pick two other prac groups and **evaluate** their procedures too, identifying their strengths and weaknesses.

6.4 Changing environments



As the world climate changes, all ecosystems on Earth will be affected to some extent. An Australian government report on the future of Australia's wildlife suggests that it is very vulnerable to climate change. Well-functioning sustainable ecosystems are necessary to maintain water quality, store carbon, dispose of natural wastes, remove pollution and maintain genetic diversity.

Predictions

Many different computer models of climate change have been created. They produce different outcomes. However, they agree that not all parts of the world will be affected in the same way. The models predict that the oceans will not warm as much as the land. The greatest increase in temperature will be in the northern parts of the northern hemisphere. Areas near the Antarctic and in the far north of the Atlantic Ocean are predicted to have the smallest temperature increase.

The area of land covered in snow will decrease and the amount of sea ice at both poles will be reduced. Satellite data have shown that the extent of Arctic sea ice has decreased by 2.7% each decade since 1978.

The number of extreme weather events such as heatwaves and tropical cyclones (such as the one in Figure 6.4.1) will increase.

Precipitation will increase towards the poles, but in subtropical areas such as the Mediterranean, parts of Queensland and Western Australia the rainfall will decrease.

Figure 6.4.1 Tropical cyclone Yasi destroyed much of the Queensland town of Tully in 2011.

6.5

SciFile

Save the whales

A lack of iron in the waters of the Southern Ocean inhibits the growth of phytoplankton (photosynthesising plankton). Twelve thousand sperm whales live there, releasing 50 tonnes of iron each year in their faeces. This iron means the plankton flourish and through photosynthesis use 400 000 tonnes of carbon dioxide—twice as much as the whales produce through respiration. The presence of the whales therefore helps take carbon dioxide out of the atmosphere.

Who will survive?

The history of the Earth reveals that climate change in the past has caused many species and entire ecosystems to become extinct. About 14 700 years ago, Earth's temperature rose by 10°C. At that time, many of the megafauna of North America such as mammoths, mastodons and giant sloths (Figure 6.4.2) began to disappear. There is debate about whether climate alone caused those extinctions or whether hunting by early humans was a contributing factor.

About 56 million years ago many large mammals disappeared due to a 7.2°C rise in temperature caused by a natural release of methane from marine sediments. Humans were not around at this time.

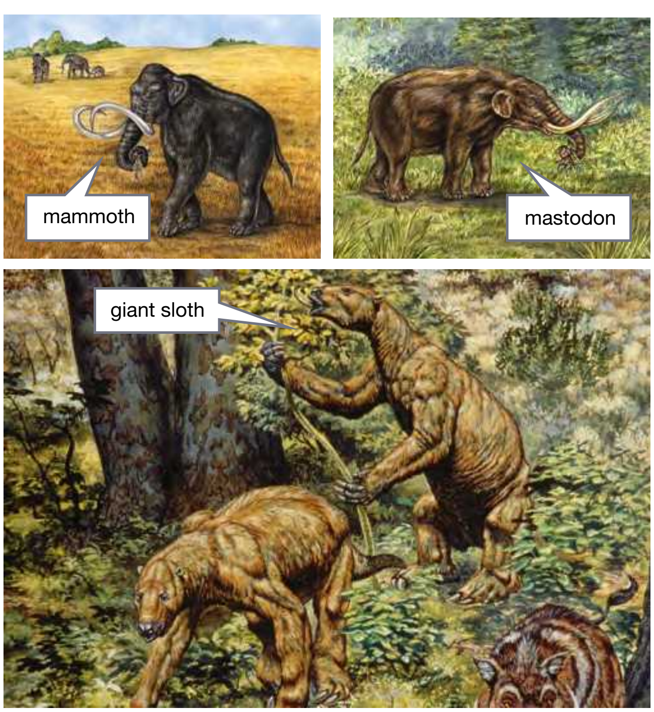


Figure 6.4.2 Extinction of the megafauna of North America may have been due to a rise in temperature as the last Ice Age came to an end.

Not all plants and animals die out when the temperature changes. When the climate warms, species move towards the poles if they are able to. During a period of cooling, they move towards the equator.

Urban development and clearing land for agriculture have destroyed some natural ecosystems and divided others into small fragments. This makes it more difficult for organisms to move away from areas that are no longer suitable.

Climate change and the destruction of ecosystems by human activity has led to a decrease in biodiversity. **Biodiversity** is the variety of ecosystems in the biosphere, the variety of species within those ecosystems and the genetic variation within those species.

Australia is very biodiverse. It is one of 17 countries that together contain more than 70% of all species found on Earth. Many species found here are unique to Australia. About 85% of Australia's terrestrial mammals, 91% of flowering plants, and 90% of reptiles and frogs are found nowhere else in the world. More than 50% of the world's marsupial species occur only in Australia.

GO TO Pearson science NSW 9 Unit 8.2

Great Barrier Reef

Corals are very sensitive to small changes in temperature. An increase in temperature of only 1–1.5°C above the summer average maximum can cause severe stress to the coral.

The health of coral reefs depends on the symbiotic relationship between the coral and unicellular, photosynthetic protists that live within their cells. As well as providing essential nutrients, these protists give corals their distinctive colour. An example is shown in Figure 6.4.3.

Figure 6.4.3 Healthy corals owe their colour to the protists that live within their cells.

When the coral is stressed, it expels the protists. The coral becomes lighter in colour—it is bleached. A bleached coral can be seen in Figure 6.4.4. Once the bleaching has begun, it does not necessarily stop once the stress has reduced. Some corals take months to recover from a bleaching episode. Other corals never recover.

Figure 6.4.4 Coral bleaching is occurring in coral reefs throughout the world. This also affects the fishing and tourism industries.

Bleached corals suffer from a lack of the nutrients that are normally provided by the protists. The corals can no longer compete with faster growing algae. The corals die and the reef is overtaken by algal growth.

A great variety of organisms depend on corals for food and shelter. These organisms will be affected directly by any change in the health of the coral reefs. Many other organisms further along the food chain will be affected indirectly.

Kakadu

Changes to the timing and intensity of fires, rising sea levels and increased storm activity are results of climate change. These could impact on Kakadu National Park in the Northern Territory.

There are large areas of wetland in Kakadu National Park. These wetlands support a large variety of species including many migratory species of bird such as magpie geese (*Anseranas semipalmata*) seen in Figure 6.4.5.

Human activity has significantly reduced many populations of this bird in southern and south-eastern Australia. Looking after the population in Kakadu is a good opportunity to conserve the species. Kakadu wetlands are fresh water. However, many areas are very low lying. A rise in sea level combined with increased storm activity would allow salt water to flood into the area. Organisms that cannot live in saline conditions will disappear from the area. Organisms tolerant of salt will flourish and the ecosystems will change.

Figure 6.4.5 Late in the dry season, millions of magpie geese flock to Kakadu to feed.

Extensive flooding also allows weed species and feral animals from surrounding areas to invade the wetlands. Feral animals such as pigs, cane toads and water buffalo (Figure 6.4.6) already pose problems in Kakadu. Water buffalo damage river banks, causing erosion. The water becomes muddy and unsuitable for the water plants and fish that normally live there. Water buffalo also eat so much that they are in direct competition with native wildlife.

Figure 6.4.6 Water buffalo (*Bubalus bubalis*) wallow in shallow waterholes in Kakadu National Park.

SciFile

More spiders

In West Greenland, higher average temperatures have led to spring arriving more than 20 days earlier than usual, giving wolf spiders more time to hunt. The average size of female spiders has increased and it is likely they will lay more eggs, leading to an explosion in the spider population in Greenland.

Species on the move

The long-spined sea urchin *Centrostephanus rodgersii* is shown in Figure 6.4.7. It is a very common species in the temperate waters of south-eastern Australia. It appears to be moving down to Tasmania, where it could damage shallow reef ecosystems and the commercial abalone and rock lobster industries. Scientists believe that a strengthening of the East Australian Current resulting from climate change is carrying the larvae south.

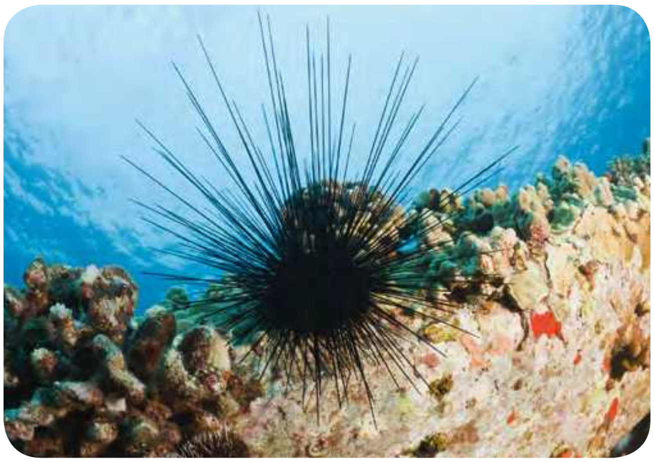
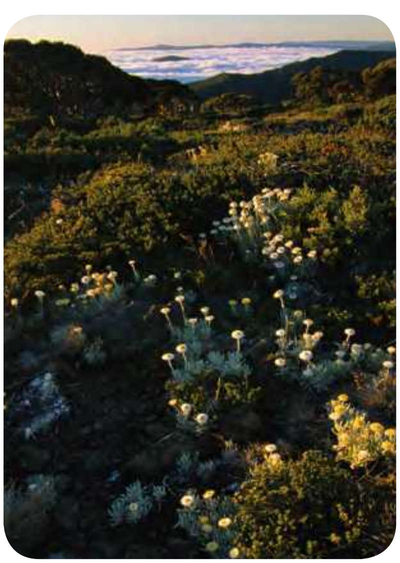


Figure 6.4.7 Long-spined sea urchins are moving south, a change that may be a response to rising sea temperatures.

In the Australian Alps kookaburras are hunting at higher altitudes and preying on alpine skinks. The alpine skinks do not recognise the kookaburras as predators and do nothing to avoid them. As a result, the alpine skink population will decrease.

Swamp wallabies and red-necked wallabies are also moving further up to graze on the herb fields high in the Australian Alps. Many plant species in the herb fields (Figure 6.4.8) will not survive continuous grazing, and biodiversity of the area will decrease.



6.6

Figure 6.4.8 Mountain ecosystems such as these herb fields survive under extreme conditions. They are very vulnerable to any added stress such as grazing.

Change in sea level

Geological history shows that sea levels have been both higher and lower than they are today. About 18 000 years ago, sea levels were about 120 metres lower. In the past 7500 years, sea levels have risen about 5.8 metres—that is about 2.5 cm every 30 years. This is a natural part of being in an interglacial warming period.

If all the ice on land on Earth were to melt, the sea level would rise about 70 metres. However, no climate change model has suggested that this could happen. Most cities are on the coast and therefore any rise in sea level is of concern. When sea levels rose in the past, cities like Sydney and Melbourne, London and New York did not exist. The industry, roads, houses, apartments and businesses you can see in Figure 6.4.9 were not in place then. As the water rose, animals moved out of the way and any early humans went with them. As the sea level fell again, they moved back to the newly exposed land. Skyscrapers, homes and businesses will not be able to be moved out of the way of the sea, so the economic impact will be huge.

Prac 1 p237 6.7 6.8

Figure 6.4.9 Development in coastal areas means that any future change in sea level will have a significant economic impact. The Gold Coast, pictured here, is at particular risk.

SciFile

Early spring

Scientists in Europe's International Phenological Gardens record the date when each tree and shrub buds, blossoms and loses it leaves each year in the gardens. These observations show that between 1959 and 1996 the growing season lengthened by eleven days with spring coming earlier. In response to the earlier spring, some migratory birds are changing the time they start their migration.

LEARNING ACROSS THE CURRICULUM

SUSTAINABILITY

Figure 6.4.10 Worldwide, millions of tonnes of carbon dioxide are produced by human activity every day.

REDUCING CARBON DIOXIDE

If carbon dioxide is contributing to climate change to the extent that most scientists believe, then reducing the amount of carbon dioxide in the atmosphere should be a priority.

The direct approach to reducing carbon dioxide is to reduce the amount entering the atmosphere from the burning of fossil fuels such as coal and oil (Figure 6.4.10). An alternative approach is to use a natural means of removing carbon dioxide from the atmosphere. Increasing the number of photosynthetic organisms in the environment will increase the amount of carbon dioxide being taken from the atmosphere and in some cases store it away for a long time.

About half of a tree's mass is carbon, so large amounts of carbon are stored in forests. The larger the tree, the more carbon is stored in it. For example, a small Eucalyptus tree with a trunk circumference of 100 cm stores about 320 kg of carbon. A tree of circumference 300 cm contains about 5540 kg of carbon. To store this much carbon, these trees would have absorbed about 1180 kg and 21 320 kg of carbon dioxide respectively. This is equivalent to the amount of carbon dioxide produced when 500–9035 L of petrol is burned. Just think how much carbon would be stored in some of the giant Eucalyptus trees in old-growth forests. Some of them have trunks with circumferences of 40 metres (Figure 6.4.11).

Governments are putting in place schemes in which people can buy carbon credits. In these schemes, people and industries plant trees for the sole purpose of reducing the amount of carbon dioxide in the atmosphere. One carbon credit is the equivalent of reducing the amount of carbon dioxide in the atmosphere by 1 tonne. That is enough carbon dioxide to fill a swimming pool 10 metres wide, 25 metres long and 2 metres deep.

Figure 6.4.11 This Eucalyptus (*E. regnans*) is 79 metres tall and stores a large amount of carbon.

In this way, an industry can balance the carbon dioxide it produces with the carbon it has stored. The effect is that no extra carbon has gone into the atmosphere.

The carbon is then stored in the trees and will remain there as long as the tree lives or as long as the wood in the tree is still intact, as in a building or furniture.

REVIEW

1 **Explain** how planting trees can reduce the amount of carbon dioxide in the atmosphere.

2 **Recall** which part of a tree stores most carbon.

3 **Explain** the concept of carbon credits and how they could reduce the level of global warming.

6.4 Unit review

Remembering

1 **List** the effects of climate change in the past.

2 **State** the source of evidence used by scientists to suggest that sea levels were higher in the past.

3 **List** the effects of climate change that are predicted to occur in Kakadu National Park.

Understanding

4 **Explain** how animals in natural ecosystems are likely to respond to rising sea levels.

5 **Explain** why it is difficult for animals to move to new areas when climate change makes their present habitat unsuitable.

6 a **Describe** what happens to corals when they are bleached.
 b **Explain** why bleaching leads to death of the coral.

7 **Explain** why an unusually high rise in sea levels caused by onshore winds could have a negative impact on the Kakadu wetlands.

8 a **Define** the term *biodiversity*.
 b **Explain** why protecting Australia's biodiversity is important.

Applying

9 **Use** examples to **describe** how climate change in the past has caused the extinction of animals.

10 Long-spined sea urchins have free-swimming larvae and these are carried south in currents. **Use** this information to **predict** possible effects of climate change on the distribution of other organisms such as corals and starfish that also have free-swimming larvae.

Analysing

11 **Compare** the potential effects on climate change on the Snowy Mountains with what might happen to the coast of NSW.

Evaluating CCT

12 **Propose** possible effects on migratory birds if wetlands such as those in Kakadu National Park were to change significantly or disappear altogether.

13 A mutualistic relationship is one in which both organisms benefit from the relationship. **Deduce** the benefits for the mutualistic relationship between protists and corals for the:
 a corals
 b protists.

14 a For each case below, **propose** which organism is more likely to survive a change in climate.
 b **Justify** your response.
  i a plant with seeds that are dispersed by wind
  OR
  a plant that depends on animals for seed dispersal
  ii an animal that produces a large number of offspring each year
  OR
  an animal that produces one offspring every two or three years
  iii plants that have very specific environmental needs
  OR
  plants that survive in a wide range of habitats

15 **Propose** what would control how far south the long-spined sea urchin shown in Figure 6.4.7 on page 233 could move and become established in large populations.

16 **Deduce** the effect on other predators of the movement of kookaburras up the slopes of the Australian Alps.

17 The short-term effect of wallabies moving up slopes in response to warmer temperature is increased grazing on the fragile herblands. **Propose** the long-term effects on the area.

Creating CCT

18 **Construct** a consequence wheel for the global implications (potential results) of reduced biodiversity.

You might like to use a program such as Popplet to help you organise your ideas.

19 **Construct** a flow diagram of possible changes for an area where the top predator (assume it is a second-order consumer) has moved away and has not been replaced.

6.4 Unit review

Inquiring

1 Use the key words *rising sea level animation* to find maps and artists' impressions of what will happen if sea levels rise due to global warming. ICT

2 Investigate plants or animals in your area that are classified as endangered or vulnerable.
- Make a list of the vulnerable or endangered plants or animals in your area.
- Select one of these organisms and investigate the reasons why it is endangered or vulnerable.
- Propose the effect on this organism of climate change.

Present your findings as a design for a webpage that addresses the three tasks above. ICT

3 Research technologies that are aimed at reducing carbon pollution. Carbon capture, sequestration and 'clean coal' are three possible starting points.

Present your findings to the class in a poster or audio-visual presentation.

4 Access a map of your local area. The map should cover an area that is about 100 km by 100 km. Research the native animals that live in your local area. Use the map to identify where a colony of a particular animal might live.

a Investigate what could happen to this animal if conditions in its present habitat were no longer suitable.

b Design a scheme to help this animal survive changing conditions.

Present your findings as a report to a wildlife preservation agency.

ADDITIONAL

5 Climate change is a worldwide phenomenon; therefore, climate change and its effects on biodiversity cannot be addressed by Australia on its own. International agreements are required.

Research:
- the 1987 Montreal Protocol and the 1997 Kyoto Protocol
- the 2009 United Nations Climate Change Conference and similar conferences held recently
- the four Intergovernmental Panel on Climate Change reports
- the implications that these treaties have for Australia and for other signatory nations.

Present a report on the international response to climate change and the challenges that face the Australian Government when trying to deal with climate change.

6 Find how computer modelling has improved our:
- knowledge of atmospheric pollution, ocean salinity and climate change
- ability to predict changes in the above.

Present your research in digital form. ICT

ADDITIONAL

Figure 6.4.12

The grey brolga (*Grus rubicund*) was once found all over Australia. It is still common in the northern tropics but loss of their wetland habitat has caused them to become endangered in NSW.

6.4 Practical investigations

1 Where will the sea go?

Purpose

To investigate the effect on Australia of rising sea levels.

Materials

- access to Google Earth
- map of Sydney, Newcastle, Wollongong or of a coastal town in NSW or elsewhere in Australia

Figure 6.4.13

Procedure

1 Draw an outline of the map, showing the coastline.
2 List important features of the city such as commercial and administrative areas, centres for transport and shops, education centres and major housing areas.
3 Mark these on your map.
4 Using Google Earth, find the elevation of these features.

Results

Using the elevations, shade the map to show the areas that would be inundated by sea water if there was a 5 metre, 10 metre and 15 metre rise in sea level.

Practical review

1 **Propose** the changes to the function of your city that would be caused by an increase in sea level of:
   a 5 m
   b 10 m
   d 15 m.
2 **Describe** the characteristics of the areas of the city that would be unaffected by the changes in sea level.
3 **Discuss** whether your city would be able to function if there was a rise in sea level.
4 **Propose** some wider effects of the changes to your city.
5 **Propose** strategies that would ensure that your state could continue to function.

6 Chapter review

Remembering

1 **Name** two substances that cycle through a natural ecosystem.

2 **Name** two major natural cycles that keep matter cycling through the environment.

3 **State** whether the following are true or false.

a Tropical cyclones form in the atmosphere but affect the other three spheres.

b The climate of Australia varies from day to day.

c The forests of the Amazon jungle reflect more of the Sun's energy than the polar ice caps.

d Large ash clouds from volcanoes can affect the weather years into the future.

Understanding

4 **Describe** the possible effects of earthquakes on the lithosphere.

5 **Outline** the information about past conditions scientists gather from ice cores.

6 Some people say that current global warming is entirely due to human activity, but others disagree. They believe it is a natural process. **Discuss** why different people have different views on the cause of current change in world climate.

Applying

7 **Identify** two ways in which greenhouse gases can be reduced.

8 A suggested strategy for reducing the impact of carbon emissions is to plant trees. **Demonstrate** why this is a useful strategy.

Analysing

9 A single cow produces more than 250 litres of methane every day. The number of cattle in Australia varies with conditions of rain and drought. Using 22 million as the cattle population, **calculate** the amount of methane produced by Australian cattle in: N

a 1 day

b 1 year.

10 **Compare** the greenhouse effect and the enhanced greenhouse effect.

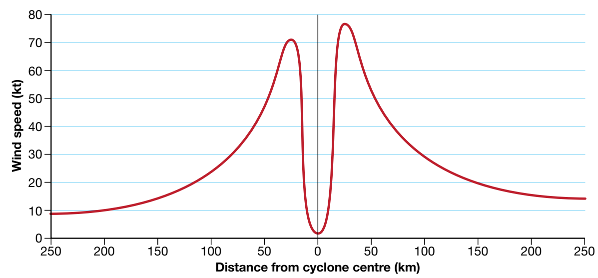
11 An Australian scientist was told by a person with no knowledge of climate science that *Studying ocean currents seems pointless because they could not affect us.* **Analyse** this statement.

Evaluating CCT

12 a **Analyse** the nitrogen cycle, identifying areas where human activity may have an impact on it.

b **Propose** possible effects these human activities may have.

13 The graph below shows the mean (average) wind speeds at different distances from the eye of a typical tropical cyclone.



a Wind speed here is given in knots. For a typical tropical cyclone, **determine**:

i the highest mean (average) wind speed in knots and km/h (1 knot = 1.85 km/h) N

ii the distance from the eye that this wind speed occurs.

b **Assess** whether it is safe to go outside when the eye of a cyclone is directly overhead.

14 a **Determine** whether you can or cannot answer the questions on page 202 at the start of this chapter.

b **Use** this to **assess** how well you understand the material presented in this chapter.

Creating CCT

15 **Construct** a diagram of the carbon cycle. **Label** the diagram to show where:

a the carbon moves quickly from one part of the cycle to the next

b carbon moves more slowly

c there are carbon sinks.

16 **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter.

greenhouse effect
global warming
nitrogen cycle
lithosphere
biosphere
hydrosphere
atmosphere
carbon cycle
climate change
enhanced greenhouse effect

6.9

Thinking scientifically

Q1 Table 6.6.1 presents data on changes in water consumption in different sectors of Australian society for the years 1996–97 and 2000–01. CCT

Table 6.6.1 Water consumption by selected industries and sectors, 1996–97 and 2000–01

Sector	Annual water consumption (GL)	
	1996–97	2000–01
Forestry and fishing	19	23
Mining	570	401
Manufacturing	728	866
Electricity and gas supply	1308	1688
Household	1829	2181

Calculate the percentage increases in water consumption and deduce which two sectors had the greatest increase in water consumption over this time.

A manufacturing and household
B mining, and electricity and gas supply
C electricity and gas supply, and household
D forestry and fishing, and manufacturing

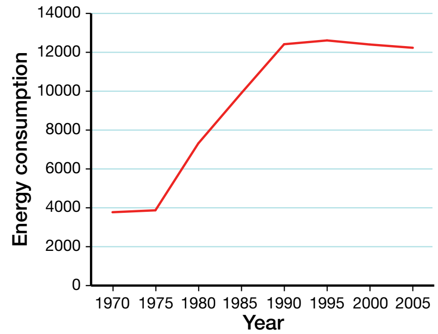
Q2 Table 6.6.2 provides data on energy use per head of population for the United Arab Emirates, one of the major oil-producing nations of the world. CCT

Table 6.6.2 Energy use per head of population for the United Arab Emirates

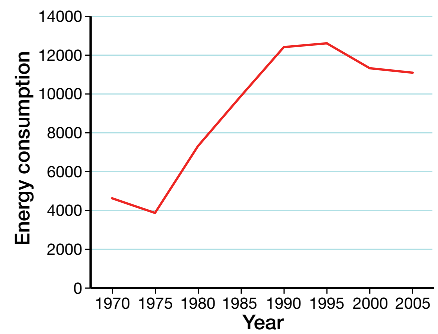
Year	Energy consumption per head of population (kg oil equivalent)
1971	3774
1975	3871
1980	7315
1985	9892
1990	12416
1995	12611
2000	11401
2005	11133

Which graph best represents the data in the table?

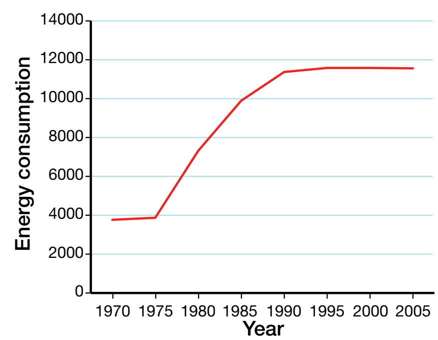
A



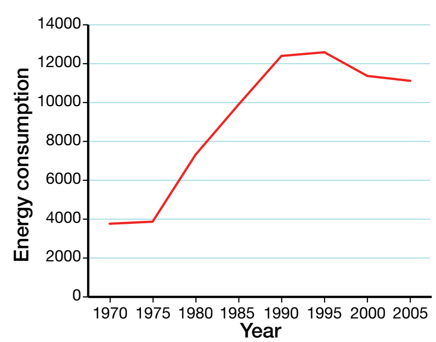
B



C



D

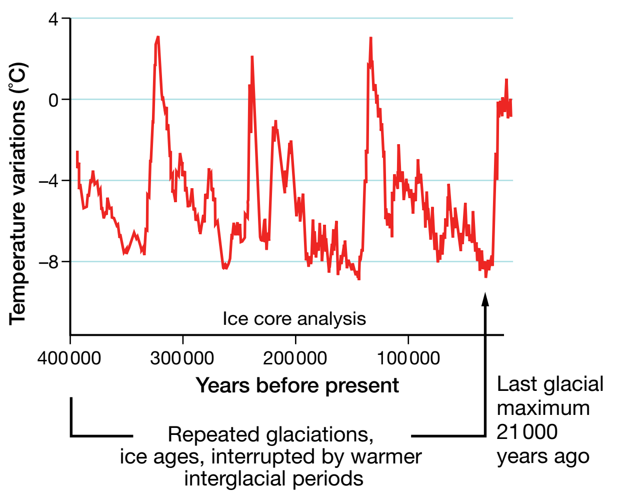


Q3 Use the data in Table 6.6.2 to determine the 10-year period that saw the greatest change in energy use. CCT

A 1975–85
B 1980–90
C 1985–95
D 1990–2000

Thinking scientifically

Q4 The graph below shows the variation in average world temperature for the past 400 000 years. CCT



Based on the information in the graph, which of the following is not a true statement?

A Earth is currently in a period of global warming that started about 20 000 years ago.

B There have been four periods of glaciation in the past 400 000 years.

C The current period of global warming has had the greatest increase in temperature of those experienced in the past 400 000 years.

D The longest period of low average temperatures was in the ice age preceding the current period of global warming.

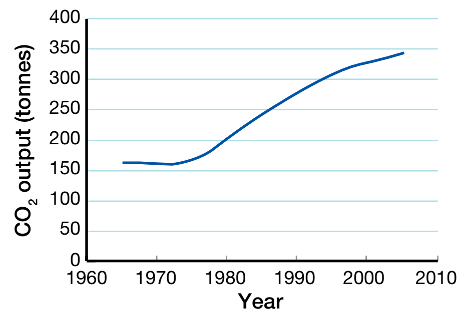
Q5 Table 6.6.3 shows the population and carbon dioxide output per head of population in Australia from 1965 to 2005. CCT

Table 6.6.3 Population and carbon dioxide output per head of population in Australia 1965–2005.

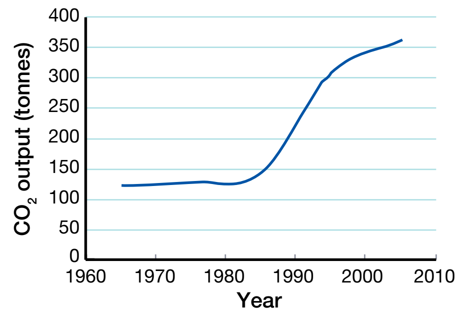
Year	Population (millions)	CO_2 output (metric tonnes per head of population)
1965	11.5	10.6
1975	14	11.9
1985	16	15.2
1995	18	17.1
2005	20	18.1

Which of the following graphs best represents the change in total carbon dioxide output for the nation?

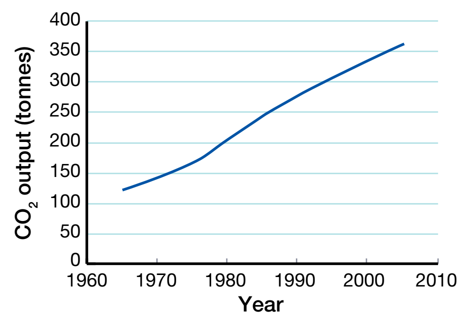
A



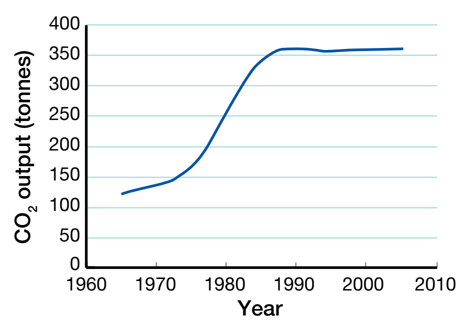
B



C



D



Q6 Use the data in Table 6.6.3 to calculate the decade in which Australians had the largest increase in carbon dioxide output per head of population. CCT

A 1965–75

B 1975–85

C 1985–95

D 1995–2005

Glossary

Unit 6.1

Atmosphere: the layers of gases surrounding the planet

Biosphere: all living things on Earth

Carbon cycle: the process by which carbon is recycled through the soil, water, living things and the atmosphere

Denitrifying bacteria: bacteria that convert nitrates back into gaseous nitrogen (N_2), which is then released back into the atmosphere

Fossil fuels: fuels that contain the carbon of plants and animals that died and were preserved millions of years ago

Fossils: the preserved remains of once-living organisms

Hydrosphere: all the liquid water on the Earth's surface

Liquefaction: a process in which soils lose their strength and behave as a liquid

Lithosphere: the land masses on Earth

Nitrogen cycle: the process by which nitrogen cycles between the living and non-living environments

Nitrogen-fixing bacteria: bacteria that absorb nitrogen from the air and convert it into ammonia and then into nitrates

Photosynthesis: process by which green plants and some other organisms use sunlight to synthesise glucose from carbon dioxide and water; it generally involves the green pigment chlorophyll and generates oxygen as a by-product

Respiration: process occurring within living cells by which chemical energy is released in a series of metabolic steps involving the consumption of oxygen and the release of carbon dioxide and water

Sustainable ecosystems: ecosystems that are diverse and provide for the needs of the organisms that live there

Sustainable ecosystems

Unit 6.2

Climate: the long-term averages of weather conditions

Climate change: change to the averages of aspects of climate that persist for decades or longer

Global conveyor belt: common name for the thermohaline circulation

Global warming: a time when the average world temperature is increasing

Greenhouse effect: the warming of Earth caused by greenhouse gases

Greenhouse gases: gases that trap heat close to the Earth's surface

Gyres: the circular patterns shown by the ocean currents in the major ocean basins

Interglacials: periods between glaciations

Ocean currents: continuous movements of ocean water

Thermohaline circulation: scientific term for the *global conveyor belt*, a continuous circulation of water that can be tracked around the whole Earth

Weather: the conditions in the atmosphere

Thermohaline circulation

Unit 6.3

Enhanced greenhouse effect: an increase in the natural greenhouse effect caused by human activity

Permafrost: areas on Earth where the temperature in layers of soil or rock beneath the surface never rises above freezing point

Permafrost

Unit 6.4

Biodiversity: the variety of ecosystems in the biosphere, the variety of species within those ecosystems and the genetic variation within those species

SCIENCE TAKES YOU PLACES

Look who is using science

COMPETITION SAILOR

My name is Cam Parsons and I am a competition sailor. I've represented Australia in a Youth World Title in Croatia and competed in a number of national events.

Competition sailors rely heavily on physics concepts. To keep the boat upright, we must counterbalance the force of the wind with our body weight. To turn the boat, we have to change the angle that the blades of the boat cut through the water. We can also turn by changing how the boat is sitting in the water. For example, if we lean the boat over, then it will change direction. Moving our weight back and forth also changes the speed at which the boat moves.

I like sailing because I travel to different places. Every time I go out it is different, every time a new experience. I also have many friends within the sailing community from all over Australia and the world.

ASTRONOMER

I am Dr John O'Sullivan. In 2009, I won the Prime Minister's Prize for Science. After I completed a double degree in physics and electrical engineering, I went on to study for a PhD in radio astronomy. This is the field of science that uses radio waves to learn about stars and galaxies.

In the 1980s, while I was working with a team that was searching for exploding black holes, I started working on a technique that allowed complex radio signals to be split up, transmitted and recombined. About 10 years later, we discovered that this same idea could be used to greatly speed up radio signals between computers, mobile phones and other electronic devices.

Today, almost every wireless (WiFi) network system in the world uses the technology that was originally inspired by a search for exploding stars. One estimate has suggested that almost a billion people around the world use our invention every day!

These days I am working on Australia's attempt to build the largest telescope ever constructed—the Square Kilometre Pathfinder Telescope.

CIVIL ENGINEER

My name is Melanie Mindum and I am a civil engineer. A civil engineer puts structures in place that help people move around. We design bridges, plan road and railway links and map drainage systems so that our streets don't flood.

Recently I worked on a project that recommends where power and water services will be positioned in a new housing area. I have also designed railway lines and tram super stops that allow better access for people in wheelchairs, and upgraded railway level crossings to make them more obvious to drivers.

A civil engineer focuses on the needs of today's society, but must also ensure that what is designed now will be sustainable for the future. I enjoy my work because I like dealing with numbers and budgets and thinking logically about how to solve a problem.

7 The universe

Have you ever wondered...

- how far away the stars are?
- how astronomers have worked out the history of the universe?
- how the universe began?
- how old the universe is?

After completing this chapter students should be able to:

- identify that all objects exert a gravitational force on each other
- outline major features of the universe, including galaxies, stars, solar systems and nebulae
- describe the sizes and distances between structures in the universe N
- describe technological developments that have advanced understanding about the universe CCT L
- outline how ideas about the origin of the universe have changed over time CCT
- explain the origins of the universe and its age using the Big Bang theory CCT L

ADDITIONAL

- describe how colours of stars relate to their age, size and distance from Earth
- describe evidence used to support estimates of time in the universe DD
- describe some recent contributions made by Australian scientists in the exploration and study of the universe DD
- outline examples where advances in science generate new career opportunities in areas such as astrophysics and space science. WE

7.1 Stars

Astronomy is the study of stars. Not all stars are like our Sun. Like people, stars can vary in age, size and appearance. Understanding the differences between stars will help us understand our universe.

INQUIRY science 4 fun

Eye parallax

YES

Do this …

1 Place an object on a table about arm's length in front of you.

2 While looking at the object, close or cover your left eye. Note the position of the object relative to its background.

3 As quickly as possible, close or cover your right eye while you open your left eye. Note how the position of the object changes.

4 Quickly swap back to looking with just your right eye. Swap from one eye to the other as quickly as possible. Note how the position of the object changes against its background as you change from one eye to the other. This apparent change in position is parallax.

5 Repeat this process with an object about 2 metres away.

6 Repeat the process with an object at the other side of the room and then with a distant object (for example, through a window).

Record this …

Describe what happened. Was the effect for more distant objects greater or smaller than for closer objects?

Explain why you think this happened. Use a diagram to help you.

The distances between stars

The distances between stars are enormous. The closest star to us (other than our Sun) is Proxima Centauri. It is about 4×10^{13} km (40 000 000 000 000 km) away. Distances such as these mean that the kilometre is not a convenient unit of length in astronomy. Astronomers often measure interstellar distances (the distances between stars) in **light-years (l.y.)**. One light-year is the distance that light will travel in one year. This distance is a little under 9.5 trillion (9.5×10^{12}) kilometres. The distance to Proxima Centauri is 4.2 l.y. This means that the light you see when you look at Proxima Centauri was emitted by the star nearly 650 years ago. Looking at stars is like looking backwards in time!

Another commonly used astronomical unit of length is the **parsec** (pc), which is equivalent to 3.26 light-years.

7.1

Converting between light-years and parsecs

To convert from light-years (l.y.) into parsecs (p.c.), divide by 3.26:

$$\text{distance in parsecs} = \frac{\text{distance in light-years}}{3.26}$$

To convert from parsecs to light-years, multiply by 3.26:

distance in light-years = distance in parsecs × 3.26

WORKED EXAMPLE
Converting between light-years and parsecs

Problem 1

The star Betelgeuse is 650 light-years away. Calculate how many parsecs this represents.

Solution

$$\text{Distance in parsecs} = \frac{650}{3.26} = 199 \text{ pc}$$

Problem 2

Beta Centauri is 107 parsecs away. Calculate how many light-years this represents.

Solution

Distance in parsecs = 107 × 3.26 = 349 l.y.

Practice

N

1 **Calculate** what the following distances would be in parsecs:
   a Proxima Centauri, 4.2 l.y. away
   b the Horsehead nebula, 1500 l.y. away
2 **Calculate** what the following distances would be in light-years:
   a Rigel, 264 p.c. away
   b Antares, 10 p.c. away

Parallax

The parsec is based on a phenomenon known as **parallax**. Parallax causes you to see different views of the same object. Shut one eye, open it, then shut the other and you will see slightly different views of the same scene. This is parallax! Parallax can be used to measure the distance between the Sun and other stars. As the Earth moves around the Sun, our changing point of view means that the positions of stars in the sky change very slightly over the course of the year. This is shown in Figure 7.1.1.

Prac 1 p250

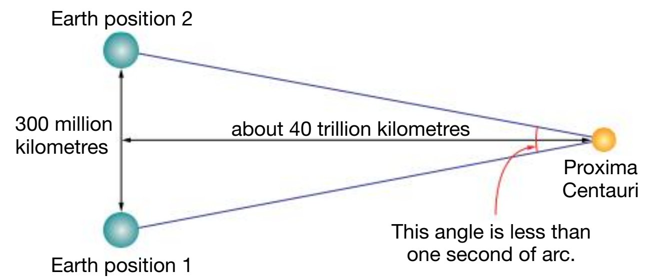


Figure 7.1.1 The position of Proxima Centauri in the sky changes slightly due to the Earth's movement around the Sun. This diagram is not to scale.

Even for the closest stars, this shift in position (known as **stellar parallax**) is tiny—less than one-thousandth of 1 degree. It is only since the 19th century that astronomers have had instruments sensitive enough to reliably measure stellar parallax and calculate the distance to the nearest stars. Many stars are so far away that their stellar parallax is too small to be measured. Astronomers need to use more indirect methods to measure the distances to these stars.

SciFile: Tiny angles

The closer a star is to our Sun, the bigger the parallax. The closest star to our Sun is Proxima Centauri, 4.2 light-years away. This corresponds to a parallax of about 0.0004 degrees—a very small angle to measure!

Gravity and the universe

Gravity is the force of attraction experienced between any two objects in the universe. It is the force that drives the universe.

Gravity is an extremely weak force that depends on the masses of the two objects. These masses need to be incredibly large for the force to become significant. For example, the force of gravitational attraction between you and a person sitting next to you is less than 1 μN—this is one-millionth of a newton. Compare this with the weight of a tennis ball, which is about 0.5 N—no wonder you don't feel the attraction!

When one of the objects is as massive as a star, gravity can become an extremely strong force. It also creates pressures within the star so immense that the atoms of hydrogen at the star's centre become fused together to form atoms of helium. This process of atoms fusing together is known as **nuclear fusion**. Nuclear fusion produces the enormous amounts of heat and light that causes stars to glow.

Unit 7.2
Pearson science NSW 9 Unit 2.4

The structure of any star is determined by the balance between two opposing forces:

- the inwards force of gravity, which causes the material within the star to fall towards its centre
- the outward force that results from pressure caused by the heat radiated from nuclear fusion in the star. This pressure is called **radiation pressure**.

Each star has a different balance point, depending on its size. This gives rise to a variety of different types of star—from average-sized stars like our Sun to massive red giants and blue supergiants (Figure 7.1.2).

Figure 7.1.2 Stars come in different varieties depending on their size—these stars are the blue supergiant star Iota Leporis and the red giant RX Leporis.

Formation of the Sun

Gravity is also responsible for creating stars from the huge clouds of interstellar gas known as **nebulae**. You can see a nebula in Figure 7.1.3.

For example, 4.5 billion years ago the region of space now occupied by our solar system was filled with a featureless cloud of gas. Most of this gas was hydrogen, with small amounts of helium and heavier elements such as carbon and iron.

Figure 7.1.3 These 'pillars' in the spectacular Eagle nebula are thought to be the birthplaces of new stars.

The slow pull of gravitational forces acting over enormous periods of time caused the cloud of gas to gather into a large clump known as a **protostar**. This protostar would eventually become our Sun. Material that was too far away from the Sun to be drawn into it clumped together to form the planets. Figure 7.1.4 shows four stages of the formation of the Sun and its solar system.

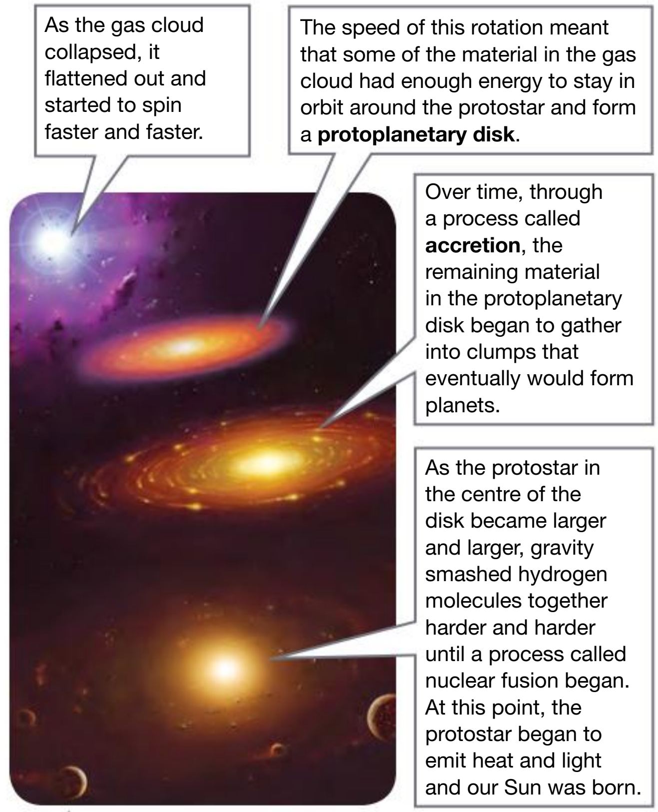


Figure 7.1.4 How the solar system is thought to have formed

Galaxies

Although gravity is a relatively weak force, it can act over enormous distances, even the incredible distances between stars. Over billions of years, the gravitational attraction between 'close' stars have caused them to clump together into gigantic structures known as **galaxies**. The size of galaxies vary greatly but all galaxies contain an enormously large number of stars, usually between 10 million (10^7) and a hundred trillion (10^{14}).

Our own Sun is part of a galaxy known as the **Milky Way**, shown in Figure 7.1.5. Beyond the Milky Way, even the closest galaxies are so far away that they show no observable parallax. Instead, alternative techniques need to be used to measure the distances to them.

GO TO Unit 7.3

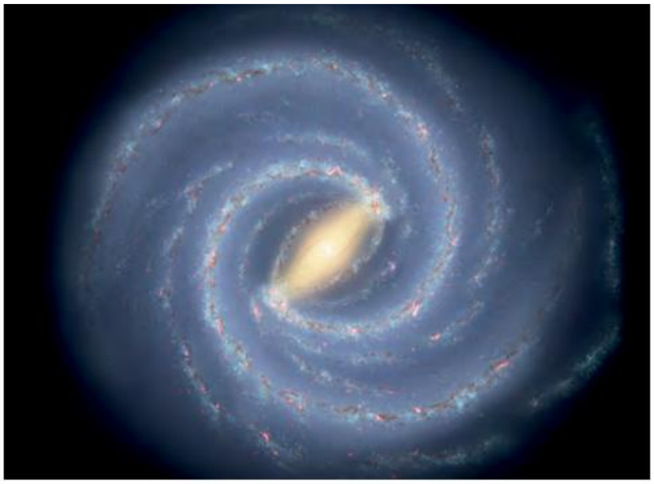


Figure 7.1.5 An artist's impression of what the Milky Way galaxy would look like when viewed from outside.

Black holes

Perhaps the most spectacular gravitational phenomena in the universe are known as **black holes**.

The gravitational field of a black hole is so strong that not even light is fast enough to escape from it. This makes black holes hard to detect as they do not emit any visible light. However, it is possible to find black holes indirectly by the effect they have on other stars. For example, a black hole is easier to detect when it is part of a **binary star system**. This occurs when two stars form close to one another and orbit a common centre of mass between them. If one of these stars becomes a black hole, its enormous gravitational field will start to strip material from the other star. As this material spirals into the black hole, it emits a distinctive high-energy X-ray signal that indicates the presence of the black hole. This process is illustrated in Figure 7.1.6.

Another way to detect a black hole is by a process called **gravitational lensing**. According to Einstein's theory of relativity, the gravitational field around a black hole is so strong that it can distort the shape of space itself. This means that light from a distant star passing either side of the black hole can be bent back towards an observer on Earth. Due to this lensing effect, the observer sees identical stars on either side of the black hole (Figure 7.1.7).

Scientists now believe that most galaxies have an enormous black hole at their centre. These **supermassive black holes** may have masses equivalent to millions or billions of stars the size of our Sun. Evidence suggests that the black hole at the centre of our Milky Way galaxy lies in the constellation Sagittarius.

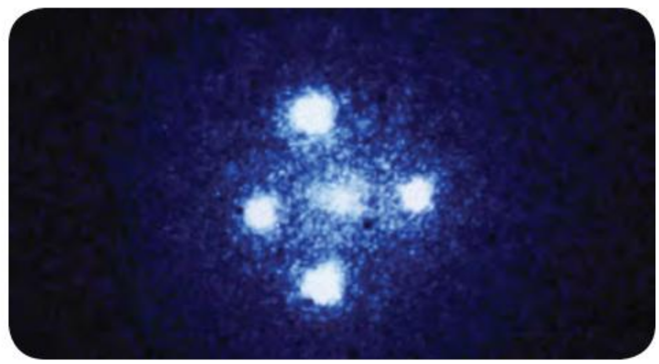


Figure 7.1.7 This image taken by the Hubble Space Telescope shows five different images of the same star. These images are caused by gravitational lensing.

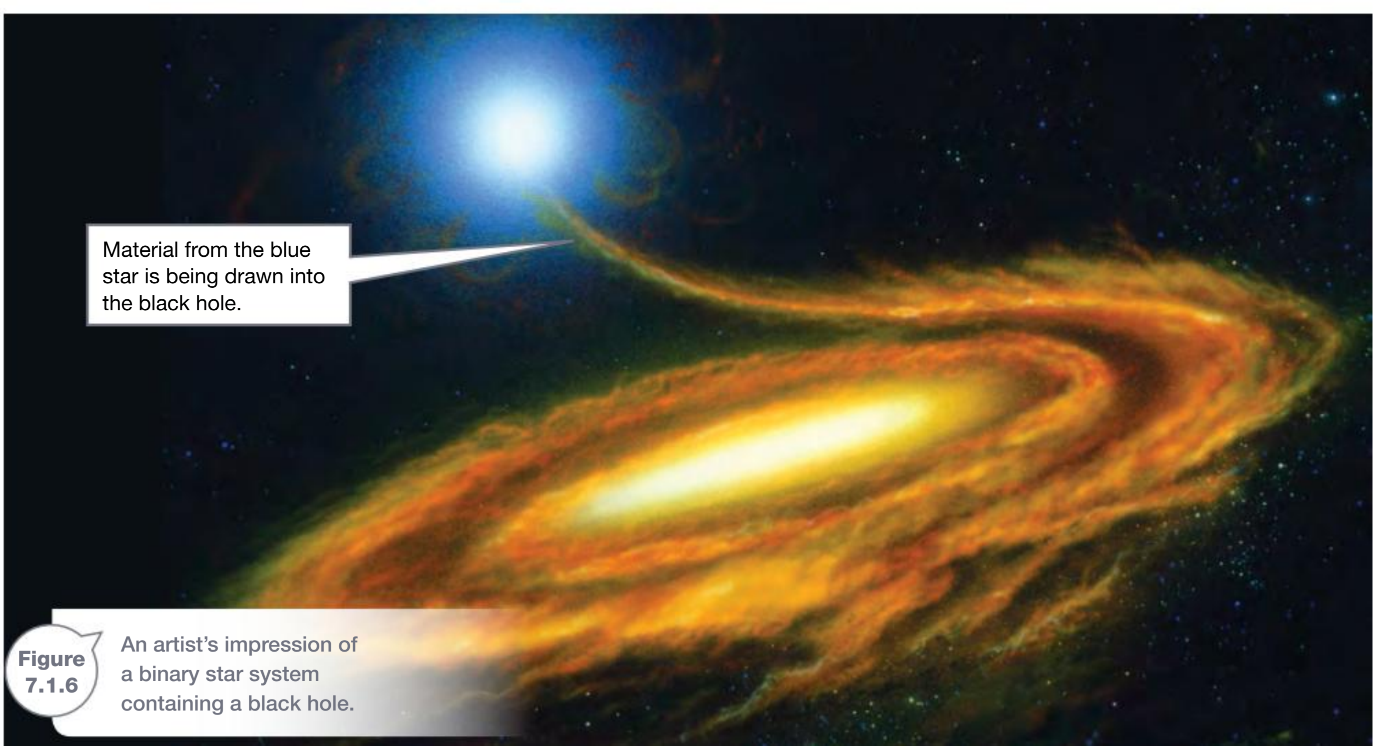


Figure 7.1.6 An artist's impression of a binary star system containing a black hole.

LEARNING ACROSS THE CURRICULUM

INTERCULTURAL UNDERSTANDING

MAGELLANIC CLOUDS

In 1519, Ferdinand Magellan (1480–1521) was sent by the king of Spain to make the first circumnavigation (trip around the circumference) of the world. He set out with 237 men and five ships. Two years later, just 18 men and one ship returned. While on his travels through the Philippines, Magellan had been killed in a battle with native tribes.

Figure 7.1.8 Ferdinand Magellan, the Portuguese explorer after whom the Magellanic Clouds are named

Fortunately for science, one of the survivors was Antonio Pigafetta (1491–1534), a scholar from Venice. He took detailed notes on the flora, fauna, geography and languages encountered on the trip. He also recorded the first Western observations of the astronomical objects now known as the Magellanic Clouds (Figure 7.1.9).

Both of these galaxies are relatively 'small' by cosmological standards—the Large Magellanic Cloud contains 'only' 10 billion stars or so. However, these are two of the closest galaxies to the Milky Way, making them the easiest to observe with the naked eye.

This was not the first human observation of these cloud-like objects. In 964 CE, the Persian astronomer Al-Sufi (903–986) observed the Large Magellanic Cloud and named it the White Ox.

Perhaps the earliest references to the Magellanic Clouds come from the stories of Indigenous Australians. These stories refer to the clouds as an old man and woman and as two 'lawmen' whose fire sent sparks into the sky to form the clouds.

REVIEW

1. **Name** the astronomer who first recorded their observations of the Large Magellanic Cloud, his nationality and the year in which he recorded his observations.
2. **Identify** the century in which the Magellanic Clouds were first observed by Europeans.
3. **Recall** a story of Indigenous Australians that is associated with these clouds.

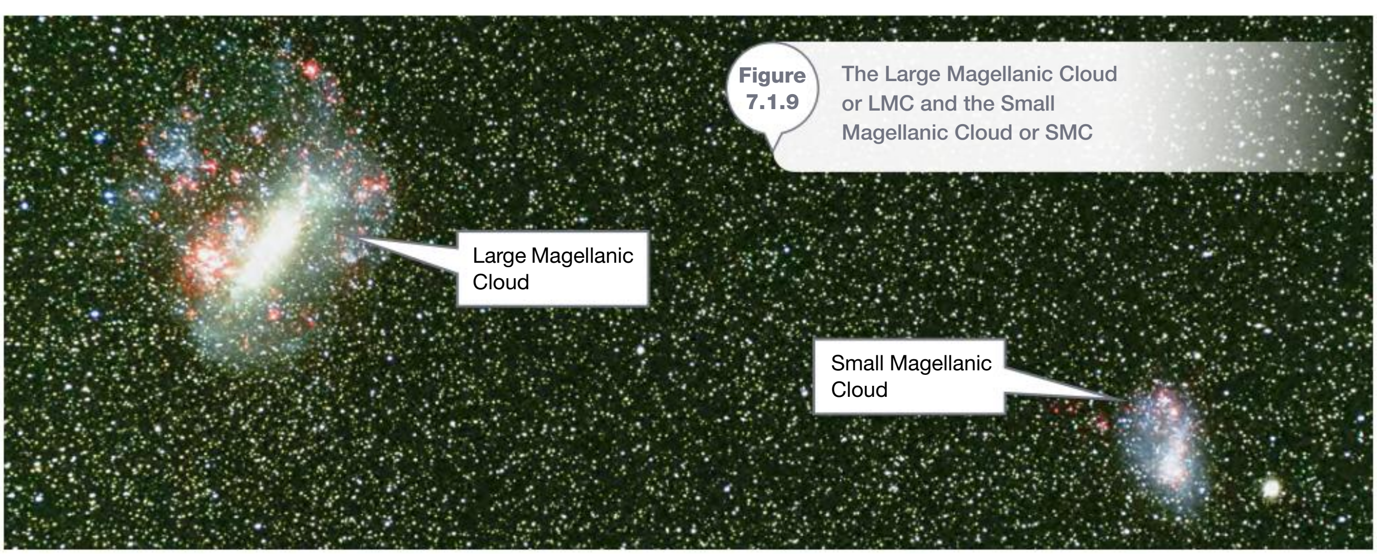


Figure 7.1.9 The Large Magellanic Cloud or LMC and the Small Magellanic Cloud or SMC

7.1 Unit review

Remembering

1 **Name** the type of nuclear reaction that produces energy in stars.

2 a **Name** the attractive force that exists between any two objects that have mass.

b **State** what happens to this force as you get further from the object.

Understanding

3 **Outline** the stages in the formation of a star from a nebula.

4 **Define** these terms. L

a light-year c nebula

b star d galaxy

5 **Determine** which is longer: a *light-year* or a *parsec*.

6 **Draw** a diagram to **explain** why a nearby object appears to move when you look it with one eye and then the other.

7 **Describe** the opposing forces that act inside a star.

8 **Outline** the formation of our solar system.

9 **Explain** how a black hole can be detected even though its gravitational field is too strong for light to escape it.

10 In the 16th century, the astronomer Tycho Brahe argued that Earth must not be moving since stellar parallax had never been observed with the naked eye. **Explain** why Brahe was wrong about the motion of the Earth.

Applying

11 a Gamma Crucis is a star that is 89 light-years away. **Calculate** this distance in parsecs. N

b Bellatrix is 75 pc from Earth. **Calculate** this distance in light-years.

12 The two brightest stars of the Southern Cross are Alpha Crucis and Beta Crucis. If Alpha Crucis is 100 pc away and Beta Crucis is 280 light-years away, **identify** which star is more distant. N

13 The Andromeda galaxy is about 800 kpc (800 kiloparsecs) away. **Calculate** how long it would take light from this galaxy to reach Earth. N

Analysing

14 **Contrast** a *protostar* with a *black hole*.

15 Just as a year can be broken up into 365 days, a light-year can be broken up into 365 'light-days'. A light-year is 9.5×10^{12} km (9.5 million million kilometres).

a **Calculate** the length of 1 light-day. N

b **Calculate** the length of:

i 1 light-hour ii 1 light-minute.

c Given that Earth is, on average, 150 000 000 km from the Sun, **calculate** this distance as a value in light-minutes.

d **Interpret** the answer to part **c** to give the time it takes for light from the Sun to reach Earth.

Evaluating CCT

16 **Propose** a reason why astronomers have two different units (parsec and light-year) for measuring interstellar distances.

Creating CCT

17 **Construct** a model that shows how two stars that are a long way apart might appear close together when viewed from Earth.

Inquiring

1 Stellar parallax relies on accurately knowing the distance between Earth and the Sun. This distance was first measured by observing an astronomical event known as the transit of Venus. Research the transit of Venus. Find:

- what the transit of Venus is
- how often it occurs
- when it last occurred
- how astronomers can use the transit of Venus to measure the distance between Earth and the Sun
- how Captain Cook's voyage of 1770 was linked to the transit of Venus.

Present your research as a digital presentation. ICT

2 Stellar parallax is not the only method used to measure interstellar distances. Research the use of Cepheid variables in astronomy. Find out:

- what a Cepheid variable is
- the properties that make it useful for measuring distances in space
- the advantages that Cepheid variables have over stellar parallax.

Present your findings as a poster.

7.1 Practical investigation

STUDENT DESIGN

1 Distances and parallax

Purpose

To use parallax to measure the distance to a nearby object.

SAFETY
A risk assessment is required for this investigation.

Materials

- as selected by students

Procedure

1 Design an experiment that uses parallax to measure the distance to a nearby object. Figure 7.1.10 might give you some ideas on how to do this.

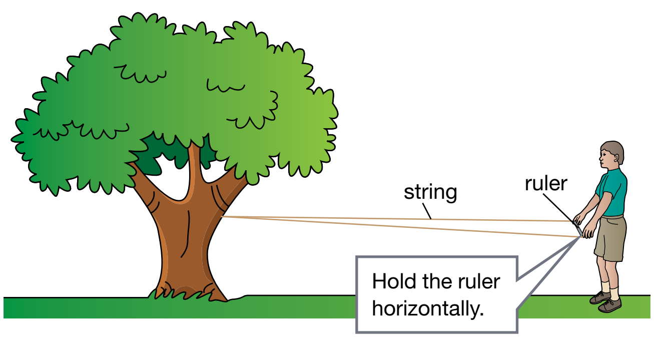


Figure 7.1.10

2 Brainstorm in your group and come up with several different ways to investigate the problem. Select the best procedure and write it in your workbook. Draw a diagram of how you intend to proceed.

3 Before you start any practical work, assess all risks associated with your procedure. Construct a risk assessment that outlines these risks and the precautions you need to take to minimise them.

4 Show your teacher your procedure and risk assessment. If your teacher approves, then collect all the required materials and start work.

5 Use your method to calculate the distance to at least three different objects.

Results

1 For each object you measure, construct a diagram of a triangle showing all lengths and angles you measure.

2 Calculate the distance to the object.

3 Test the accuracy of this technique by comparing the calculated distance with the distance measured directly with a tape measure.

4 Construct a table to display your calculations and measured distances.

Hints

- Choose two points roughly the same distance from the object.
- Measure the distance between the points.
- Construct an isosceles triangle (with two equal sides).
- Measure the angles at the base of this triangle and all its sides.
- Use trigonometry to find the perpendicular height of the triangle—this will be the distance to the object.

Practical review

1 **Evaluate** the accuracy of the parallax technique.

2 **Identify** a situation where a parallax technique would be preferable to measuring the distance directly.

3 **Evaluate** your procedure. Pick two other prac groups and **evaluate** their procedures too, identifying their strengths and weaknesses.

4 **Construct** a conclusion for your investigation.

SciFile

Depth perception

It's more difficult to catch a ball when one of your eyes is covered. This is because your brain uses parallax to judge distances. When both eyes are open, your brain compares the images formed by each eye and then uses these images to determine the distance to the ball. This ability is known as binocular vision. Many predatory animals use binocular vision to accurately target their prey.

ADDITIONAL

7.2 Colour and magnitude

The universe is not a static, unchanging place. Much like a living organism, each star has a history—the star is ‘born’ and eventually it will ‘die’. Astronomers can uncover a star’s history by carefully observing the light it produces. This gives us clues to its size and temperature, how it formed and even what will happen to it at the end of its life.

Brightness

Look up at the night sky and you will see that stars differ from one another in brightness (Figure 7.2.1). Astronomers refer to the brightness of a star as its **magnitude**.

A star’s **apparent magnitude** is a measure of how bright it will appear to an observer on Earth. Although it is confusing, the brightest stars are given the lowest magnitudes, while dimmer stars are given higher magnitudes. The very brightest stars are given negative magnitudes. For example, Alpha Centauri (the brighter of the two Pointers to the Southern Cross) has an apparent magnitude of –0.27. In most cities, the dimmest stars that can be observed with the naked eye have a magnitude of 3.5. Under ideal conditions, the human eye can see stars down to a magnitude of 6.5.

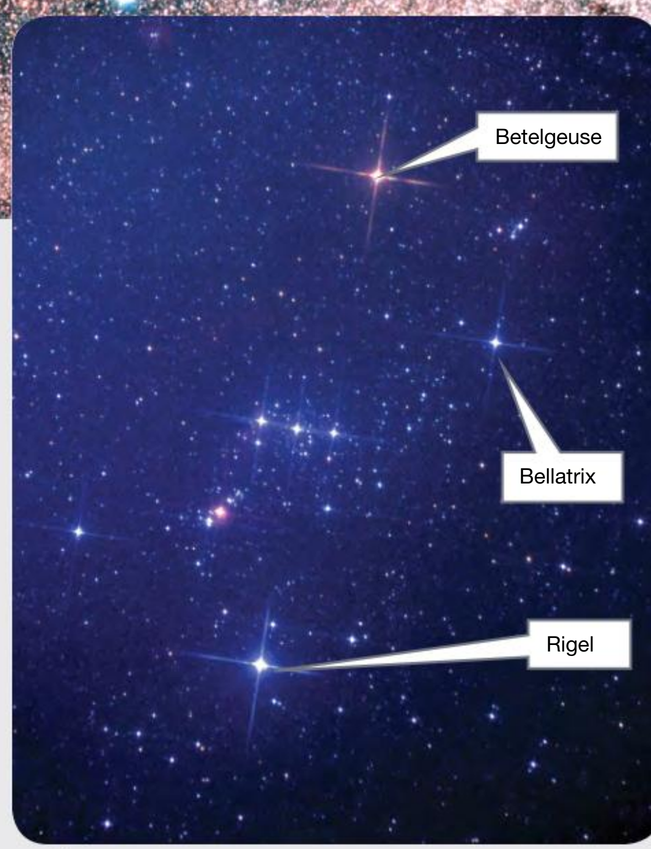


Figure 7.2.1 The constellation Orion (the hunter) contains stars of different brightness and colour.

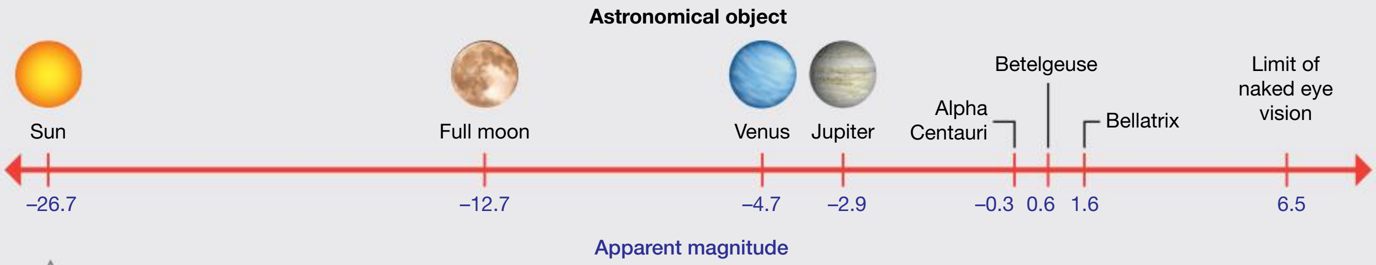


Figure 7.2.2 The apparent magnitudes of various astronomical objects. The magnitudes of planets such as Venus change over time and so the values given here are their maximum values.

Apparent magnitude is measured on a logarithmic scale. A change of one unit on this scale changes the brightness of the star by a factor of about 2.5.

For example, two of the brightest stars in the constellation Orion are Betelgeuse and Bellatrix. Betelgeuse is the bright red star that makes the right shoulder of the hunter in the constellation; Bellatrix is the hunter's left shoulder. Betelgeuse has an apparent magnitude of 0.6 and Bellatrix has an apparent magnitude of 1.6. Figure 7.2.2 and Table 7.2.1 compare these two stars. Betelgeuse's apparent magnitude is one unit lower than that of Bellatrix, so it appears about two and a half times brighter than Bellatrix.

Table 7.2.1 Comparing Betelgeuse and Bellatrix

Star	Betelgeuse	Bellatrix
Colour	Red	White
Apparent magnitude	0.6	1.6
Appearance	Brighter	Dimmer
Distance	200 pc	75 pc
Absolute magnitude	–5.14	–2.72

There are two main factors that determine a star's apparent magnitude:

- the amount of light the star emits
- the distance between the star and Earth—the greater the distance between the star and Earth, the dimmer the star will appear.

In order to study stars, it is important to eliminate the effect of distance on our measurements.

7.2

Absolute magnitude

As a way of measuring a star's actual brightness, scientists use a measurement called **absolute magnitude**. This measures how bright a star would appear to us if it was a distance of 10 parsecs from Earth. Using absolute magnitudes allows the brightness of stars from different parts of the galaxy to be meaningfully compared.

Betelgeuse is almost 200 pc from Earth whereas Bellatrix is only 75 pc away. Betelgeuse has an absolute magnitude of –5.14. This means that if it was only 10 pc from Earth, it would be almost 200 times brighter than it currently appears. In comparison, the absolute magnitude of Bellatrix is –2.72, meaning that even if Betelgeuse and Bellatrix were the same distance from Earth, Betelgeuse would still be the brighter of the two stars.

Colour

The colour of a star is due to its temperature and the elements it contains. Each star emits light at a range of different wavelengths. Some of this light is in the visible part of the **electromagnetic spectrum**, while some of it will be in the invisible infrared or ultraviolet range (Figure 7.2.3). Your eyes collect the visible light from stars and your brain performs a complex averaging process that results in you perceiving the star as a particular colour.

Rather than rely on the human eye and the brain to interpret the colour, scientists analyse the light from a star by using filters. By comparing the magnitude of the star when viewed through coloured filters, its colour can be precisely measured.

A star's spectrum is mainly determined by its surface temperature. Cooler stars emit most of their energy in the infrared and visible red parts of the spectrum and therefore appear red to your eyes. Very hot stars emit a lot of energy in the visible violet and ultraviolet part of the spectrum and appear blue. Stars with temperatures in between these extremes emit light across a range of wavelengths and can appear orange, yellow or white.

Another device that is used to analyse starlight is a **spectrometer**. This is a device that splits light into a spectrum to reveal its component colours.

Scientists can determine what chemical elements are present in a star from distinctive lines that appear in its spectrum. Particular elements emit colours of particular wavelengths. These can be measured precisely to determine the elements in the star.

When studying the spectra from stars, scientists also see dark lines showing missing colours. The Sun has dark lines called Fraunhofer lines in its spectrum. You can see them in Figure 7.2.4. Fraunhofer lines are due to light interacting with atoms in the outer layers of the star.

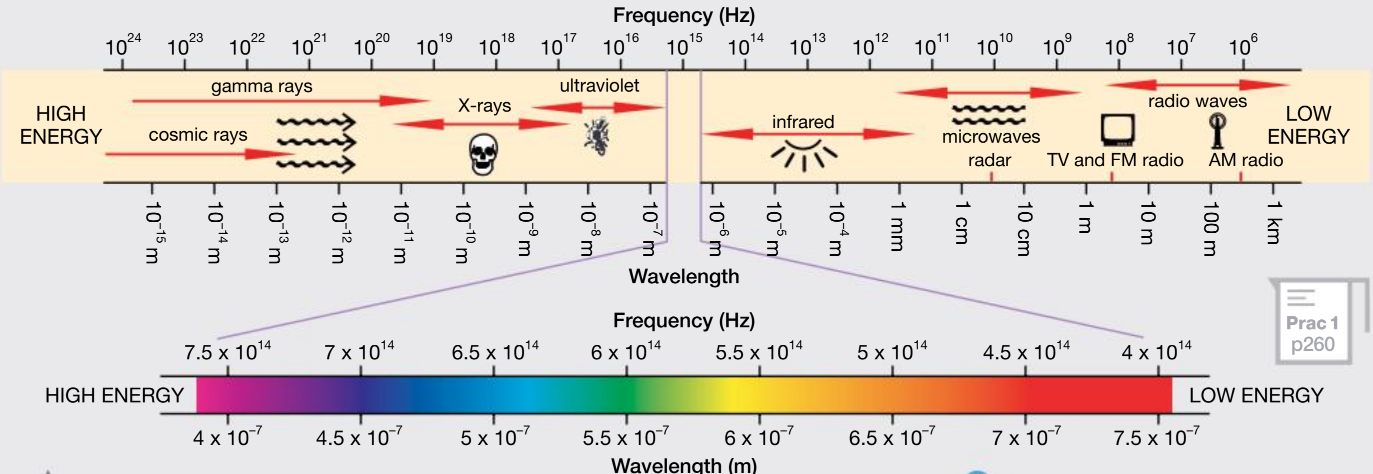


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Figure 7.2.3 Visible light is just a small part of the electromagnetic spectrum.

Pearson science NSW 9 Unit 4.2
Pearson science NSW 9 Unit 4.3
Pearson science NSW 9 Unit 4.4

The light energy is absorbed by electrons in atoms of all the elements in the outer gas layers. These electrons absorb light energy of particular wavelengths. The absorption occurs at exactly the same wavelength that the element would emit when it is extremely hot.

Using the spectra from different stars, scientists have created a classification system called **spectral class**. Spectral class indicates the elements present in the star, the temperature and colour of a star. This is shown in Table 7.2.2. Our Sun has a surface temperature of just under 6000°C so it is classified as a G-type star. It has a yellow colour.

Table 7.2.2 Spectral classes and their associated temperatures and colours

Spectral class	Temperature (°C)	Colour of star
O	50 000–28 000	Blue
B	28 000–10 000	Blue-white
A	10 000–7500	White
F	7500–6000	White-yellow
G	6000–4900	Yellow
K	4900–3500	Orange
M	3500–2000	Red

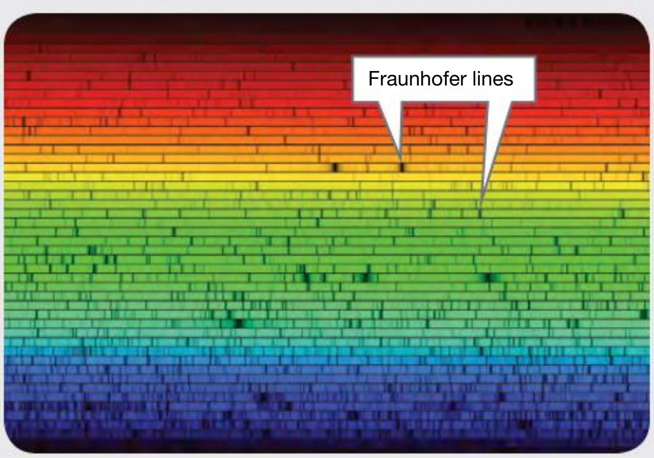

Figure 7.2.4 The spectrum of the Sun, showing dark vertical lines called Fraunhofer lines

SciFile: Seeing the colour of stars

The colours you see in the stars in this chapter probably seem much clearer than those you see when you look at the night sky. The colour receptors in your eyes require a lot of light and do not work well at night. Also our eyes have difficulty in detecting the colour of small points of light. The long exposure time used in taking images like that in Figure 7.2.5 makes many small stars appear as small discs instead of points of light. This makes their colour easier to see.

Figure 7.2.5 This is a photo taken by the Hubble Space Telescope of a section of sky in the constellation Sagittarius. It shows some of the variety in the colour of stars in our galaxy.

Nuclear fusion

Data from spectral analysis indicates that three-quarters of the material in a typical star is hydrogen. Most of the remaining quarter consists of helium and small amounts of oxygen and other heavy elements.

The enormous gravitational forces within a star can heat the material at its centre to a temperature of almost 15 million degrees Celsius. Hydrogen is the simplest element in the periodic table, consisting usually of a single proton and an electron. At the enormous temperatures inside a star, the electrons have too much energy to stay bound to the protons so the material takes the form of **plasma**. Plasma is a state of matter consisting of a 'soup' of positively charged ions and free electrons.

Protons are positively charged and so they strongly repel each other. However, in the centre of a star, the massive gravitational force is enough to bring individual protons close enough to fuse together into a new nucleus. This is shown in Figure 7.2.6.

During fusion, one of the protons is converted into a neutron and two tiny particles are released—a small positively charged

Figure 7.2.6 In the centre of a star, protons join to form a new nucleus called deuterium (a proton and neutron joined), a positron and a neutrino.

particle called a **positron** and a tiny, neutral particle called a **neutrino**. A positron is the antimatter particle for an electron. It is identical to an electron except that it has a positive charge. The positron does not stay in existence for long. As it is positively charged, it will be attracted to any electrons in the plasma. When a positron collides with an electron, the two particles annihilate (destroy) each other and become two high-energy **gamma rays**. As these gamma rays make their way out from the core of the star, their wavelengths increase and they are stretched into the heat, light and ultraviolet radiation that we can observe from Earth.

The new nucleus formed in this fusion reaction consists of a proton and a neutron. This is still the nucleus of a hydrogen atom, but it is an **isotope** of hydrogen known as deuterium.

The deuterium can undergo further fusion reactions as shown in Figures 7.2.7 and 7.2.8.

Figure 7.2.7 Hydrogen fusion reaction

Figure 7.2.8 Helium–helium reaction (protons shown in red, neutrons in blue)

The overall result of all these reactions is that hydrogen is converted into helium, neutrinos and energy.

SciFile

Neutrinos

Neutrinos are extremely difficult to detect. They have almost no mass and, as they have no charge, they are not affected by electric or magnetic fields. It is suspected that trillions of neutrinos produced by the Sun pass through your body each second without having any effect on you at all!

Figure 7.2.9 This neutrino detector tank at Los Alamos (USA) contains over 150 tonnes of oil. A neutrino interacting with oil produces a tiny blue flash known as Cherenkov light.

The life cycle of stars

In the early part of the 20th century, two astronomers, Ejnar Hertsprung of Denmark and Henry Norris Russell of the United States, independently came up with the idea of plotting stars on a diagram. Absolute magnitude (brightness) was placed on one axis and spectral class (colour) on the other. When they did this, they noticed that the stars fell into a number of clearly defined groups. This type of diagram became known as the Hertzsprung–Russell or H–R diagram.

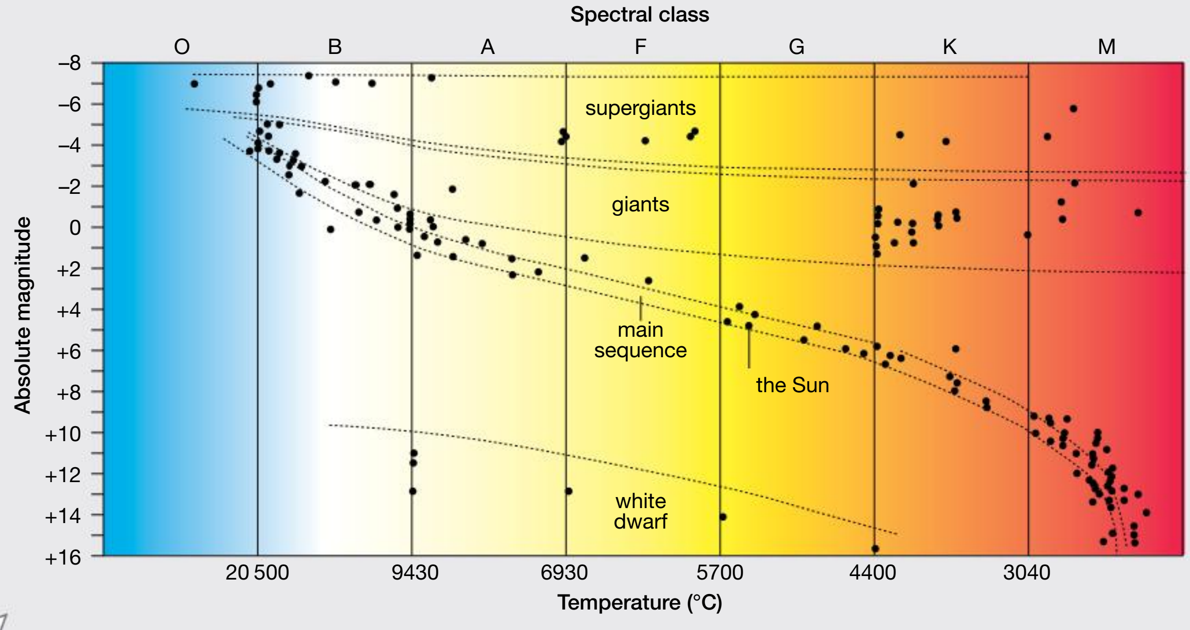

Figure 7.2.10 Hertzsprung–Russell diagram

Hertzsprung—Russell diagrams

A typical H–R diagram is shown in Figure 7.2.10. The H–R diagram revolutionised astronomy because it showed that there was a relationship between the brightness and temperature of stars. H–R diagrams were also interpreted as showing that stars were changing from one 'type' to another. These changes became known as the 'life cycle' of a star. Using an H–R diagram is a bit like going into a forest and seeing all the trees at different stages of growth and concluding that the stages represent different life stages of the species. You can't actually see a tree at one stage grow into the other, but it is clear that they must. It became apparent that as stars develop and change, they shift from one section of the H–R diagram to another. In this way the H–R diagram acts as a map of the life-cycle of a star.

7.3

Main sequence

On an H–R diagram, most stars fall on a broad line running from the top left-hand corner to the bottom right-hand corner. This line is known as the **main sequence**.

In a main sequence star, gravity and radiation pressure are in equilibrium—they balance each other out, giving the star a constant radius and brightness. This equilibrium can last for millions or even billions of years until the hydrogen in the core of the star starts to run out.

For main sequence stars, there is a simple relationship between the mass of the star and its temperature and brightness—the heavier the star, the hotter and brighter it will be. This is because more mass results in a greater gravitational force. The greater gravity from the large mass causes the core of the star to be more tightly compressed and therefore nuclear fusion occurs more rapidly. Hydrogen is converted into helium more quickly and produces more heat and light. This also means that more massive stars burn up their fuel more quickly.

Our Sun is a medium-sized star on the main sequence. At a temperature of around 6000°C, our Sun's nuclear fuel will last for about 10 billion years. In comparison, a star ten times as massive as the Sun will be 10 000 times brighter, have a temperature of 22 000°C and burn out in just 20 million years.

On an H–R diagram, the stars in the top left-hand corner are brighter, hotter and larger. Stars in the bottom right-hand corner are dim, cool and small.

Typical stars in the main sequence start their lives at the bottom right-hand corner of the main sequence and move towards the top left of the H–R diagram. When the hydrogen in the core of a main sequence star runs out, it undergoes a dramatic transformation and moves off the main sequence. Where it goes next on the diagram depends on its mass.

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Red giants

When the hydrogen in the core of a medium-sized star runs out, fusion stops and the outward radiation pressure also stops. Gravity causes the star to collapse inwards and the outer layers of the star to start to fuse. Heat from this fusion produces radiation pressure, which causes these outer layers to expand and cool. The star becomes a **red giant** with a small dense core and a large, relatively cool outer atmosphere.

Fusion in the outer layers of a red giant occurs at a lower temperature than in a main sequence star. A red giant produces more light in the red part of the spectrum, giving the star its distinctive red colour. As the hydrogen in the outer layers of the red giant fuses, the helium produced sinks into the core of the star. As more and more matter is added to the core, its gravitational force and temperature increase until helium atoms start to fuse into heavier elements such as beryllium and carbon. This is shown in Figure 7.2.11.

Typically, a red giant that has formed from a medium-sized star has enough helium fuel in its core to last for around 100 million years. When this runs out, the star collapses further and the outer layers escape to become a cloud of gas known as a **planetary nebula.** Almost half of the mass of the original star is lost into this planetary nebula. The remaining core of the red giant is extremely hot and emits ultraviolet light. This causes the planetary nebula to glow in spectacular patterns. You can see some in Figure 7.2.12.

Over a 'short' period of 20 000 years, a planetary nebula will disperse to reveal the hot, dense sphere of carbon and hydrogen that is the remains of the red giant (its core). This fades to become a very dense star called a **white dwarf**. White dwarfs are so dense that if our Sun became a white dwarf, its mass could be packed into a sphere only slightly larger than Earth. Although a white dwarf is very hot, it is much dimmer than the red giant from which it forms. The lower brightness now places it off the main sequence and this means that the white dwarf drops to the bottom of the H–R diagram.

Nuclear fusion has ceased in a white dwarf, so the star will eventually fade to become a cold, dark ball of inert matter known as a **black dwarf**.

Supergiants

'Planetary' nebula

SciFile

The name *planetary nebula* was first used in the late 18th century by William Herschel, the discoverer of Uranus. Through the low-power telescopes available at the time, these clouds of gas looked like Uranus and other gaseous planets. The name is misleading since scientists now know that that these phenomena have nothing to do with planets.

Do black dwarfs really exist?

SciFile

Since white dwarfs are very small and have a relatively small surface area, they radiate heat very slowly. It would take hundreds of billions of years for a white dwarf to turn into a black dwarf. Scientists currently believe that the universe is less than 20 billion years old, so it is possible that black dwarfs exist only in the imaginations of astronomers!

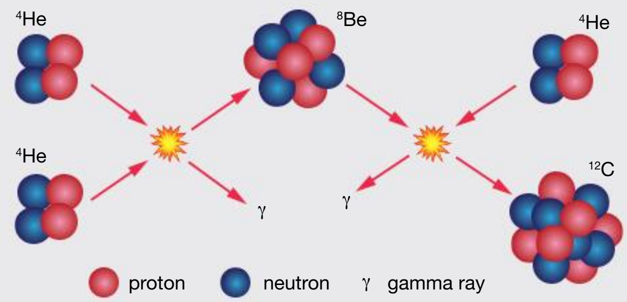

Figure 7.2.11 Fusion can create heavier elements from helium (He). This example shows how beryllium (Be) and carbon (C) form.

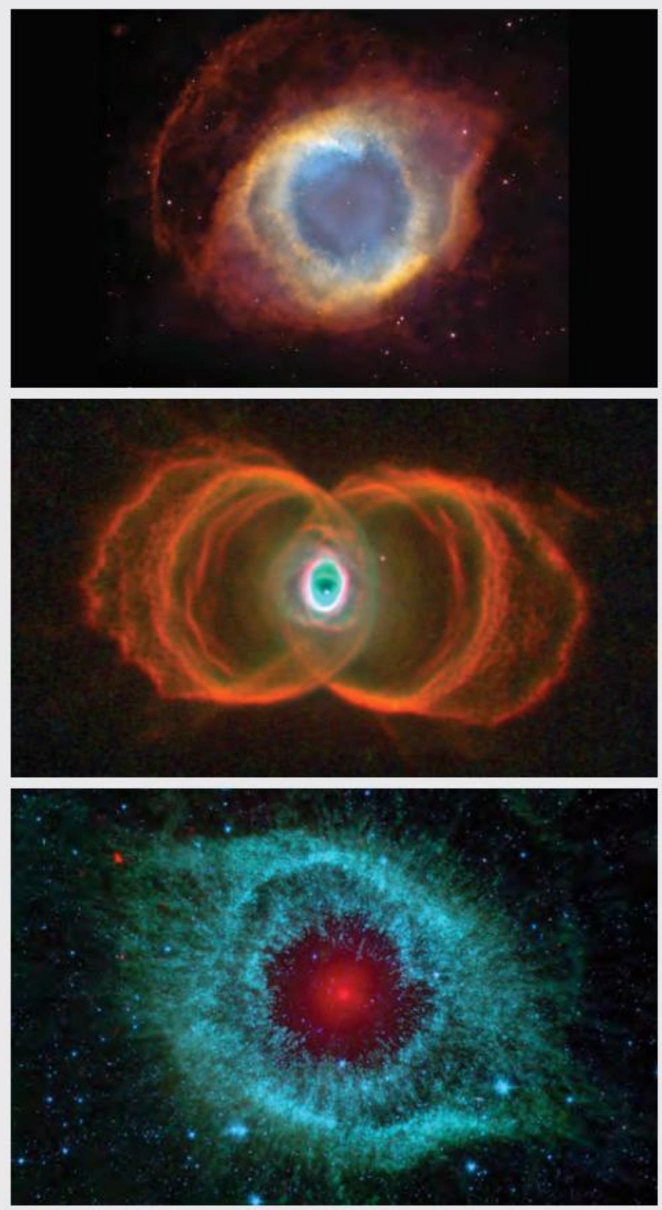

Figure 7.2.12 Planetary nebulae form spectacular shapes and patterns.

Stars that are ten or more times as massive as our Sun follow quite a different life-cycle from the stars on the main sequence. These massive stars start at the top left-hand corner of the H–R diagram and are known as **blue supergiants**. Being much larger than main sequence stars, they have much higher gravitational forces and consume their hydrogen much more quickly—in millions rather than billions of years.

When the hydrogen runs out and helium fusion begins, the star maintains its brightness but it slowly cools down. On the H–R diagram, this is seen as movement from left to right. Once all the helium has been fused into carbon and oxygen, the temperature in these massive stars is hot enough to cause these atoms to fuse into heavier and heavier elements. Eventually though, even this fuel will have to run out and then the results are nothing short of spectacular—a **supernova** occurs!

Supernovae

Once all the material in the core of a supergiant has been fused into iron, it cannot easily fuse any further. Creating elements that are heavier than iron absorbs more energy than it releases. If the core of a star stops producing energy, there is no force to act against gravity and all of the material in the outer layers collapses inwards at incredible speeds. When this material reaches the solid core, it rebounds in a massive explosion called a supernova. The star will become over 100 million times brighter than it was originally, outshining the rest of the stars in its galaxy combined! In 1987, astronomers were fortunate enough to capture this process occurring in a star in the Large Magellanic Cloud. The black and white images in Figure 7.2.13 show that the star has become much brighter.

When a star explodes this violently, much of its mass is blown in to space. You can see this in the bottom photo of Figure 7.2.13 and in Figure 7.2.14 on page 258. This material is mostly in the form of neutrons, which collide with other atomic nuclei as they are flung outwards. Many of the neutrons are captured by these nuclei to form heavy elements such as gold and silver.

What happens to the material left behind by this explosion depends on the size of the star.

Neutron stars

If the amount of material left behind by a supernova is between 1.4 and 3 times the mass of our Sun, then gravitational forces are strong enough to cause the structure of the atoms within it to break down. Electrons and protons combine to form neutrons. The resulting **neutron star** has an enormous **density** since its entire mass can be compressed into a sphere about 10–15 km across.

Black holes

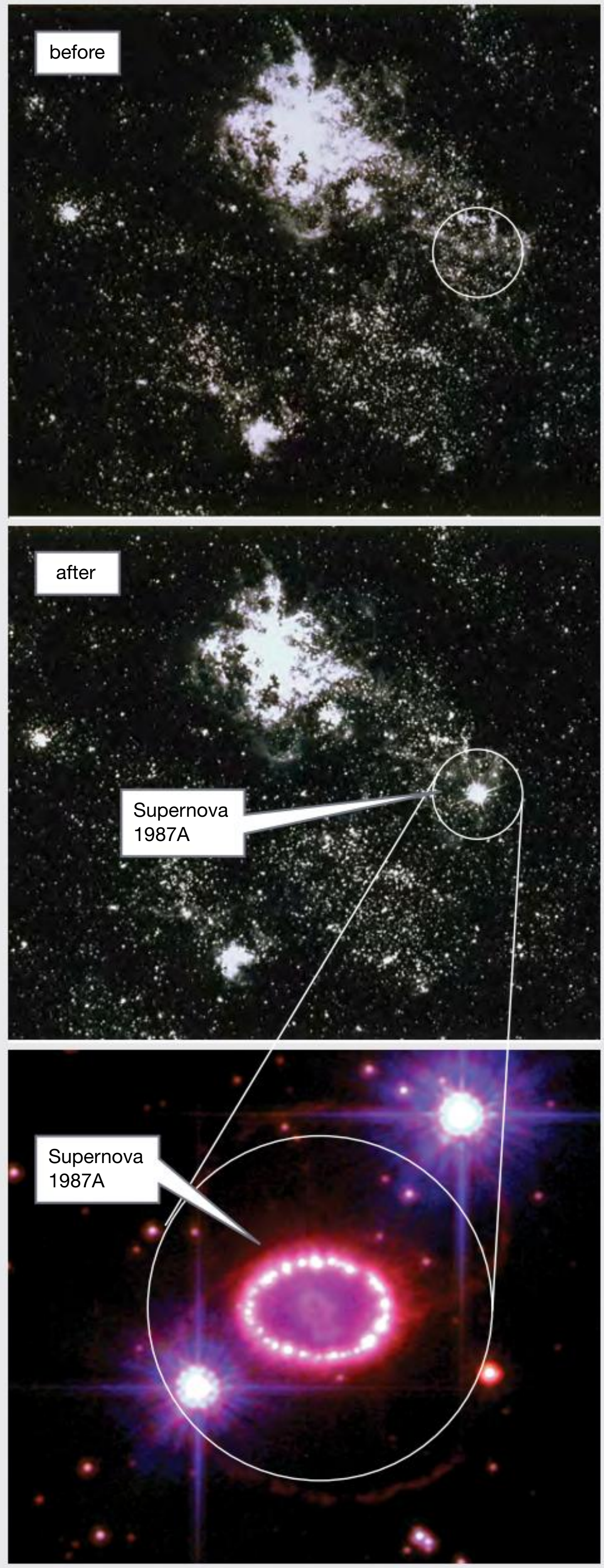

Figure 7.2.13 Before and after photos of Supernova 1987A.

Supernova—'big, new star'

SciFile

In Latin, the word *nova* means 'new'. This term was originally used by the earliest astronomers because it seemed that a 'new' star was being born. A nova would appear, burn brightly for a few weeks or months and then fade dramatically. If a nova was particularly spectacular, it came to be known as 'supernova'. Scientists now understand that a nova or supernova is not a new star at all. The star that exploded into the supernova was always there, it may just have been too dim for astronomers to notice it.

Figure 7.2.14 This image shows a section of the Cygnus Loop, a cloud of gas produced in a supernova explosion. The bright colours indicate the presence of elements such as oxygen.

For supernova remnants that are more than three times the mass of our Sun, the process of collapse after a supernova does not end with the formation of a neutron star. The immense gravitational forces cause the star to shrink even further into what scientists refer to as a **singularity** or black hole.

The initial size of a star is critical in determining its life cycle and the type of star it will eventually become. The various possibilities are summarised in Figure 7.2.15.

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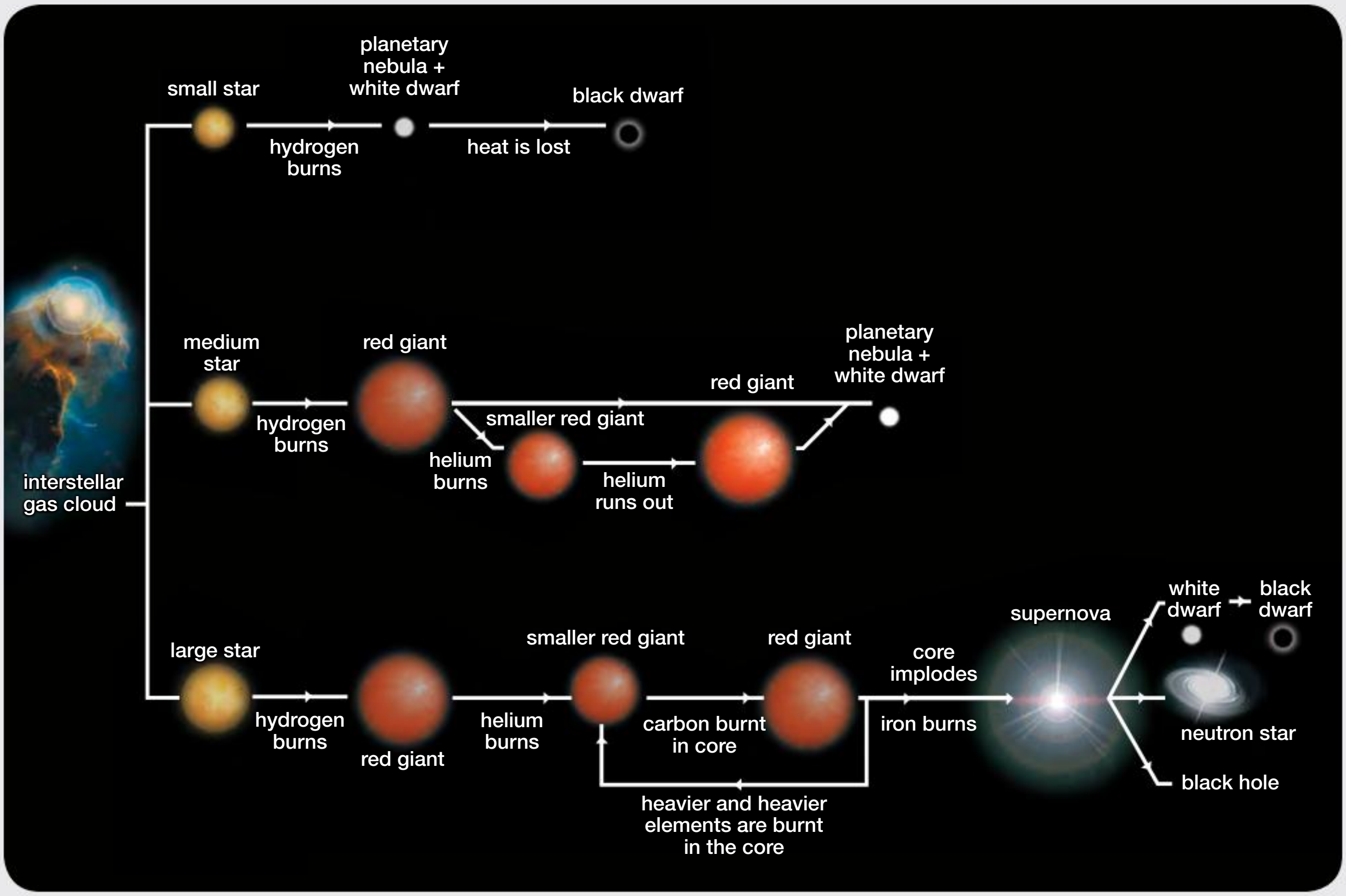
Figure 7.2.15 Possible life cycles of a star



7.2 Unit review

Remembering

1 **Name** the device that is used to split light into its component colours.

2 **Recall** the type of star produced by the collapse of a star that is the same size as our Sun.

3 **Recall** where the main sequence can be found on an H–R diagram.

4 **List** the following in order of increasing density: black hole, main sequence star, neutron star, red giant.

Understanding

5 **a** **Define** the term *spectral class*. L

b **Name** the device used to measure it.

6 The 'twins' of the constellation Gemini are the stars Castor and Pollux. **Explain** how these two stars can have almost identical apparent magnitudes when Castor (50 l.y.) is almost 1.5 times further away than Pollux (33 l.y.).

7 **Explain** why a neutron star has its name.

8 **Explain** why stars on the main sequence get brighter as they get bigger.

9 **Predict** what will happen to a star 15 times the size of our Sun when the hydrogen fuel in its core runs out.

Applying

10 **Use** Table 7.2.2 on page 253 to **identify** the colour of the following stars:

- **a** Bellatrix, surface temperature 22 000°C
- **b** Rigel, surface temperature 12 000°C
- **c** Canopus, surface temperature 7100°C
- **d** Pollux, surface temperature 4200°C
- **e** Betelgeuse, surface temperature 3400°C

11 Rigel and Betelgeuse are the two brightest stars in the constellation Orion. Rigel has an apparent magnitude of 0.18 and an absolute magnitude of –6.8. Betelgeuse has an apparent magnitude of 0.6 and an absolute magnitude of –5.1.

- **a** **Identify** which of the two stars appears brighter.
- **b** **Identify** which of the two stars produces more light.

12 In a particular constellation, star α appears red and has an apparent magnitude of 2. Star β appears blue and has an apparent magnitude of 3.

- **a** **Identify** which star appears brighter.
- **b** **Identify** which star has a higher surface temperature.

13 **Use** word equations to **describe** three different fusion reactions that can occur in a star.

14 **Use** Figure 7.2.10 on page 255 to:

- **a** **state** the spectral class of each of the following stars
- **b** **identify** the star as a main sequence star, white dwarf, giant or supergiant.

Star	Absolute magnitude	Temperature (°C)
Aldebaran	–0.6	3600
Sirius A	1.4	9600
Sirius B	11.2	25 000

Analysing

15 **Contrast** the terms *absolute magnitude* and *apparent magnitude*. L

16 **Compare** a white dwarf with a black hole.

Evaluating CCT

17 The term *supernova* literally means 'big, new star'. Modern astronomers now understand that supernovae are not 'new' stars but stars that have suddenly become much brighter, so this term is misleading. **Propose** a more scientifically accurate name for this type of star.

18 **a** **Critically analyse** the accuracy of the term *planetary nebula*.

b **Propose** a more appropriate term.

Creating CCT

19 **Construct** a series of flash cards containing all the different types of star shown in Figure 7.2.15. Arrange these in the correct order to represent the life cycle of a star.

Inquiring

Research pulsars. Find out:

- when pulsars were first observed
- how pulsars are related to the types of stars discussed in this unit
- how pulsars are used by astronomers
- why Australia is a world leader in research into pulsars.

Present your research as a poster or digital presentation. ICT

ADDITIONAL

7.2 Practical investigations

1 Using a spectrometer

Purpose

To compare the spectrum of light produced by different sources.

Materials

- spectrometer (spectroscope)
- light globe and coloured filters (a Hodgson's light box or similar would be suitable)
- fluorescent light tube
- coloured pencils

SAFETY
Never look directly at the Sun, whether using a spectroscope or not.

Procedure

1. Use a spectrometer to study the spectrum of light from a light globe. Sketch this spectrum.
2. Use a red filter to change the colour of the light. Observe and sketch this spectrum.
3. Use a blue filter to change the colour of the light. Observe and sketch this spectrum.
4. Use the spectrometer to study the spectrum of light from a fluorescent tube. Sketch the spectrum from the fluorescent tube, clearly showing the differences between it and the one produced by the light globe.
5. Looking through a window, observe and sketch the spectrum of light reflected off the ground or a building. (Do *not* point the spectrometer directly at the Sun!)

Practical review

Compare the spectrum observed for:

a. light seen through the red filter and light seen through the blue filter
b. sunlight and light from a fluorescent tube
c. light from a fluorescent tube and from an incandescent light globe.

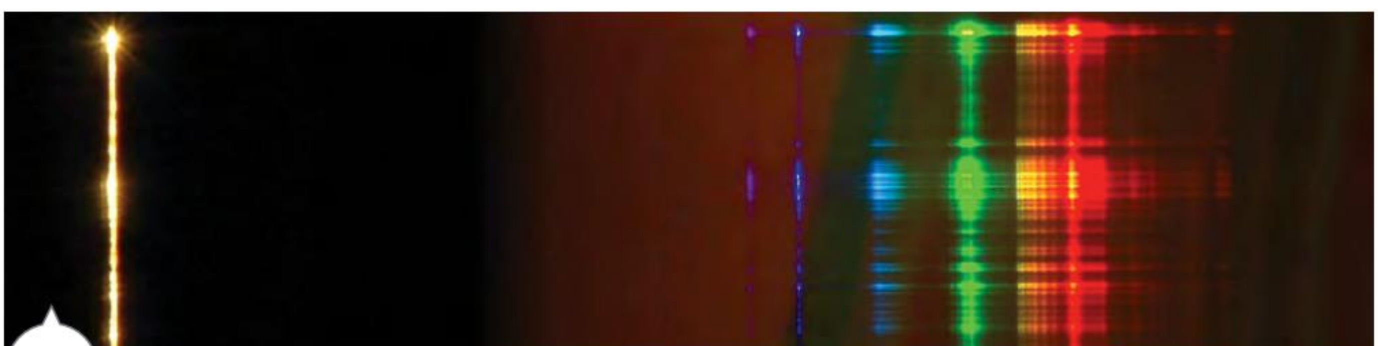


Figure 7.2.16 A typical image through a spectrometer

2 Modelling the collapse of a neutron star

Purpose

To model the change in density that occurs when a star collapses to form a neutron star.

Materials

- 2–3 metres of aluminium foil
- round balloon
- tape
- electronic balance
- metre rule
- pin

Procedure

1. Copy the table from the Results section into your workbook.
2. Inflate the balloon to a diameter of about 15 cm. Tie the balloon so it remains inflated.
3. Cover the outside of the balloon with aluminium foil. Leave no gaps. Use tape to fix the foil to the balloon if necessary. This model represents the original star.
4. Measure the diameter of the model with the ruler. Halve this measurement to get the radius. Record this measurement in your table.

5 Measure the mass of the foil covered balloon with the electronic balance. Record this in your table.

6 Prick the balloon with a pin so that it bursts. Crumple the foil into a very loose ball. This model represents the star as it starts to collapse. Repeat steps 4 and 5 for this model.

7 Crush the foil into the smallest ball possible. This model represents the neutron star. Repeat the measurements for this model.

8 Calculate the volume and density of each model. N

Results

Record all your measurements and calculations in your results table.

Model	Mass (g)	Radius (cm)	Volume (cm^3)	Density (g/cm^3)
Original star				
Collapsing star				
Neutron star				

Hints

For a sphere, $V = \frac{4}{3}\pi r^3$

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

Practical review

1 **Discuss** the changes (if any) in the following quantities as the 'star' collapses:
- mass
- volume
- density.

2 **Assess** the ways in which this model is like a collapsing star.

3 Scientists estimate that a neutron star is 100 000 000 000 000 or 10^{14} times more dense than the star that formed it. If you wanted to crush your model enough to make it 100 000 000 000 000 times more dense than the original model, **calculate** the volume and radius it would need to be. N

STUDENT DESIGN

3 Constructing a spectrometer

Purpose

To construct a spectrometer from a CD.

SAFETY
A risk assessment is required for this investigation.

Materials

- CD
- as selected by students

Procedure

1 Search the internet for a design of a spectrometer that uses an old CD. Save or print out the design you wish to build. ICT

2 Before you start any work, assess all the risks associated with your design and its construction. Construct a risk assessment that outlines these risk and the precautions you need to take to minimise them.

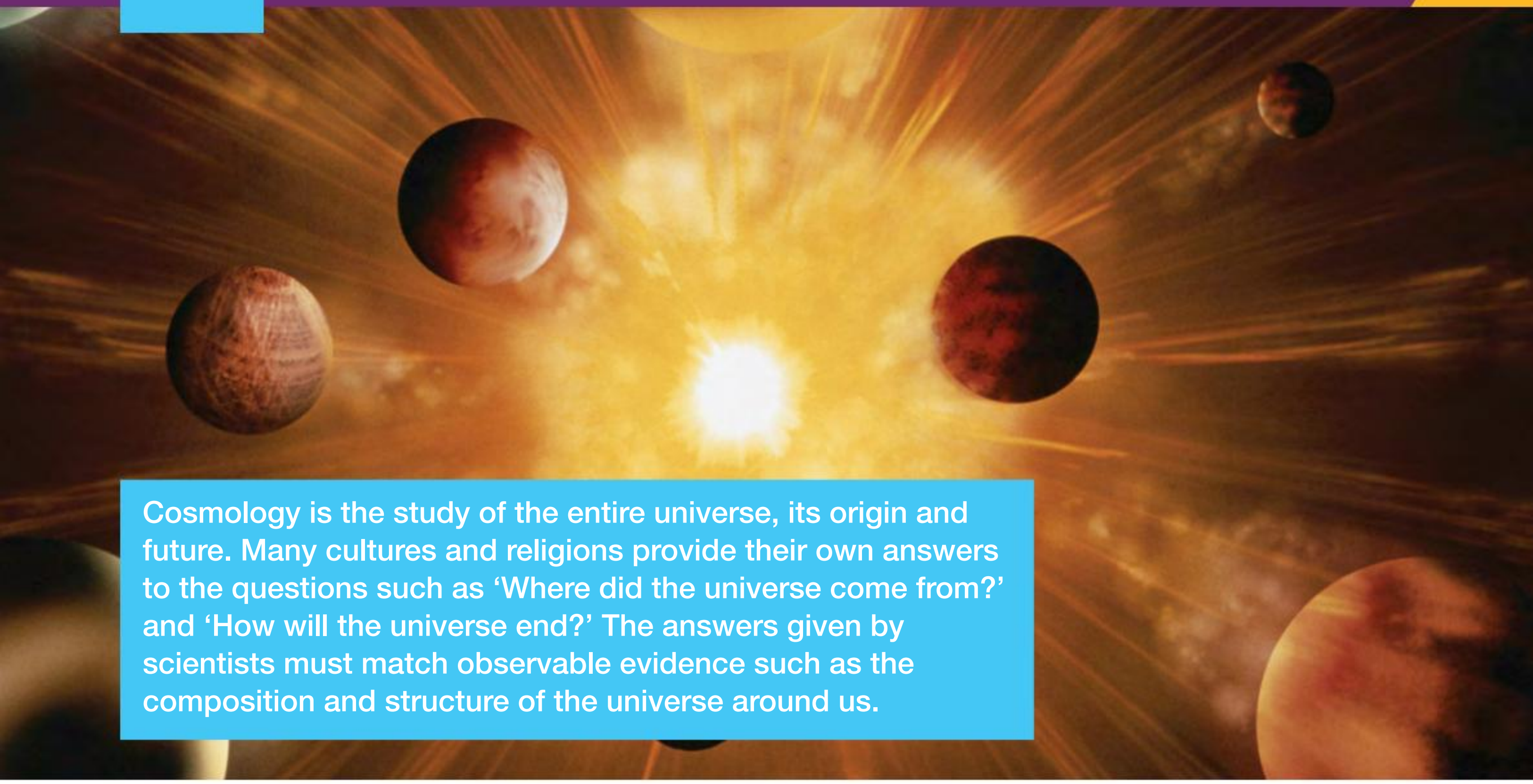
3 Show your teacher your design and your risk assessment. If your teacher approves, then collect all the required materials and start work.

Practical review

1 **Compare** the image observed using your spectrometer with those observed using the spectrometer used in prac 1.

2 **Evaluate** your spectrometer. Pick two other prac groups and **evaluate** their procedures too, identifying their strengths and weaknesses.

7.3 Cosmology



Cosmology is the study of the entire universe, its origin and future. Many cultures and religions provide their own answers to the questions such as 'Where did the universe come from?' and 'How will the universe end?' The answers given by scientists must match observable evidence such as the composition and structure of the universe around us.

Galaxies

Our modern understanding of the structure of the universe began with the Ancient Greek philosopher Democritus (circa 460–370 BCE). In the fourth century BCE, he suggested that the Milky Way could be made up of many distant stars. This idea was rejected by other philosophers of his time, who believed the Milky Way was an atmospheric phenomenon. Democritus' theory was not confirmed until the 17th century. This was when Galileo Galilei (1564–1642) looked through his newly invented telescope at the Milky Way and saw its individual stars.

Astronomers now know that the Milky Way is just one of billions of galaxies in the observable universe. Some of the shapes galaxies can take are shown in Figure 7.3.1. This has caused scientists to change their estimate of the size of the universe. The Milky Way is estimated to contain between 200 and 400 billion stars and be about 100 000 light-years across. The Canis Major dwarf galaxy is the closest galaxy to the Milky Way. It is 25 000 light-years away from us. Only four galaxies are closer than 2 million light-years away. Most galaxies are many millions of light-years away. Recent estimates put the number of observable galaxies at around 500 billion. This makes the universe unimaginably large.

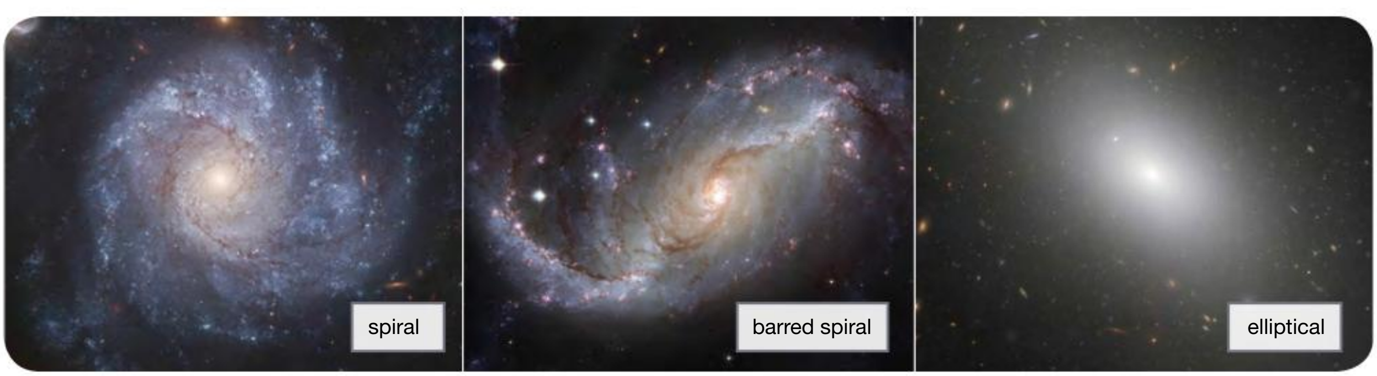


Figure 7.3.1 Galaxies can take various shapes including spiral, barred spiral and elliptical.

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7.4

Measuring distances to galaxies

The distances to other galaxies are far too big to be measured by parallax methods. One of the best techniques for measuring the distance to another galaxy uses a special type of star known as a Cepheid variable. A Cepheid is a type of star that has variable brightness—over a certain period of time, it changes from bright to dark and back to bright again (Figure 7.3.2). The period of this variation is directly related to the absolute magnitude of the star.

To measure the distance to another galaxy, an astronomer must first identify a Cepheid variable inside the galaxy. Then, by measuring the period of variation of the Cepheid, the absolute magnitude of the star can be determined. By comparing this to the star's apparent magnitude, the distance to the star (and the galaxy that contains it) can be calculated.

Steady state theory

Fifty years ago, the most popular cosmological model was the **steady state** or infinite universe theory. This theory suggested that the universe is infinite in extent and has always existed in roughly the same form as observed today. This theory matches the fact that galaxies seem to be spread relatively evenly across the sky, as shown in Figure 7.3.3. This theory was expressed in its most complete form in 1948 by English astrophysicist Sir Fred Hoyle (1915–2001). Although the steady state theory enjoyed great favour through the 1950s and early 1960s, by the 1970s most scientists had rejected it.

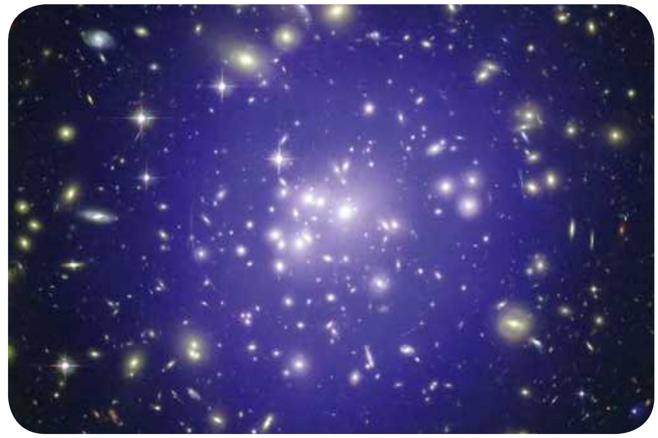


Figure 7.3.3 Galaxies appear to be relatively evenly distributed throughout space. This was used as evidence of a steady state universe.

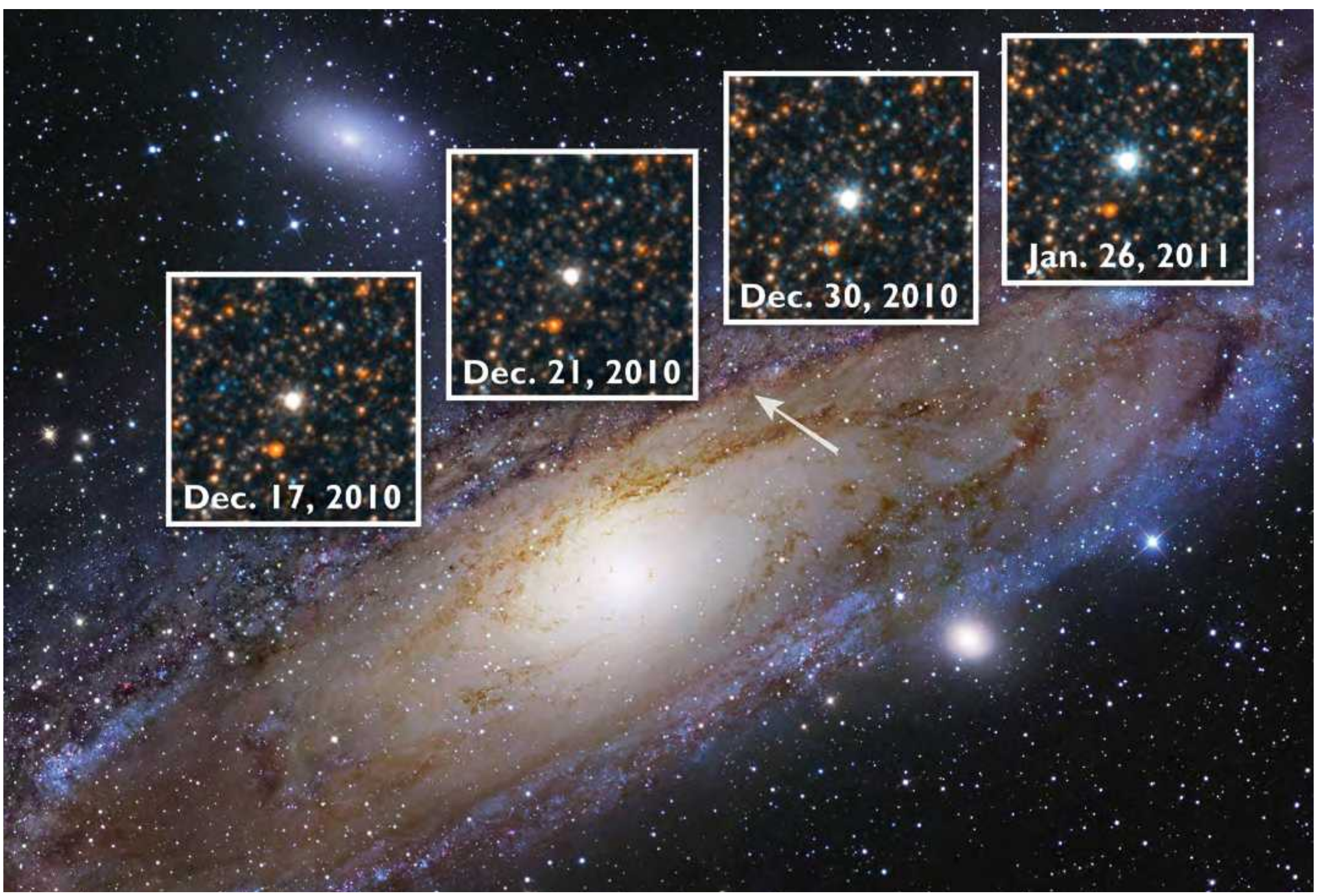


Figure 7.3.2 This series of images shows the change in brightness of a Cepheid variable over a period of almost 40 days. The variable star is in the centre of each frame.

Big Bang theory

The first evidence to undermine the steady state model was American astronomer Edwin Hubble's discovery that the universe is expanding. Hubble used Cepheid variables to measure the distance to a number of galaxies. He then carefully observed the spectrum of light from these galaxies and discovered that, in almost every case, it was distorted in a manner known as cosmological red-shift, or simply as red-shift.

Red-shift is similar to a phenomenon known as the Doppler effect.

The Doppler effect

The **Doppler effect** happens because waves produced by a moving source are either lengthened or shortened due to the motion of the source. You may notice the Doppler effect when something fast and noisy passes by. For example, the siren of the ambulance in Figure 7.3.4 sounds as if it has a much higher pitch as it approaches you than when it is has passed you. You hear the same effect when an aircraft flies overhead or a mosquito buzzes past your ear.

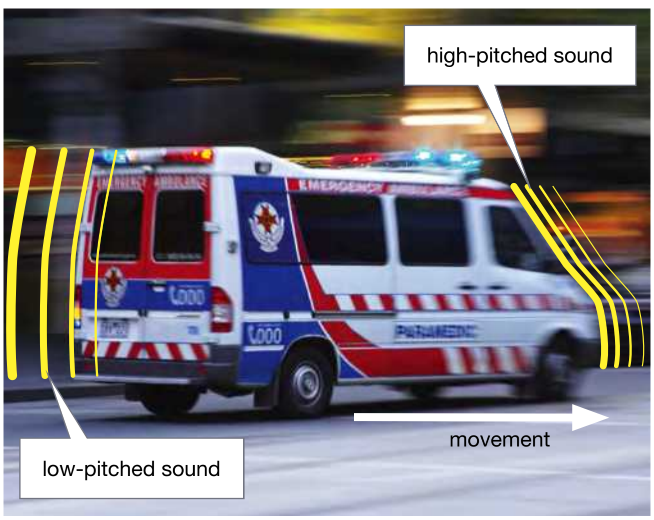


Figure 7.3.4 The Doppler effect causes an ambulance siren to change pitch as it passes.

Red-shift

A phenomenon similar to the Doppler effect can be observed with light emitted from stars and galaxies. Light from stars moving towards us will be compressed, making the light appear bluer than it should. This is known as **blue-shift**. **Red-shift** is what happens when light from stars moves away from us—light shifts towards the red end of the spectrum, making it appear redder (Figure 7.3.5).

Hubble's observation was that the light from almost all galaxies was red-shifted. Hubble's measurements of this red-shifted light led him to the following conclusions:

- Almost all galaxies in the universe are moving away from the Milky Way galaxy.
- The further away a galaxy is, the more its light is red-shifted. This means that the more distant galaxies are moving away from the Milky Way faster than the closer galaxies are.

Taken together, these observations suggested that the universe is expanding.

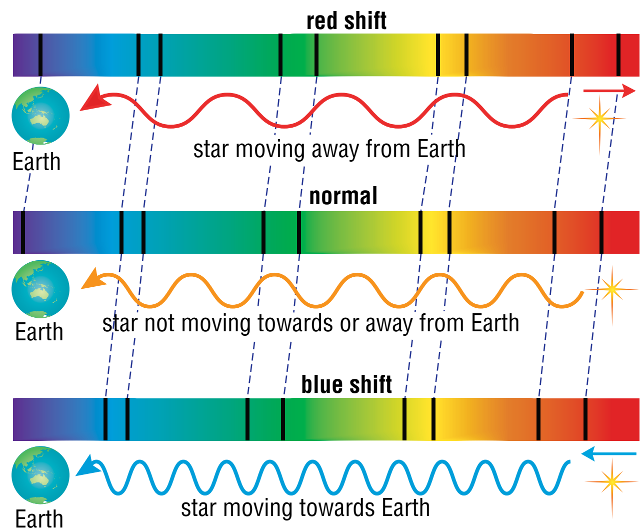


Figure 7.3.5 The colour of a star changes depending on whether the star is moving away from Earth (red-shift) or towards Earth (blue-shift).

This conclusion has important implications. If the universe is expanding, then it is reasonable to assume that at some point all the matter in the universe was condensed into one point. This represents the birth of the universe, the moment of an enormous explosion of energy now known as the 'Big Bang'.

Prac 2 p268
7.5

Stretching space

SciFile

Cosmological red-shift is *not* caused by the Doppler effect since light waves do not travel through a medium as sound waves do through air. The expansion of the universe should not be visualised as stars expanding out into empty space. Instead, it is the space between stars that expands. It is the expansion or stretching of space itself that causes electromagnetic radiation to be stretched and become red-shifted.

Cosmic microwave background radiation

In 1965, two American astronomers, Arno Penzias (1933–) and Robert Wilson (1927–2002), were trying to study radio signals from the Milky Way. They kept finding an annoying background signal coming from all directions in the sky that interfered with their measurements. By chance, they called a cosmologist, Bob Dicke (1916–1997), who realised that this background signal was the 'afterglow' of the Big Bang. It was radiation emitted approximately 400 000 years after the Big Bang.

This afterglow is now known as the **cosmic microwave background radiation**. You can see an image of the cosmic background radiation in Figure 7.3.6. It is consistent with predictions that radiation from the early universe should have been red-shifted into the microwave part of the spectrum by the expansion of the universe since the Big Bang.

It was this discovery, together with Hubble's demonstration of the expansion of the universe, that convinced most scientists to accept the Big Bang model.

A brief history of the universe

Once the rate of expansion of the universe is accurately measured, it is possible to extrapolate back through time to the Big Bang. Astronomers currently estimate that the Big Bang occurred just under 14 billion years ago. They have also been able to suggest a rough outline of the history of the universe, as shown in Table 7.3.1 and Figure 7.3.7.

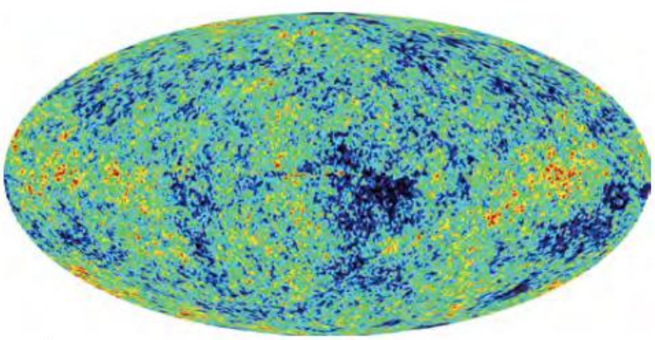


Figure 7.3.6 This image maps the cosmic microwave background radiation. Different colours show slight variations in the temperature of the universe.

Einstein's big mistake

SciFile

When Albert Einstein (1870–1955) was working on his theory of general relativity, he realised that it suggested that the universe was expanding. He disliked the idea of an expanding universe so much that he added a 'cosmological constant' to his theory to ensure that it matched the steady state model. Einstein later described this as the 'biggest blunder' (mistake) of his life.

Table 7.3.1 History of the universe

Time from the Big Bang	Events
0	Big Bang—space and time come into existence along with all the energy that will ever exist. The universe undergoes a period of rapid inflation.
0.000 001 s	The universe expands and cools. Basic forces of nature come into existence. Protons, neutrons and electrons come into existence.
3 s	Protons and neutrons start to combine to form the nuclei of simple atoms—hydrogen (75%), helium (25%) and lithium (trace amounts).
10 000 years	The universe cools as high energy forms of electromagnetic radiation (X-rays and gamma) stretch into light and microwaves.
300 000 years	Electrons start to be captured by atomic nuclei to form simple atoms.
300 million years	Pockets of gas start to condense into the earliest stars and galaxies.
9 billion years	Our solar system begins to form.
13.7 billion years	Today's universe

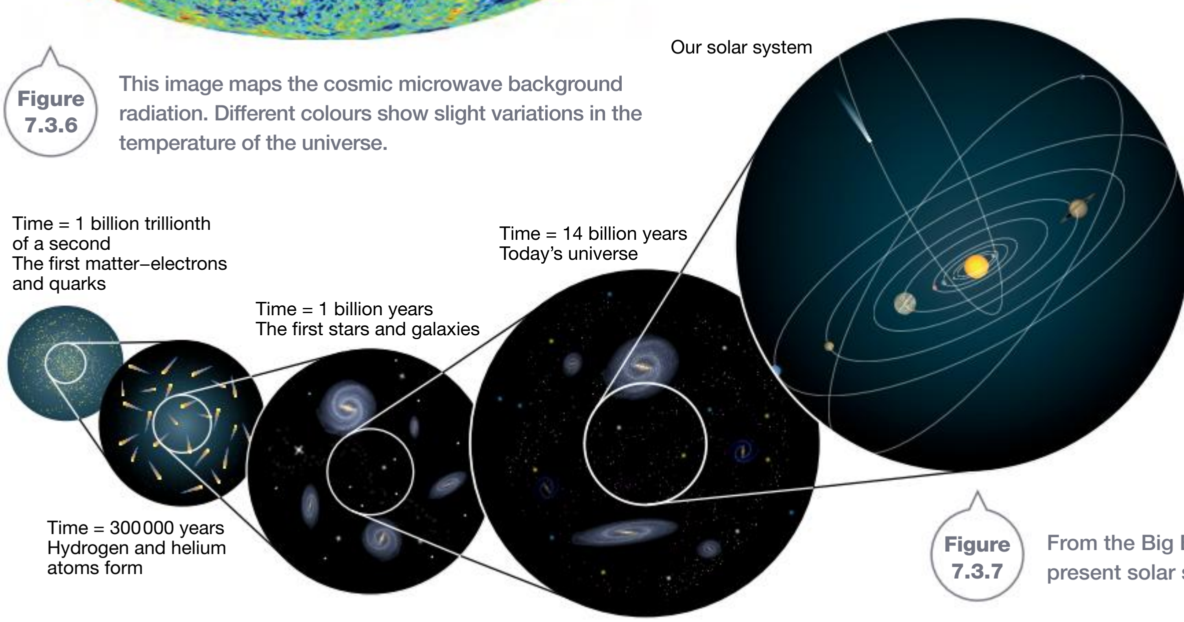


Figure 7.3.7 From the Big Bang to our present solar system

LEARNING ACROSS THE CURRICULUM

WORK AND ENTERPRISE

Figure 7.3.8 A computer simulation of a subparticle collision

RECREATING THE BIG BANG

One of the challenges faced by cosmologists is that many of the objects and processes they study are very different from those found in a standard laboratory. The conditions in the centre of a star or in the early moments of the Big Bang involve extremes of pressure and temperatures that are hard to physically recreate on Earth.

One way to explore the extraordinary conditions of the Big Bang on a microscopic scale is to use an instrument known as a particle accelerator. This takes tiny subatomic particles such as protons and electrons and uses magnetic fields to accelerate them to within 0.01% of the speed of light. Two beams of these particles can then be made to collide with each other (Figure 7.3.8). Scientists study the debris produced by these collisions, hoping to observe the sort of particles and interactions that might have occurred in the very early moments of the universe's existence.

Figure 7.3.9 A section of the Large Hadron Collider

One of the great puzzles of science is that the theory used to explain the universe on the smallest scale (called *quantum mechanics*) and the theory used to explain the universe as a whole (*general relativity*) are very different and incompatible. Scientists hope that by studying the high-energy systems generated inside a particle accelerator, they can find a single model that will fit any situation.

The biggest particle accelerator ever built is the Large Hadron Collider or LHC (Figure 7.3.9). The LHC was completed in 2008, and is not only one of the most complex scientific instruments ever constructed, but it is also one of the most significant examples of international scientific cooperation and collaboration.

The LHC consists of a ring-shaped tunnel 27 km long buried beneath the border between France and Switzerland. It has a staff of over 1800 scientists from 35 countries, including Australia. Collaboration is required at every stage of the LHC's operation, even to process the 15 petabytes of data it produces each year (1 petabyte = 1 million terabytes). Rather than try to process this on a single computer, the Worldwide LHC Computing Grid consists of a network of over 100 000 computers in 34 different countries.

One of the first major successes of the LHC was the discovery of the Higg's boson, a particle that helps explain why objects have mass. This exciting news was announced at the 36th International Conference on High Energy Physics in Melbourne in 2012. Australians helped to develop the ATLAS detector, one of two detectors in the LHC that collected evidence for the existence of the Higg's boson.

REVIEW

1 **State** the location of the LHC.
2 **Describe** the purpose of the LHC.
3 **Describe** how the LHC attempts to reproduce the conditions of the Big Bang.
4 **Explain** how particles are accelerated and made to travel around the LHC.

7.3 Unit review

Remembering

1 **Name** the first person to suggest that the Milky Way was made up of stars.

2 **Recall** the estimated number of stars in the Milky Way galaxy.

3 **Recall** the distance to the closest galaxy to the Milky Way.

4 **Name** the type of star used by Hubble to measure the distance to other galaxies.

5 **State** two pieces of evidence that support the Big Bang theory.

Understanding

6 **Define** the term *cosmology*. L

7 **Describe** what you hear when an ambulance passes with its siren sounding.

8 **Explain** the phenomenon of the Doppler effect.

9 a **Outline** the two main characteristics of Hubble's red-shift data.

b **Explain** why these are significant.

10 Some cosmologists believe that eventually the universe will stop expanding and start to contract due to gravity. **Explain** why this would cause the light from most of the stars to be blue-shifted.

Applying

11 **Identify** an observation that supports the steady state model of the universe.

Analysing

12 **Contrast** red-shift with blue-shift.

13 **Compare** the Doppler effect with the cosmological red-shift.

14 **Contrast** the Big Bang theory with the steady state model of the universe.

15 Scientists define the *observable universe* as anything within 13.7 billion light-years of Earth. **Analyse** why it is impossible for us to observe anything further away than this.

Evaluating CCT

16 The Magellanic Clouds are not widely visible in the northern hemisphere. **Assess** whether or not you think European astronomers would have developed the idea of galaxies outside the Milky Way if they had been able to see the Magellanic Clouds. IU

Creating CCT

17 The table below shows the distance to a number of galaxies and the speed (recession velocity) at which each galaxy is moving away from us. N

Galaxy	Distance (billions of light-years)	Recession velocity (× 1000 km/s)
A	4.50	114
B	1.80	46
C	2.40	61
D	1.10	28
E	0.85	22
F	3.30	84

a **Use** the data in this table to **construct** a line graph showing the relationship between distance and recession velocity.

b **Describe** the mathematical relationship between distance and recession velocity.

c **Use** the graph to **predict** the recession velocity of a galaxy 2.8 billion light-years away.

18 **Construct** a diagram to show how the motion of a star produces red-shift.

Inquiring

1 Research the work done at Australia's only particle accelerator, the Australian Synchrotron. Find:

- where the Synchrotron is located
- how many scientists work there
- the questions that scientists are trying to answer using the Synchrotron.

Present your answer as a brochure for visitors to the Synchrotron. ICT

2 Research the work of Nobel laureate Brian Schmidt into *dark energy*. Find:

- what dark energy is
- what dark matter is
- why Professor Schmidt's discovery was surprising to the scientific community
- the implications of dark energy on the possible future of the universe
- who Professor Schmidt collaborated with to make his discovery.

Present your research as a PowerPoint presentation. ICT

7.3 Practical investigations

1 Classifying galaxies

Purpose

To develop a system for classifying galaxies on the basis of their shape.

Materials

- astronomy reference book or internet
- paper
- pencil
- cardboard
- tape

Procedure

1 Search for pictures of at least eight different galaxies including the Milky Way, Andromeda, Large Magellanic Cloud and Small Magellanic Cloud. ICT

2 Sketch or print out the image of each galaxy on a small sheet of paper. Write the name of the galaxy on the back of the piece of paper.

3 Arrange the images into three or four groups according to their shape. Think of a name that describes the shape of each group.

4 Stick all the images from one group of galaxies onto a piece of cardboard to create a poster. Write the name of the group on the poster.

5 Repeat step 4 for each group of galaxies.

6 Copy a table like that shown in the Results section to summarise your results.

Results

Copy and complete the following table or construct a similar one.

Shape	Distinctive features	Examples

Practical review

1 Scientists classify galaxies into the following groups: spiral, barred spiral, elliptical and irregular. **Discuss** how your groups compare with these, and then **classify** the galaxies in this investigation into the scientific groups.

2 **Identify** the advantages and disadvantages of each system of classification.

2 An expanding universe

Purpose

To model the expanding universe.

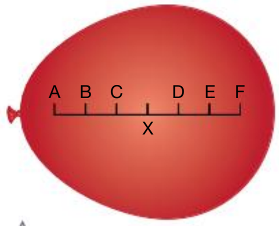


Figure 7.3.10 A balloon can be used to model the expansion of the universe.

Materials

- balloon
- felt-tip pen
- ruler or measuring tape

Procedure

1 Copy the table from the Results section into your workbook.

2 Partially inflate a round balloon. Mark seven points in a line, each 1 cm apart. Each point represents a galaxy. Label the points as shown in Figure 7.3.10.

3 Inflate the balloon to its maximum size. Measure the distance between the central galaxy X and each of the other galaxies.

Results

Copy and complete the following table.

Galaxy	Initial distance from galaxy X (cm)	Final distance from galaxy X (cm)	Change in distance (cm)
A	3		
B	2		
C	1		
D	1		
E	2		
F	3		

Practical review

1 **Construct** a graph of change in distance against initial distance.

2 **Compare** this with Hubble's data on stellar red-shift.

7 Chapter review

Remembering

1 **List** two methods that can be used to locate a black hole.

2 **Name** the scientist whose work on stellar red-shift provided the first evidence for the expansion of the universe.

Understanding

3 **Define** the term *nebula*. L

4 **Explain** why we don't feel constantly pushed and pulled by gravitational forces from the people and objects around us.

5 **Describe** cosmic microwave background radiation.

6 **Explain** why the steady state model of cosmology is no longer accepted by most scientists

7 **Explain** why astronomers do not use parallax to measure the distances to other galaxies.

Applying

8 **Calculate** the distance to the following objects in light-years (Note: 1 kpc = 1000 pc). N

- a Sirius, distance = 2.6 pc
- b Alpha Crucis, distance = 100 pc
- c Crab nebula, distance = 2 kpc
- d Large Magellanic Cloud, distance = 50 kpc

9 Aldebaran is a star that is 65 light-years away. **Calculate** this distance in parsecs. N

10 The 'twin' stars of the constellation Gemini are named Castor and Pollux. Castor is 15.6 pc away and the distance to Pollux is 34 l.y. By converting these two distances to the same units, **identify** which of these twin stars is closest to us. N

Analysing

11 **Contrast** a black hole with the Sun.

12 a **Discuss** whether or not a parallax method could be used to measure the distance between the Earth and other planets in the solar system.

b **Identify** any problems that would be associated with this.

13 **Use** the images shown in Figure 7.3.1 on page 262 to **classify** the galaxy shown below as spiral, barred spiral or elliptical.

Evaluating CCT

14 Some scientists believe that the term Big Bang is too informal to describe the origin of the universe.

- a **Propose** an alternative name for this event.
- b **Justify** your proposal in terms of our scientific understanding of this event.

> **SciFile**
> **Big Bang**
> The term *Big Bang* was actually first used by Fred Hoyle, a key defender of the steady state theory. He meant it as a joke, but the name caught the imagination of the public and has been linked closely with cosmology ever since.

15 Science fiction writers have proposed that a black hole might act as a gateway to another galaxy. **Evaluate** whether or not this is a believable idea.

16 a **Determine** whether you can or cannot answer the questions on page 243 at the start of this chapter.

b **Use** this to **assess** how well you understand the material presented in this chapter.

Creating CCT

17 **Construct** a diagram to **explain** how stellar parallax can be used to measure the distance between the Sun and another star.

18 **Use** the following ten key terms to **construct** a visual chapter summary of the information presented in this chapter.

star	gravity
parallax	nuclear fusion
cosmology	Big Bang
red shift	structure
galaxy	
cosmic microwave background radiation	

7.6

Thinking scientifically

Questions 1 and 2 refer to the information in the table, which shows the proportion of elements that make up the Sun.

Element	Proportion of Sun
Hydrogen	90.97%
Helium	8.89%
Oxygen	0.08%
Carbon	0.03%
All others	0.03%

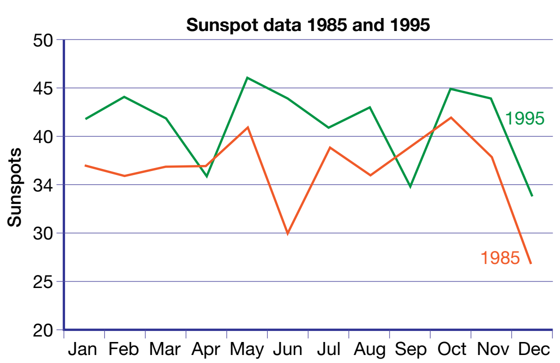
Q1 Approximately what percentage of the Sun is made of elements other than hydrogen? CCT

A 90.97% **B** 8.97%
C 9.03% **D** 0.03%

Q2 According to this data, what is the maximum proportion of the Sun that could be made of metals? CCT

A 9% **B** 0.14%
C 0.11% **D** 0.03%

Questions 3 and 4 refer to the following information. Sunspots are dark regions that appear on the Sun. The line graph below shows the number of sunspots observed each month in the years 1985 and 1995.



Q3 Which of the following conclusions could reasonably be drawn from the sunspot data shown? CCT

A The average number of sunspots in 1985 was lower than in 1995.

B December is a month in which there are always relatively low numbers of sunspots.

C There is a link between the number of sunspots and global warming.

D The number of sunspots observed in a particular month in 1995 was always higher than the number of sunspots observed in the corresponding month in 1985.

Q4 The highest number of sunspots in each year occurred in: CCT

A May 1985 and May 1995

B October 1985 and October 1995

C May 1985 and October 1995

D October 1985 and May 1995.

Q5 Many galaxies contain a super-massive black hole at their centre. Astronomers currently disagree over which came first—the black hole or the galaxy. Which of the following observations would support the idea that galaxies exist first and that, over time, enough material builds up in the centre of the galaxy to collapse and form a black hole? CCT

A The mass of a black hole is always larger than its surrounding galaxy, regardless of the age of the galaxy.

B The mass of a black hole is always smaller than its surrounding galaxy, regardless of the age of the galaxy.

C The mass of a black hole in comparison to its surrounding galaxy is relatively smaller in younger galaxies than in older galaxies.

D The mass of a black hole in comparison to its surrounding galaxy is relatively larger in younger galaxies than in older galaxies.

Q6 The Hubble constant, H_0, is a value first calculated by Edwin Hubble to measure the rate of expansion of the universe. It can be used to estimate the age of the universe, T, according to the equation: CCT

$$T = \frac{1}{H_0}$$

The currently accepted value for the Hubble constant is approximately 2.3×10^{-18} s^{-1}. Based on this value, the age of the universe is:

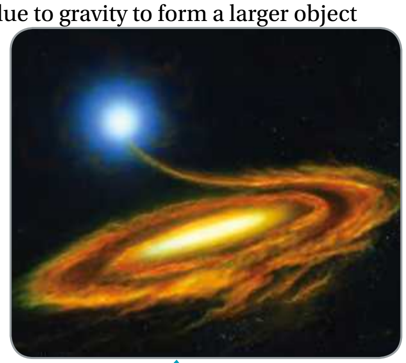
A 4.4×10^{-18} s **B** 2.3×10^{17} s
C 4.4×10^{17} s **D** 4.4×10^{18} s

Glossary

Unit 7.1

Accretion: the process in which particles of dust and rock slowly come together due to gravity to form a larger object

Binary star system: two stars that orbit a common centre of mass

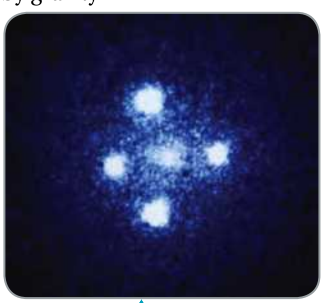


Binary star system

Black hole: also known as a singularity, a collapsed star so massive that not even light can escape from its gravitational field

Galaxy: a large group of stars attracted to one another by gravity

Gravitational lensing: the bending of light rays due to the distortion of space caused by a massive object such as a black hole



Gravitational lensing

Gravity: the force that causes all matter to collect together

Light-year (l.y.): the distance light travels in a year, approximately 9 500 000 000 000 km

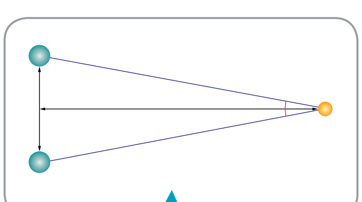
Milky Way: the galaxy in which the solar system is located

Milky Way

Nebula: a cloud of gas found in the empty space between stars; birthplace of new stars

Nuclear fusion: the process in which hydrogen is converted into helium to produce light and heat

Parallax: a technique used to measure the distance to other stars



Parallax

Parsec: an astronomical unit of length equal to 3.26 light-years

Protoplanetary disk: disk of gas surrounding a protostar that will form into planets

Protoplanetary disk

Protostar: a collapsing cloud of gas that will eventually become a star

Radiation pressure: the force produced by radiation from pressure caused by heat

Stellar parallax: the apparent change in the position of a star throughout the year due to the Earth's motion around the Sun

Supermassive black hole: a black hole millions or billions of times the mass of our Sun found at the centre of a galaxy

Unit 7.2

Absolute magnitude: a measure of how bright a star would appear if it was 10 parsecs from Earth

Apparent magnitude: a measure of the brightness of a star as it appears to an observer on Earth

Blue supergiants: stars that are ten or more times more massive than the Sun

Black dwarf: cold dark remains of a white dwarf

Density: mass per unit volume of a material

Electromagnetic spectrum: different types of electromagnetic radiation ranging from radio waves to gamma rays

Gamma rays: very high-energy electromagnetic rays

Isotope: atoms with the same number of protons but different numbers of neutrons

Magnitude: a measure of the brightness of a star

Main sequence: a group of stars lying on a line running from the top left to the bottom right of the H–R diagram

Neutrino: an almost mass-less, neutral particle released during some nuclear reactions

Neutron star: remnant of a supernova, consisting entirely of neutrons

Plasma: state of matter consisting of positively charged ions and free electrons

Glossary

Positron: a positively charged electron

Planetary nebula: a cloud of gas produced when a red giant runs out of fuel

Planetary nebula

Red giant: a star produced when the core of a Sun-sized star runs of hydrogen

Singularity: also called a black hole

Spectral class: a classification system for stars based on their colour

Spectrometer: a device that splits light into a spectrum to show its component wavelengths

Supernova: a giant explosion that occurs when a star many times larger than our Sun runs out of nuclear fuel

Supernova

White dwarf: hot, dense star that is the remains of a red giant

Unit 7.3

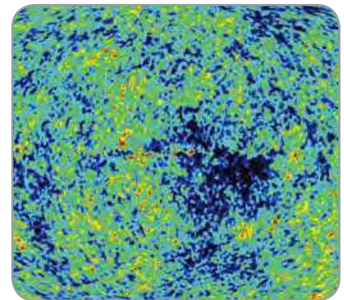
L

Big Bang: theory that the universe began with an enormous explosion of energy

Blue-shift: the compression of light waves due to the motion of stars towards Earth; blue-shift makes light appear bluer than it should

Big Bang

Cosmic microwave background radiation: the afterglow of the Big Bang; low-energy radiation that fills the universe



Cosmic microwave background radiation

Cosmology: the study of the history and structure of the entire universe

Doppler effect: the expansion or compression of waves due to the motion of the object making the waves

Red-shift: the stretching of light waves due to the motion of stars away from Earth; red-shift makes light appear redder than it should; also known as cosmological red-shift

Doppler effect

Steady state theory: now discounted theory that the universe has always existed in the form that it is in today; also known as the 'infinite universe' theory

8 Motion and energy

Have you ever wondered...

- why objects speed up as they fall to the ground?
- why you might fall over when standing in a train that starts or stops?
- why it is hard for a heavy truck to stop quickly?
- how a rocket is launched?

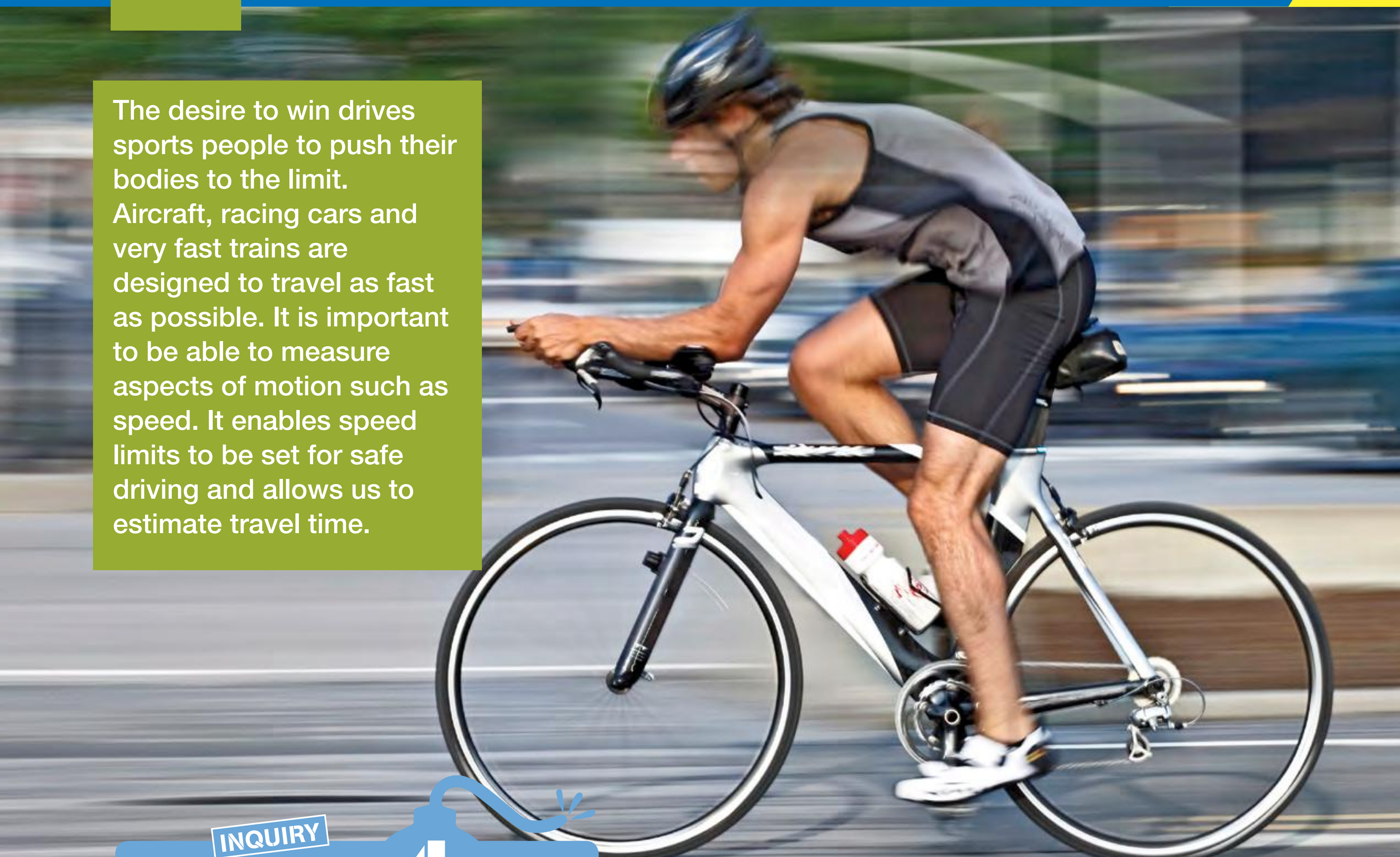
After completing this chapter students should be able to:

- qualitatively explain the relationship between distance, speed and time
- qualitatively describe the relationship between force, mass and acceleration
- qualitatively analyse everyday situations in terms of Newton's laws of motion CCT
- qualitatively explain that acceleration is the result of a net force
- apply the law of conservation of energy to energy transfers and transformations
- describe how energy transfers and transformations are never 100% efficient
- discuss the need to increase the energy efficiency of everyday appliances CCT S EU

ADDITIONAL

- explain the difference between speed and velocity
- quantitatively describe the relationships between displacement, time, velocity and acceleration using equations of motion N
- quantitatively describe the relationship between force, mass and acceleration N
- apply Newton's laws of motion to space travel CCT
- compare energy changes in sporting activities. CCT

8.1 Describing motion

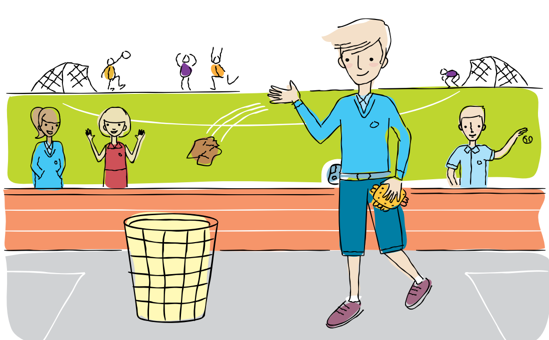


The desire to win drives sports people to push their bodies to the limit. Aircraft, racing cars and very fast trains are designed to travel as fast as possible. It is important to be able to measure aspects of motion such as speed. It enables speed limits to be set for safe driving and allows us to estimate travel time.

INQUIRY **science 4 fun**

Lunchtime marathon

How far do you travel during a typical lunch break and how far do you end up from where you started?



Collect this …

- pedometer
- ruler, trundle wheel or tape measure

Do this …

1. Clip a pedometer onto yourself at school at lunchtime, or for an hour after school once you get home.
2. Record the number of steps you take in this time.
3. Measure the length of a typical step that you take.
4. Calculate the approximate total distance that you covered during the trial.
5. Measure the distance between where you started and where you finished the trial using measuring tape, trundle wheel or by estimating using pace length.

Record this …

Describe any differences in your answers to steps 4 and 5.
Explain why these were different.

Distance and displacement

When planning a trip around New South Wales, you would need to consider the **distance**, or how far away places to visit are. You would also need to consider the amount of time you have. In this case, distance would be measured in kilometres, and your time in days or weeks. If considering a trip to the end of your street, then distance would most likely be measured in metres and the time would be measured in minutes or even seconds.

You also need to consider where you will end your journey. Your **displacement** is the straight-line distance between your finishing and starting points. For example, if you travel from home to the house of a friend who lives 200 km south, then your displacement is 200 km south. Displacement specifies not only the distance from the starting point, but also the direction of the end point from your starting point.

Figure 8.1.1 compares displacement with distance. When travelling on a return trip, you can cover a large distance, but your displacement upon returning home is zero.

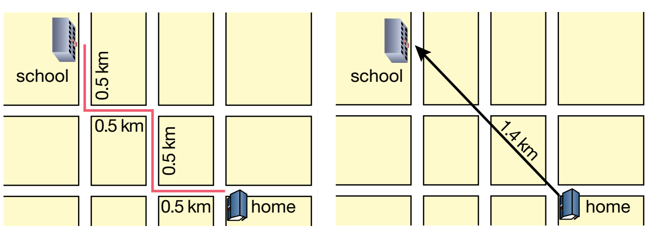


Figure 8.1.1 Greg walks to school and travels a distance of 2 km. His displacement is 1.4 km north-west.

Giddy-up?

SciFile

Humans appear to be getting faster with every new world record set in running. Are animals getting faster? Research of data from horse and dog racing has shown that the top speed of a horse has not increased since the 1940s and the speed of a dog has not increased since the 1970s.

Speed

Speed is a measure of how fast something moves. An object moves faster when it travels a greater distance in a certain time, or covers a set distance in a shorter time.

Average speed

Average speed is a measure of how fast something moves overall. The average speed ignores the stops and changes in speed that happen in any journey and instead assumes that the object was travelling at the same speed for whole time. If you travel twice as far in the same time, then you are travelling at twice your original average speed. Likewise, your average speed is doubled if you travel the same distance but in half the time.

Instantaneous speed

Average speed does not give any indication of how slowly or how quickly you may have travelled in a trip, or how long you were caught in a traffic jam or stopped at traffic lights. Your speed at a particular instant is called your **instantaneous speed**.

In a car instantaneous speed is measured by its speedometer (speedo). The instantaneous speed of a car can also be measured using a mobile speed camera like the one in Figure 8.1.2. Handheld speed cameras send a beam of laser light across a road. Cars reflect this beam and alter its frequency (the number of waves passing every second). This change in frequency allows the exact speed of the car to be calculated—the faster the car's speed, the greater the change in frequency will be. This phenomenon is called the Doppler effect.

GO TO Unit 7.3

Figure 8.1.2 Speed cameras measure the instantaneous speed of a vehicle.

Measuring speed

There are many different ways of measuring speed. Fixed speed cameras operate using two electronic sensors embedded in each lane of a road. A car that travels over one sensor is timed as it travels to a second sensor. The speed of the car can then be determined. Light gates can be used to time sporting events such as downhill skiing (Figure 8.1.3). Light gates use a sensor to trigger an electronic timing mechanism when an object breaks through a light beam.

Figure 8.1.3 Light gates measure time to the millisecond and produce very accurate measurements of an object's speed.

A motion sensor (Figure 8.1.4) sends out pulses of radiation, such as ultrasonic sound waves, microwaves or infrared radiation. The reflection of this radiation from an object provides data about its position and speed.

Figure 8.1.4 Motion sensors provide the driver with information about how close they are to a barrier.

A multi-flash photograph records motion as a series of images. For example, Figure 8.1.5 shows six images taken of a serve in tennis. The spacing between each image represents exactly the same time. The further apart the images, the faster the racquet is travelling. The racquet moves the greatest distance at the end of the serve and so the racquet's motion is fastest then.

Figure 8.1.5 The distance moved by this racquet in each time interval provides a measure of its instantaneous speed.

A ticker timer is is another device that can be used to measure speed (Figure 8.1.6). When the timer is attached to an object moving in a straight line, dots record its motion (Figure 8.1.7).

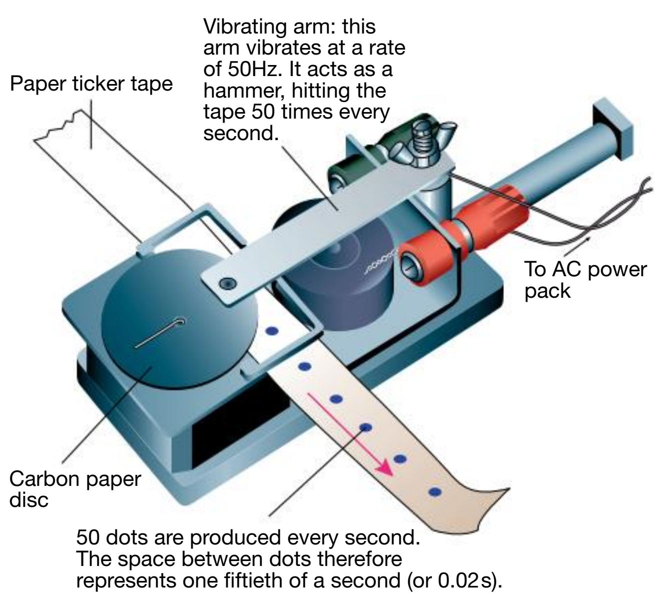


Figure 8.1.6 Analysing the distance between dots recorded on a strip of ticker tape reveals the speed of the moving object used to produce the trace.

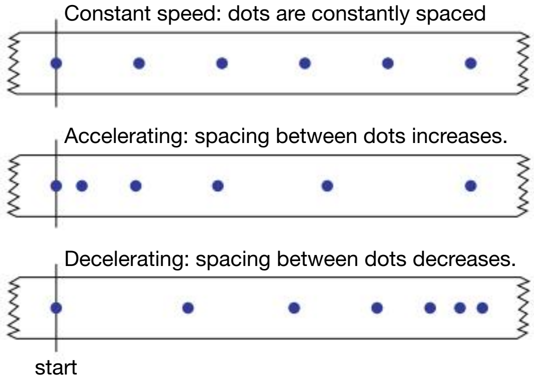


Figure 8.1.7 The spacing of the dots on a ticker tape tells you what type of motion it is. Each new dot represents 0.02 seconds has passed.

Speed and driving

When driving a car, it is vital to stay alert. If a child runs onto the road, or a car breaks down in front of you, you need to react and apply the brakes as quickly as possible. The time it takes for someone to react to an emergency is known as their **reaction time**. For a person who is alert and concentrating, this reaction time is typically 0.15–0.30 seconds.

Consider an emergency that happens while driving. During the reaction time the car is still travelling at the speed it was travelling at just before the emergency. A car travelling at 100 km/h will cover 4–8 m before the driver even starts to apply the brakes or swerve! This distance is known as **reaction distance**. When trying to avoid a collision, this distance is critical. A driver's reaction time is slowed by distractions in the car.

Distractions could be caused by:

- other people
- speaking or texting on a mobile phone
- changing the radio station or inserting a CD.

Additional factors such as a person's age, fatigue and the influence of drugs and alcohol also slow a person's reaction time.

Once you have reacted and applied the brakes, the car covers additional distance as it comes to a stop. This is the car's braking distance. The total distance taken to stop the car is the sum of the reaction distance and the braking distance.

Prac 1 p284 | 8.1 | 8.2

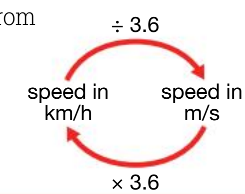
stopping distance = reaction distance + braking distance

SciFile: Busted on average!

Since 2012, point-to-point speed cameras have measured the average speeds of heavy vehicles such as trucks and buses travelling on most major highways in NSW. These cameras record the time the vehicle takes to travel between cameras. If it takes less time than it should, then the driver must have been speeding!

Converting units

It is easier to compare things such as distance and speed if people in different parts of the world agree to describe these in the same units. The International System of Units, called SI units (from the French, Le Système International d'Unités), is a standard that was introduced in 1960. The SI unit for distance is metres and the unit for time is seconds. This makes the SI unit for speed metres/second or m/s. However, the speed of a car is usually measured in kilometres per hour (km/h). Speeds can be converted from m/s into km/h and km/h into m/s by multiplying or dividing by 3.6 as shown here.



WORKED EXAMPLE
Converting units

Problem

1 Convert 3 m/s into km/h.

2 Convert 54 km/h into m/s.

Solution

1 3 m/s = 3 × 3.6 km/h = 10.8 km/h

2 54 km/h = 54 ÷ 3.6 m/s = 15 m/s

Practice

N

Calculate the missing values to complete these unit conversions.

Animal	Speed (m/s)	Speed (km/h)
Cheetah		102
Red kangaroo	17.5	
Giraffe		56
Emu		50
Human	7.5	
Elephant		24
Chicken		4
Giant tortoise	0.075	

ADDITIONAL

Calculating average speed

Average speed is the distance an object travels divided by the time this takes. Mathematically, this can be expressed by the formula:

$$\text{average speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

or

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

where v is average speed, d is distance travelled and t is time taken.

WORKED EXAMPLE
Calculating average speed

Problem 1

Theo spent 8 hours travelling 400 km from his home in Albury to visit his sister in Wollongong. Calculate Theo's average speed for the journey.

Solution

$$v = \frac{400}{8} = 50\ \text{km/h}$$

Problem 2

Joe ran the 100 m in 15 seconds. Calculate his average speed.

Solution

$$v = \frac{100}{15} = 6.7\ \text{m/s}$$

Practice N

1 Isabel catches a bus and spends 6 hours travelling 240 km from her home to visit her grandmother. **Calculate** Isabel's average speed for the journey.

2 In his school sports, Michael swam the 50 m backstroke in 25 seconds. **Calculate** his average speed.

Calculating distance

The equation for average speed can be rearranged to calculate distance travelled in a certain time:

$$\text{distance} = \text{average speed} \times \text{time}$$

or

$$d = v \times t$$

WORKED EXAMPLE
Calculating distance

Problem

Trinh rides her bike with a constant speed of 5 m/s. It takes her 3 minutes to get to the milk bar. Calculate how far away it is.

Solution

Speed here is in m/s, so time must first be converted from minutes into seconds.

$t = 3 \times 60 = 180$ s

Trinh has travelled:

$d = v \times t$

$= 5 \times 180$

$= 900$ m

The milk bar is 900 m away.

Practice N

While Jacinta is riding on a bus, a toddler runs onto the road ahead. It takes the driver 0.5 s to react. **Calculate** how far the bus travels before the driver applies the brakes if the speed of the bus is 15 m/s.

ADDITIONAL

INQUIRY

science 4 fun

Ups and downs

How does the motion of a ball change as it is tossed up into the air and falls down?

Collect this ...

- video camera or mobile phone with video
- tennis ball

Do this ...

1 Work with a partner. One of you tosses a tennis ball about a metre into the air and tries to catch it while the other records the motion with the camera.

2 Replay the motion slowly and watch it carefully.

Record this ...

Describe the motion of the ball, including when it got faster and when it slowed down.

Explain why you think this happened.

Figure 8.1.8 This soccer ball has suddenly stopped—it has decelerated.

Acceleration

In everyday language, acceleration is a change in speed. When an object speeds up, it has accelerated. When it slows down, it has decelerated. Figure 8.1.8 shows a soccer ball that has just decelerated.

In physics, acceleration is not just a change of speed—it is a measure of how quickly the change of speed happens. In physics, acceleration is defined as the rate at which something changes speed.

For example, compare two cars (one red, one blue) stopped at traffic lights. Both cars accelerated away when the lights changed to green and both reached the same speed of 60 km/h. The red car took 3 seconds to do so, while the blue car took 5 seconds. The change in speed was the same for both cars but the time taken was different—this makes their accelerations different too. In this case, the red car accelerated to 60 km/h in 3 seconds, an average of 20 km/h/s. This means that its speed increased by 20 km/h every second. It was travelling at roughly 20 km/h after 1 second, 40 km/h after 2 seconds and 60 km/h after 3 seconds. The blue car took longer to reach the same speed, so its acceleration was less than that of the red car. As Figure 8.1.9 shows, the average acceleration of the blue car was 12 km/h/s—its speed increased by 12 km/h every second.

Table 8.1.1 compares the performance of a number of cars. The shorter the time a car takes to reach 100 km/h, the greater its acceleration.

Table 8.1.1 Time taken to accelerate from 0 to 100 km/h

Car	Time (s)
Bugatti Veyron 16.4 Grand Sport Vitesse (2012)	2.6
Nissan GT-R (2012)	3.0
Jeep Grand Cherokee 6.4 V8 SRT8 (2012)	5.0
BMW 135i (2012)	5.2
VW Golf GTI DSG 2.0 Turbo (2013)	6.5
Honda Civic 2.0i VTEC (2011)	6.6
Holden Monaro GTS V8 (1968)	7.5
Mini Cooper Paceman (2012)	10.7
Toyota Land Cruiser 3.0 TD (1994)	16.9
Peugeot 403 1500 (1955)	24.8

Source: Autosnout.com

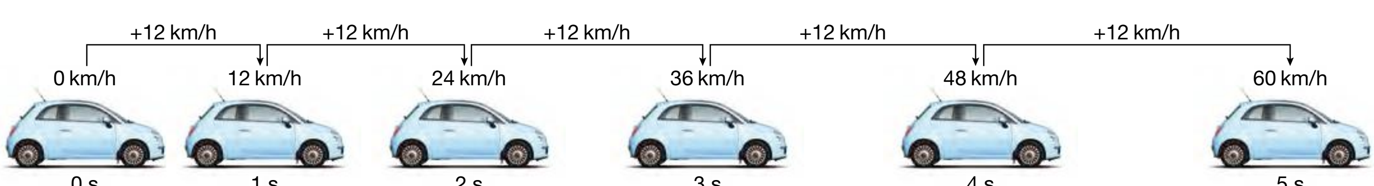


Figure 8.1.9 This car has a constant acceleration of 12 km/h/s. Its speed has increased by 12 km/h every second.

Acceleration due to gravity

Although the accelerations of the red car and blue car were measured using the unit km/h/s, the SI units for acceleration are m/s/s or m/s^2. These are the units normally used to measure the acceleration of something that is falling.

A falling object (like the person in Figure 8.1.10) accelerates towards Earth because of the force of gravity. This means that it speeds up as it falls. Acceleration due to gravity is 9.8 m/s^2, so the speed of an object increases by almost 10 m/s (or 36 km/h) for every second that it falls. In the first second, the object's speed increases from zero to about 10 m/s (or 36 km/h). Another 10 m/s is added to its speed over the next second so that it is falling at approximately 20 m/s (72 km/h). After 3 seconds, it is falling at about 30 m/s (108 km/h). An acceleration of 9.8 m/s^2 is called '1 g'. You may think it could reach enormous speeds, but friction between the air and a moving object will eventually reduce this acceleration to zero.

The friction between the air and a falling body is called **air resistance**, and the final velocity is called **terminal velocity**.

Human tolerance of acceleration depends on the rate of acceleration/deceleration, how long it lasts, the direction of the acceleration/deceleration and the part of the body it affects (Figure 8.1.11). Humans can tolerate horizontal accelerations much better than vertical accelerations. Accelerations experienced in a vertical drop are particularly dangerous as blood flow to the brain can be disrupted and can cause loss of consciousness or death. Your body can withstand high accelerations for a moment with no damage, but accelerations of longer duration are deadly. Some typical accelerations are shown in Table 8.1.2.

Figure 8.1.10 This daredevil is jumping out of a plane wearing a full body suit, complete with nylon 'wings'. This person falls at about 100 km/h, and deploys a parachute to decelerate, slowing their fall before reaching the ground.

Table 8.1.2 Typical accelerations

Situation	Acceleration (m/s^2)
Free-fall	9.8 = 1 g
Rocket at take-off	29.4 = 3 g
Typical rollercoaster	29.4 = 3 g
A sneeze	29.4 = 3 g
Slap on the back	39.2 = 4 g
Human in a rocket sled (maximum)	451 = 46 g
Car accident at 48 km/h with airbag (force on chest)	588 = 60 g
Motorbike accident with no helmet (force on head)	1470–1960 = 150–200 g

SciFile

Gee-force!

American Air Force physician John Strapp decided to test the human g-force limits. He strapped himself into a sled, powered by nine solid fuel rockets on a railway track. Strapp accelerated to 1017 km/h in 5 seconds, before stopping in 1 second. John Strapp's body withstood a momentary deceleration of –46 g!

Figure 8.1.11 Six images showing John Strapp accelerating then decelerating rapidly.

Graphing motion

A graph is a useful way of illustrating an object's motion.Time is always placed on the horizontal axis.

Distance–time graphs

A distance–time graph shows how far an object travels as time progresses. A flat line on this graph indicates that the motion has stopped. A line with a steep slope indicates that the object covers greater distance and is moving faster than a line of gentle slope does. The slope is also known as the **gradient**. The slope or gradient of a distance–time graph is equivalent to the object's average speed over a time interval. Figure 8.1.12 shows three possible distance–time graphs of a cyclist.

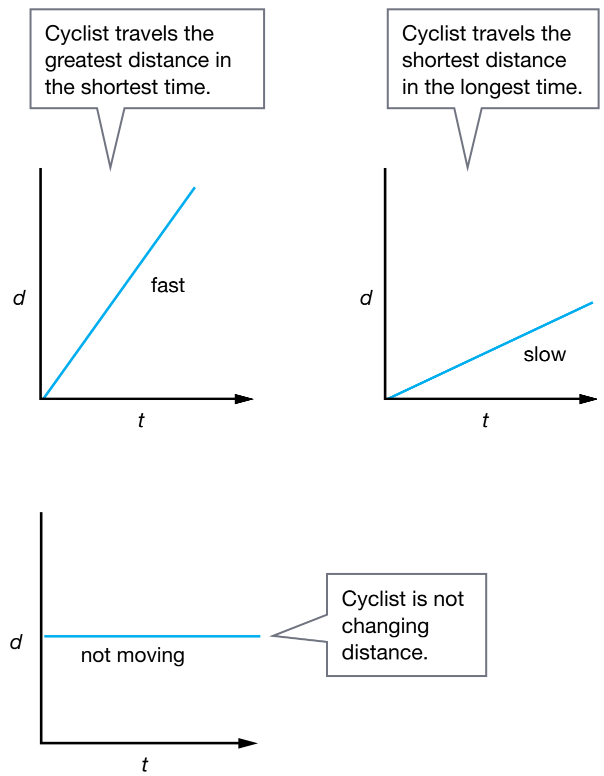


Figure 8.1.12 The steeper the gradient, the faster the object is moving.

Super bird!

The peregrine falcon is a raptor that hunts and kills other birds. Its vision is about eight times stronger than human sight. These raptors knock their prey unconscious in a vertical dive at speeds up to 300 km/h. As it pulls out of a dive, the peregrine falcon can withstand decelerations of up to –25 g!

SciFile

Displacement–time graphs

Alternatively, an object's displacement can be shown on the vertical axis of a graph instead of distance. In this case, the graph shows how the position of the object changes compared to where it started. Figure 8.1.13 illustrates a displacement–time graph for Mitsu walking to and returning from a friend's house.

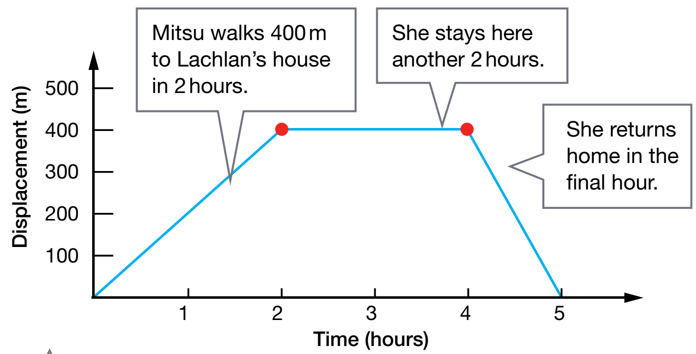


Figure 8.1.13 This graph indicates that Mitsu has travelled out and then returned to her starting point.

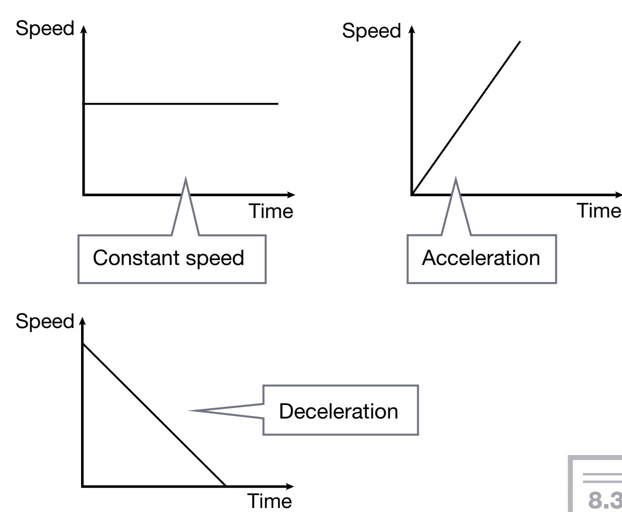
Speed–time graphs

A speed–time graph shows how an object's speed changes over time (Figure 8.1.14). An object's speed may:

- be constant, shown by a flat line
- increase (acceleration), shown by the graph rising upwards
- decrease (deceleration), shown by the graph falling downwards.

Prac 2 p285
Prac 3 p286

On a speed–time graph, acceleration is shown by the slope or gradient. The greater the acceleration, the steeper the graph will be. If the slope is negative then the object is decelerating.



8.3

Figure 8.1.14 The gradient (slope) of a speed–time graph indicates whether motion is constant, speeding up or slowing down.

8.1 Unit review

Remembering

1 **Recall** the SI units for: N
- **a** distance
- **b** time
- **c** speed
- **d** acceleration.

2 **State** what is represented by the gradient of a speed–time graph.

3 **State** whether a speedometer reading of 45 km/h is the average or instantaneous speed of the car.

4 In the science4fun on page 279, a ball is tossed up and down. Imagine the ball reached a height of 2 metres above your hand before returning to it. For this up-and-down motion, **state**:
- **a** the distance the ball travelled
- **b** the displacement of the ball at the top of its journey
- **c** the displacement of the ball when it returned to your hand.

Understanding

5 Jo's displacement is 100 m north. **Explain** what this means.

6 Acceleration due to gravity is 9.8 m/s^2, but in practice, an object dropped on Earth will not accelerate this rapidly. **Explain** why.

7 Joe says that something that is thrown vertically upwards isn't accelerating. Jo thinks it is. **Discuss**.

8 Figure 8.1.15 shows a graph of the speed of a leaf floating in a running stream of water.

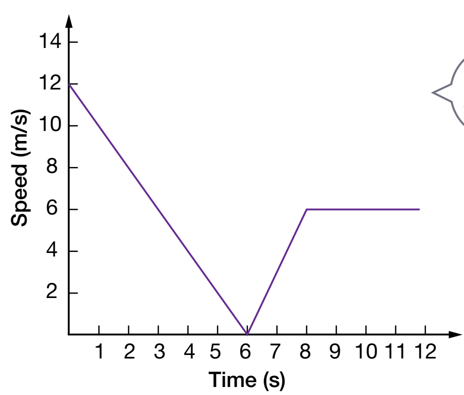


Figure 8.1.15

Describe the motion of the leaf for the time intervals:
- **a** 0–6 seconds
- **b** 6–8 seconds
- **c** 8–12 seconds.

9 **Calculate** what the following speeds would be in the units shown. N
- **a** 60 km/h in m/s
- **b** 100 m/s in km/h

Applying

10 For each of the objects shown in Figure 8.1.16, **calculate**: N
- **i** the distance travelled
- **ii** its displacement

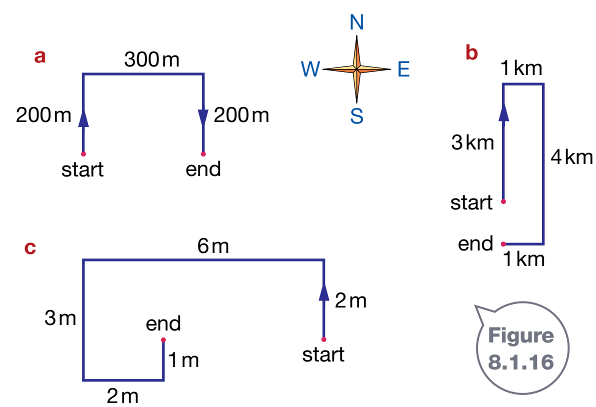


Figure 8.1.16

11 Figure 8.1.17 shows the displacement of six objects over a time period. **Identify** which graph/s represent:
- **a** a stationary object
- **b** an object moving backwards
- **c** the fastest forward-moving object
- **d** the fastest backward-moving object.

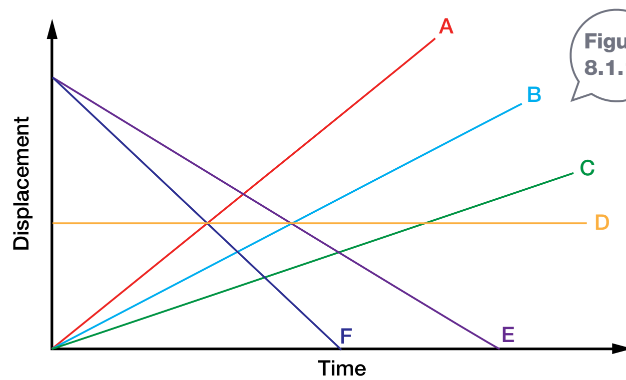


Figure 8.1.17

12 A toy truck was stationary then rolls down a long ramp with a constant acceleration of 0.2 m/s^2. **Calculate** its speed after: N
- **a** 1 second
- **b** 2 seconds
- **c** 3 seconds
- **d** 10 seconds.

Analysing

13 You probably travel a considerable distance during lunch break at school, yet your displacement over that time is likely to be zero. **Use** your movement over lunch break to **compare** distance with displacement.

14 **Analyse** Figure 8.1.18 and **describe** the motion of car A and car B.

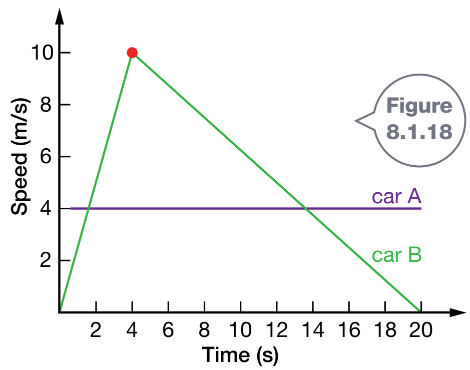


Figure 8.1.18

15 **Analyse** the three distance–time graphs shown in Figure 8.1.19 to determine which shows an object:

- **a** speeding up
- **b** slowing down
- **c** travelling at constant speed.

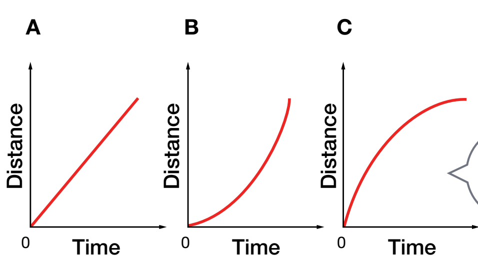


Figure 8.1.19

Evaluating CCT

16 **Propose** what an object is doing if it is accelerating at $-10\,m/s^2$.

17 Refer to Figure 8.1.13 on page 281 showing Mitsu's walk to Lachlan's house. N

- **a** **State** how long Mitsu stayed at Lachlan's house.
- **b** **State** whether Mitsu travelled faster when travelling to or from Lachlan's house.
- **c** **Justify** your answer to part **b**.
- **d** **Calculate** the total distance that Mitsu travelled over her 5-hour journey.
- **e** **State** Mitsu's displacement over the 5-hour journey.

18 **Analyse** the motion of the gymnast on page 273.

- **a** **Use** the spacing of the images to **state** where:
  - **i** his legs are moving fastest
  - **ii** his head is moving slowest
  - **iii** his hands moving so slowly that they are almost stopped
  - **iv** his head is accelerating.
- **b** **Justify** each of your answers above.

Creating CCT

19 The table below shows the speed of a cheetah at 1-second intervals as it chased its prey.

Time (s)	0	1	2	3	4	5	6	7	8	9	10
Speed (m/s)	0	6	14	27	27	27	27	20	12	3	0

- **a** **Construct** a speed–time graph from this data.
- **b** **Identify** the time intervals in which the acceleration of the cheetah is:
  - **i** zero
  - **ii** positive
  - **iii** negative.

Inquiring

1 Investigate current NSW road statistics and select a key area that influences the number of fatalities, such as driver distraction, fatigue, speed, drug or alcohol use.

Present your findings as an advertising campaign (billboard, radio commercial or TV commercial). Your aim is to raise awareness of this issue.

2 Aristotle was an ancient Greek philosopher. He believed that objects fell towards Earth because of a homing instinct, and that heavier objects fell faster than lighter objects. These ideas were popular for some 2000 years, but were challenged by the Italian physicist Galileo Galilei (1564–1642).

- **a** Explain how Galileo's approach to science differed from that of Aristotle.
- **b** Describe experiments Galileo conducted with falling bodies.
- **c** State Galileo's conclusion about falling objects.

Present your findings in digital form. ICT

8.1 Practical investigations

1 Reaction time

Purpose

To simulate a driving experience and test your reaction time.

SAFETY

Be careful not to fall from the chair. Ensure it is in a stable position on the table by having a partner hold it in place.

Materials

- metre ruler
- table or bench
- calculator

Procedure

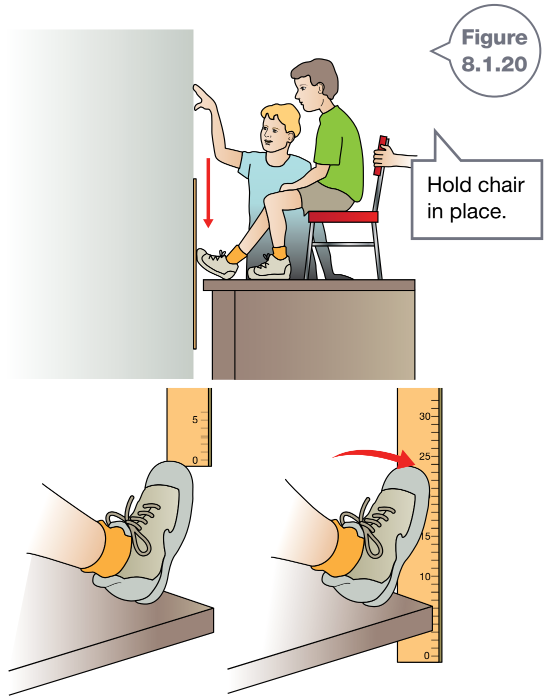
1 Copy the table from the Results section into your workbook.

2 Work with two partners. Select a 'driver' for this activity. This person should stop reading or writing from here and listen to their partners' instructions.

3 For the non-drivers, copy the table from the Results section.

4 Position a chair on top of a bench or table, close to a wall as shown in Figure 8.1.20.

Figure 8.1.20



5 The driver sits on the chair that is held in position by another student. The remaining group member holds the ruler (or brake pedal), flat against the wall so that zero on the ruler is aligned with the driver's toes as shown.

6 Tell the driver that when the ruler starts to fall, they need to 'hit the brakes' and stop it with their foot.

7 Release the ruler and record the distance it falls before the driver stops it.

8 Complete three trials of this test.

9 Repeat the three trials, but this time keep talking to the driver while performing each trial.

10 Repeat the three trials again, but ask the driver to read or send a text message from a mobile phone, or to read a paragraph of printed text out loud.

Results

1 Record all measurements in your results table.

Test conditions	Reaction distance (cm)			Average reaction distance (cm)	Reaction time (s)
	Trial 1	Trial 2	Trial 3		
No distractions					
Distraction (talking)					
Distraction (reading a message)					

2 Calculate the average reaction distance from each set of trials and add them to your table. N

3 Calculate the reaction time for each set of results by:
- taking the square root of the reaction distance (in cm)
- multiplying your answer by 0.045. N

Practical review

1 **State** the spread, or range, of results of reaction time measured in the first three trials.

2 **Describe** the effect of the distractions on the reaction time.

3 Taking longer to react to a traffic hazard or travelling over the speed limit will result in a driver travelling further before being able to stop their car. **Discuss** why this is the case in each situation.

4 **Propose** ways in which driver distraction can be minimised in a car.

2 The speed of toy cars

Purpose

To analyse the motion of a toy car.

Materials

- toy car
- motion sensor with computer interface

OR

- ticker timer, ticker tape, AC power supply, ruler, sticky tape

Procedure

1 Work with a partner. Use the procedure appropriate to the equipment you have.

Motion sensor

2 Position the motion sensor at the end of a workbench. Attach the sensor to a computer interface.

3 Align the toy car about a metre away from the sensor. Check that the sensor is detecting motion of the car.

4 Set the computer so that a recording of the speed of the car is plotted against time.

5 Push the car towards the sensor and record the speed–time relationship of the journey.

6 Capture a screen shot of the motion.

7 Repeat with four more attempts in which the speed of the car varies.

Ticker timer

8 Attach about 1 metre of ticker tape to the back of the toy car.

9 Turn on the ticker timer and push the car across the bench. A series of dots should be made on the ticker tape.

Results

1 If you used a motion sensor then save screen shots of the five graphs showing how the speed of the car varied with time.

2 If you used a ticker timer then follow the Skill builder below to analyse your tape and to construct a speed–time graph. You will also need to construct a results table like this.

Section	Total time (s)	Length of section (mm)	Time interval of each section(s)	Average speed of section (mm/s) (length of section/0.1)
1 (dots 0–5)	0.1		0.1	
2 (dots 5–10)	0.2		0.1	
3 (dots 10–15)	0.3		0.1	

Practical review

1 **Describe** the motion of the toy car in each test.

2 For each test, **identify** where on the speed–time graph the toy car:

a recorded the greatest instantaneous speed

b experienced its greatest acceleration.

3 **Use** your graph to **determine** if the toy car ever slowed down (that is it experienced negative acceleration).

SKILL BUILDER

Analysing ticker tapes

1 Mark the first clearly seen dot on your tape, and then mark every fifth dot recorded after this. Number each group of dots as shown in Figure 8.1.21.

2 Cut the tape into sections at the points you've marked. Paste these strips in order to construct a speed-time graph like that shown in Figure 8.1.22. Each new dot represents 0.02 seconds so five dots represent 0.1 s.

3 Calculate the average speed of each strip of five dots:

$$\text{Average speed of each section} = \frac{\text{length of section}}{0.1}$$

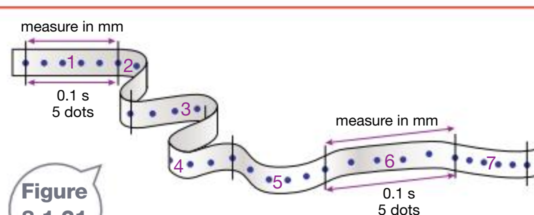


Figure 8.1.21

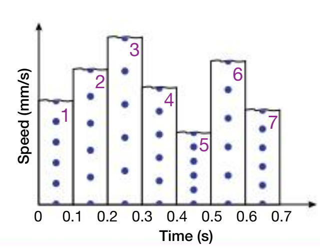


Figure 8.1.22

8.1 Practical investigations

3 Measuring acceleration

Purpose

To determine the acceleration of a trolley rolling down a ramp.

Materials

- ramp
- books or bricks to prop up ramp
- slotted masses
- sticky tape
- trolley
- motion sensor with computer interface

OR

- ticker timer, ticker tape, AC power supply, ruler, sticky tape

Procedure

1. Prop up the ramp so that it is at an angle (roughly 30° to the horizontal).
2. If your trolley is very light then tape a number of slotted masses to its top surface.
3. Set up the motion sensor or ticker timer at the top of the ramp OR tape a strip of ticker tape to trolley (Figure 8.1.23).
4. Use the motion sensor or ticker timer to record the changing speed of the trolley as it rolls down the ramp after being released.

Figure 8.1.23

Results

Take a screen shot of the speed–time graph you obtain using the motion sensor equipment or arrange sections of ticker tape to produce this graph as shown in Figure 8.1.24.

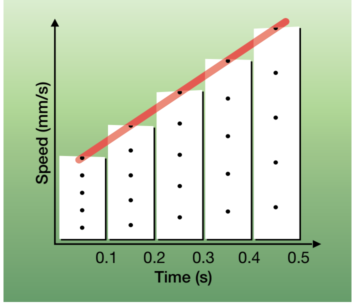


Figure 8.1.24

Practical review

1. The gradient of the line of best fit is a measure of the acceleration of the cart. **Use** your speed–time graph to **describe** the motion of the cart as it moved down the ramp.
2. **Propose** one way in which the speed of the trolley could have been increased.
3. **Discuss** any sources of error that could affect the accuracy of your results.

SciFile

Accelerometers

An accelerometer is a device that detects acceleration. Many mobile phones and computer tablets contain accelerometers that detect when you rotate them. This results in the screen automatically rotating to always appear the right way up. Accelerometers also trigger the release of airbags in a car that is involved in a collision.

8.2 Newton's laws of motion

Forces are pushes, pulls or twists. A force can make an object start moving, speed up, slow down, stop, change direction or even change its shape. Sometimes it is hard to tell that forces are acting because they are balanced and an object does not change its motion. In a car accident, the effect of forces is obvious. The English scientist Isaac Newton formulated three laws of motion in 1687. These three laws explain why everything around you moves the way it does.

INQUIRY

science 4 fun

Loose change

YES

What can you do to a pile of coins without them falling over?

Collect this …

- 5 × 20-cent pieces
- ruler
- piece of paper

SAFETY

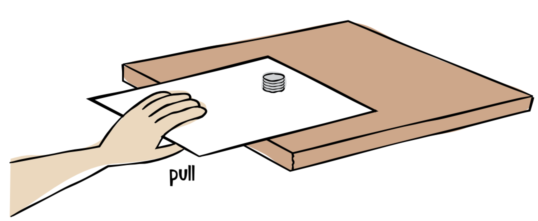
Do not flick objects at or near people.

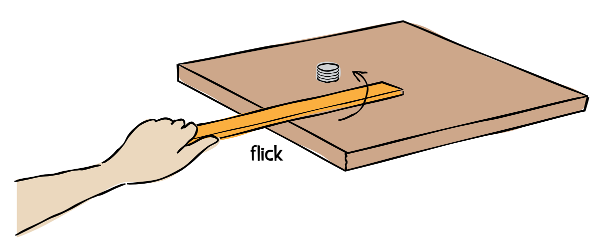
Do this …

1. Rest the piece of paper on a bench so that a little of it overhangs the edge.
2. Put the pile of 20-cent pieces on the other end of the paper
3. Quickly pull the sheet of paper out and note what happens to the coins.
4. Put a pile of coins on a bench, and flick a ruler towards them to try to knock out the bottom coin. (Place a rolled-up towel near the pile to stop the coins from hitting anything.)

Record this …

Describe what happened.
Explain why you think this happened.





Newton's first law

When you give a pencil case a light push, it moves a small distance across the desk and stops. For thousands of years, people believed that such an object stopped because the force you gave the pencil case stops working. Galileo Galilei realised that these objects stop because the force of friction acts in the opposite direction to their motion. He reasoned that if there was no friction, then a single push would be enough to keep it moving. The object would only be stopped by some other force.

Isaac Newton (1642–1727) developed Galileo's ideas further and developed three laws of motion.

Newton's first law of motion states that:

- An object at rest will remain this way unless it is acted upon by a force.
- An object that is moving will continue to move at the same speed and in the same direction unless an unbalanced force acts upon it.

In other words, this law states that a force is needed to get something moving. A force is also required to change the speed or direction of something that is already moving. This tendency to resist any change in motion is called an object's **inertia**. The larger the mass of an object, the greater its inertia, and the harder it is to change its motion. This explains why it is easier to stop an empty runaway shopping trolley than one that is full. It also explains why it takes much more fuel for a heavy truck to start moving than for a small car.

Examples of Newton's first law

You feel the effects of inertia whenever you are in a train that suddenly accelerates, stops or turns (Figure 8.2.2).

When a train begins to move, your feet move forwards with it. However, your body tends to remain stationary, making it appear as if you are 'falling backwards'. Once you are moving in the train, the brakes that slow the train act on the train, but not on you. As the train slows, your feet slow down but your body continues its motion, and you can fall forwards.

Figure 8.2.2 Inertia causes you to lurch about as a train accelerates and decelerates.

Consider what happens in a car accident. If you are travelling in a car at 60 km/h that is suddenly brought to a stop, then your body continues to travel forwards at 60 km/h. Figure 8.2.3 shows this situation using crash-test dummies. Seatbelts restrain your body so that you come to a stop with the car. Airbags in a car will inflate when the car collides with a solid object at speeds above 18 km/h. The airbag reduces the force on a passenger in a collision and prevents their head hitting the steering wheel or the side of the car.

SciFile

Isaac Newton

The English scientist and mathematician Isaac Newton made enormous contributions to scientific knowledge. He discovered that white light consists of many colours and that gravity is a force that affects all objects on Earth. In using mathematics to explain motion, Newton changed the way that people understood the world.

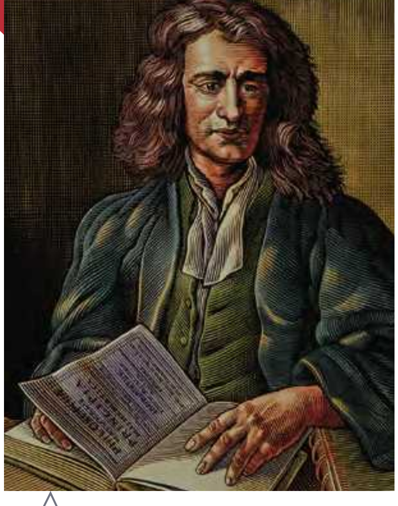


Figure 8.2.1 Sir Isaac Newton

Figure 8.2.3 This high-speed photograph shows crash-test dummies in a car that hits a wall at 56 km/h. The dummies continue to travel at this speed, colliding with objects in the car, other passengers and the car itself.

Newton's second law

Newton's second law of motion states that:

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

According to Newton's second law:

- a larger force is needed to accelerate a heavy load (such as the one shown in Figure 8.2.4) than a lighter load
- a larger force is required to make something accelerate at a faster rate.

Figure 8.2.4 The more massive an object, the more force is required for it to accelerate.

To understand how this law works, imagine pushing Sally, a 60 kg girl standing on a skateboard. Sally will accelerate in the direction in which you push her. If you push Sally with twice the force, then she will accelerate at twice the rate as before. Now imagine that Sally hops off the skateboard and is replaced by her younger sister, Sianne, who has a mass of 30 kg. You push Sianne with the same force. This will cause Sianne to move with twice the acceleration of Sally. This situation is shown in Figure 8.2.5.

No pain, more gain!

Catching a cricket ball with a rigid grip will hurt more than if you increase the time of your catch by following through the motion of the ball with your hand. Similarly, a car airbag increases the time interval of a collision and reduces the force of impact.

SciFile

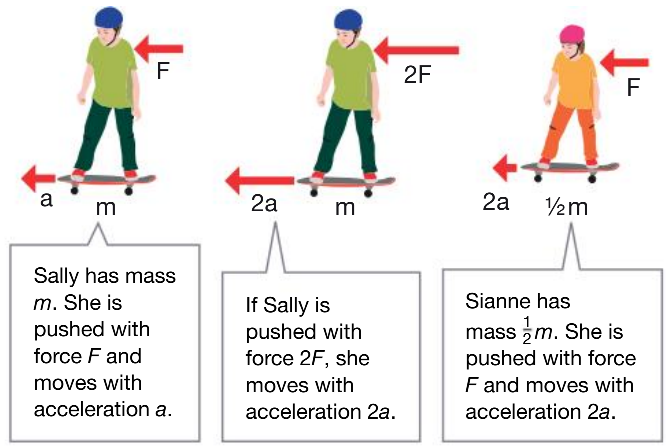


Figure 8.2.5 Newton's second law describes the relationship between net force, mass and acceleration.

There is usually more than one force acting on an object any one time. In this case it is important to work out the overall (net) force that acts. Figure 8.2.6 shows Carl pulling a crate with a force of 1100 newtons (1100 N) to the right. Friction exists between the crate and the floor and this force must be overcome to start the crate moving. If the frictional force is 500 N, then the crate will not move until Carl pulls with a force larger than 500 N. In the case shown, the overall or net force acting on the crate is 600 N to the right. Newton's second law means that this force will cause the crate to move and accelerate to the right.

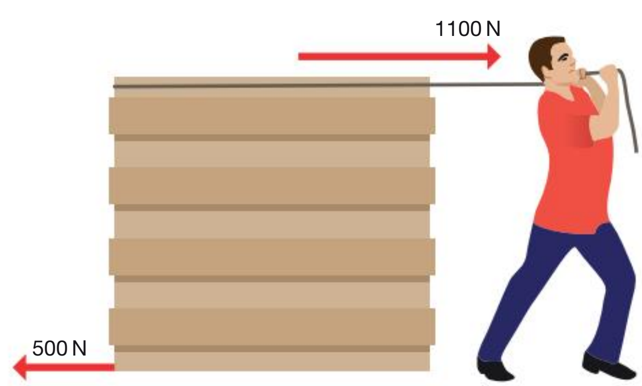


Figure 8.2.6 The net force acting here is 600 N to the right. This means the crate will accelerate to the right.

Figure 8.2.7 on page 290 shows what happens if all forces on an object are balanced. In this case, the overall, or net, force acting on the car is zero. If the car was stationary (at rest), then it would stay at rest. Since the car is moving, it will travel at constant speed.

Prac 1 p294

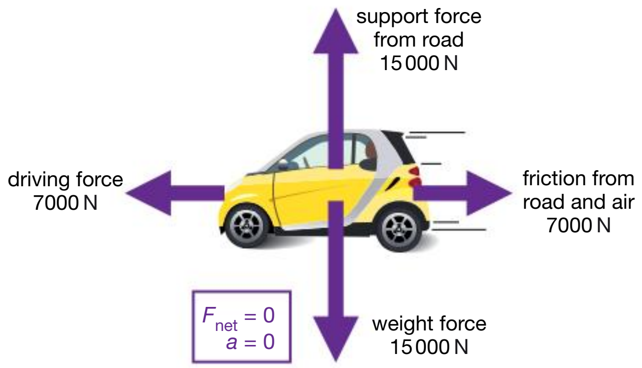


Figure 8.2.7 The vertical and horizontal forces acting on this car are balanced, so the net force acting on the car is zero. The car will travel at a constant speed.

Newton's third law

Isaac Newton realised that forces always occur in pairs. If a tennis ball is hit by a racquet, the racquet applies a force on the ball, and the ball accelerates forwards. This is called an action force. However, the ball also exerts a force back onto the racquet. You can feel this force as you hit the ball. It is called a reaction force.

Newton's third law of motion states that:

For every action force there is an equal and opposite reaction force.

Some action–reaction force pairs are shown in Table 8.2.1.

Table 8.2.1 Some pairs of action and reaction forces

Action force	Reaction force
A nail is hit by a hammer.	The nail exerts an equal force back on the hammer.
A sprinter pushes back on the starting blocks as a race begins.	The starting blocks push forward on the sprinter.
A book resting on a table exerts its weight force onto the table.	The table exerts an equal support force upwards on the book.
An octopus squirts water out as jets through a tube just below its head.	These water jets push back on the octopus, propelling it in the opposite direction.
You stand on a skateboard and push against a wall.	The wall pushes back on you with equal force, and you move away.

According to Newton's second law, the acceleration that an object experiences due to a force depends upon its mass. Although the size of action and reaction forces is the same, an object of low mass will travel with much greater acceleration than a more massive object. Figure 8.2.8 shows the different effects of the action–reaction forces from a cannon.

Prac 2 p295

INQUIRY science 4 fun

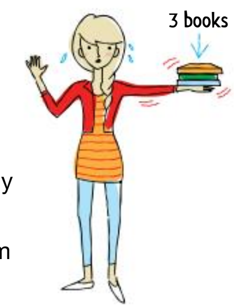
Heavy reading

YES

A book rests on a table. Does the book exert a force on the table? Does the table exert a force on the book?

Collect this ...

- some heavy books
- stopwatch



Do this ...

1. Ask a volunteer to extend an arm at right angles to their body with palm facing up.
2. Place three books on their palm and ask the volunteer to keep their arm straight.
3. Time them for a minute, then ask how they are feeling and remove the books.

Record this ...

Describe what happened.
Explain why you think this happened.

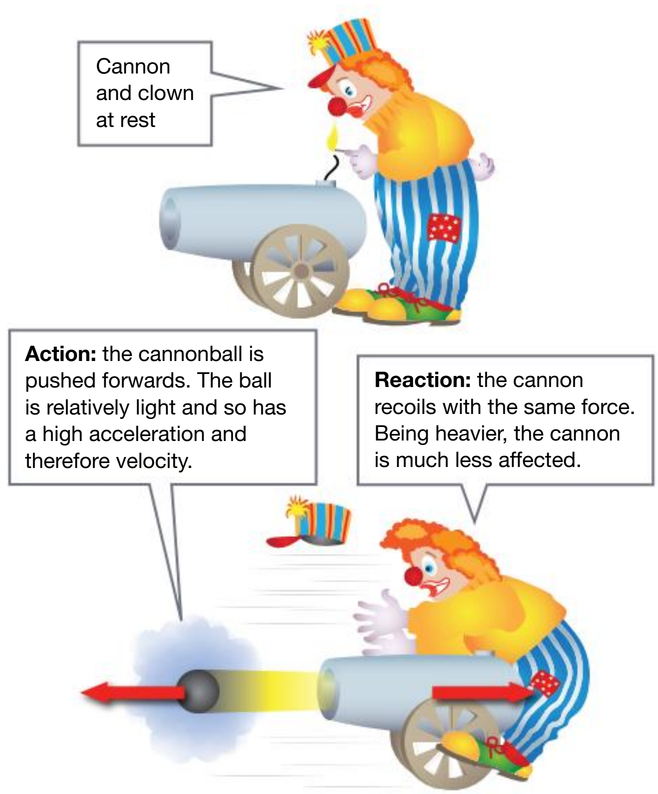


Figure 8.2.8 The action and reaction forces on the cannon and cannonball are the same. The cannonball has greater acceleration because it has a lower mass.

ADDITIONAL

Newton's laws and space travel

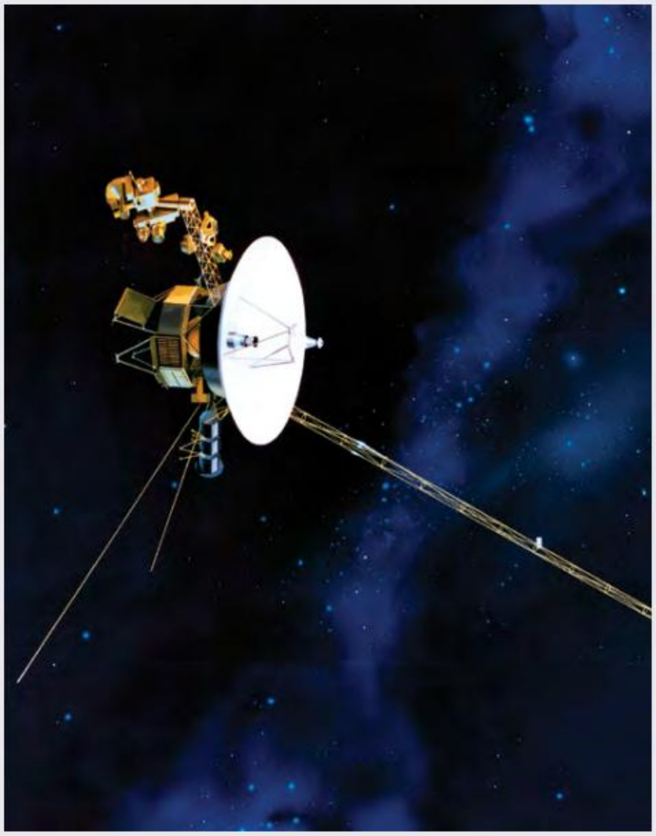


Figure 8.2.9 An artist's impression of *Voyager 1*. It left the solar system in 2012 and passed into interstellar space.

Space has no air and so there is no air resistance to slow down a spacecraft. Once launched and outside Earth's atmosphere, a spacecraft continues to travel through space long after its fuel has gone. This is Newton's first law in action. For example, the *Voyager I* space probe was launched in 1977. Its inertia ensures that it will keep travelling forever into deep space. You can see *Voyager 1* in Figure 8.2.9.

At launch, a rocket is at its heaviest and it needs to break free of Earth's gravity. According to Newton's second law, this enormous mass requires an equally enormous force. As the rocket rises it experiences far less resistance than at sea level because gravity decreases and the atmosphere gets thinner and eventually disappears completely. Also, there is now much less fuel on board, making the rocket much lighter. Fuel tanks are jettisoned (thrown away) as they empty, making the rocket even lighter still. You can see this happening in Figure 8.2.10. As the rocket rises, it requires a smaller force to keep it accelerating because it is lighter.

Figure 8.2.10 Rockets lose mass as they use fuel and jettison empty fuel tanks. This is an artist's impression of the *Arianne 5* soon after launch.

Rockets ignite and expel exhaust gases from them. Newton's third law states that for every action force, there is an equal and opposite reaction force. In this case, the action force is the expulsion of exhaust gases. The reaction force pushes the rocket in the opposite direction. This action–reaction pair is obvious at launch (Figure 8.2.11), but is also the only way a rocket can change direction, accelerate or decelerate in space.

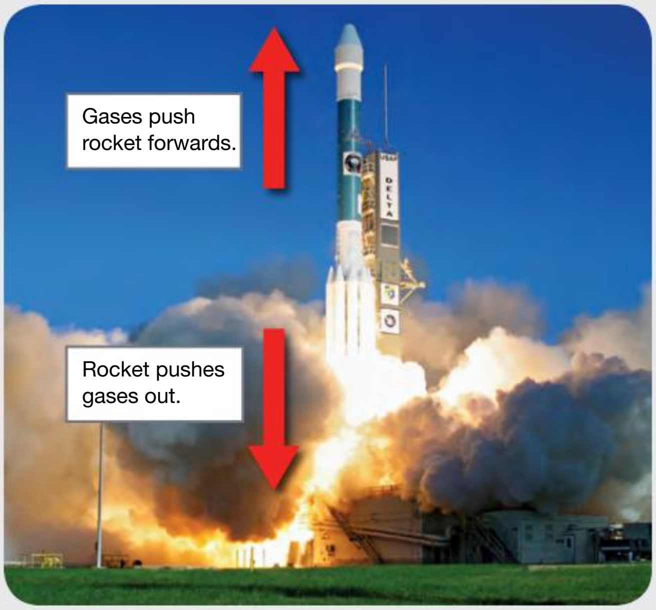


Figure 8.2.11 Explosive exhaust gases expelled from the base of a rocket exert an opposite reaction force to launch the rocket into space.

ADDITIONAL

8.2 Unit review

Remembering

1 **State** Newton's three laws of motion.

2 **State** the impact speed above which an airbag will inflate.

3 **State** whether each of the following statements are true or false:

a A truck has greater inertia than a bicycle

b If all of the forces acting on an object are balanced then the object is moving with constant acceleration.

c Newton's second law explains why you lean to the side in a car when turning a sharp corner

d The purpose of a seatbelt is to restrain your body so that you come to a stop with the car.

e Forces always occur in sets of three.

Understanding

4 **Explain** how it is possible for the car shown in Figure 8.2.7 on page 290 to be in motion, even though the net force acting on it is zero.

5 **Explain** how hitting the ball with a tennis racquet involves action and reaction forces.

6 **Predict** what will happen in the science4fun on page 290.

Applying

7 **Use** Newton's first law to **explain**:

a why it would be dangerous in an accident to have sharp edges on the dashboard of a car, the steering wheel or rearview mirror.

b why loose objects and unrestrained pets in the back of a car can cause injury or death in an accident.

8 **Use** your understanding of Newton's third law to **identify** the reaction force that acts with each action force listed.

a Mylinh's foot pushes back on the footpath as she walks down the street.

b Ted applies a force to a cricket ball as he catches it.

c Sally pushes on the handle of a lawnmower.

d Alf pushes a punching bag.

e Jade pushes on pizza dough as she kneads it.

9 Consider the forces acting on each object shown in Figure 8.2.12. In each case:

a **Identify** whether the forces acting are balanced or unbalanced.

b If the forces are unbalanced, **predict** the direction each object will accelerate.

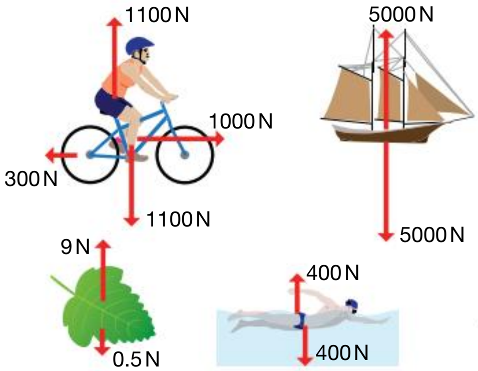


Figure 8.2.12

10 If you kicked a brick wall, you might hurt your foot. **Use** Newton's laws to **explain** why.

11 **Identify** which has greater inertia—a suitcase packed for a holiday or the same suitcase after its contents have been packed away.

12 Figure 8.2.3 on page 288 shows the motion of crash test dummies in a car that hits a wall. **Use** one or more of Newton's laws of motion to **explain** the motion seen in the photograph.

13 A similar activity to the science4fun on page 287 is the 'magician's trick' in which a tablecloth is swiftly pulled out from underneath a table setting of crockery and glasses (Figure 8.2.13). If done correctly, the cloth can be removed without disturbing the dinnerware on top.

a **Identify** which of Newton's laws of motion this trick relates to.

b **Use** Newton's laws to **explain** how the trick works.

Figure 8.2.13

Analysing

14 Figure 8.2.14 shows a person or two people pushing either a small red car or a large van. Assume that two people push the car with twice the force of a single person and that the van has larger mass than the car.

- **a** **Compare** the acceleration of the red car in the two situations in which it is pushed.
- **b** **Rank** the resulting acceleration of the vehicles in the three situations from greatest to least.

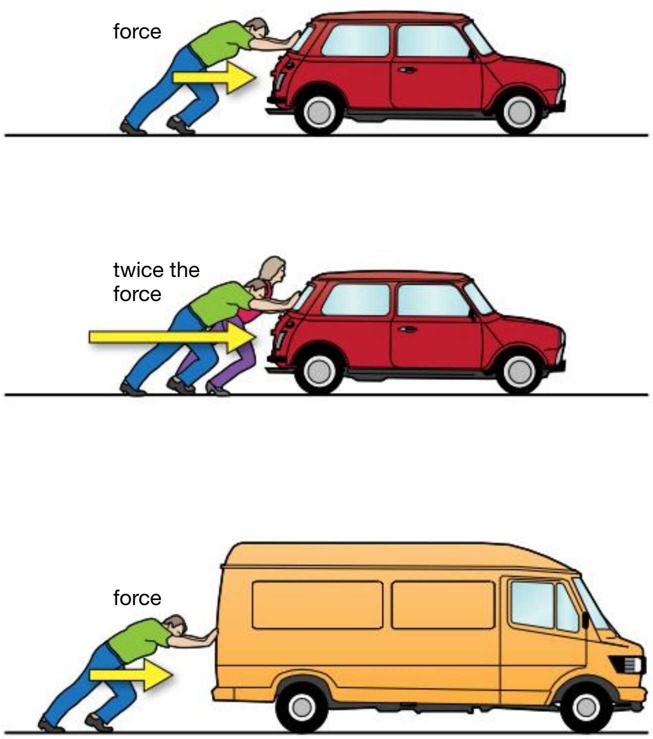


Figure 8.2.14 Acceleration depends upon the size of the force acting and the mass of the object.

15 A cart is pushed with force F. Ignoring any friction, **compare** the acceleration of the same cart when:

- **a** pushed with a force $2F$
- **b** pushed with a force $\frac{1}{2}F$
- **c** pushed with force F but loaded up so that its mass is now twice the mass it was before ($2m$)
- **d** pushed with force $2F$ and with a mass of $2m$.

Inquiring

1 Rollercoasters at theme parks are designed to give you a thrill from the effect of different forces on your body. When you ride over the top of a rise on a rollercoaster you will feel lighter in weight. When you speed down into a dip, your body feels much heavier.

- Search the internet to find the website of Luna Park in Sydney.
- View the list of rides available and watch clips showing five of the rides in action.
- Sort these rides into groups according to what types of forces they apply to a person. For example, are they spinning forces, sharp turns, impacts, free fall or rollercoaster effects.
- Select one ride and analyse how the forces act on the passenger in terms of Newton's laws.

Present your research and design in digital form. ICT

2 Research an accredited website such as the Motor Accident Authority of NSW or Victoria's TAC's 'How safe is your car?' to summarise information about the safety of your family car or of a car in which you sometimes travel. Present your information in a multimedia display or a poster. ICT

ADDITIONAL

3 Search the internet to find videos or animations showing

- rockets launching ICT
- the jettisoning of rocket parts after launch
- spacecraft using small rockets to manoeuvre in space.

Present your research as a digital slide show or downloaded videos.

4 Research the Voyager space missions. Find:

- why they were sent into space
- the years in which they were launched
- their path through the solar system
- a list of discoveries they have made
- why they keep on moving through space, despite having run out of fuel years ago.

Present your findings in digital form. ICT

ADDITIONAL

8.2 Practical investigations

STUDENT DESIGN

1 Investigating Newton's second law

Purpose

To test an aspect of Newton's second law.

Hypothesis

How do you think:

- the angle of a ramp will affect the acceleration of a trolley rolling down it?
- the mass on a trolley affects the acceleration when pulled by masses hanging over a pulley?
- the acceleration of a spring-loaded dynamics trolley that is released from a barrier is affected by increasing mass on its surface?

Select one of the above aspects of Newton's law. Before you go any further with this investigation write a hypothesis in your workbook regarding your chosen aspect.

Materials

As selected by students, but could use the following materials:

- datalogger motion sensor and computer interface, or measuring tape and stopwatch
- datalogger force sensor and computer interface or spring balance
- dynamics cart
- ramp
- pulley and string
- protractor
- various masses to place on trolley

SAFETY
A risk assessment is required for this investigation.

Procedure

1. Design an experiment to test the aspect of Newton's second law you chose earlier.
2. Brainstorm in your group and come up with several different ways to investigate the problem. Select the best procedure and write it in your workbook. Include a diagram showing your equipment and set-up.
3. Before you start any practical work, assess all risks associated with your procedure. Construct a risk assessment that outlines these risks and the precautions you need to take to minimise them.
4. Show your teacher your procedure and your risk assessment. If your teacher approves, then collect all the required materials and start work.

Results

1. Record your observations in written format, or using datalogger software.
2. Describe what you observed when changing variables in your investigation.

Practical review

1. a **Construct** a conclusion for your investigation.
   b **Assess** whether your hypothesis was supported or not.
2. **Identify** any sources of error in your investigation.
3. **Evaluate** your procedure. Pick two other prac groups and **evaluate** their procedures too, identifying their strengths and weaknesses.

STUDENT DESIGN

2 Investigating Newton's third law

Purpose

To investigate Newton's third law of motion.

Materials

As selected by students but could include materials such as:

- string or fishing line
- flexible drinking straw
- balloon
- masking tape
- piece of dowel
- pivot pin

SAFETY

A risk assessment is required for this investigation.

Hypothesis

What do you think will happen to the device in Figure 8.2.15 when more air is expelled? Before you go any further with this investigation write a hypothesis in your workbook.

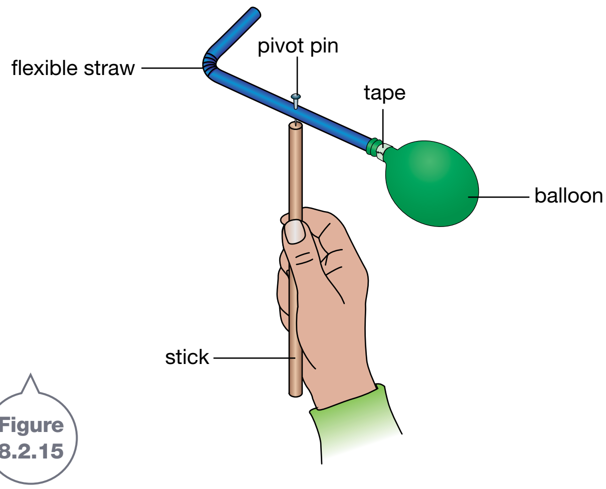


Figure 8.2.15

Procedure

1. Design an experiment that tests how the size of the reaction force varies as more air is released from a balloon.
2. Brainstorm in your group and come up with several different ways to investigate the problem. Select the best procedure and write it in your workbook. Include a diagram showing your equipment and set-up.
3. Before you start any practical work, assess all risks associated with your procedure. Construct a risk assessment that outlines these risks and precautions you need to take to minimise them.
4. Show your teacher your procedure and your risk assessment. If your teacher approves, then collect all the required materials and start work.

Hints

The balloon could move:

- horizontally along a string or piece of fishing line
- spin on an axis such as that shown in Figure 8.2.15.

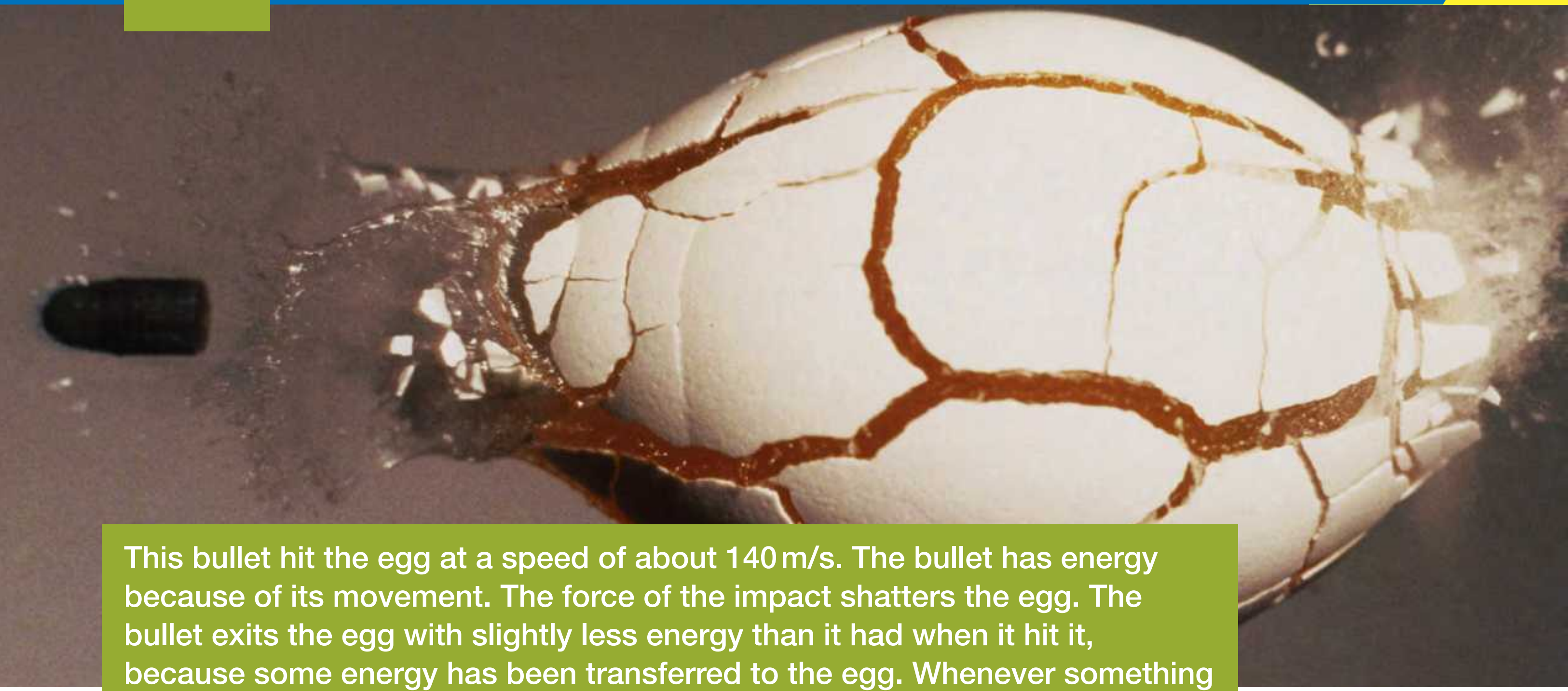
Results

Record your observations in writing or as video.

Practical review

1. **Describe** what you observed when changing variables in your investigation.
2. a **Construct** a conclusion for your investigation.
   b **Assess** whether your hypothesis was supported or not.
3. **Identify** any sources of error in your investigation.
4. **Evaluate** your procedure. Pick two other prac groups and **evaluate** their procedures too, identifying their strengths and weaknesses.

8.3 Energy changes



This bullet hit the egg at a speed of about 140 m/s. The bullet has energy because of its movement. The force of the impact shatters the egg. The bullet exits the egg with slightly less energy than it had when it hit it, because some energy has been transferred to the egg. Whenever something happens around you, energy has been transferred or transformed.

INQUIRY science 4 fun

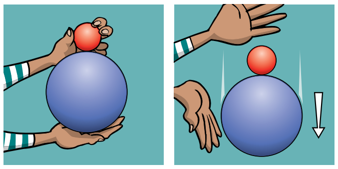
Energy transfer

YES

What happens when the kinetic energy of one ball is transferred to another ball?

Collect this ...

- basketball
- tennis ball
- video camera (optional)



Do this ...

1 Hold a basketball about a metre above a hard floor.

2 Hold a tennis ball just above the basketball.

3 Drop both balls at exactly the same time and record what happens.

Record this ...

Describe what happened.
Explain why you think this happened.

Forms of energy

Energy is needed to make things happen. Energy is needed whenever something moves, makes a sound, falls, warms up or changes colour. Some tasks, like that shown in Figure 8.3.1, require more energy than others.

Figure 8.3.1 The mass of this four wheel drive vehicle means a lot of energy is required to make anything happen!

There are many different types of energy. These include kinetic energy, sound energy, light energy, heat energy and electrical energy. Objects that have the potential to use energy possess potential energy. Energy can be passed or transferred from one object to another. This happens when you feel the heat from an oven or hot kettle. Energy can also be changed or transformed from one form into another. This happens when you use a mobile phone. Chemical potential energy within the phone's battery is transformed into the sound energy you hear and the light energy that comes from its screen. The phone also wastes some its energy as heat.

Kinetic energy

The energy of a moving object is called **kinetic energy.** The amount of kinetic energy an object has depends upon its mass and its speed. If an object's mass doubles, its kinetic energy also doubles. However, if an object's speed doubles, its kinetic energy increases by a factor of four. In a collision, this kinetic energy is transferred to other objects or transformed into other forms of energy. The heavier the vehicle and the greater its speed, the more energy it will transfer to the object it collides with and so the greater the damage it will do. This is why even a small increase in speed rapidly increases the risk of death or injury when travelling in a car. This is shown in Figure 8.3.2 and Table 8.3.1.

Another reason why increased speed is more dangerous is that cars travelling at higher speed require longer distances to brake and stop.

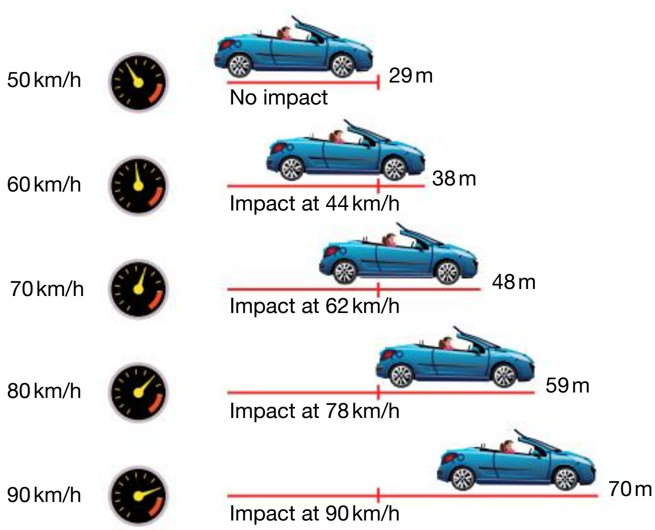


Figure 8.3.2 The distance required for a car to stop increases dramatically as its speed increases.

Table 8.3.1 Speed and injury risk

Speed (km/h)	Risk of death or injury compared with travelling at 60 km/h
65	Double
70	4 times
75	11 times
80	32 times

Source: *Road Traffic Authority of NSW*

Potential energy

Potential energy is energy that an object has because of its position or structure. For example, chemicals in foods, fuels and explosives contain energy in their chemical bonds. Potential energy is often called stored energy. Potential energy gives objects the capacity to makes things happen.

Gravitational potential energy

An object positioned above the ground has **gravitational potential energy**. For example, a tree branch has gravitational energy. If it falls, then it will scratch, dent or squash any car it hits.

An object that is positioned high above the ground has greater gravitational potential energy than the same object found closer to the ground. Also, the greater the mass of an object, the greater its gravitational potential energy will be. The gravitational potential energy of an object also depends on gravitational field strength (gravity). This varies very slightly at different positions on Earth, but is only noticeably different if you are travelling to the Moon or another planet. These relationships are shown in Figure 8.3.3.

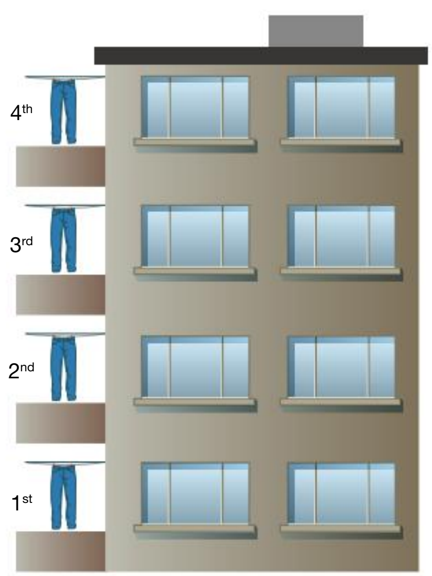


Figure 8.3.3 A pair of jeans hanging on a washing line on the fourth floor has four times the gravitational potential energy of the same pair of jeans hanging on a line on the first floor.

Elastic potential energy

A stretched or compressed spring has **elastic potential energy**. So too do elastic materials such as rubber. This energy is converted into kinetic energy when the spring is released and returns to its original shape. Springs on a trampoline, car bumpers, bungee cords, sling shots, mouse traps (Figure 8.3.4) and even tennis balls store elastic potential energy and release it in different ways.

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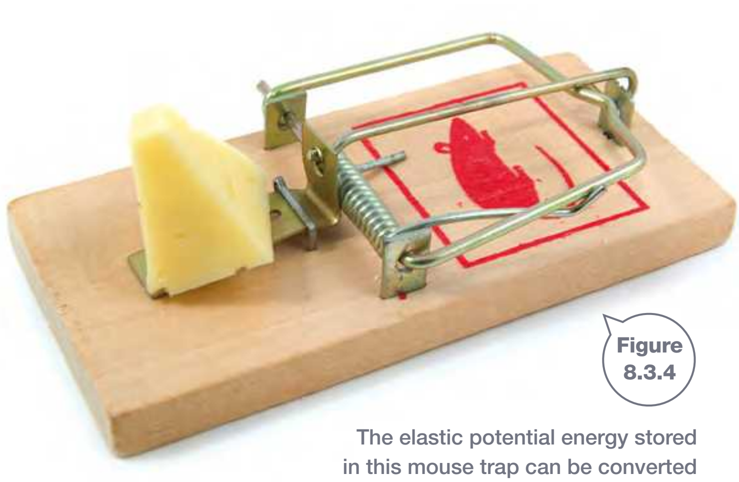


Figure 8.3.4

The elastic potential energy stored in this mouse trap can be converted in an instant into kinetic energy, sound energy and heat energy.

Conservation of energy

The **law of conservation of energy** states that energy may be transferred from one object to another, but is never created or destroyed. For any situation in which energy is transferred between objects, there is always the same amount of energy at the end as there was at the start. In other words, the total energy involved in the system remains the same.

An example of this is shown in Figure 8.3.5. A tennis ball dropped from a height initially has only gravitational potential energy. As it falls, its gravitational potential energy decreases and its kinetic energy increases and the ball speeds up. Just before the ball hits the ground, all of the energy it started with has been converted into kinetic energy.

Inductive charging

SciFile

In a typical household, there are numerous electronic devices that require charging to operate. A number of companies have developed a process called inductive charging, in which a device needing power is able to wirelessly accept energy from a transmitter in a charging pad. One company, WiTricity, aims to enable devices to be charged without the need for any cables or plugs at all. The challenge is to make these methods of energy transfer more efficient as the technology improves.

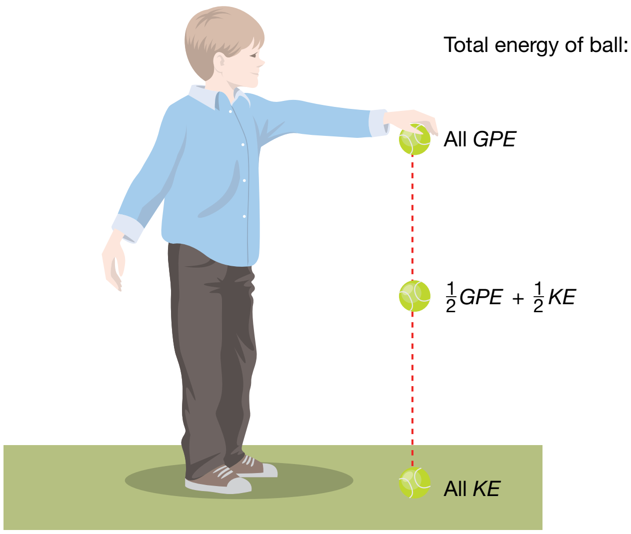


Figure 8.3.5

The total energy possessed by the ball is the sum of its gravitational potential energy (GPE) and its kinetic energy (KE) at any time. This sum is constant throughout its fall.

Prac 2 p303

Energy efficiency

Although energy is always conserved in an energy transfer, a little energy is usually 'lost' because it changes into non-useful forms such as heat and sound. For example, some energy is 'lost' as heat and sound energy each time a ball bounces. You hear the bounce and feel the ball getting hotter (particularly noticeable with a squash ball). If no energy was lost then the ball would keep bouncing forever. Every day you use many electronic devices that transform energy from one form into other forms. Each of these devices uses energy. The energy used is referred to as input. Input is converted into other energies, only some of which are useful. These useful energies are known as output. These energy changes can be shown in a flow diagram. For example, an electric drill has a typical flow diagram:

electrical energy → kinetic energy + sound energy + heat energy

In an electric drill, the kinetic energy of the spinning drill is the only useful form of energy output. Sound and heat will be produced, but these are not useful. These forms of energy reduce the useful energy output of the device. The **efficiency** of an energy transfer is a measure of how much useful energy is produced. It can be expressed as:

$$\text{efficiency} = \frac{\text{useful energy}}{\text{total energy}} \times 100\%$$

ADDITIONAL

Energy interactions in sport

Energy interactions happen whenever two objects are in contact. Energy is transferred from one object (the source) to another (the receiver)—the source loses energy and the receiver gains energy. In this way the total amount of energy in the system remains the same, as expected according to the law of conservation of energy.

Energy interactions happen in daily life in activities such as picking up a ball to throw. In this case, you are the source of energy. The energy you use is chemical potential energy. You gained this energy from the food you have eaten. This chemical potential energy is transferred to the receiver—the ball. In raising the ball you have given it kinetic and gravitational potential energy.

Energy interactions occur in all sporting events. Figure 8.3.6 shows some common energy interactions that occur in sporting activities.

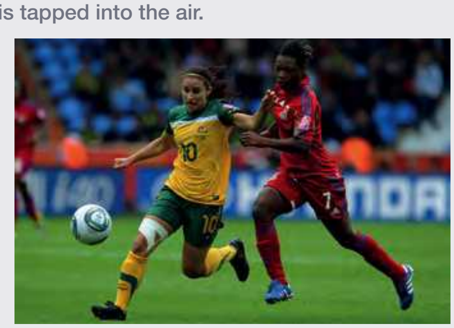
SciFile

Efficient travel

Cycling at speeds of about 16–24 km/h is the most efficient form of transport for humans. 500 kJ can power a cyclist a distance of around 5 km, but the same energy will only power a car about 100 m!

An NRL player relies on physical strength to keep possession of the ball. Chemical potential energy of the player is transformed into kinetic energy of the ball.

In an AFL ruck contest, chemical potential energy of the player is transformed into kinetic and gravitational potential energy of the ball as it is tapped into the air.



Chemical potential energy of the soccer player is transformed into kinetic and gravitational potential energy of the ball.

A diver converts their own chemical potential energy, gravitational potential energy and kinetic energy into elastic potential energy of the diving board when jumping on the board. The board then compresses and bounces back, transferring its elastic potential energy to the diver. This energy is converted into gravitational potential energy and kinetic energy of the diver as they fall into the pool.

When a tennis ball is hit, the kinetic energy of the ball is transformed into elastic potential energy of the racquet strings, which compress inwards. When the strings bounce back, this elastic potential energy is converted into kinetic and gravitational potential energy of the ball.

Figure 8.3.6

ADDITIONAL

8.3 Unit review

Remembering

1 **State** the unit used to measure energy.

2 **List** five different types of energy.

3 **Recall** the equation used to calculate energy efficiency.

4 **State** whether a car has more kinetic energy when travelling at 10 km/h or when travelling at 60 km/h.

5 **List** the three factors that change the amount of gravitational potential energy possessed by an object.

Understanding

6 **Define** the term *kinetic energy*. L

7 a **Define** the term *potential energy*. L
b **Recall** three different types of potential energy.

8 **Describe** what happens to the:
a gravitational potential energy of an object when its height above the ground is doubled
b kinetic energy of an object when its speed is doubled.

9 **Describe** the main useful form of energy that is produced by each of the following:
a hairdryer
b cement mixer
c washing machine
d LED torch

10 **Explain** what is meant by the Law of Conservation of Energy in terms simple enough that a Year 7 student could understand.

11 a **Predict** which form of energy is most commonly not useful in an energy transformation.
b **Explain** how the production of this type of energy reduces energy efficiency of an electrical appliance.

Applying

12 **Draw** an energy flow diagram to **demonstrate** the energy transformations in the following situations:
a a marble is fired from a sling shot
b a branch falls from a tree
c a wind-up mouse darts across the floor
d a car is driven down a road
e you brush your hair

Evaluating CCT

13 a **Predict** which would possess greater gravitational potential energy: a 1 kg bowling ball held 1 m above the surface of Earth, or the same ball held the same distance above the surface of the Moon.
b **Justify** your answer.

14 In the science4fun on page 296, the small ball is dropped on top of the larger ball.
a **Predict** what would happen if the position of the balls was reversed.
b **Justify** your prediction.

15 Refer to Table 8.3.1 on page 297 and **propose** why police advert campaigns often target speeding drivers.

16 Researchers estimate that the risk of serious injury or death approximately doubles for every 5 km/h that a car travels above 60 km/h. **Propose** reasons why.

17 Figure 8.3.7 shows a section of a rollercoaster used at a theme park.

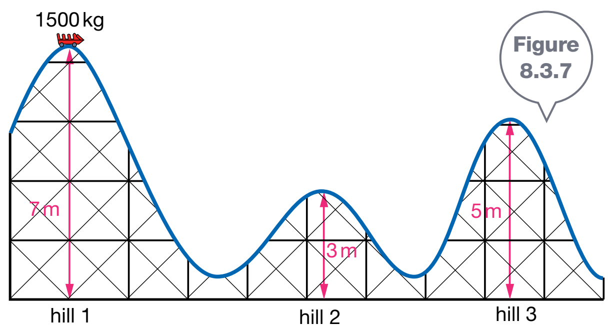


Figure 8.3.7

Assume that the rollercoaster starts from rest and ignore the effects of friction.
a **Identify** the hill on the top of which the rollercoaster passengers possess the greatest gravitational potential energy.
b **Identify** at which point or points in the journey the the rollercoaster passengers travel the fastest.
c **Justify** your answers to parts **a** and **b**.

18 The first hill on a rollercoaster track is usually the largest. **Propose** a reason why this might be.

Creating CCT

19 A bouncing ball eventually stops bouncing because of energy being converted into heat and 'wasted' on each bounce.

- **a** **Describe** what a ball would do if each bounce was 100% efficient.
- **b** **Construct** an energy flow diagram showing what happens to the energy of a ball as it:
  - **i** hits the ground
  - **ii** bounces back upwards.
- **b** **Design** an investigation that would test whether the efficiency is the same for each bounce or if it is different.

Inquiring

1 The greater the energy efficiency of a device, the less energy must be input to the device in order to achieve the output required. Saving energy has layers of benefits. These include:

- reducing the depletion of fossil fuels
- preserving the environment in which fossil fuels are mined
- reducing the emissions of carbon dioxide that enter the atmosphere
- reducing the severity of the flow-on effects associated with global warming, such as the frequency of severe weather events and loss of species diversity
- reducing the global warming effects of carbon in the atmosphere
- reducing pollution in the atmosphere
- saving energy costs to consumers.

The energy rating of an appliance gives an indication of the energy efficiency of the device. The more stars on the energy rating, the greater the efficiency.

One way to save energy in your home is to replace older models of appliances such as refrigerators and washing machines.

- Select one common household appliance.
- Find how the design of this appliance has changed over recent years to become more energy efficient. For example, the use of LEDs in television has improved the efficiency by enabling brighter light output for less energy use.

Present your findings either as a brochure or as a digital presentation. ICT

2 Energy can be transferred from one object to another or transformed from one type into another. The flow of energy can be seen when watching a line of dominoes fall after the first domino has been pushed over. Search the internet for the video clip to the song by OK Go *This too shall pass* – a Rube Goldberg machine version of this energy transformation process. ICT

- **a** List ten different example of energy transfer or transformation as seen in this clip.
- **b** Research the meaning of the term 'Rube Goldberg machine.' Write a definition of this term and refer to an image of such a machine.
- **c** Design and construct a version of your own Rube Goldberg machine. Set it in motion and use a phone or video to capture your energy changes.

ADDITIONAL

3 Research the design of sports shoes and find how they return some of the energy back to the sportsperson in each step.

Present your findings as a brochure to be handed out in sports clubs or shoe stores.

4 Find images of a particular sport you are interested in. Print out or save selected images and annotate them with labels indicating the energies that are involved and how they are being transferred, transformed and 'lost' (being converted into non-useful forms). ICT

Present your research as a set of annotated images.

ADDITIONAL

8.3 Practical investigations

1 Extension of an elastic band

Purpose

To investigate the effect of weight on the stretching of an elastic band.

Hypothesis

Which of the arrangements of elastic bands in Figure 8.3.8 below do you expect to be the stiffest? Before you go any further with this investigation write a hypothesis in your workbook.

Materials

- 2 similar elastic bands
- retort stand and clamp
- 5 × 50 g hanging masses
- ruler

Procedure

1. Copy the table in the Results section. Use it or a spreadsheet to record your findings.
2. Hang an elastic band from a retort stand as shown in Figure 8.3.8 and measure its natural, unstretched length.
3. Hang a 50 g mass from the elastic band and measure its new length.
4. Calculate the extension caused by the 50 g mass.
5. Repeat for masses of 100, 150, 200 and 250 g.
6. Repeat this process using two elastic bands looped together end to end and then positioned in parallel. (Make sure you first record the unstretched length of each combination.)

Results

1. Record all measurements in your results table.

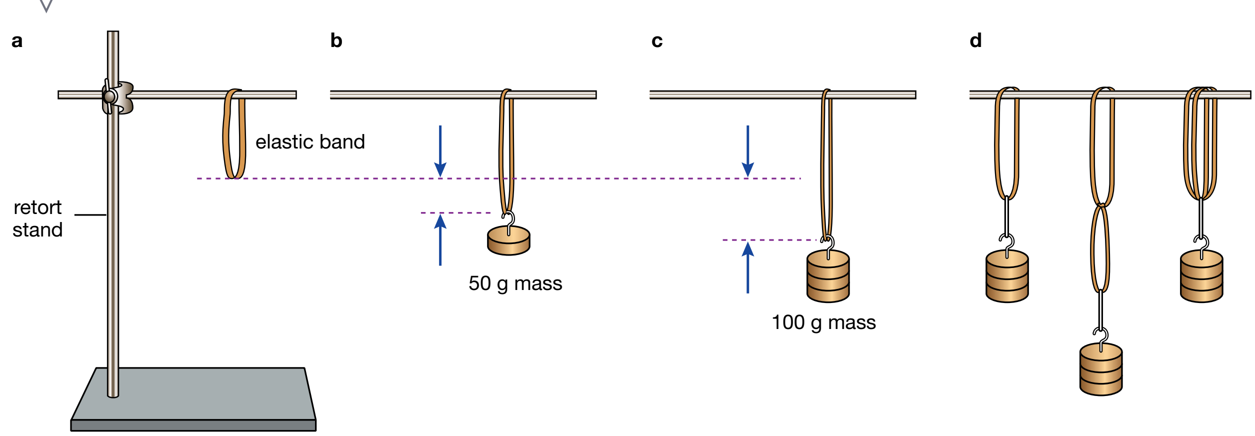
Mass attached (g)	Elastic band length (mm)			Extension of single band (mm)	Extension of two bands end to end (mm)	Extension of two parallel bands (mm)
	Single	Two bands end to end	Two bands parallel			
0				0	0	0
50						
100						
150						
200						
250						

2. Plot a graph of the extension (mm) on the vertical axis against mass (g) on the horizontal axis. Draw a line of best fit through the points. N
3. On the same set of axes, plot the graphs for the double elastic band combinations.

Practical review

1. **State** which type of energy is stored in the elastic bands.
2. **Describe** which arrangement produced the stiffest combination of elastic bands.
3. **Discuss** any sources of error from your experiment.
4. **Construct** a conclusion for your investigation.

Figure 8.3.8



STUDENT DESIGN

2 Energy changes in a rollercoaster

The efficiency of a rollercoaster can be found by calculating:

$$\text{efficiency} = \frac{\text{height ball reaches}}{\text{height ball was released}} \times 100\%$$

Purpose

To investigate the efficiency of three rollercoaster tracks of different designs.

Hypothesis

Which of the rollercoaster tracks below do you think will be the most efficient and which will be the least efficient? Before you go any further with this investigation, write a hypothesis in your workbook.

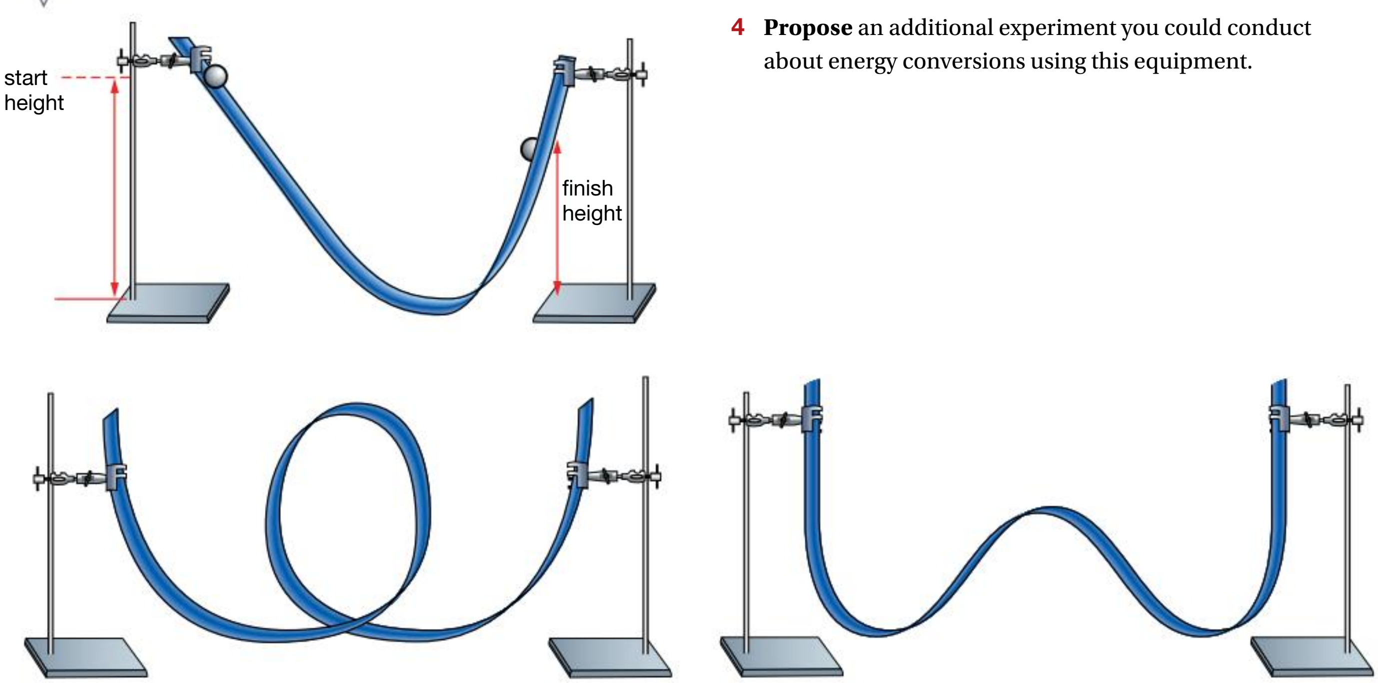
Materials

You can use your own selection of materials, which may include:

- clear plastic tubing or computer cable channel
- retort stands and clamps
- marbles or ball bearings.

SAFETY
A risk assessment is required for this investigation.

Figure 8.3.9



Procedure

1. Design an investigation to test the efficiency of three different rollercoaster tracks. These could have the shapes shown in Figure 8.3.9 or be some of your own designs.
2. Brainstorm in your group and come up with several different track shapes. Select the three best track shapes and draw diagrams of them in your workbook.
3. Before you start any practical work, assess all risks associated with your procedure. Construct a risk assessment that outlines these risks and the precautions you need to take to minimise them.
4. Show your teacher your procedure and risk assessment. If your teacher approves, then collect all the required materials and start work.

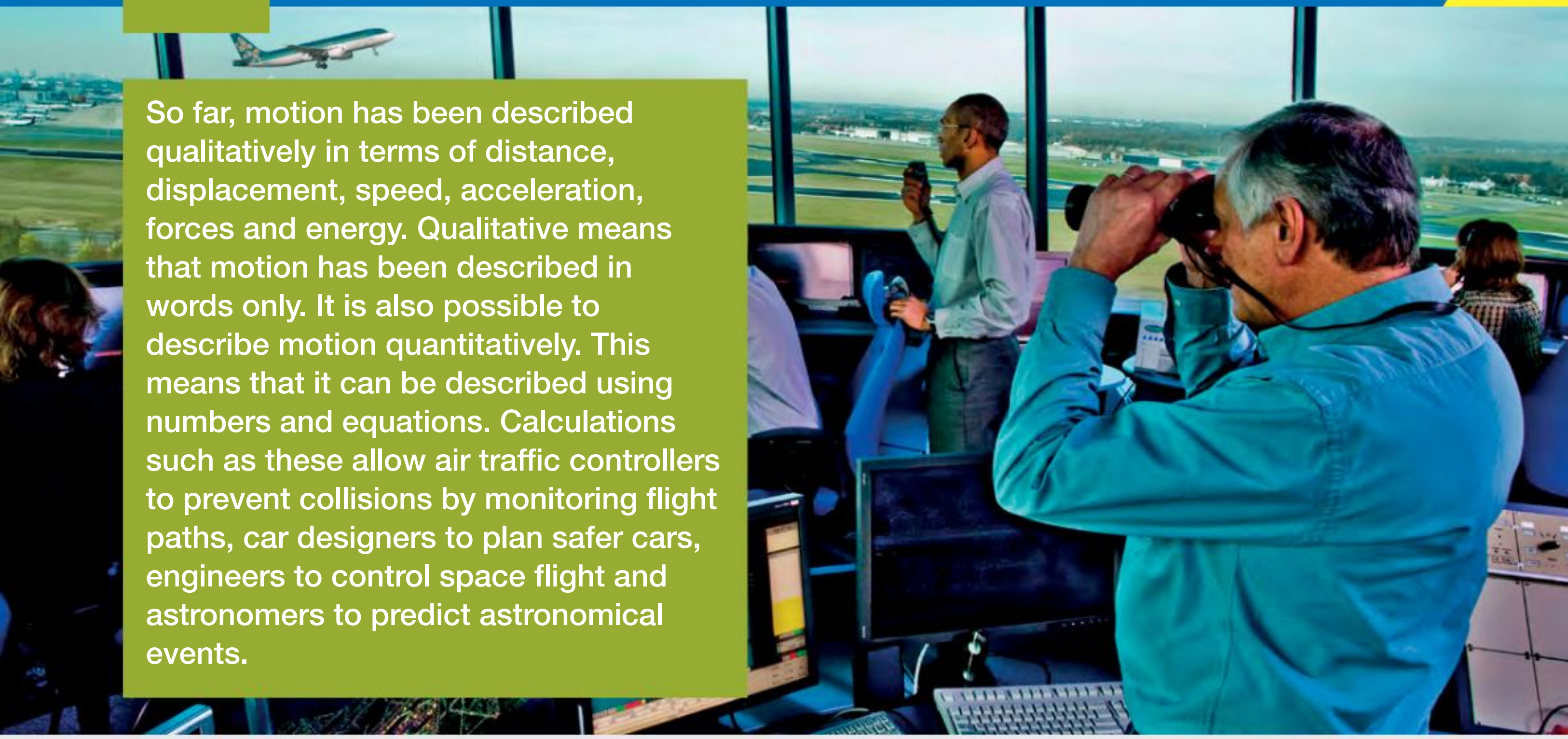
Results

Construct diagrams to show the design of each track, marked with the heights of release and finish heights.

Practical review

1. **Calculate** the efficiency of each design and explain why the efficiency was less than 100%. N
2. **Discuss** any areas of difficulty you encountered in your investigation.
3. **Evaluate** your track designs by identifying their strengths and weaknesses.
4. **Propose** an additional experiment you could conduct about energy conversions using this equipment.

8.4 Motion calculations



So far, motion has been described qualitatively in terms of distance, displacement, speed, acceleration, forces and energy. Qualitative means that motion has been described in words only. It is also possible to describe motion quantitatively. This means that it can be described using numbers and equations. Calculations such as these allow air traffic controllers to prevent collisions by monitoring flight paths, car designers to plan safer cars, engineers to control space flight and astronomers to predict astronomical events.

Scalars and vectors

A **scalar quantity** is one that requires only a size (and appropriate units) to describe it. Temperature and mass are scalar quantities. For example, 30°C specifies exactly how hot something is. Likewise, 5 kg specifies exactly the mass you are talking about. Directions such as up, down, north or south are not needed.

A **vector quantity** is one that requires size (and units) *and* direction to describe it. For example, acceleration due to gravity is a vector quantity—it needs the direction to be included. Its value is $9.8\ m/s^2$ down (or more correctly towards the centre of Earth).

Distance and displacement

Distance is a scalar quantity—it has size but not direction. In contrast, displacement is a vector quantity—it has both size and direction.

Speed and velocity

Average speed can be calculated using the formula:

$$\text{Average speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

or

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

where v is average speed, d is distance travelled and t is time taken.

Velocity differs from speed in that it is a vector quantity. A car travelling at a constant speed around a curved track, such as that shown in Figure 8.4.1 has a changing velocity because the direction of its motion is constantly changing. Average velocity is defined as:

$$\text{Average velocity} = \frac{\text{displacement}}{\text{time}}$$

or

$$\boldsymbol{v} = \frac{\boldsymbol{x}}{t}$$

where $\boldsymbol{v}$ is average velocity (the bold symbols indicate that these are vector quantities that have direction), $\boldsymbol{x}$ is displacement and t is time taken.

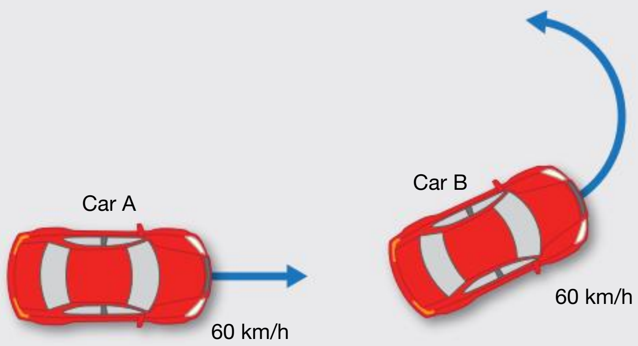


Figure 8.4.1 These cars are travelling at the same speed, but have different velocities.

Acceleration

When something changes speed, it has accelerated. However, if an object changes direction then it has accelerated too. This is because acceleration is the rate of change in the velocity of an object. Acceleration should therefore be stated with a direction. Like displacement and velocity, acceleration is a vector quantity. A positive acceleration means that something is speeding up in a particular direction and a negative acceleration means it is slowing down in a particular direction.

If the motion is in a straight line then acceleration can be calculated using the formula:

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time}} = \frac{\text{final velocity} - \text{initial velocity}}{\text{time taken}}$$

or

$$\boldsymbol{a} = \frac{\boldsymbol{v} - \boldsymbol{u}}{t}$$

where $\boldsymbol{a}$ is acceleration, $\boldsymbol{v}$ is final velocity, $\boldsymbol{u}$ is initial velocity and t is time taken.

The SI units for acceleration are m/s/s or m/s^2. Other units can also be used. For example, a car that increases its speed by 5 km/h every second has an acceleration of 5 km/h/s.

Equations of motion

The formula used to calculate average acceleration can be rearranged to allow the final speed of an object to be calculated:

final velocity = initial velocity + (acceleration × time taken)

or

$\boldsymbol{v} = \boldsymbol{u} + \boldsymbol{a}t$

When considering constant acceleration of an object in a straight line, a number of additional equations can be used. These are:

$\boldsymbol{v}^2 = \boldsymbol{u}^2 + 2\boldsymbol{ax}$

$\boldsymbol{x} = \boldsymbol{u}t + \frac{1}{2}\boldsymbol{a}t^2$

$\boldsymbol{x} = \frac{(\boldsymbol{v} - \boldsymbol{u})t}{2}$

These equations are particularly useful when considering the motion of an object under gravity. Ignoring the effects of friction, the acceleration of any object due to the Earth's gravity is 9.8 m/s^2 down. For most calculations, 10 m/s^2 down will do.

WORKED EXAMPLE
Equations of motion

Problem 1

A car is at traffic lights. It accelerates for 5 seconds to reach a speed of 50 km/h. Calculate the acceleration of the car in km/h/s.

Solution

$u = 0$, $v = 50$ km/h, $t = 5$ s, $a = ?$

$\boldsymbol{a} = \frac{\boldsymbol{v} - \boldsymbol{u}}{t} = \frac{50 - 0}{5} =$ km/h/s

$= 10$ km/h/s

The of the car increases by 10 km/h each second.

Problem 2

A train initially travelling at 5 m/s accelerates at the constant rate of 2 m/s^2 for 10 seconds. Calculate its final speed.

Solution

$u = 5$ m/s, $a = 2$ m/s^2, $t = 10$ s, $v = ?$

$\boldsymbol{v} = \boldsymbol{u} + \boldsymbol{a}t$

$= 5 + (2 \times 10)$

$= 25$ m/s

After 10 seconds, the train is travelling at 25 m/s.

Problem 3

A stone is dropped from a 120 m high vertical cliff. Calculate the time it takes for the stone to reach the bottom.

Solution

You can assume that the stone was dropped from rest and not thrown, and that there was no air resistance.
Use 10 m/s^2 as the acceleration due to gravity.
Hence $u = 0$, $a = 10$ m/s^2, $x = 120$ m, $t = ?$

$\boldsymbol{x} = \boldsymbol{u}t + \frac{1}{2}\boldsymbol{a}t^2$

$120 = \frac{1}{2} \times 10 \times t^2$

Rearranging the equation:

$t^2 = \frac{120}{5} = 24$

$t = 4.9$ s

The stone takes 4.9 s to reach the water below.

Practice

N

1 Su-Lin rides her scooter along a footpath. She starts from rest and accelerates at a constant rate of 2 m/s^2. **Calculate** her final speed after she has travelled 25 m.

2 Dean is riding his motorbike at a speed of 20 m/s. He travels 28 m as he brakes and comes to a stop in 4 seconds. **Calculate** Dean's acceleration as he comes to a stop.

(Hint: Because Dean is slowing down, his acceleration is negative.)

3 A model aircraft is flying at a speed of 5 m/s. It then accelerates 1 m/s^2 for 4 seconds. **Calculate** the final speed of the aircraft.

Interpreting motion graphs

In addition to reading values from a graph, information can be gained by calculating the gradient of a graph or by calculating the area between the graph and its horizontal axis.

The gradient of a:

- distance–time graph is average speed
- displacement–time graph is average velocity
- velocity–time graph is average acceleration.

The area below:

- a speed–time graph is distance travelled
- a velocity–time graph is displacement
- an acceleration–time graph is change in velocity.

Figure 8.4.2 shows how gradient is used to calculate the average speed of a cyclist.

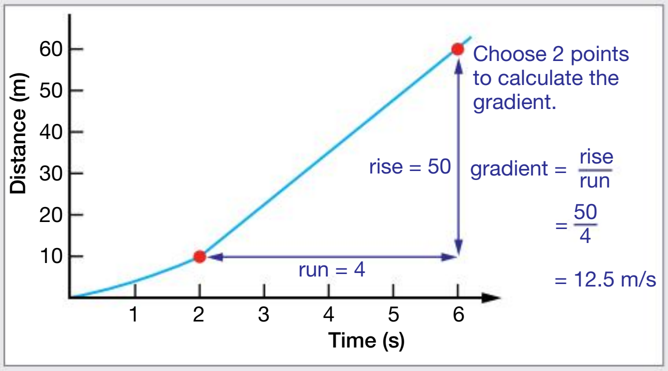


Figure 8.4.2 After gradually increasing their speed, this cyclist travels at a constant speed of 12.5 m/s.

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8.4

WORKED EXAMPLE

Interpreting speed–time graphs

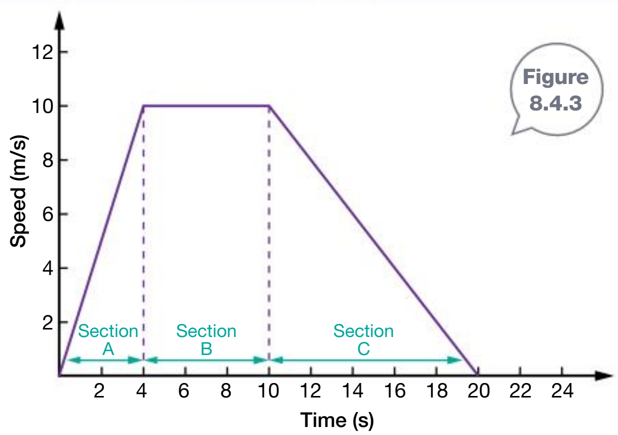

Figure 8.4.3

Problem

Sanjiv rides his scooter as described by Figure 8.4.3.

a Calculate his acceleration in sections A, B and C of his journey.

b Describe his motion in sections A, B and C.

c Calculate the distance Sanjiv covers in section A.

Solution

a Sanjiv's acceleration is the gradient of the graph in each section:

For A: acceleration $= \frac{\text{rise}}{\text{run}} = \frac{10-0}{4} = 2.5\ \text{m/s}^2$

For B: acceleration $= \frac{10-10}{10-4} = 0$

For C: acceleration $= \frac{0-10}{20-10} = -1\ \text{m/s}^2$

b In A: Sanjiv accelerates at 2.5 m/s^2 until reaching a velocity of 10 m/s.

In B: He travels at a constant velocity of 10 m/s (with zero acceleration).

In C: Sanjiv slows down, or decelerates at 1 m/s^2 until he comes to a stop.

c The distance covered is the area under this section of the graph:

distance $= \frac{1}{2} \times 4 \times 10 = 20$ m

Sanjiv travels 20 m while accelerating to 10 m/s in section A.

Practice

N

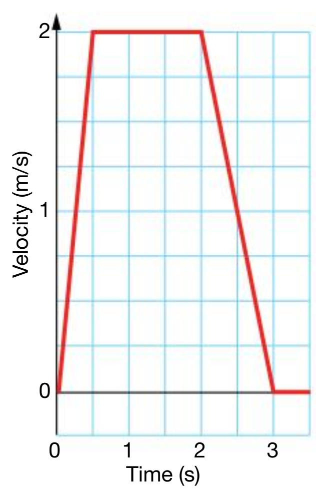

Figure 8.4.4

Figure 8.4.4 shows 3 seconds of the motion of a postie as she delivers some mail.

a **Calculate** the postie's acceleration in the first 0.5 second.

b **Describe** the motion of the postie from 0.5 to 2 seconds into the journey.

c **Calculate** the acceleration of the postie over the last second of motion.

d **Describe** what type of motion happens in this last second of motion.

e **Calculate** the distance the postie has travelled in these three seconds.

Newton's second law of motion

Newton's second law of motion states that an object will accelerate in the direction of an unbalanced force acting upon it. The size of this acceleration depends upon the mass of the object and the size of the force acting.

$\text{Force}_{\text{net}} = \text{mass} \times \text{acceleration}$

This can be expressed mathematically as:

$\boldsymbol{F}_{\text{net}} = m \times \boldsymbol{a}$

where F_{net} = total force acting on an object measured in newtons (N)

m = mass of the object (kg)

a = acceleration of the object (m/s^2)

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8.5

This formula can be rearranged to express acceleration as:

$\boldsymbol{a} = \frac{\boldsymbol{F}_{\text{net}}}{m}$

Energy calculations

The kinetic energy of an object is related to its mass and its velocity.

$\text{Kinetic energy} = \frac{1}{2} \times \text{mass} \times \text{speed}^2$

This relationship can be expressed mathematically as:

$E_K = \frac{1}{2}mv^2$

where E_K is kinetic energy, m is the mass of the object (kg) and v is its speed (m/s).

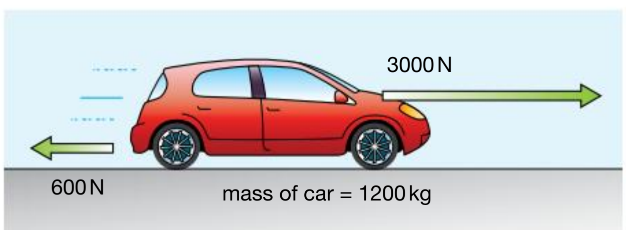
The gravitational potential energy (GPE) of an object is related to the mass of the object, its height above the ground and the acceleration due to gravity at this point.

GPE = mass × acceleration due to gravity × height

WORKED EXAMPLE
Force and acceleration

Problem 1

Calculate the acceleration of the car shown.



Solution

The net horizontal force acting on the car is:

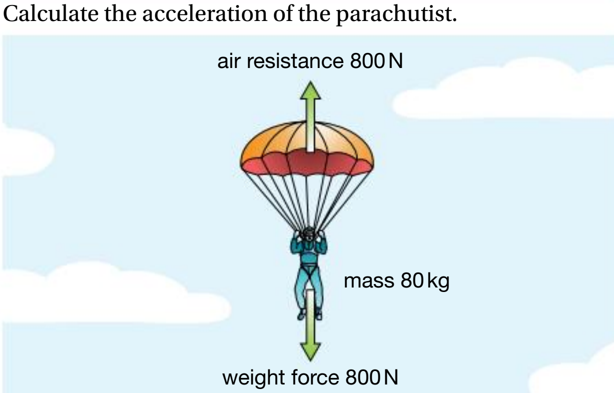
3000 – 600 = 2400 N to the right

So, the car will travel with acceleration:

$\boldsymbol{a} = \frac{\boldsymbol{F}_{\text{net}}}{m} = \frac{2400}{1200} = 2 \text{ m/s}^2$ to the right

Problem 2

Calculate the acceleration of the parachutist.



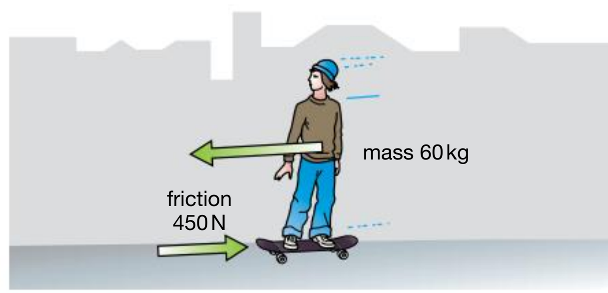
Solution

The net force acting on the parachute is zero. Its acceleration is zero and it falls with a constant velocity.

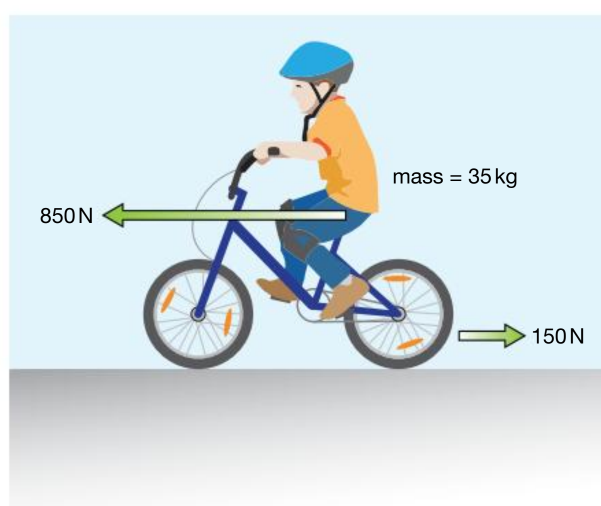
Practice

N

1 The skateboarder below is moving to the left. **Calculate** his acceleration.



2 **Calculate** the acceleration of the cyclist shown.



This can be expressed mathematically as:

$E_p = mgh$

where E_p is gravitational potential energy, m is the mass of the object (kg), h is the height of the object above the ground (m) and g is the gravitational field strength (9.8 m/s^2 for objects near Earth; for most calculations 10 m/s^2 will do).

These relationships can be used to calculate the kinetic and acceleration due to gravity of an object. The total energy always remains constant, so these relationships can also be used to analyse the total energy at any given moment.

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8.6

GPS in sport — SciFile

Global positioning system (GPS) equipment is used by a number of sporting teams to record real time data, such as:

- distance travelled by a player
- a player's speed (maximum, minimum, average)
- intensity of impacts
- heart rate.

The data is relayed to a laptop computer or handheld device.

WORKED EXAMPLE
Energy calculations

Problem 1

Calculate the kinetic energy of this car travelling at 5 m/s (18 km/h).

Solution

$E_k = \frac{1}{2}mv^2$

$= \frac{1}{2} \times 1300 \times 5^2$

$= 16\,250$ J or 16.25 kJ

Problem 2

Sara is 6 years old and has a mass of 30 kg. Calculate Sara's gravitational potential energy when she climbs 2 m up a vertical ladder to the top of a slide.

Solution

$E_p = mgh$

$= 30 \times 10 \times 2$

$= 600$ J

Sara's gravitational potential energy at the top of the slide is 600 J.

At the base of the slide, Sara's height above ground is zero, and so her gravitational potential energy is zero.

Problem 3

A 0.5 kg ball is dropped from a height of 3 metres. Calculate its:

a gravitational potential energy when it is released

b total energy when it is released

c kinetic energy when it has fallen half way

d kinetic energy when it hits the ground.

Solution

a $m = 0.5$ kg, $g = 9.8$ m/s^2, $h = 3$ m

$E_p = mgh$

$= 0.5 \times 10 \times 3$

$= 15$ J

b When released, the ball has no kinetic energy, so the total energy is 15 J.

c Half way, the ball is at a height of 1.5 m and has gravitational potential energy:

$E_p = mgh$

$= 0.5 \times 10 \times 1.5$

$= 7.5$ J

The total energy is still 15 J, so the kinetic energy must be 15 – 7.5 = 7.5 J.

The ball has the same amount of kinetic energy as potential energy at this point.

d When it reaches the ground, there is no gravitational potential energy, so kinetic energy is 15 J.

Practice N

1 **Calculate** the kinetic energy of the car in Problem 1 when it is:

a stopped at traffic lights

b travelling at 16 m/s.

2 **Calculate** the gravitational potential energy of a 40 kg child:

a at the bottom of a water slide

b when he is 15 m above the ground.

3 A 12 kg crate of potatoes is tipped off a bench in a warehouse. It falls 2 m to land on the ground.

Calculate its:

a gravitational potential energy when it is dropped

b total energy when it is dropped

c kinetic energy when it has fallen halfway

d kinetic energy when it reaches the ground.

8.4 Unit review

Remembering

1 **State** the formula used to calculate average acceleration.

2 a **State** the formula for Newton's second law that is used to calculate force.

b **State** this law expressed in terms of acceleration.

3 **Recall** the equation used to calculate kinetic energy.

Understanding

4 Raj jogs at a constant rate of 5 km/h around the block of streets around his home. Jane thinks that Raj's speed and velocity remain constant. **Discuss** whether Jane is correct.

Applying

5 a **Use** a mathematical formula to **define** gravitational potential energy.

b **Explain** each quantity.

6 Look at the displacement–time graph of Mitsu walking from home to Lachlan's house, as shown in Figure 8.1.13 on page 281.

a **Calculate** Mitsu's average speed (in km/h): N

i travelling to Lachlan's house over the first 2 hours (Hint: Convert metres to kilometres.)

ii while returning from Lachlan's house over the last hour.

b **Explain** why Mitsu's displacement does not change from 2 to 4 hours of the journey.

c **Explain** how you know Mitsu has reached home at the end of the journey.

7 **Calculate** the average speed of each of the following in the units specified in the brackets. N

a Tim hikes 10 km in 2 hours in the bush (km/h).

b A frog leaps 16 m in 4 seconds (m/s).

c A racing car travels 3 km around a circuit in 6 minutes (km/h).

8 A parachutist is falling with a constant speed of 8 m/s. **Calculate** how long it will take the parachutist to reach the ground 1600 m below. N

9 A motorcyclist accelerates from a traffic light. Initially at rest, the rider accelerates to 60 km/h over 5 seconds. He moves 40 m as he is accelerating. **Use** this information to **identify** the values for u, v, a, x and t. N

10 Tony accelerates from a set of traffic lights at a rate of 3 m/s² for 4 seconds. **Calculate**: N

a Tony's velocity after 4 seconds.

b The distance he travels during this time.

11 A stone is tossed vertically into the air with an initial velocity of 2 m/s. Assuming acceleration due to gravity is –10 m/s², **calculate** how long the stone will take to reach its highest point before falling down again. N

Hint: Assume that at the highest point of its journey the velocity of the stone is zero for an instant.

12 Copy the following table and then **use** Newton's second law to **calculate** the missing values. N

Net force (N)	Mass (kg)	Acceleration (m/s²)
24.0	6.0	
13.5	3.0	
	58.0	1.5
	25.0	3.5
1160.0	80.0	
5.5		1.1

13 The mass of a Nissan GT-R is 1740 kg. N

a **Calculate** the net force required for the car to travel with an acceleration of 3 m/s².

b If there was a 2000 N force of friction opposing the car's motion, **calculate** the size of the driving force that must be provided by the engine to maintain this acceleration.

14 **Calculate** the net force and the acceleration of each object shown in Figure 8.4.5. N

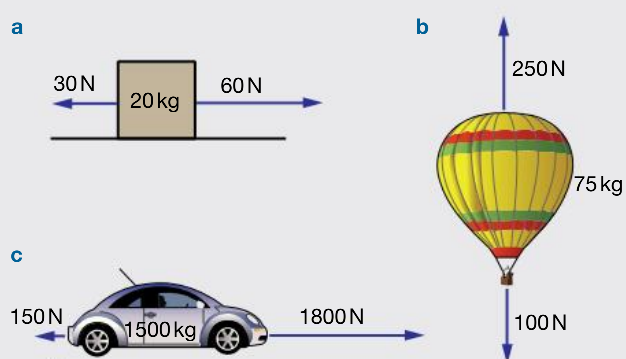


Figure 8.4.5

8.4 Unit review

15 Phil, a motorcyclist, takes off from rest and reaches 17 m/s in 4 seconds. N

- a **Calculate** what 17 m/s is in km/h.
- b **Calculate** Phil's acceleration in m/s^2.
- c If the mass of Phil's bike plus Phil is 190 kg, calculate the force required to produce this acceleration.

16 **Calculate** the kinetic energy of: N

- a an 80 kg jogger running at 4 m/s
- b a 10 000 kg bus travelling at 54 km/h
- c a 100 g tennis ball hit at 30 m/s.

17 **Calculate** the gravitational potential energy of a: N

- a 0.5 kg bird flying 20 m above the ground
- b 20 000 kg helicopter hovering 300 m above the ground
- c 2 kg money box sitting on a bookshelf at a height of 2 m.

Analysing

18 Figure 8.1.18 on page 283 shows the motion of car A and car B. N

- a **Use** this graph to **calculate** the acceleration of:
  - i car A
  - ii car B during the first 4 seconds
  - iii car B after the first 4 seconds of its motion.
- b **Calculate**:
  - i the total distance travelled by car A
  - ii the total distance travelled by car B.
- c **Compare** the motion of car A and car B.

19 A 1 kg ball is dropped onto concrete from a height of 2 m. **Analyse** this situation and **calculate**: N

- a its gravitational potential energy before it is dropped
- b its kinetic energy as it hits the ground
- c the speed with which it hits the ground (round off to one decimal place).

Creating CCT

20 Catarina is on yard duty collecting litter at school. She walks 300 m north, then 100 m west, finally turning to walk 300 m south. The journey takes 5 minutes. N

- a **State** the total distance travelled.
- b **Calculate** Catarina's average speed in m/s.
- c **Construct** a diagram of Catarina's journey.
- d **State** her displacement.
- e **Calculate** Catarina's average velocity.

21 The table below contains data about the speed of the racehorse Newton's Wings in a race. N

Time (s)	0	20	40	60	80	100	120	140	160	180
Speed (m/s)	0	3	5	7	9	9	9	9	9	9

- a **Construct** a speed–time graph of this data
- b **Calculate** Newton's Wings' top speed in km/h.
- c **Use** your graph to **calculate** the distance run by the horse in the race.

Inquiring

1 At many times in the flight of a rocket there are unbalanced forces acting on it. Research to find:

- the relative sizes of the downwards force of weight and the upwards force of thrust from the engine that act on a rocket the moment it is launched
- a diagram that shows this relationship
- what happens to the rocket on launch
- how the path of a rocket will be changed when it passes close to massive objects in space such as a moon or planet.

Present your research as a series of annotated diagrams. Explain each of the above in terms of Newton's first law.

2 The acceleration of a rocket is equivalent to the force applied to it divided by its mass at that moment.Research:

- how the mass of a rocket varies throughout its journey
- what effect this has on the motion of the rocket.

Present your research as a series of annotated diagrams. Explain each of the above in terms of Newton's second law.

3 A rocket accelerates because of the gases it expels behind it. Research to find:

- a diagram showing how Newton's third law explains what happens to a rocket as it is launched
- how launching a rocket from the Moon is different from launching a rocket from Earth.

Present your research as a series of annotated diagrams. Explain each of the above in terms of Newton's third law.

ADDITIONAL

8.4 Practical investigations

1 Graphing motion

Purpose

To use a datalogger motion sensor to detect changes in position and to produce a graph of this motion.

Materials

- a datalogger motion sensor with computer interface
- a volunteer

Procedure

1. Connect the motion sensor to the computer interface and position this on a table.
2. Ensure there is at least 3 m of space clear in front of the motion sensor.
3. Position a volunteer about 0.5 m in front of the motion sensor.
4. Ask the volunteer to try to move away from the sensor at a constant or steady speed.
5. Record this motion using the sensor and capture this as a displacement–time graph.
6. Repeat steps 4 and 5, but ask your volunteer to try to accelerate away from the sensor, increasing speed as they move away.

Results

Print or save a screen shot of the two displacement–time graphs.

Practical review

1. **Compare** the motion in each of the graphs.
2. **Recall** what is represented by the gradient of the graphs that you have produced.
3. **Use** the graphs to **calculate** the average velocity in each case.
4. **Evaluate** the success of the investigation in first producing motion of a constant speed and then producing motion of a constant acceleration.

2 $F_{net} = ma$

Purpose

To test whether an object moves with greater acceleration when the size of a pulling force is increased.

Materials

- trolley
- piece of wood
- G-clamp
- string or fishing line
- electronic balance
- pulley and clamp
- 50 g slotted masses
- calculator
- stopwatch and ruler (to measure acceleration)
  (Alternatively, use light gates for data-logging or ticker timer and ticker tape and carbon disks.)

SAFETY
Keep your feet away from the falling masses. Put padding (such as books) on the floor under the falling masses.

Procedure

1. Copy the table from the Results section into your workbook or use a spreadsheet.
2. Measure the mass of a trolley and record this value.
3. Clamp a piece of wood and a single pulley to a bench top.
4. Set up the trolley and hanging masses as shown in Figure 8.4.6.
5. Pull the trolley back so that when it is released it accelerates towards the edge of the bench.
6. Measure the distance from the starting point of the trolley to the pulley.
7. Release the trolley from its starting position and use a stopwatch, ticker tape or light gates to measure the time taken to reach the pulley.
8. Record three trial measurements of time.
9. Repeat this task for increasing hanging masses as shown in the results table.

Hints

When setting up, make sure the masses do not reach the ground when the trolley reaches the pulley.

Results

1 Calculate the average time taken by the trolley for each hanging mass tested. N

2 Using a set of axes, plot a graph of force applied (N) on the vertical axis against time taken (s) on the horizontal axis.

3 Use equations of motion to calculate the acceleration of the trolley in each case. Alternatively, calculate acceleration using the ticker tape method shown in the Skill Builder on page 285, but divide mm/s^2 by 1000 to obtain acceleration in m/s^2. Add your accelerations to your Results table.

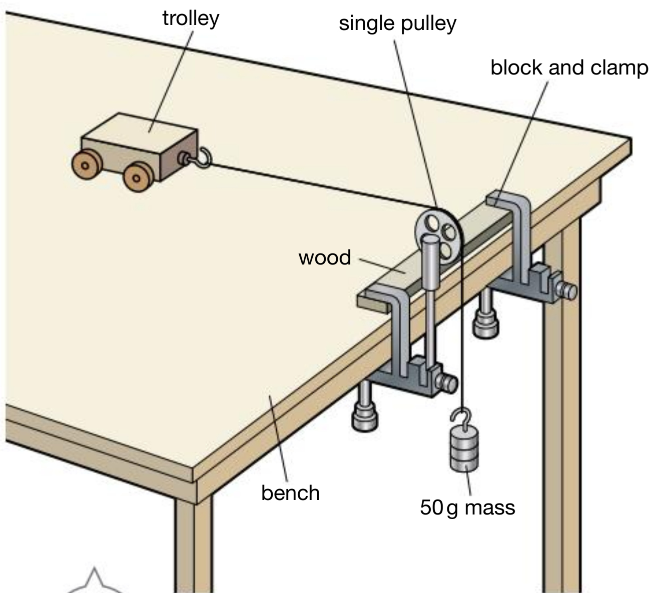


Figure 8.4.6

Practical review

1 **Describe** the effect of increasing force on the time taken for the trolley to reach the pulley.

2 As the distance the cart moves is the same in each trial, moving in a shorter time corresponds to greater acceleration. With this in mind **propose** the effect of increasing force on the acceleration of the cart.

3 **Propose** any sources of error that would affect the results you obtained in this experiment.

Hanging mass (g)	Force applied (N) (hanging mass × gravity)	Time for trolley to reach pulley			Average time (s)	Acceleration (m/s^2)
		Trial 1 (s)	Trial 2 (s)	Trial 3 (s)		
100	1					
200	2					
300	3					
400	4					
500	5					

STUDENT DESIGN

3 Kinetic energy of a ball

Purpose

To calculate the kinetic energy of a ball.

SAFETY
A risk assessment is required for this investigation.

Materials

- as selected by students

Procedure

1. Design a way of collecting all the data you need to:
   - calculate the kinetic energy of a ball that is kicked or thrown at a wall a short distance away from you
   - compare the kinetic energies of different balls and with different people kicking or throwing.
2. Brainstorm in your group and come up with several different ways to investigate the problem. Select the best procedure and write it in your workbook. Draw a diagram of the equipment you need.
3. Before you start any practical work, assess all risks associated with your procedure. Construct a risk assessment that outlines these risks and the precautions you need to take to minimise them.
4. Show your teacher your procedure and risk assessment. If they approve, then collect all the required materials and start work.

Hints

To calculate kinetic energy you will need to determine the mass and speed of the ball (average speed will do).

To ensure your results are as accurate as possible, have multiple people take the same measurements (especially time).

Results

Calculate the kinetic energy (in joules) for each ball and for each kick or throw. Display your measurements and results in an appropriate table. N

Practical review

1. **Identify** the situation (ball and person) that resulted in the:
   a. greatest kinetic energy
   b. smallest kinetic energy.
2. a. **List** potential sources of error in this experiment.
   b. **Describe** what you did to minimise these errors.
3. **Evaluate** your procedure. Pick two other prac groups and **evaluate** their procedures too, identifying their strengths and weaknesses.

8 Chapter review

Remembering

1 **Recall** the SI units from the following list: kilogram, centimetre, second, gram, milligram, year, hour, tonne, minute, kilometre.

2 **Recall** two units that can be used to measure speed.

3 **State** what is represented by the gradient of a:

- **a** distance–time graph
- **b** speed–time graph.

Understanding

4 If a horse stops running when it comes to a fence, its rider can be thrown over the top of the fence. **Explain** why.

5 Wearing a helmet when riding a bike reduces the force of an impact if the rider is involved in a collision. **Explain** why.

6 **Define** the term *acceleration*. L

Applying

7 Figure 8.5.1 shows the displacement of Steve as he rides his bike.

Use this to **state**:

- **a** the total distance travelled
- **b** his displacement
- **c** the time interval in which he rides the fastest
- **d** the time at which he was stationary
- **e** the time/s when he was 3 km away from home.

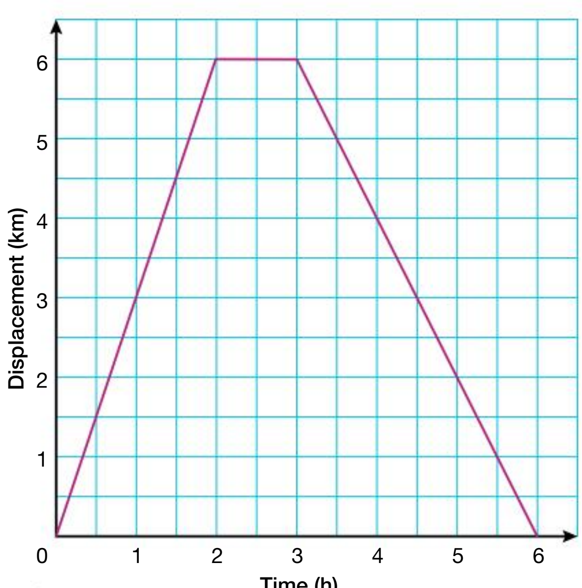


Figure 8.5.1

8 Figure 8.5.2 represents a constant force applied to push a couch 6 m across a floor.

Use one or more of Newton's laws of motion to **explain** how and why the couch has moved.

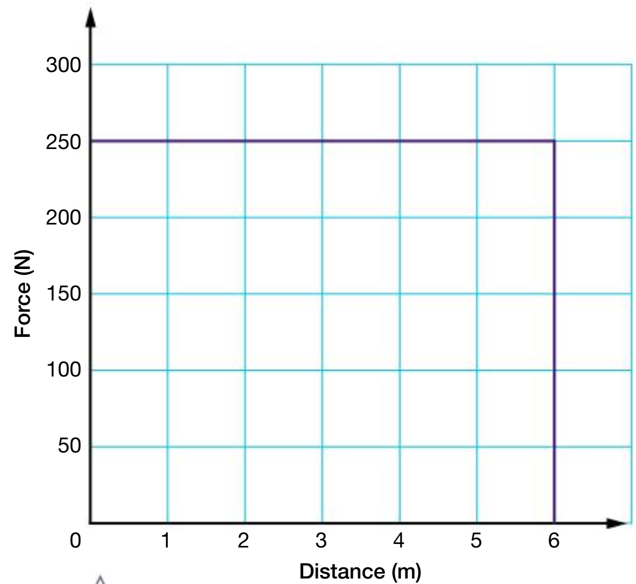


Figure 8.5.2

9 Tahlia is caught in a burning building and needs to jump from a window near the top of the building to be saved by the rescue team below. The total energy in a system is conserved. **Use** this fact to **calculate** the missing values in the Figure 8.5.3.

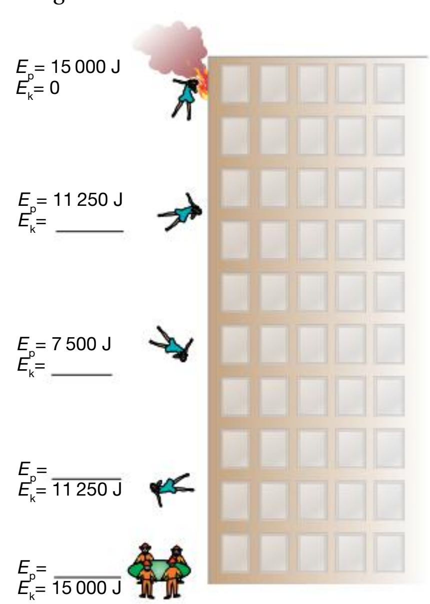


Figure 8.5.3

Analysing

10 **Compare** distance and displacement.

11 **Analyse** the three speed–time graphs shown in Figure 8.5.4 and **describe** the motion represented by each.

Evaluating CCT

12 You travel from the ground to the 20th floor in a lift. **Propose** a reason why you feel very heavy through most of the journey.

13 Two astronauts, William and Shilpa, are making in-flight repairs to their space shuttle in zero gravity. Shilpa asks William to pass her a toolbox, which has a mass of 5 kg and a hammer of mass 1 kg. William pushes each of these towards Shilpa with an equal force.

- **a** **Predict** how the acceleration of the toolbox will differ from the acceleration of the hammer.
- **b** **Justify** your response

14 **a** **Predict** what will happen to the hanging paperclip in the jar shown in Figure 8.5.5 when the jar:

- **i** accelerates by being shoved across a bench
- **ii** slides smoothly across a bench with no change in speed
- **iii** slows to a stop.

b **Use** Newton's first law to **justify** your answers above.

15 **a** **Determine** whether you can or cannot answer the questions on page 273 at the start of this chapter.

b **Use** this to **assess** how well you understand the material presented in this chapter.

Creating CCT

16 **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter.

distance
displacement
speed
velocity
acceleration
force
Newton's laws
work
kinetic energy
gravitational potential energy

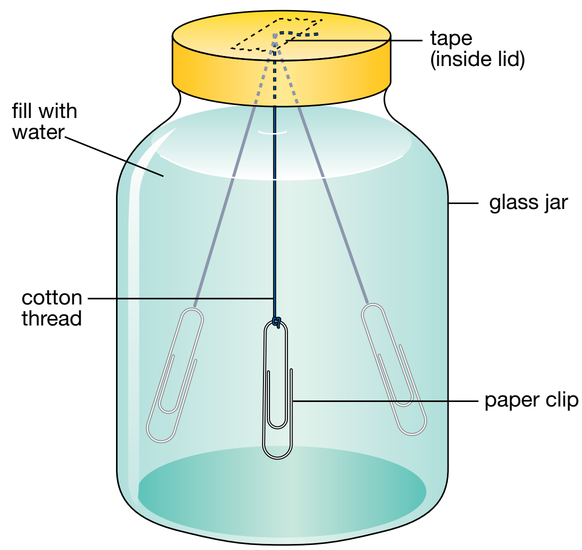


Figure 8.5.5 The suspended paper clip in this accelerometer reacts to acceleration.

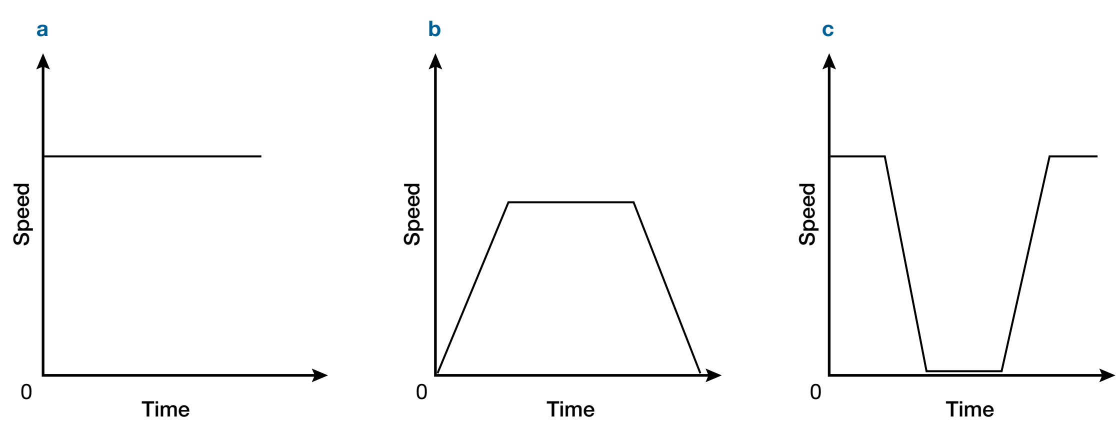


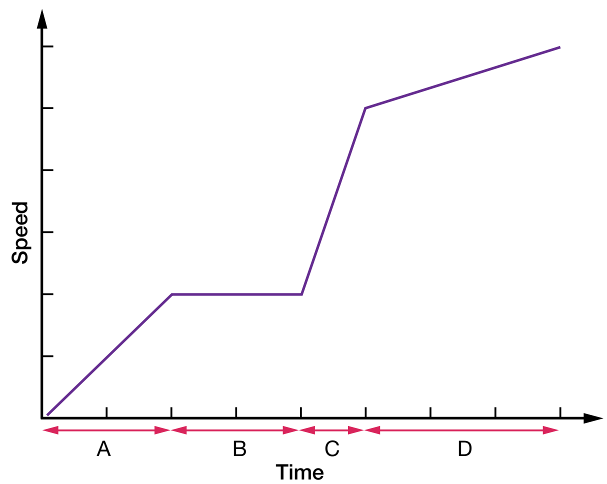
Figure 8.5.4

8.7

Thinking scientifically

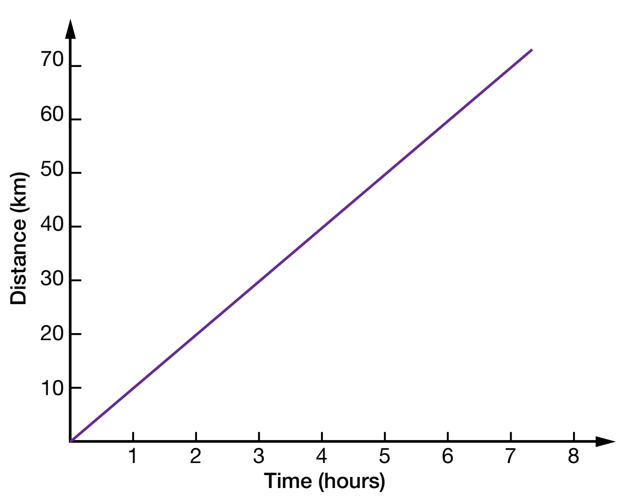
Q1 The graph below shows the motion of Tina, riding a bike home from school. Given that the gradient of a speed–time graph is Tina's acceleration, the time interval over which Tina has the greatest acceleration is: CCT

A section A
B section B
C section C
D section D.

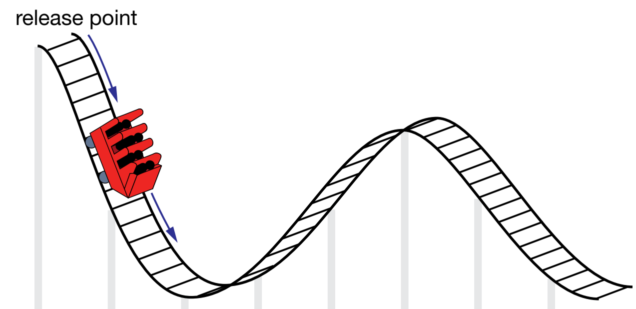


Q2 The distance–time graph of Ben's motion as he rides in a long-distance cycling event is shown below. Given that Ben's average speed is the distance travelled divided by time taken, his average speed across this time interval is: CCT

A 10 km/h
B 10 m/s
C 1 km/h
D 1 m/s.



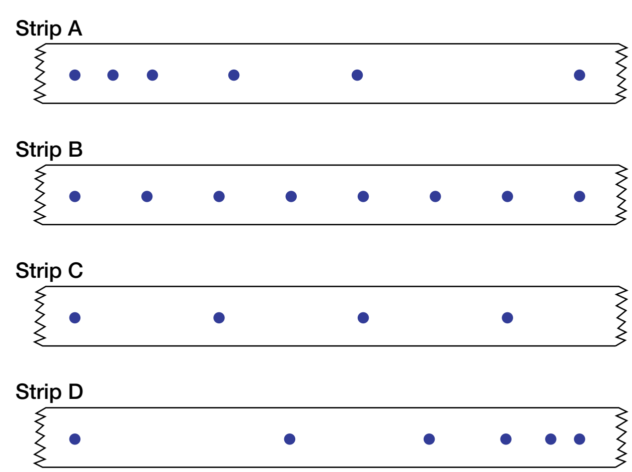
Q3 The diagram shows the position of a rollercoaster cart soon after it is released on a track. Select the alternative that describes how its energy is changing at this moment in time. CCT



A increasing kinetic energy, constant gravitational potential energy
B increasing kinetic energy, decreasing gravitational potential energy
C decreasing kinetic energy, increasing gravitational potential energy
D decreasing kinetic energy, constant gravitational potential energy

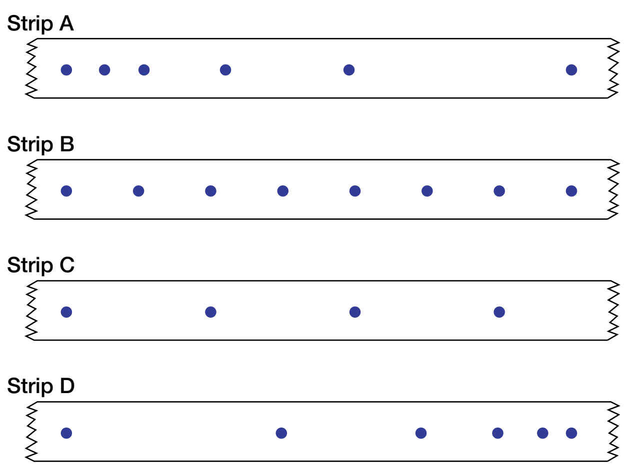
Q4 The hammer on a ticker timer vibrates up and down 50 times per second. The following four strips of ticker tape were attached to a moving object. These dots display a record of its motion. The strip that indicates the fastest constant speed is: CCT

A strip A
B strip B
C strip C
D strip D.



Q5 The hammer on a ticker timer vibrates up and down 50 times per second. The following four strips of ticker tape were attached to a moving object. These dots display a record of its motion. The strip that indicates an object that is slowing down is: CCT

A strip A
B strip B
C strip C
D strip D.

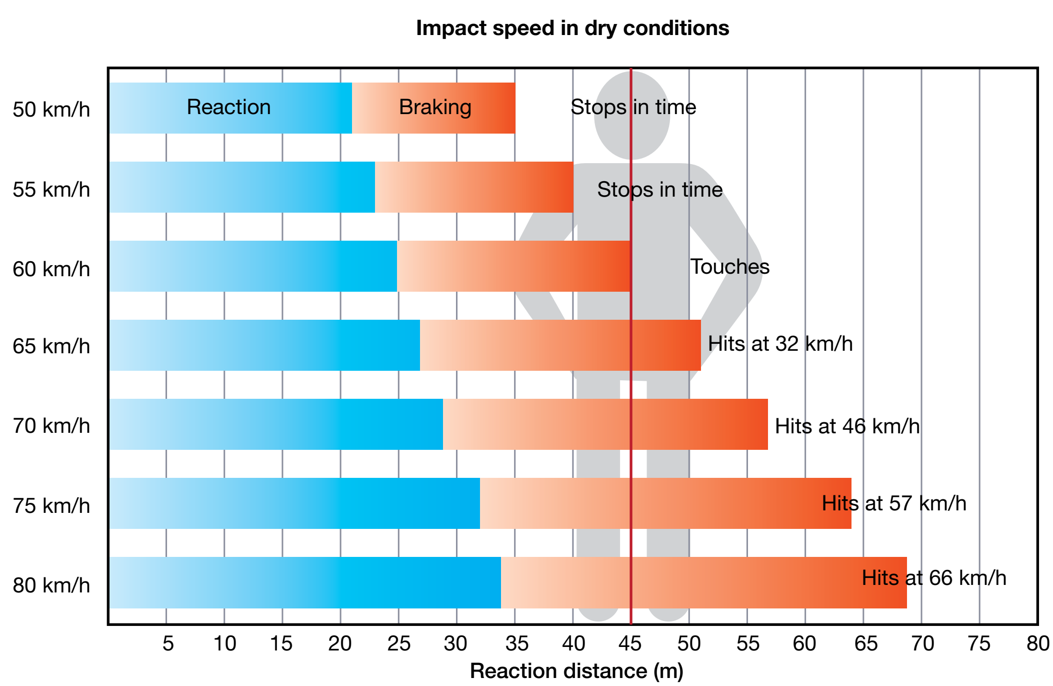


Q6 Cathy pushes a shopping cart of mass m with force F. By Newton's second law of motion (and ignoring friction), the cart has acceleration $a = F/m$. Cathy now uses the same-sized force to push a cart that has three times the mass. Its acceleration is: CCT

A double the acceleration of the first cart
B three times the original acceleration
C one-third of the original acceleration
D half of the original acceleration.

Q7 Study the graph below, which estimates the typical reaction time and reaction distance for drivers travelling at various speeds. Imagine that two cars are travelling along a multilane highway, car A at 55 km/h and car B at 75 km/h. A wombat staggers onto the road 50 m ahead of the cars the instant they are both the same distance away from it. Assuming the drivers react as shown in the graph, determine the correct alternative. CCT

A Both cars stop in time.
B Only car A stops in time.
C Only car B can stop in time.
D Neither car is able to stop in time.



Glossary

Unit 8.1

L

Acceleration: rate of change of velocity

Air resistance: friction between the air and a moving object

Average speed: a measure of how fast something moves on average.

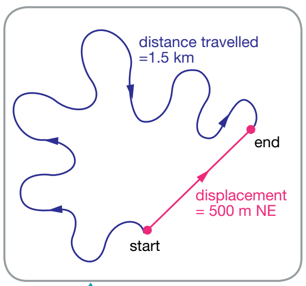
Acceleration

Displacement: a measurement of the change in position of a moving body; a straight line connecting the start and end points is specified in terms of length and direction

Distance: a measurement of how far apart objects are

Gradient: slope of a hill of a graph: gradient = $\frac{\text{rise}}{\text{run}}$

Instantaneous speed: the speed of an object at a particular moment



Displacement

Reaction distance: distance moved while reacting to an emergency

Reaction time: the length of time it takes a driver to respond to a hazard

Speed: the rate of change of distance

Terminal velocity: the final velocity that an object falls with no further acceleration possible due to air resistance

Velocity: the rate of change of displacement

Unit 8.2

L

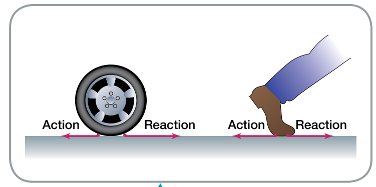
Inertia: the tendency of an object to resist changes in its motion

Newton's first law of motion: an object at rest will remain this way unless it is acted upon by an unbalanced force; an object that is moving will continue to move in the same manner unless acted upon by an unbalanced force

Inertia

Newton's second law of motion: an object will accelerate in the direction of an unbalanced force acting upon it such that: $F_{net} = m \times a$

Newton's third law of motion: for every action, there is an equal and opposite reaction



Newton's third law of motion

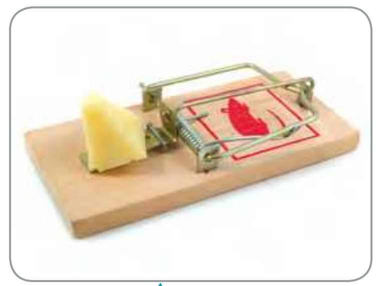
Unit 8.3

L

Efficiency: a measure of the useful energy output of an energy transfer

Elastic potential energy: energy stored in a stretched or compressed material, such as a spring or elastic band

Gravitational potential energy: the potential energy possessed by an object due to its position above the ground

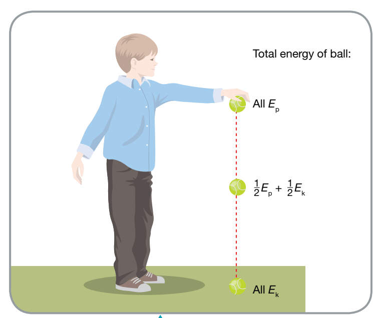


Elastic potential energy

Kinetic energy: the energy of a moving body

Law of conservation of energy: energy may be transferred but is never created or destroyed

Potential energy: energy possessed by an object because of its position or structure, also called stored energy



Gravitational potential energy

Unit 8.4

L

Scalar quantity: a quantity, such as distance or time that has size but not direction

Vector quantity: a quantity, such as displacement or velocity, that has size and direction

9 Forensic science

Have you ever wondered...

- why police record eyewitness accounts of a crime as soon as possible?
- how images of suspects are constructed?
- what police can tell from fibres collected from a crime scene?
- how DNA is extracted from samples and matched?
- how hard it is to make fake banknotes?

After completing this chapter students should be able to:

- apply the processes of Working Scientifically to develop creative solutions to problems CCT EU PSC
- report data, evidence and findings with accuracy and honesty EU
- identify data which supports or discounts a hypothesis CCT
- draw conclusions that are consistent with evidence
- evaluate conclusions and evidence, identify sources of uncertainty and possible alternative explanations
- describe the effect of temperature on the rate of chemical reactions
- identify that genetic information is transferred in DNA
- discuss advantages of biotechnology, including social and ethical considerations PSC EU
- evaluate the benefits and problems associated with nuclear energy EU S PSC
- describe where advances in science generate new career opportunities PSC L WE

ADDITIONAL

- assess the role of the development of fast computers in the analysis of DNA sequences ICT
- research how information technology is applied in bioinformatics. ICT

9.1 Crime scene

Crime ranges from shoplifting, theft and forgery to assault and murder. All these crimes leave clues that point to those most likely to have committed the crime. The analysis of these clues is the work of forensic scientists. The information that they obtain from these clues is then used against suspects in court. Sometimes clues are used to defend suspects instead.

INQUIRY science 4 fun

Sandpit tracks

What can footprints and a track tell you?

YES

Collect this …

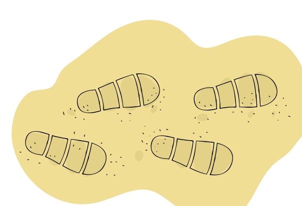
- access to a sandpit (such as a long-jump pit)
- rake

Do this …

1. Rake over the sandpit so that it is smooth.
2. Walk slowly across the pit.
3. Walk across the pit again, parallel to your original tracks, but try:
   - walking faster
   - walking backwards
   - changing direction midway.
4. Compare the:
   - tread of the footprints with the sole of your shoes
   - depth of the footprints (for example, did the faster walk produce deeper prints?)
   - spacing of the footprints.

Record this …

Describe what you saw.
Explain what you think caused each of the features you saw.



First on the scene

The first authorities to arrive at a crime scene will usually be the police. They will quickly cordon off (rope off) the crime scene, call for back-up from other police, detectives, crime scene units, ambulance and fire brigade and start interviewing eyewitnesses (people who were there).

CSU

A **crime scene unit (CSU)** is a team of specialist police, photographers and forensic scientists trained in collecting and analysing evidence. Normally the CSU does not deal with less serious crimes such as burglary but concentrates on more complex and serious crimes such as **homicide** (where another human is killed), terrorist attacks, **arson** (when a fire is started deliberately) or sexual assault.

Every piece of evidence from a crime scene is a clue, and the CSU thoroughly searches the area to ensure that nothing is missed. Figure 9.1.1 shows three different ways the CSU can do this. Every piece of evidence is then marked and photographed while in position.

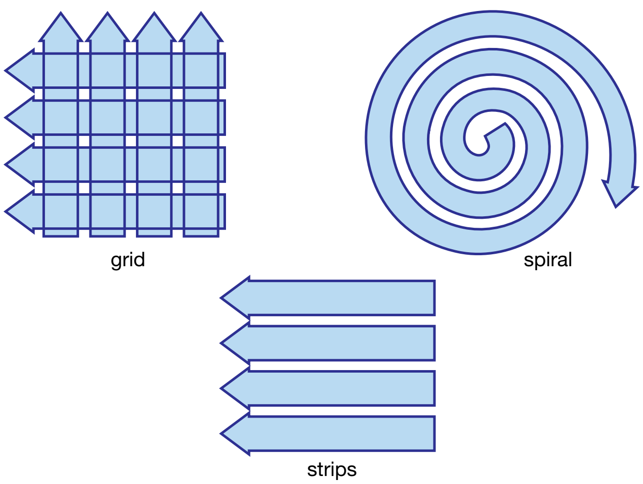


Figure 9.1.1 Three different methods are used by crime scene units to ensure that the crime scene is thoroughly searched.

The crime scene is then cleared and everything is sent away to be analysed by forensic scientists specialised in particular fields, such as **pathology** (the study of disease and cause of death), **ballistics** (the study of guns and bullets), **toxicology** (the study of the effects of poisons and chemicals on the body), **fingerprints**, fibres, chemistry and dentistry.

The materials found at a crime scene can be classified broadly as either physical evidence or trace evidence.

Physical evidence

Anything that is reasonably large and easy to see is **physical evidence**. It includes dead bodies, weapons, tool marks, tracks, damaged furniture, fingerprints, blood spatters, bullets and bullet holes like the one in Figure 9.1.2.

Figure 9.1.2 Bullets and the holes they make are physical evidence.

Corpses

A **corpse** is a dead body. The identity of a corpse will need to be determined, so the CSU records or collects anything on or around the body that might help in its identification. This includes personal items such as wallets or purses, which might contain driver's licence, Medicare card and credit cards. Mobile phones are likely to provide a list of friends and family, and computers, smartphones and tablets can provide the email and the social media accounts of their user. If the crime scene is a home or apartment, then family photos and telephone, gas and electricity bills all provide further information about the person who lived there.

Evidence of time of death

A series of changes in a corpse begins immediately after death and can be used to determine how long a person has been dead. This information is vital for investigators since it will confirm the day (and possibly the hour) the crime was committed. This then allows police to narrow their range of suspects of who committed the murder.

One obvious change is body temperature. A healthy living human has a **core body temperature** of 37°C. After death, this falls at a rate of about 0.8°C every hour until it reaches room temperature—the exact rate of cooling depends on the victim's clothing and the surrounding temperature. This means that a body usually cools completely within one day.

Other changes that can be used to determine the time of death are the:

- extent of rigor mortis (stiffening of muscles)
- colour of the skin (shown in Figure 9.1.3)
- extent of decomposition
- type and life-cycle stage of insects present on and around the body.

Figure 9.1.3 Skin takes on a greenish appearance within two days of death because bacteria are starting to decompose the body.

9.1

Tool marks

Every type of tool leaves its own characteristic **impression** or **tool mark**. For example, the jemmy bar being used in Figure 9.1.4 will leave scratches, dents and cuts in the window frame and sill. Different marks would have been left by a screwdriver, hammer, axe, knife or chisel.

Tool marks depend on:

- the type of tool being used
- whether the material being marked is hard (such as wood or bone) or soft (such as fabric, paper, skin, fat or muscle)
- the sharpness of the individual tool. For example, a sharp saw will produce a fine, crisp cut in wood, while a blunt one will rip the wood and produce a ragged edge
- faults in the tool, such as missing teeth or heavy wear patterns.

Figure 9.1.4 The marks on a window frame allow investigators to determine whether a screwdriver or a jemmy bar was used to lever open a window. These will be photographed and compared with tools collected from the suspect or the suspect's residence.

Track impressions

Footprints and impressions from shoes and tyres are often left behind at a crime scene. A **positive impression** is an image that is exactly the same as the pattern on the shoe or tyre. Positive impressions are left on hard surfaces by feet, shoes and tyres that are dirty or soaked with water, oil or blood. A **negative impression** is formed if the suspect crossed damp sand, mud, snow, grease or congealing (thickening) blood. This is because the material only gathers in gaps in the tread of the shoes or tyres.

All impressions are photographed next to a ruler to indicate their actual size. You can see this in Figure 9.1.5. Negative impressions will have wet plaster poured into them to form a mould that can be taken back to the laboratory for analysis.

Figure 9.1.5 The make and style of shoe that a criminal wore can be determined from its prints. Even more information comes from cuts, stones, scuffing and wear on the sole.

Collecting fingerprints

In the grooves of your fingerprints are glands that secrete (release) sweat, oils and amino acids. A little of these secretions is left behind as an image of the fingerprint whenever something is touched or picked up. **Non-porous** materials like metal and glass do not absorb sweat, oil or amino acids and so clear fingerprints are most likely to be found on:

- metallic objects such as doorknobs, forks, saucepans, knives and guns
- glass and ceramics such as drinking glasses, windows, mirrors, bathroom tiles, cups, mugs and plates
- the plastics that make up light switches, car dashboards, steering wheels and broom and brush handles
- painted surfaces such as cars and front doors and their surrounds
- polished or varnished surfaces of furniture and stair railings.

As Figure 9.1.6 shows, fingerprints are revealed by brushing special types of powder onto the surface so that it sticks to the oils left behind. Black carbon powder is dusted onto light-coloured and clear surfaces and white aluminium powder is brushed onto dark surfaces.

Prac 1 p327

Figure 9.1.6 Black carbon powder is brushed onto glass to show fingerprints on its surface.

Porous materials such as fabrics and raw timber absorb body fluids, making it difficult to find fingerprints on them. However, fingerprints can still be revealed by brushing them with chemicals that react with the secretions of the fingerprint. For example, ninhydrin is a chemical that reacts with amino acids, turning the fingerprint a bluish purple. Light can also help to reveal fingerprints. This is what is happening in Figure 9.1.7.

SciFile

Superglue fingerprints

Superglue reacts with the oils that make up fingerprints and superglue vapour is sometimes blown onto prints to make them stickier and more visible. Sealed objects such as fridges and cars can be filled with superglue vapour, revealing all the prints inside them.

Figure 9.1.7 Some types of light cause fingerprints to **fluoresce** or glow. Here an investigator is searching for fingerprints left by the 2002 Bali bombers.

Blood spatters

Drops of blood tell investigators a lot about what happened at a crime scene. As Figure 9.1.8 shows, blood spatters change shape and size depending on the height and direction from which they fall. Blood that has been wiped up or washed from surfaces or clothing can be revealed using ultraviolet (UV) light.

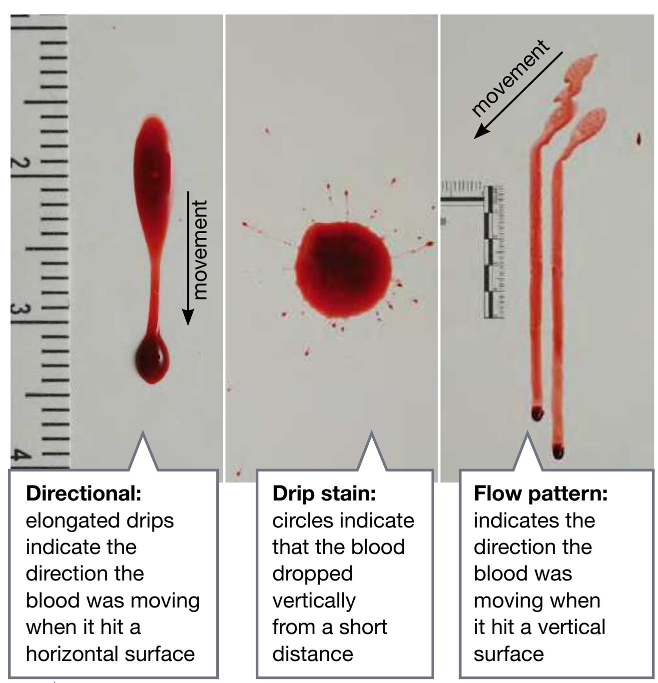


Figure 9.1.8 Blood spatters change shape depending on the direction they hit a surface.

9.2

Trace evidence

Microscopic materials found at the crime scene are known as **trace evidence**. Trace evidence is incredibly useful to investigators since the criminal cannot see it and so cannot collect it or wipe it away.

Fibres

Fibres are strands of natural materials such as hair, fur, fluff, wool and cotton, and synthetics such as nylon and polyester. Wherever you go, a few hairs are likely to fall from your head and body and a few threads are likely to drop from your clothes. These get trapped in the carpet, on furniture and on other people's clothes. A violent struggle will cause even more fibres to drop. Investigators can collect these fibres by picking them up with sticky tape or by using a specialised vacuum cleaner.

A microscope is then used to compare fibres with those from other crime scenes and those of the victim and suspects. Fibres can be identified from their characteristic surfaces. Figure 9.1.9 shows how.

Fibres do not prove that a particular person was at the crime scene. Many people have the same shirt, jeans or dress and the same colour and type of hair. For this reason, fibres are only **circumstantial evidence**—they point to a suspect but cannot be used as proof that the person was there.

Prac 2 p328

Seeds

Microscopic grains of pollen and seeds found at a crime scene can be compared with plants nearby and in the areas in which the suspects live. This helps investigators to piece together what happened. For example, a body that has been shifted might have seeds from another area on it.

DNA

Wherever you go, you leave a little bit of yourself behind. It might be a few cells of skin, a smear of body oil, sweat, a strand of hair, a few flakes of dandruff or saliva. Saliva is being collected in Figure 9.1.10. **DNA** (deoxyribonucleic acid) is a chemical present in the nucleus of body cells. Everyone has different DNA. This makes DNA the 'ultimate fingerprint'.

Some of the DNA found at a crime scene will come from the victim, some may come from people known to be innocent and some will probably come from the suspect. This proves that the suspect was there at some time.

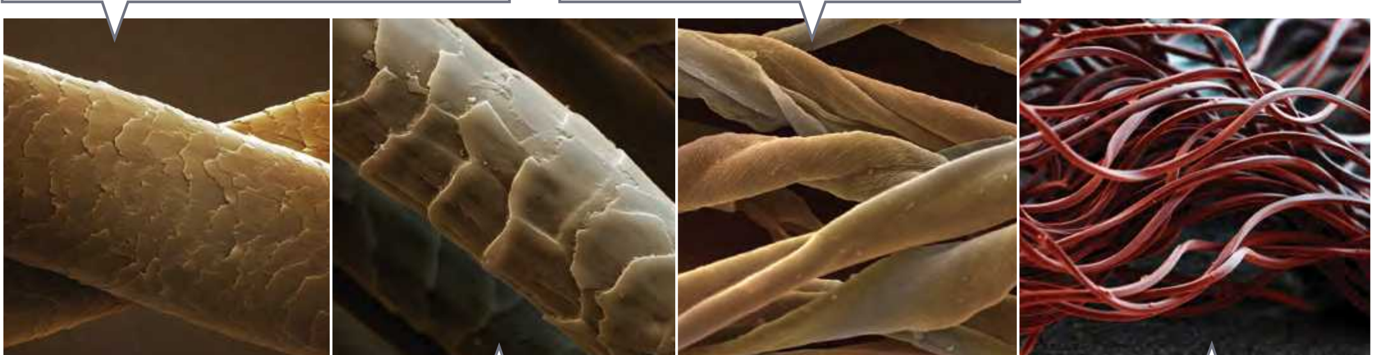
GO TO Unit 1.1

Figure 9.1.10 The saliva on this cigarette stub will contain the DNA of whoever smoked it.

Prac 3 P328
Prac 4 P329

Human hair
All types of hair and fur have overlapping scales that give the strands a rough and scaly surface.

Cotton
All plant fibres (including cotton) twist, change thickness and have a rough surface.



Wool
Wool is a form of hair and it has a more pronounced pattern of overlapping scales.

Synthetic
Like all synthetic fibres, strands of polyester are smooth with no surface pattern. Thickness is the same along the strand.

Figure 9.1.9 Fibres can be easily identified since each type has its own characteristic surface texture. These images were taken with a scanning electron microscope (SEM).

9.1 Unit review

Remembering

1 **List** the materials that are left behind on a surface that form a fingerprint.

2 **Name** the chemical used to highlight fingerprints on:
  a light-coloured surfaces
  b dark surfaces
  c porous materials.

3 Many criminals clean up a crime scene before they leave it. Even so, they probably leave behind traces that will help identify them. **List** what these traces might be.

4 **List** two forensic uses for light at a crime scene.

Understanding

5 A firm, green banana has fallen off a tree.
  a **List** the signs that could be used to determine how long the banana has been off the tree.
  b **Explain** how these changes in a banana relate to determining the time of death of a body.

6 a **State** what the core temperature of a healthy human is.
  b **State** how much the temperature of a corpse usually drops per hour after death.
  c **Calculate** what the temperature would be at 1 hour, 2 hours, 3 hours etc. after death. Stop calculating when you reach 24 hours. N

7 **Explain** why fibres can only ever be considered circumstantial evidence.

Analysing

8 **Analyse** the two crime scenes shown in Figure 9.1.11 below and **list** 20 differences.

9 **Compare** the impressions the following shoe tracks would make by listing their similarities and differences.
- wet shoes walking across dry concrete
- dry shoes walking across thick grease
- dry shoes walking across snow

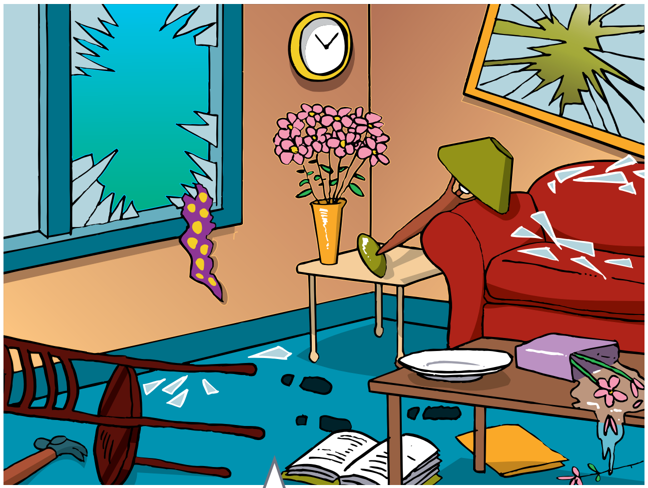
10 **Classify** the following as physical or trace evidence.
  a DNA
  b broken window
  c pollen

11 Imagine running across a sandpit. As you run, you place different pressure on different parts of your foot, producing a print of different depths. **Analyse** the distribution of pressure on your feet as you:
  a run forwards
  b run backwards
  c turn quickly.

Evaluating CCT

12 Fingerprints are rarely found on clothes. **Propose** a reason why.

13 a **Assess** which of the methods in Figure 9.1.1 on page 321 is the best way of searching a crime scene.
  b **Justify** your response.



Crime scene A

Crime scene B

Figure 9.1.11 Spot the differences between these two crime scenes.

9.1 Unit review

14 The two people in Figure 9.1.12 were both seen at a crime scene.

- a **Identify** who would be easier for an eyewitness to describe.
- b **Justify** your choice.

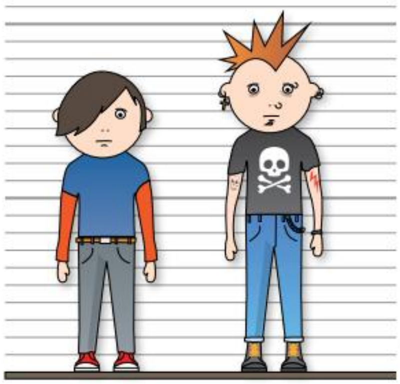


Figure 9.1.12

15 CSU teams wear gloves, masks and full body suits whenever they collect evidence that might contain DNA. **Propose** reasons why.

Creating CCT

16 a From memory, **construct** a detailed eyewitness description of:

- i your maths teacher
- ii what happened between getting up and arriving at school this morning
- iii your family car
- iv the room in which you last had English.

b **Assess** how well you remembered in part **a**.

17 The pattern of blood spatters and drips from a wound can help investigators determine exactly where injuries happened.

- a Copy Figure 9.1.13 into your workbook.
- b Add lines to **construct** a diagram that locates where in the room the person was wounded. One has already been done for you.

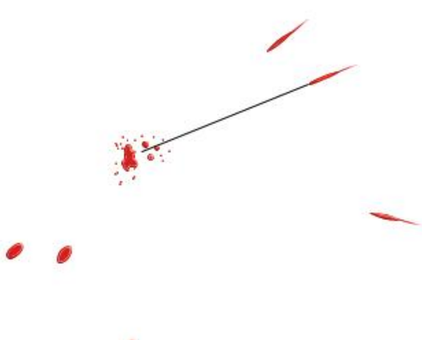


Figure 9.1.13

Inquiring

1 Use the key words *eyewitness games* to search the internet to find interactive games that test how accurate your memory is. ICT

2 Use the keyword *edheads* to find games that test your skills as a forensic investigator. ICT

3 Many conspiracy theories surround the assassination of US President John F. Kennedy in 1963, largely because of conflicting evidence, eyewitness accounts and the strange history of the main suspect. Research this assassination.

- a Find the name of the main suspect and summarise his history.
- b Summarise what you see in the Zapruder film.
- c List some of the conspiracy theories and evidence relating to the assassination.
- d Assess the material you found and classify it as reliable or unreliable evidence.

Present your research as a case study in which you complete all of the above tasks.

4 In 1980, baby Azaria Chamberlain went missing from her parent's tent in the camping ground of Uluru (Ayers Rock) in the Northern Territory. Azaria's mother, Lindy, said she had seen a dingo coming from the tent carrying something, leaving behind a pool of blood. Although this was accepted at first, Lindy was jailed for Azaria's murder in 1982. Research the evidence found at the crime scene (tent, car and nearby bush), how that evidence was treated and the conclusions prosecutors drew from it. Look at the importance of Azaria's jumpsuit and matinee jacket in Lindy's conviction and the later overturning of Lindy's conviction and her release from prison.

Present your findings as a detailed analysis of the evidence.

5 TV shows such as CSI show the methods that forensic scientists use. Watch an episode of one such TV show and:

- state what the crime was
- list the forensic evidence collected
- list other evidence that was collected
- suggest improvements to the episode to make it more accurate.

Present your findings in written form. Include the name of the show and the date and time it was originally broadcast.

9.1 Practical investigations

1 Lifting fingerprints

Purpose

To detect fingerprints on different surfaces.

Materials

- variety of objects with different surfaces of different colours (such as glass microscope slide, white tile, glossy wrapping paper, soft-drink can, fabric)
- carbon powder (or manganese dioxide)
- talcum powder

- sheets of newspaper
- soft fine-haired brush
- plastic teaspoon
- broad, clear sticky tape
- white and black cards

Procedure

1. Cover your workbench top with newspaper.
2. Hold each different material or object in your fingertips and then place each on the newspaper.
3. Use the teaspoon to sprinkle carbon or talc onto each object. Choose carbon for light-coloured objects and talc for dark.
4. Use the brush to *gently* dust off excess powder.
5. Place a strip of sticky tape over any prints that you find.
6. *Gently* peel off the tape and stick it onto the card that will best show the print.

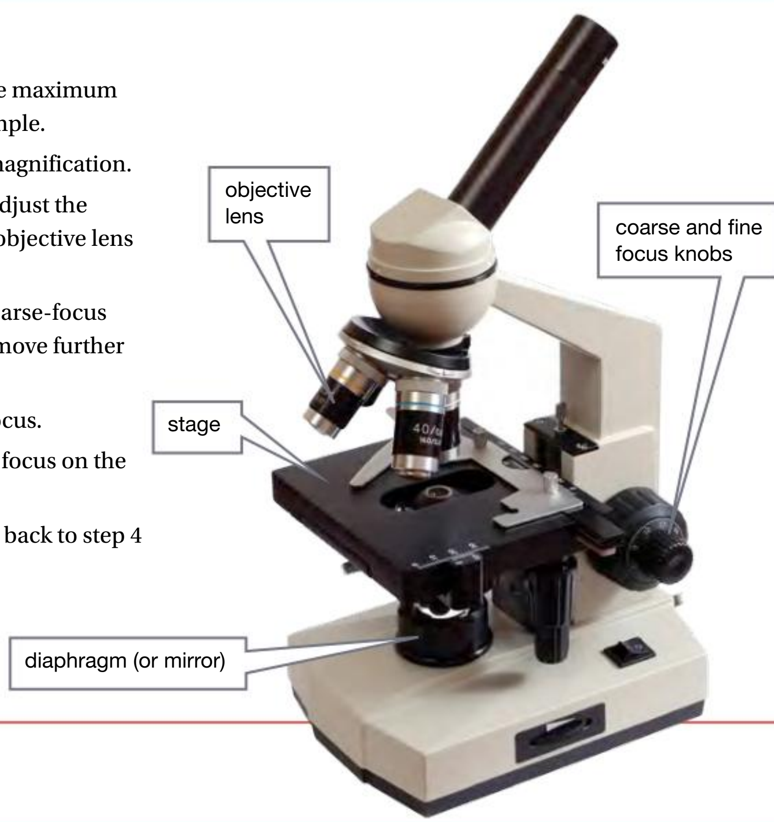
Practical review

1. Some of your lifted fingerprints might only be partial (not complete). **Explain** why.
2. **Identify** the types of materials on which no prints were found.
3. **Explain** why prints are difficult to lift from porous materials.

SKILL BUILDER

Using a microscope

1. Adjust the mirror or diaphragm so that the maximum amount of light is passing through the sample.
2. Select the objective lens with the lowest magnification.
3. Looking at the microscope from its side, adjust the coarse-focus knob to bring the stage and objective lens as close to each other as possible.
4. Looking through the eyepiece, turn the coarse-focus knob so that the stage and objective lens move further apart.
5. Keep doing this until the specimen is in focus.
6. Adjust the fine-focus knob to sharpen the focus on the specimens.
7. If you can't focus the microscope, then go back to step 4 and start again.



9.1 Practical investigations

2 Analysis of fibres

Purpose

To compare different types of fibres.

Materials

Part A: Under the microscope

- labelled samples of different fabrics made of:
  - natural fibres (such as wool, cotton, linen, silk)
  - synthetic fibres (such as nylon, polyester, rayon)
- labelled samples of other fibres (such as human hair, fur, coir)

SAFETY
Some fabrics release poisonous gases when burning.
Do part B in a fumehood or outside.
Wear safety glasses at all times in part B.

- clear sticky tape
- tweezers or pins
- access to stereomicroscope

Part B: Flame tests

- metal tongs
- matches
- bench mat

Procedure

Part A: Under the microscope

1. Remove an individual thread (about 2 cm long) from each fabric sample.
2. Most threads are made from a number of individual fibres. Use the pin or tweezers to tease them apart.
3. Peel off a strip of clear sticky tape and pat it against the thread so that it sticks.
4. Place the stuck fibres under the microscope and focus to obtain a clear image.

Part B: Flame tests

5. Cut or tear a strip about 2 × 1 cm from each fabric.
6. Use tongs to hold a strip over the bench mat. Hold a lighted match under the strip.

Results

1. In your workbook sketch and label each fibre, taking note of its surface.
2. Record your observations for each fabric when placed in the flame. Did it catch fire, melt or char? What colour was the flame and smoke? What was left?
3. Compare the surface of each fibre with the simplified diagrams shown in Figure 9.1.14 and classify each.

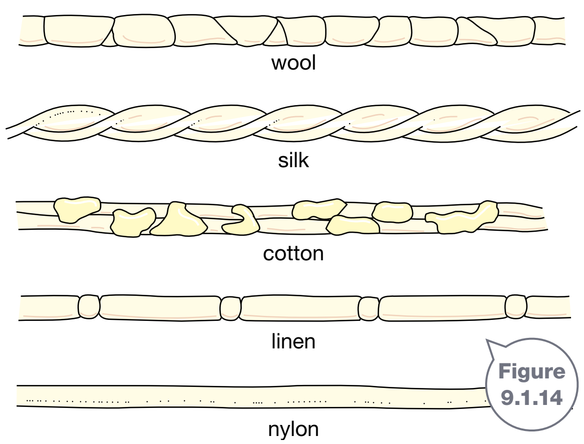


Figure 9.1.14

Practical review

1. **Explain** why fibres are considered to be trace evidence.
2. **Compare** the surfaces of the natural fibres with those of the synthetic fibres.
3. **Classify** the fibres you tested as fibres that burn, fibres that melt or fibres that char (go black but with no flame).

STUDENT DESIGN

3 Blood spatter analysis

Purpose

To analyse blood spatters

Materials

- as selected by students

SAFETY
A risk assessment is required for this investigation.

Procedure

1. Use the key words blood spatter experiments or blood splatter experiments to search the internet for a way of testing blood spatters. Bookmark the page, take a screendump of it or print it out. ICT
2. Before you start any practical work, assess all risks associated with the procedure you found. If using

chemicals, then refer to their MSDS. Construct a risk assessment that outlines these risks and precautions you need to take to minimise them.

3 Show your teacher your procedure and your risk assessment. If your teacher approves, then collect all the required materials and start work.

Results

Display your results in an appropriate format.

Practical review

1 **Assess** the value of blood spatters as forensic evidence.

2 **Propose** other evidence that might come from blood left at a crime scene.

STUDENT DESIGN

4 Predicting a suspect's height

When walking or running, tall people take longer steps than short people.

Purpose

To determine a relationship between a person's height and their step length.

Hypothesis

What relationship do you think will exist between a person's height and the length of their step—will step length vary directly with height or will there be some other relationship? Before you go any further with this investigation, write a hypothesis in your workbook.

SAFETY

A risk assessment is required for this investigation.

Materials

- as selected by students

Procedure

1 Design a way of determining the height of a person based on the length of their steps.

2 Brainstorm in your group and come up with several different ways to investigate the problem. Select the best procedure and write it in your workbook. Draw a diagram of the equipment you need.

3 Before you start any practical work, assess all risks associated with your procedure. Construct a risk assessment that outlines these risks and the precautions you need to take to minimise them.

4 Show your teacher your procedure and your risk assessment. If your teacher approves, then collect all the required materials and start work.

Hints

You will need to find some way of leaving footprints or recording the steps, such as walking on sand or through water then onto a hard dry surface.

Carry out each set of measurements a number of times and find averages.

Results

1 Construct an appropriate table into which you can write your measurements.

2 Construct a line graph showing your results. Place step length (independent variable) on the horizontal axis and height (dependent variable) on the vertical axis.

3 Select a student in the class who you have not yet tested.
   a Use your procedure above to determine their step length.
   b Use your graph to predict what their height *should* be.
   c Check your prediction against their actual height. Assess how accurate your graph is as a way of determining the height of a person from the length of their steps.

Practical review

1 **Describe** the shape of your graph. For example, was it linear (a straight line)?

2 a **Construct** a conclusion for your investigation.
   b **Assess** whether your hypothesis was supported or not.

3 **Predict** what would happen to step length if the person was running, not walking.

4 **Propose** how investigators might use the results from this experiment in finding a suspect.

5 **Evaluate** your procedure. Pick two other prac groups and **evaluate** their procedures too, identifying their strengths and weaknesses.

9.2 Victims and suspects

A lot can be learnt from a body. Its features and proportions help forensic scientists to identify it and marks on it can suggest the cause of death. Likewise, forensic science can provide investigators with the evidence they need to successfully identify and convict those who committed the crime.

INQUIRY science 4 fun

Teeth impressions

Can you be identified from your teeth?

Collect this ...

- large 'jelly' lollies such as jelly frogs or snakes (one per student)

Do this ...

1 Put the jelly lolly into your mouth, placing the lolly so that most of your teeth will bite into it.
2 Carefully bite *once* into the jelly lolly. If possible, bite right through it.
3 Compare the teeth impression with your actual teeth. Did it have the same number?

Record this ...

Describe any differences between your teeth impression and your actual teeth.

Explain how teeth impressions might be used to solve a crime.

Identifying victims

Any corpse found at a crime scene needs to be identified. So too do bodies found after natural disasters such as bushfires, floods and earthquakes, and accidents such as car, boat and aircraft accidents.

A corpse will be sent from a crime scene to the morgue or coroner's office where identification will take place. Identification involves three stages:

- collection of ante-mortem data
- autopsy or post-mortem examination
- reconciliation.

Ante-mortem data

The term *ante-mortem* means 'before death' so any information relevant to the person before they died is ante-mortem data. This data includes the person's sex, age, ethnicity, height, medical and dental records, fingerprints, recent photos, tattoos, piercings, scars and samples of their DNA.

A corpse is easy to identify if an ID card, a driver's licence, credit cards or a Medicare card are found on or near it. Photos of the person can be matched with the body and card numbers can be checked against home addresses. A mobile phone will hold phone numbers of friends and relatives who can be called. They can then view the body and confirm its identity.

Even without these forms of identification, police can be reasonably certain about who the person was. For example, a body found in a burnt-out house is most likely to be someone who lived there. Similarly, the body in the driver's seat of a badly damaged car was probably the registered owner or someone closely related to them. Hire cars are even easier to track since the driver's name and address will have been left at the hire-car company.

Autopsy

If there is doubt about the identity of a corpse or the way they died, then the coroner will instruct that an autopsy be performed. An **autopsy** is a systematic dissection of a corpse. The main steps in an autopsy are shown in Figure 9.2.1.

The **coroner** is a judge who is in charge of inquiries into the death of people in accidents or suspicious circumstances. An autopsy is performed by a **pathologist**, a doctor who specialises in the study and diagnosis of diseases.

If the body is relatively intact, then the pathologist:

- takes fingerprints and extracts DNA
- inspects the body for identifying marks such as birthmarks, tattoos or scars
- takes samples of clothing and jewellery or takes photos of them
- determines whether injuries happened before death (ante-mortem), at death (peri-mortem) or after death (post-mortem)
- determines which injuries or disease led to death.

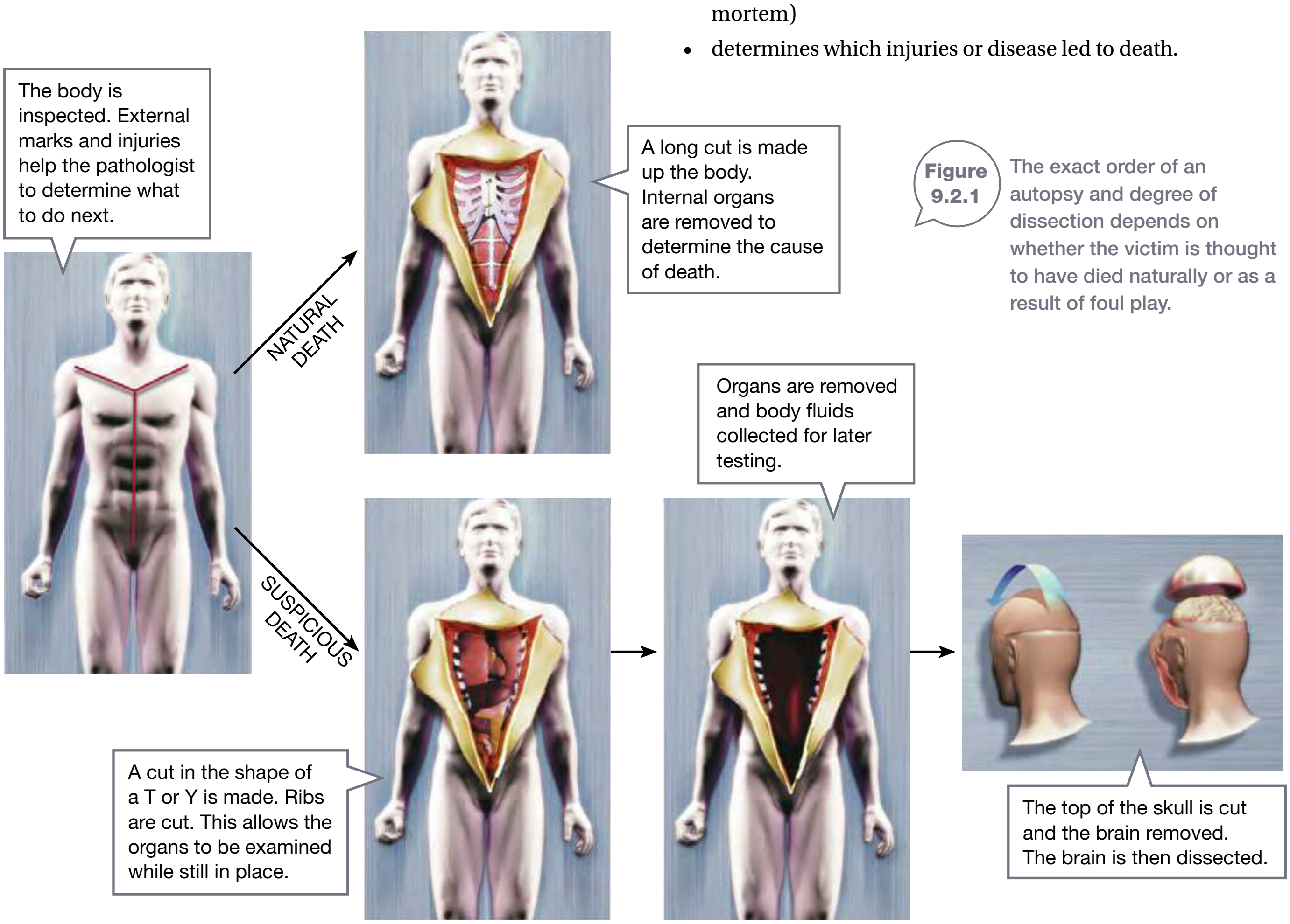


Figure 9.2.1 The exact order of an autopsy and degree of dissection depends on whether the victim is thought to have died naturally or as a result of foul play.

From the information collected at the autopsy, the pathologist can construct a timeline of how and when certain injuries happened. For example, any cut made before death will clot and partially or completely heal. Its edges might be red and swollen and there may be pus, a sign of infection. There would be little or no evidence of fresh blood. If a cut was inflicted as the person died or just before (for example during an accident or assault) then there would be no chance for clotting, swelling, healing or infection to take place. However, there would be clear signs of bleeding. The heart stops on death so any cut made after death would produce no blood. In the same way, bruises made before death will spread and show signs of repair, changing colour as they heal. Bruises happening at death have less chance to spread and no chance of changing colour. Bruises do not form at all after death.

Reconciliation

The information collected in the autopsy must be compared with any ante-mortem data that has been collected. This process is called **reconciliation** and is especially important when identification of the corpse is difficult. Reconciliation compares:

- fingerprints with those on police files or those found around the home or apartment of the person thought to be the victim
- identifying marks with those seen on the likely victim in family photos or on the database of missing persons
- clothing and jewellery with those worn by the likely victim when last seen alive
- DNA with the DNA collected from the clothing, toothbrush or hairbrush of the likely victim. If the person has been missing for a long time, then comparison might need to be with their direct relatives, who will have similar DNA.
- DNA with Guthrie cards. These cards store small samples of blood taken 48 to 72 hours after babies are born (Figure 9.2.2). Most people born in Australia since 1970 have a Guthrie card and so there is a sample of their blood and DNA on file.

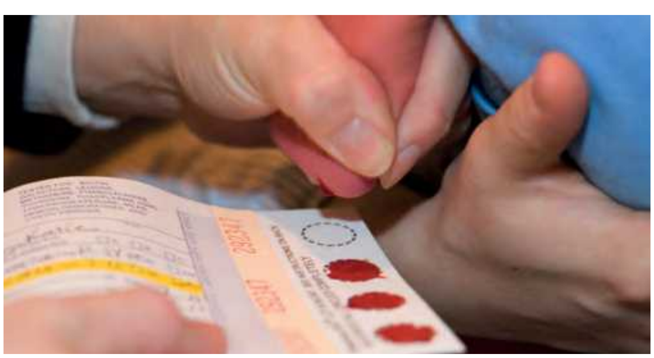


Figure 9.2.2 Blood is taken from the heel of a newborn. The sample is kept on a Guthrie card and will be tested for rare genetic diseases.

DNA matching

SciFile

DNA matching has different success rates depending on which sample it comes from:

- blood 90% success
- saliva on a cigarette butt 67% success
- fallen hair 25% success
- sweat on a weapon handle 17% success.

Identifying skeletons

DNA deteriorates with time, especially when exposed to intense heat. There might even be no tissue left on the skeleton to analyse on corpses that were not discovered for a long time. Investigators then compare the medical and dental records of the likely victim with the injuries and dental work found on the skeleton. Badly broken bones commonly have pins, plates and screws inserted in them to help them repair. An example is shown in Figure 9.2.3. Finding these in a skeleton can confirm its identity, as can replacement hips or knees.

Teeth grow until about the age of 20, so their development can be used to determine the age of someone in that age group.

Figure 9.2.3 This artificial knee and the pegs used to fix it to the bones are clearly visible on an X-ray. They would quickly confirm the identity of a body.

Jewellery, belt buckles and buttons left on the skeleton will also give an idea of the victim's sex and age. Styles change and so this will suggest roughly when the person died.

If none of this if possible, then the age and sex of the corpse can be determined from the size and density of large bones such as the pelvis, skull and femur (the main bone of the leg). Figure 9.2.4 shows a forensic scientist taking some of these measurements.

Prac 1 p342

Anthropometry

Alphonse Bertillon became chief of criminal investigation for the Paris police after he developed a way of identifying people from their body proportions. His system (called **anthropometry** or the Bertillon system) was widely used from 1882 to 1905 until a twin brother was incorrectly jailed!

SciFile

Figure 9.2.4 Measurements of a skeleton can provide information about the sex and age of the victim.

9.3

Cause of death

A forensic pathologist must determine whether death was natural or caused by someone or something else. Each cause of death such as shooting, stabbing and drowning leaves its tell-tale signs.

Return of the king

King Richard III died in the Battle of Bosworth Field in 1485. Until recently, his skeleton was lost. But in 2012 it was rediscovered under a carpark built over an old church cemetery in Leicester, UK. In 2013, DNA from his bones was found to match the DNA of Canadian-born Michael Ibsen, the king's 17th great-nephew. This proved that the skeleton was Richard III.

SciFile

Shooting

Bullets may still be in a body or may have exited and lodged in furniture or walls nearby. This allows the path of the bullet to be determined. Shotguns shower a victim with multiple pellets. A single wound suggests that the shotgun was close while a scattering of wounds like those in Figure 9.2.5 suggests that the victim was shot from a distance. If there are burn marks from the exploding gunpowder then this would indicate that the gun was shot from close range.

Figure 9.2.5 These wounds are from the pellets of a shotgun. They are spread out, indicating that the shooter was some distance from the victim. The individual wounds would join to form one large wound if the shooter was close.

Wounds

Knives leave their own tool marks on the body. For example, a wound produced by a straight-edged knife is different from that caused by a knife with a serrated edge. The depth of the wound gives an idea of the force used in the attack, and its angle suggests the direction of the attack. (Sometimes the angle will even suggest that it was not an attack at all but a horrible accident.) Where the wounds are located also provides information about the attacker. For example, wounds on the right side of the chest suggest that the attacker was left-handed. Wounds on the right of the back suggest the attacker was right-handed.

Bruises like those in Figure 9.2.6 on page 334 indicate that a blunt object was used as the weapon.

Figure 9.2.6 Skin bruises badly if punched, kicked or hit. The skin won't be pierced but it might split and bones underneath are likely to fracture.

Drowning

Water will be in the lungs and stomach of a victim who has drowned. This water will contain **diatoms**. These are small single-celled organisms that are partly made of silica, a very hard material that forms a variety of shapes. Some diatoms are shown in Figure 9.2.7. Each creek, lake or dam has different-shaped diatoms and so their shape can pinpoint the location of a drowning and whether the body was shifted after death.

Figure 9.2.7 Diatoms come in an amazing variety of shapes, as this scanning electron microscope (SEM) image shows. The characteristic shapes of diatoms can point to where a drowning occurred.

Identifying suspects

Photographs

Photographs are excellent for proving identity and are used in passports, driver's licences and student identification cards. They are not as useful for identifying suspects for several reasons:

- The only photos police have will be of those who have already been found guilty of previous crimes. First offenders won't yet have their photos on file.
- An eyewitness needs to sift through hundreds of photographs. This exposure can lead to **retroactive interference**, a process in which eyewitnesses involuntarily merge images in their memory to form a 'suspect' who looks nothing like the person who committed the crime.

Identikit

Sketched portraits have long been used as a method of identification. At first these sketches were drawn by professional artists from descriptions from eyewitnesses. However, the quality of these portraits depended as much on the ability of the artist as it did on the accuracy of the eyewitness account.

Identikit became widely used after 1959. It used sets of pre-drawn facial features (such as eyes, mouth and chin shape) that slotted together to form a portrait. Identikit had many advantages over artist-drawn portraits. It:

- allowed a realistic image to be constructed at any police station
- did not depend on the ability or availability of an artist
- allowed various combinations of features to be tried to trigger the memory of the eyewitness.

Today, police use computerised versions of Identikit like the one shown in Figure 9.2.8. The computer-composite images are fast, can be digitally enhanced to make them even more realistic and can be three-dimensional. Some are incredibly accurate, like the one in Figure 9.2.9.

Prac 2 p343

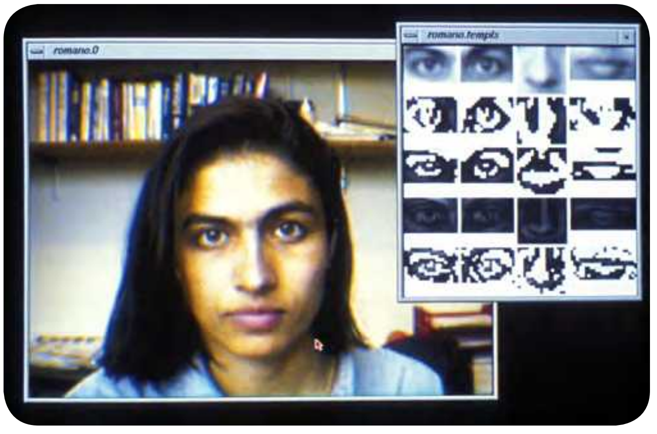


Figure 9.2.8 Computer software allows realistic images to be produced by dragging across different facial features from its database of images.

Figure 9.2.9 This computer-generated Identikit image of a criminal helped to catch him in 2005. It shows a remarkable similarity to the real man.

SciFile

Home-grown FACE

In 1989, Australia was the first country to produce a coloured computerised version of Identikit. Called FACE, it allowed police to take laptop computers to the crime scene and immediately identify criminals. FACE helped to identify the three men who had set off explosives in the 2002 terrorist bombing in Bali.

Proving the suspect was there

For a prosecution to be successful, police need to be able to prove that a suspect was at the scene of a crime. This can be done in a number of ways, including:

- electronic tracking
- fingerprints
- DNA.

Electronic tracking

Security cameras and **CCTV** (closed circuit TV) are now common in shopping centres, banks, train stations and airports, outside nightclubs and even in city streets and lanes. Video from these can prove that a suspect was at the scene at the time of the crime. They may even show the suspect carrying out the crime.

Biometric facial recognition technologies that allow a CCTV to scan a crowd and identify known offenders are now being trialled. Most of these techniques compare the positions of points on the face with those of known criminals. Figure 9.2.10 shows how it is done.

SciFile

Warning, warning!

Some police districts in the United Kingdom have been trialling CCTV cameras that speak! The cameras have small speakers in them and police use them to warn people who are misbehaving that they are being watched.

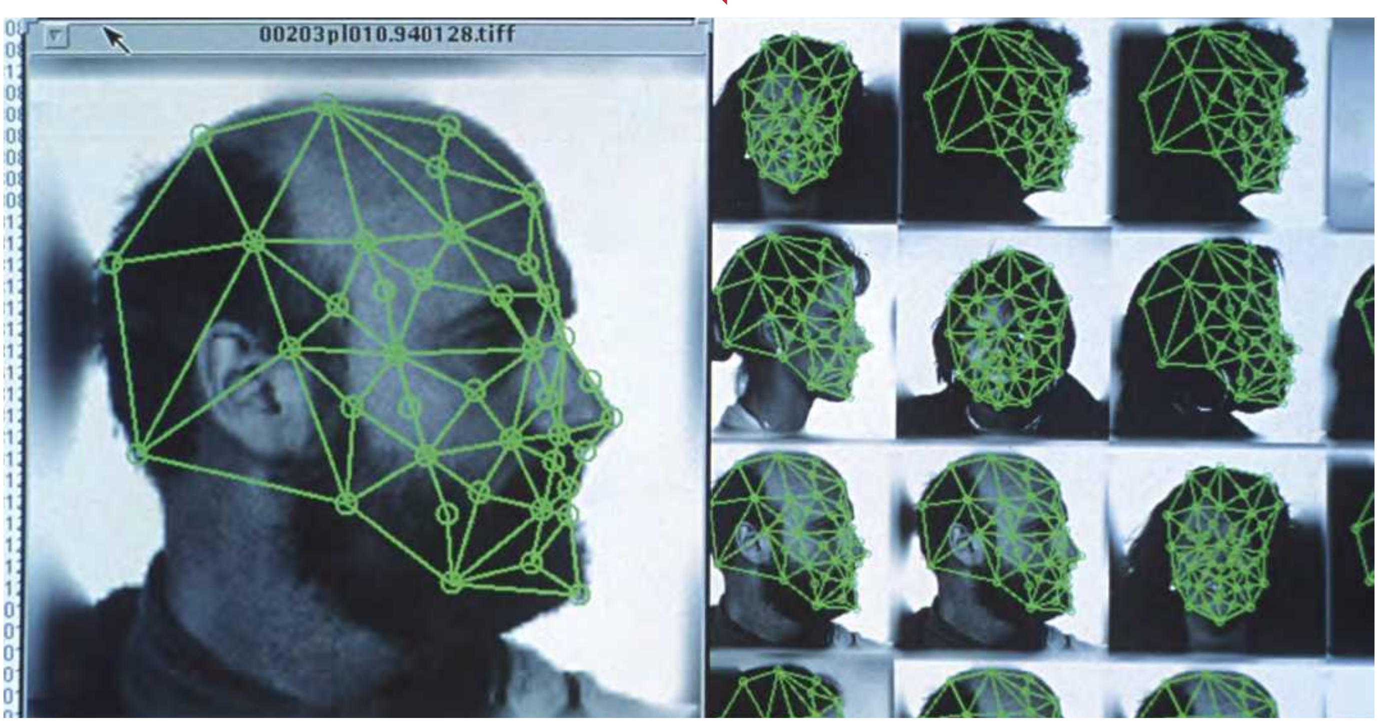


Figure 9.2.10 Biometric facial recognition involves scanning features and comparing them with those on a computer data base. Here, a person's face has been scanned and converted into a 'net' that the computer software can compare. Fingerprint scanning is another form of biometric identification.

When switched on, your mobile phone or smartphone can enable your phone company to locate you to within 10 to 50 metres. This allows police to track suspects (and victims) and gives an easy way of proving that the suspect was close to the scene at the time the crime happened.

Photos or video of unlawful behaviour sometimes ends up on social networking sites. Once there, it can be used as evidence in court. For example, in 2009, police used a video posted on Facebook to convict a 20-year-old Victorian man of hoon (dangerous) driving. His $21 000 Ford Falcon utility was confiscated, his licence was disqualified for 18 months and he was fined $2000.

Fingerprints

No two sets of fingerprints from different people have ever been found to be the same. This makes fingerprints an excellent method of identifying suspects or proving that the suspect was at the scene of a crime. The patterns that fingerprints form can be classified as **loops**, **whorls**, **arches** or **composites**. These are shown in Figure 9.2.11.

Before computers, fingerprints were unlikely to be stored outside the state or country of the suspect. Also, manual comparison of fingerprints was difficult since it is slow and prone to mistakes. For these reasons, some criminals were able to move about undetected, committing crimes as they went. Computers have overcome most of these problems by storing, sharing, comparing and matching fingerprints across different states and countries.

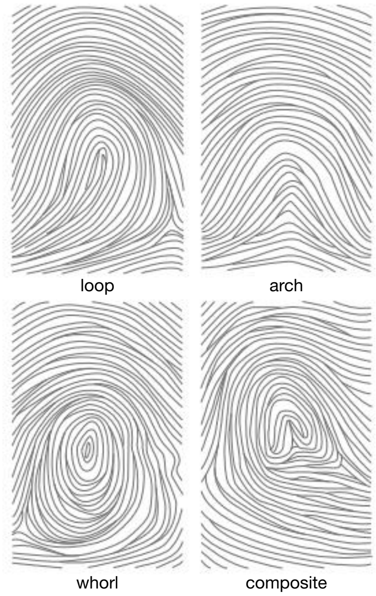


Figure 9.2.11

There are four basic fingerprint types: loops, whorls, arches and composites. About 60–65% of all fingerprints are loops, about 35% are whorls and 5% are arches. Composite fingerprints are even more uncommon.

SKILL BUILDER

Taking fingerprints

Good fingerprints can end up being smudged or with too much or too little ink. To take a good fingerprint, follow these steps.

1. Roll your thumb across the damp surface of the inkpad.
2. As Figure 9.2.12 shows, roll it *once* across white paper.
3. If the print is smudged or has too much ink, then *do not* get more ink but 'dry' your thumb by rolling out more prints of it.

Figure 9.2.12 Roll your finger and don't squash it.

INQUIRY science 4 fun

Taking fingerprints

YES

Can you take good fingerprints?

Collect this …

- ink pad
- scissors
- white paper
- glue or sticky tape

Do this …

1. Refer to the Skill builder and follow its steps to produce two good thumbprints.
2. Repeat with another finger.
3. Cut out the best two images of your thumb and two of your finger.
4. Paste one of each into your workbook, writing your name above them.
5. Swap the others with someone else in the class. Paste theirs in your workbook too, writing their name above theirs.
6. Construct a tally of the different types of fingerprints in your class. From this tally, identify which type is:
   a most common
   b least common.

Record this …

Describe the fingerprints you produced. Are they loops, arches, whorls or composites?

Explain what you think your results suggest about finding suspects based on their fingerprints.

DNA analysis

DNA can be extracted from even the tiniest samples of flesh, blood, hair, saliva or semen left at a crime scene. For example, a knife used in an attack will contain the DNA of the victim in blood on its blade and the DNA of their attacker in sweat and oils on its handle. Everyone's DNA is different and so finding a suspect's DNA at a crime scene is proof that they were there at some time. However, it does not suggest when they were there or for what reason.

Your genetic code is determined by the sequence of nitrogen-rich bases adenine (A), thymine (T), guanine (G) and cytosine (C) along the DNA strand. These bases form complementary base pairs A–T or G–C. You have a unique genetic code so the order of bases and base pairs along your DNA is unique too. Hence, a person can be identified by the order of these base pairs.

This order can be determined from a sequence of bars called an **autoradiogram**. An example is shown in Figure 9.1.13. If the order of bars in two autoradiograms is identical then it proves that the DNA is identical and that both samples came from the same person.

An autoradiogram is produced by chopping up DNA and then separating its fragments. This process is called **gel electrophoresis** and is shown in Figure 9.2.14.

GO TO Unit 1.1

GO TO Unit 3.3

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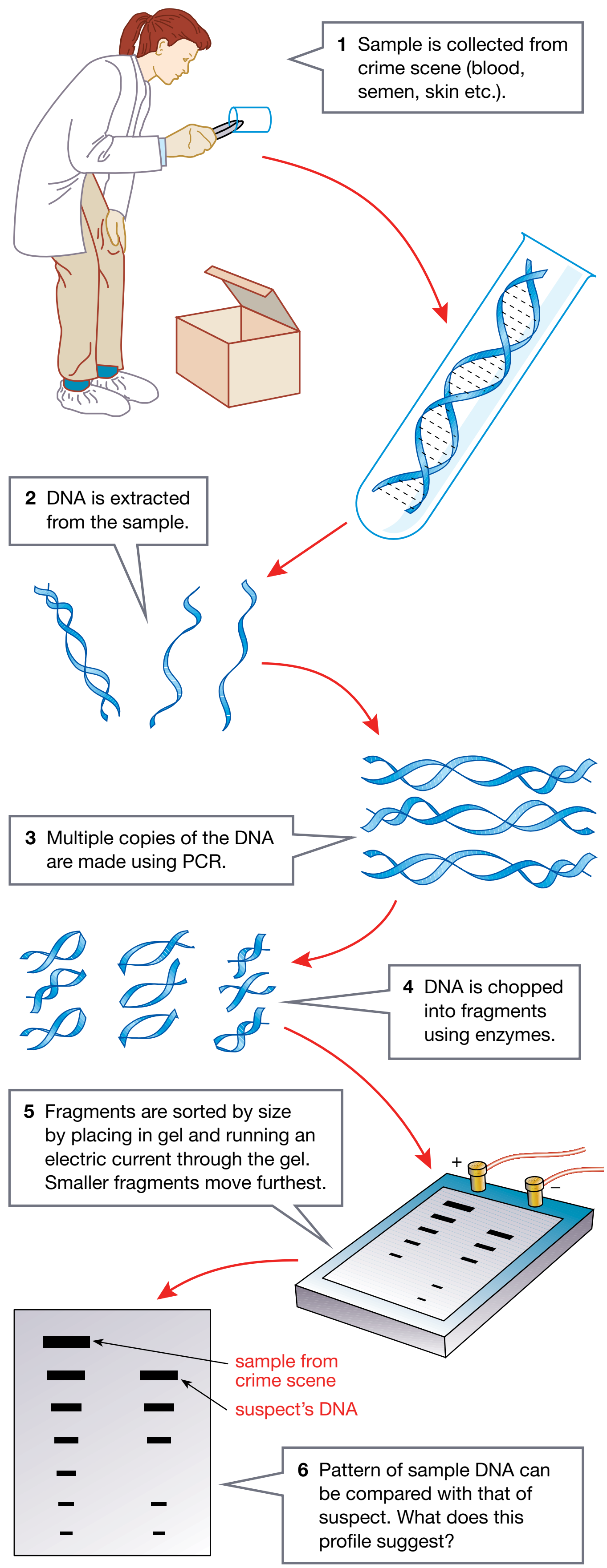
Figure 9.2.13 An autoradiogram codes DNA as a series of black bars. If the pattern of the bars for a suspect matches those from a crime scene, then it proves the suspect was there at some time.

Figure 9.2.14 DNA from a crime scene is extracted, copied, chopped and then separated using gel electrophoresis. The end result is an autoradiogram.



ADDITIONAL

The role of fast computers

Normally about 400 base pairs need to be compared to match a person's DNA to a sample at a crime scene. Manual matching of the autoradiogram of a suspect against those on police files would be near-impossible due to the multitude of black bars on an autoradiogram and the number of files that would need to be checked. The development of fast computers has made this comparison quick and accurate. Computers allow the autoradiogram of DNA found at a crime scene to be compared with those on police databases from people convicted of other crimes, DNA from other crime scenes, from corpses and from missing-person files.

Twins

It is even more difficult to match DNA if the suspect is an identical twin (Figure 9.2.15). This is because identical twins have near-identical DNA. Identical twins initially have the same DNA as the fertilised egg that split and formed them. As identical twins develop, small differences in their DNA occur due to copying errors (mutations) as the DNA replicates. To find these differences, billions of base pairs need to be compared. This would clearly be impossible without fast computers.

Figure 9.2.15 The DNA of identical twins is almost the same, making it difficult to tell them apart.

SciFile

Twin fingerprints

Identical twins do not have identical fingerprints. However, their fingerprints do share more similarities than found between non-twin brothers and sisters.

SciFile

Expensive justice!

In 2013, identical twins were accused of a series of assaults in France. Both pleaded not guilty despite clear CCTV footage, eyewitness accounts and DNA samples that indicated that at least one of them had committed the crimes. However, which identical twin had actually committed the assaults? Or was it both of them? The extensive DNA matching required in this case was estimated to have cost $1.3 million!

Cold cases

The quick comparison that computers bring also allows police to reopen **cold cases**. These are cases that stalled long ago because a lack of evidence. Before the mid 1980s, the technology for testing and comparing DNA did not exist. Hence, DNA could not be used in forensics.

Usually, DNA is extracted from the nuclei of cells found in body tissue collected from a crime scene. However, this nuclear DNA deteriorates quickly, sometimes leaving none for analysis years later. When this has happened, DNA can be extracted from cell mitochondria instead. This **mitochondrial DNA** (mtDNA) is passed on only from the mother, in contrast to nuclear DNA which is inherited equally from both parents. mtDNA is less likely to deteriorate than nuclear DNA, allowing it to be extracted and matched regardless of the age or condition of the sample.

DNA analysis has provided evidence to successfully convict criminals many years after their crime. DNA analysis has also proven some people to be innocent of the crimes they were jailed for. This has allowed them to be released, pardoned and financially compensated.

GO TO Unit 3.4

SciFile

The leech did it!

In 2008, a Tasmanian called Peter Cannon was arrested on drug charges. His DNA was tested. Unfortunately for him, it matched DNA in blood found in a leech that was evidence at the scene of a 2001 armed robbery. The leech and the blood it contained proved that Cannon had been there. He was convicted.

9.4

ADDITIONAL

LEARNING ACROSS THE CURRICULUM

PERSONAL AND SOCIAL CAPABILITY

Figure 9.2.16 Dioxins failed to kill Victor Yushchenko in 2004 but he still bears the scars of the assassination attempt. These two photos were taken 5 months apart.

NEW POISONS

There is a long history of using poisons for assassinations (political murders). Assassins in ancient Rome commonly used poisons to kill opponents. Poisonous mushrooms killed the Roman emperor Claudius, and his successor Nero used cyanide to kill relatives who threatened his power. Family dinners were simply murder!

Since ancient Roman times antinomy, arsenic, lead, mercury and thallium have all been used to kill. However, the symptoms of these poisons are now so well known that doctors quickly realise that they are not dealing with simple illness. Police quickly realise that an attempted assassination has taken place. For these reasons, assassins have recently used some very different poisons.

DIOXINS

Dioxins are poisonous chemicals that are present in tiny quantities in cigarette smoke, plastics and some industrial wastes. In 2004, assassins used dioxins in an attempt to kill Victor Yushchenko while he was campaigning to become President of the Ukraine. He suddenly fell ill with suspected food poisoning. Five days later he developed lesions and ulcers on his face, chest and stomach and throughout his digestive tract. Blood tests showed extremely high levels of dioxins in his blood. He survived, eventually won the election and became president in 2005. Figure 9.2.16 shows him before and after being poisoned.

RICIN

Ricin is a poison extracted from castor beans that is about 200 times more deadly than cyanide. Its symptoms are similar to natural diseases and vary depending on whether it has been eaten, injected or breathed in. There is no test that will confirm its presence and there is no known antidote (cure).

In most cases, ricin has been detected before it had a chance to poison anyone. For example, ricin was found in mail sent to the White House (USA) in 2003.

Ricin was used in the bizarre assassination of Georgi Markov in 1978 in London (UK). Markov had defected (escaped) from communist Bulgaria seven years earlier and wrote anti-communist books and plays. Markov collapsed after being 'accidentally' jabbed in the leg with the tip of an umbrella by a passerby. Markov died three days later. An autopsy found a tiny metallic pellet in his calf. The pellet had been drilled out and contained traces of ricin. It seems that the umbrella was a specially designed gun and the passerby an assassin. The umbrella probably looked like the one shown in Figure 9.2.17. There had been a similar, failed, assassination attempt ten days earlier in Paris (France) on another Bulgarian defector, Vladimir Kostov. The KGB (Soviet secret police) is thought to have been behind both incidents.

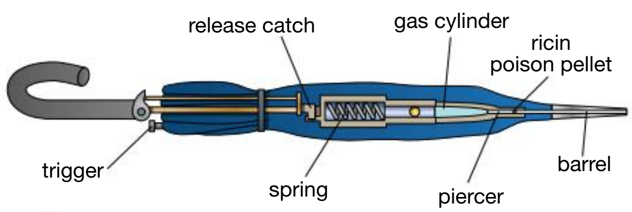


Figure 9.2.17 An artist's impression of the umbrella 'gun' used to shoot Georgi Markov in 1978.

RADIOACTIVE POISONS

Radioactive materials are incredibly dangerous and exposure to them is usually accidental or highly controlled. For example, radiotherapy uses controlled doses to kill cancerous cells. However, the radioactive element **polonium-210** was used to kill Alexander Litvinenko (Figure 9.2.18) in London in 2006. Litvinenko once worked for the KGB but had defected to the United Kingdom. There he was highly critical of the Russian government, and its then-president Vladimir Putin. It has also been claimed that prior to his death, Litvinenko was working with MI6, Britain's secret service, putting him at even more risk. Litvinenko fell seriously ill soon after meeting with two ex-KGB officers for lunch. Polonium-210 was found in his urine and 3 weeks later he was dead. Investigators are certain that Litvinenko's poisoning was deliberate. This is because polonium emits **alpha rays**, a type of nuclear radiation that is easily blocked. If exposure was accidental, then his clothes and skin would have stopped it entering his body. It is currently believed instead that the tea he drank with lunch may have been spiked with polonium-210.

A nuclear reactor is needed to produce radioactive materials such as polonium-210, probably putting the murder well beyond the normal assassin and even organised crime.

In 2007, the United Kingdom charged Andre Lugovoy with the murder of Litvinenko. He was one of the ex-KGB officers who had lunch with Litvinenko the day he fell ill. Russia has so far refused to extradite (release) him for trial.

GO TO Pearson science NSW 9 Unit 2.4

9.5

REVIEW

1 **Define** the term *assassination*. L
2 **Name** the rays that polonium-210 emits.
3 **Explain** why Alexander Litvinenko's exposure to polonium-210 could not have been an accident.
4 The initial symptoms of ricin, dioxin and polonium poisoning can look like simple food poisoning. **Propose** what advantages this gives an assassin.
5 There are extremely strict controls on the release of dioxins from industry into the environment. **Propose** a reason why.

Figure 9.2.18 Alexander Litvinenko before and after he was poisoned with polonium-210. Polonium emits radioactivity in the form of alpha rays. Traces of polonium-210 were found in his urine, the restaurant where he ate, his home, his office, a hotel and two aircraft he travelled on.

9.2 Unit review

Remembering

1 **State** two pieces of evidence that might suggest a murder happened well away from where a body is found.

2 **State** how accurately authorities can locate you using the signal from your mobile phone.

3 **List** three things that you carry with you that could be used to identify you.

Understanding

4 **Outline** the procedure that should be followed to take good fingerprints.

5 **Explain** what DNA found at a crime scene:
  - a tells police
  - b doesn't tell police.

6 Hairbrushes and toothbrushes are often taken by forensic investigators. **Explain** why they would take them from the:
  - a home of a missing person
  - b homes of their blood relatives.

7 People born before 1970 are a little more difficult to identify than those born after. **Explain** why.

8 **Explain** how investigators determine if a shotgun blast came from close or far away.

9 **Explain** how Facebook led to the confiscation of a Ford Falcon utility in 2009.

Applying

10 **Use** Figure 9.2.19 to **identify** the origin of:
  - a trace evidence 1
  - b trace evidence 2.

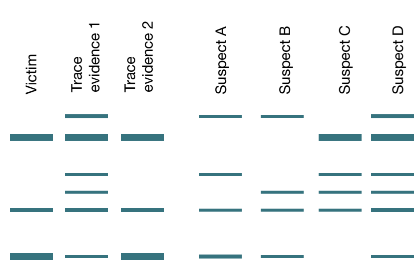


Figure 9.2.19

Analysing

11 **Contrast** the terms *ante-mortem*, *peri-mortem* and *post-mortem*. L

12 **Contrast** the role of a coroner with that of a pathologist.

13 **Compare** the structure of whorl, loop, arch and composite fingerprints.

Evaluating CCT

14 An autopsy is often called a post-mortem examination. **Propose** a reason why. L

15 **Propose** ways in which teeth impressions might be used in forensic science.

16 The access to Guthrie cards is strictly controlled by law. **Propose** reasons why.

17 Facial recognition software will eventually allow CCTV to track people, whether they are known offenders or innocent people going about their daily business. **Evaluate** whether this is fair and give your opinion on whether it should be allowed.

18 **Propose** how a mobile phone can be used to fake an alibi, suggesting that suspect was well away from a crime scene when they were really there.

Inquiring

1 Perform an interactive autopsy on an artificial human by searching for a *virtual autopsy* site on the internet. ICT

2 Use the following as key words to search the internet to find forensic games to play. ICT
  - Identikit games
  - fingerprint games
  - DNA fingerprint or DNA matching games

  Present your research in a digital form. ICT

3 DNA has sometimes led to the wrong person being found guilty. Research the case of Farah Jama and outline what went wrong.

  Present your findings as a timeline showing the main events in the case and the dates on which they occurred.

ADDITIONAL

4 Find out how mitochondrial DNA is used to determine ancestry.

  Present your research as a flow diagram or series of dot points.

5 Research what bioinformatics is and how it is applied to forensic science.

  Present your findings in digital form. ICT

ADDITIONAL

9.2 Practical investigations

1 Measuring the body

Anthropometry is the measurement of the human body.

Purpose

To determine whether anthropometry accurately predicts height.

Materials

- dressmakers' tape measure or string and metre ruler
- access to skeleton (or photo of skeleton)
- calculator

Procedure

1. Use Figure 9.2.20 to locate the femur, noting where the bone begins and ends.
2. In pairs, use the tape measure to determine the length of each other's femur. Alternatively, mark the length on the string and then use the ruler to measure its length. Record its length in a table like that shown below.
3. Measure your actual height and that of your partner (in centimetres). Record the height in the table.
4. In a similar way, measure the femur on the skeleton and its overall height, recording each measurement in the table.

Results

1. In your workbook, construct a table like that shown below for all your results:

	Length of femur (cm)	Actual height (cm)	Calculated height (cm)
Me			
My prac partner			
Skeleton (male)			
Skeleton (female)			

2. Anthropometry uses the following mathematical formulas to predict the height of a person based on the length of their femur.
   For males:
   predicted height (cm) = femur length × 2.38 + 69.089
   For females:
   predicted height (cm) = femur length × 2.32 + 61.412
   Use these formulas to calculate your predicted height and that of your partner.
3. Assume the skeleton was male. Use its femur length to calculate its likely height.
4. Repeat the calculation, but this time assume the skeleton was female.

Practical review

1. **Compare** your actual height with the height predicted by the formula.
2. **Assess** how accurate the formula was.
3. **Compare** the actual height of the skeleton or poster-skeleton with the predicted heights for males and females.
4. **Use** this information to **identify** the skeleton as male or female.

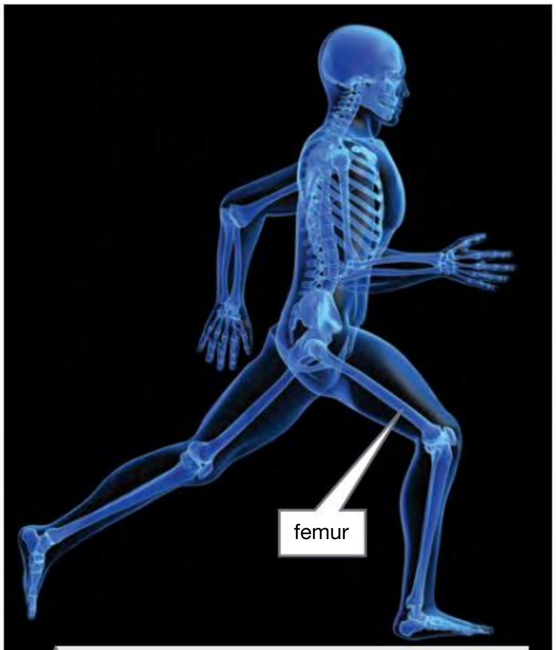


Figure 9.2.20 The femur is sometimes known as the thigh bone. It goes from your hip to your knee.

2 Identikit

Purpose

To construct an Identikit.

Materials

- access to digital camera (tripod optional)
- access to computer and printer
- access to photocopier
- A4 paper
- scissors or Stanley knife
- sticky tape or glue

SAFETY

Be extremely careful with a Stanley knife. Always cut against a hard surface. Retract its blade when not in use.

Procedure

1. Set up a brightly lit corner in which each person in the class is to have their photo taken.
2. Photograph each person in the class. Zoom the lens in or out to ensure that their face (including hair) takes up most of the screen on the digital camera.
3. Print out all the photos in black and white, either individually or in groups of two or four photos per A4 sheet. Photocopy all the photos so that every group of 4–6 students has a complete set. Cut each photo into sections as shown in Figure 9.2.21. Use features from different people to construct different and imaginary faces.

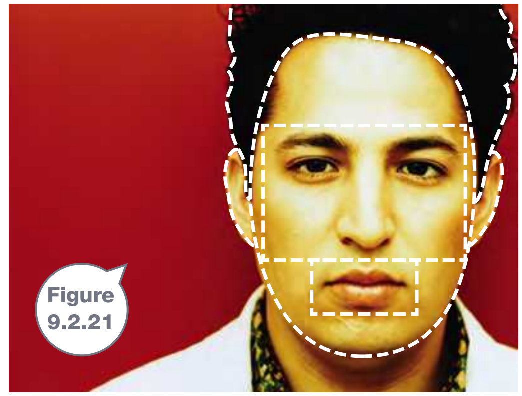


Figure 9.2.21

4. Alternatively, use an appropriate program on your computer to cut, paste and edit parts of different people to form imaginary faces.

Results

When you have a face that 'works', stick it onto a clean sheet of A4 paper. Alternatively, save and print one of your digital faces.

Practical review

1. **Assess** how realistic the faces were that you constructed.
2. **Assess** whether any of them looks like someone in your school. By coincidence, they often do!
3. **Identify** what other features you would need to construct images of everyone in your school.

3 Gel electrophoresis

Purpose

To use gel electrophoresis to separate dyes.

Materials

- food dyes (blue, red, green and yellow)
- 0.1% sodium hydrogen carbonate buffer solution (0.2 g sodium hydrogen carbonate in 200 mL water)
- 1% agar (1 g agar in 100 mL sodium hydrogen carbonate buffer solution)
- felt-tip pens (blue, red, green and yellow)
- rectangular plastic container (such as a margarine or takeaway food container)
- hard plastic (such as that of ice-cream containers)
- aluminium foil
- scissors
- power pack
- 2 electric leads with alligator clips
- filter paper
- hotplate or Bunsen burner, tripod, bench mat and gauze mat
- cling wrap

SAFETY

Tie long hair back.

Turn Bunsen burner flame to yellow or off when not in use.

All chemicals, including sodium hydrogen carbonate should be considered to be toxic.

9.2 Practical investigations

Procedure

1 Cut the plastic container down so that its walls are about 3 cm high.

2 Cut the hard plastic to form a comb that fits across the plastic container with two 'prongs' holding it in place. There should be about 6–8 teeth in the comb. Trim the teeth so that they don't touch the container bottom. It should look like that shown in Figure 9.2.22.

3 Cut off aluminium foil to form two strips about 5×8 cm in size.

4 Fold the foil over the ends of the plastic container. The strips should cover the ends and should reach the bottom inside the container.

5 Heat the 1% agar until it boils then let it cool.

6 Meanwhile, prepare samples of food dye or felt-tip pens. To do this, paint or draw 1 cm diameter spots of different colours onto filter paper.

7 Pour agar gel into the plastic container until it reaches a depth of 1 cm.

8 Place the comb across the container, about 2 cm from one end. The agar gel should reach just below the top of the comb's teeth.

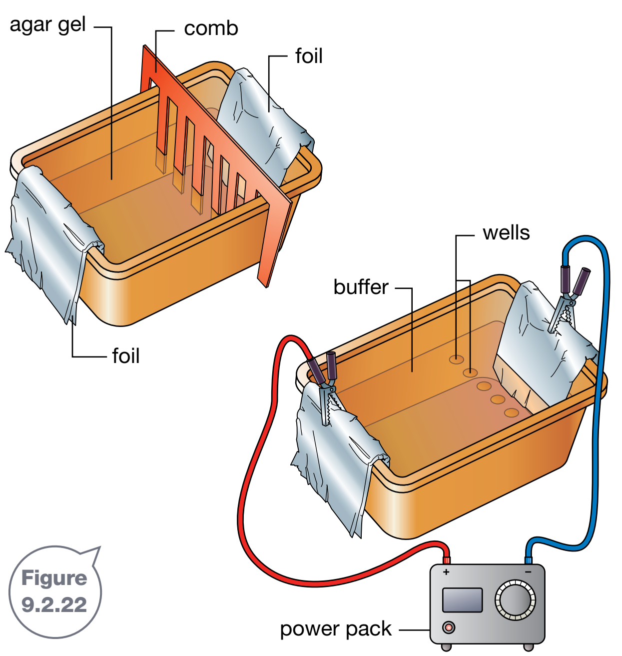


Figure 9.2.22

9 Leave the gel to set. This should take about 15 minutes or it can be covered in plastic cling wrap and left overnight in the refrigerator.

10 When the gel is set, carefully remove the comb.

11 For each of the colours prepared in step 6, cut rectangular strips small enough to fit in the 'wells' left behind when the plastic comb was removed.

12 Insert a strip in each of the wells.

13 Carefully pour about 100 mL of buffer solution over the gel so that the gel is completely covered.

14 Connect the aluminium strip at the end near the wells to the negative terminal of the power pack and the other strip to the positive terminal. Set the power pack to 4.5 V.

15 Keep the power pack on for about 45 minutes or until colours have obviously separated.

Results

Measure how far each of the colours moved (in mm) down the gel. Record your measurements in a table like that below.

Sample	Distance colour moved (mm)
Blue food dye	
Blue pen	
Red food dye	
Red pen	
Green food dye	
Green pen	
Yellow food dye	
Yellow pen	

Practical review

1 The voltage causes the dye particles to move towards the positive terminal. Small particles move the furthest, while large particles move more slowly. **Use** this information to **list** the samples in order from smallest to largest particles.

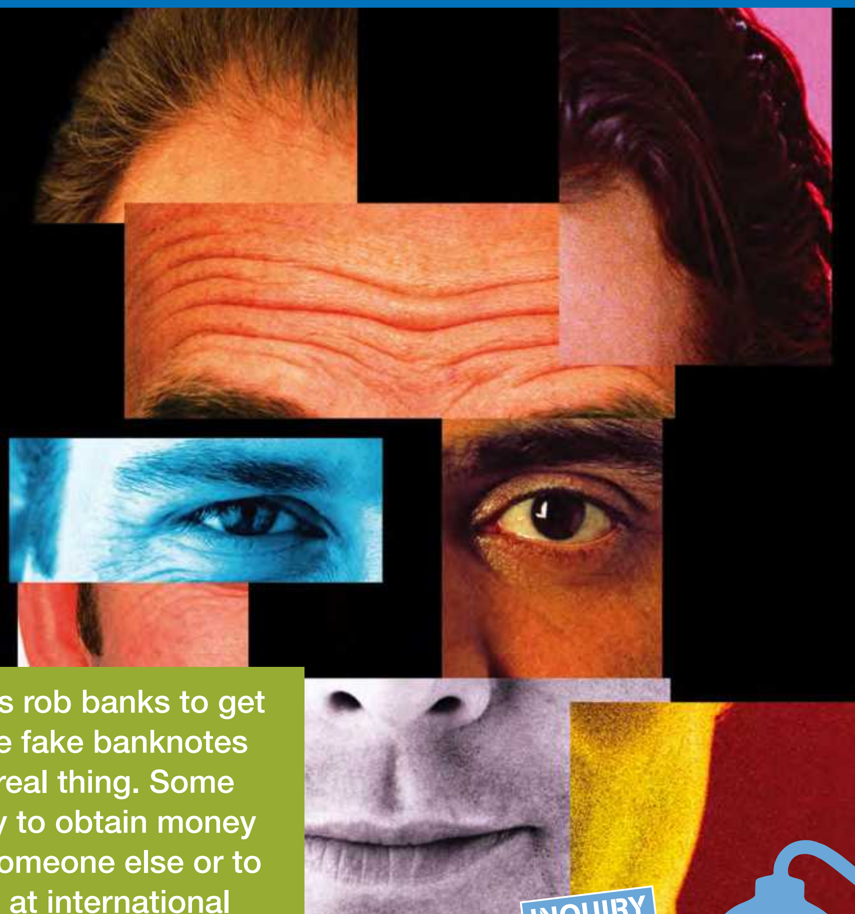
2 **Compare** the size of the particles of the same colour dye and pen (for example, compare the red food dye with the red pen).

3 **Propose** whether the dye particles are charged positive or negative.

4 **Justify** your answer.

5 **Compare** the results obtained here with an autoradiogram like that shown in Figure 9.2.13 on page 337.

9.3 Fakes and extortion



Criminals don't always rob banks to get money. Some produce fake banknotes that can pass for the real thing. Some fake their own identity to obtain money by pretending to be someone else or to pass through security at international borders. Others try and get money by threats. Forensics provides ways of detecting what and who is fake and who is making threats.

False identities

Knowing the true identity of a person is vital whenever they:

- cross an international border
- claim money from the government (such as Centrelink), institutions (such as banks, insurance companies) or individuals (such as the inheritance from a will)
- gain access to high-security institutions (such as bank vaults, military installations and biochemical laboratories)
- gain access to sensitive files (such as those held by hospitals, state and federal police, espionage or spy organisations such as ASIO or ASIS).

Identity fraud takes place when someone pretends to be someone else. It costs Australia billions of dollars each year and so increasingly complex methods are being used to stop it.

INQUIRY
science 4 fun

Fake signatures

YES

Can you fake someone's signature?

Collect this ...

- pen
- paper (preferably lined)

Do this ...

1 Write your signature on a piece of paper.
2 Swap signatures with another classmate and then try and reproduce their signature.
3 Take particular notice of the features shown in Figures 9.3.7 on page 349.

Record this ...

Describe what happened.
Explain why you think signatures are difficult to forge.

Documents proving identity

Passports, driver's licences and credit cards are easy ways of proving your identity. All these documents have features to ensure they are secure and cannot be used by anyone but their 'owners':

- Passports once had photos pasted into them but this proved too easy to change or replace. Modern passports (and driver's licences) contain scanned images that are difficult to alter.
- Passports now have an electronic chip in their centre page that contains the name, sex, nationality, date of birth and a digital version of the passport-holder's photograph. This chip is activated when scanned and its details can be checked against the passport's front page. These 'chipped' passports are known as ePassports and Australia was one of the first countries in the world to introduce them. The 'chip' symbol in Figure 9.3.1 but indicates that the document is an ePassport.
- Modern credit and identity cards usually include features such as holograms (like the ones in Figure 9.3.2) that make them difficult to reproduce. Credit cards also include magnetic strips and chips that contain the customer's details and a personal identification number (PIN). Signatures are easily forged but only the true owner of the card should know its PIN.

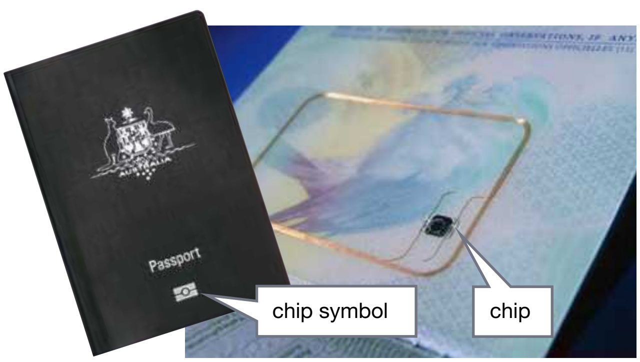


Figure 9.3.1 ePassports carry a chip that contains all your information and a digital version of your photo.

Figure 9.3.2 Credit cards and identity cards commonly have holograms that make them more difficult to fake.

Mission very possible!

SciFile

In 2009, two well-dressed men entered an expensive jewellery store in London (UK) and left with £40 million ($78 million) of watches, rings, bracelets and necklaces. Although their images were recorded by CCTV cameras, it is thought that they were wearing rubber masks like those used in the film *Mission: Impossible*!

Biometric facial recognition

Most people identify you by your face. Biometric facial recognition software allows a computer to do this too. It measures the position of your facial features and compares them with those of photographs on file. International airports around Australia and many airports overseas have special self-service gates (Smartgates) that photograph travellers and identify them with the digital photo on the chip in their ePassports. You can see a Smartgate in Figure 9.3.3.

Figure 9.3.3 Smartgates scan your face and use biometric recognition software to match it with the image in your ePassport.

Want chips with that?

SciFile

In 2004, microchips were implanted under the skin of important lawmakers in Mexico that give them (and only them) access to computer files containing sensitive information on criminal activity. Some European nightclubs now give VIP access and service to members who are implanted with microchips containing their personal details.

Fingerprint scans

Most countries have increased their border security since the terrorist attacks of 11 September 2001 (commonly known as '9/11'). For example, all visitors entering and leaving the USA via its international airports have their fingerprints scanned. These are then checked against files of known terrorists. Scanned fingerprints and whole handprints are also increasingly being used to sign in and out of work and as a 'key' to access computers, secure facilities or bank accounts (Figure 9.3.4). Access is only gained if the match is positive.

Figure 9.3.4 Fingerprint scanners are now used in some shops and banks overseas to match prints with customers' banking details. Money is then directly debited from their accounts.

Iris and retina identification

The iris is the coloured ring of muscle in the eye that controls the size of the pupil. As Figure 9.3.5 shows, its patterns and colouring are incredibly complex. Each person has unique iris patterns and each eye has a different pattern. For these reasons, the iris provides a far better method of identification than a fingerprint. It is also impossible to fake—the iris contains 266 identifiable features and constantly moves, whereas a fake eye remains static.

The retina is at the rear of the eye and its pattern of blood vessels is even better than the iris as proof of identity. Although more difficult to obtain, retina scans are more accurate than iris scans.

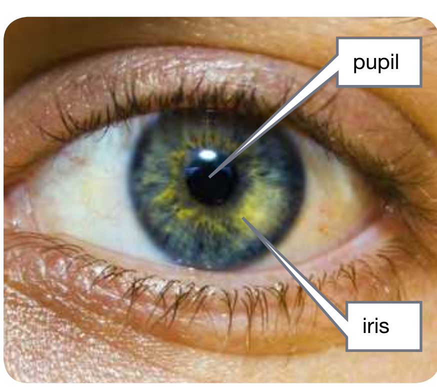


Figure 9.3.5 The iris gives the eye its colour. It has 266 identifiable features and it does not change with age. This makes it an accurate way of identifying someone.

Forgery

Counterfeit (fake) banknotes are relatively rare because real notes include special features that make them difficult to reproduce. Some of these features are shown in Figure 9.3.6 on page 348.

Australia was the first to use **polymer film** (plastic) notes. They are harder to counterfeit and last four or five times longer than paper ones—while a paper $5 note had an average life of about 6 months, a plastic one lasts more than 3 years.

Organised crime groups are usually the only ones with sufficient money to purchase the technology, materials and skills needed to produce realistic counterfeit banknotes.

Realistic counterfeit banknotes are difficult to detect by shop assistants and bank tellers unless they know what to look for. It might be the feel of the paper used, its colours or its serial number. (Real banknotes all carry different serial numbers, whereas counterfeits usually have the same serial number.) Unfortunately, these differences may only become apparent after many fake notes have already been passed off as real.

INQUIRY science 4 fun

Inspecting banknotes

YES

Can you find the anticounterfeit features on a banknote?

Collect this ...

- banknote (it doesn't need to be Australian)
- magnifying glass or stereomicroscope
- ultraviolet (UV) light (optional)

Do this ...

1. Carefully inspect the banknote. Take note of the features shown in Figure 9.3.6 on page 348.
2. Use the magnifying glass or stereomicroscope to find microprinting and the UV light for fluorescing inks.

Record this ...

Describe what you found.
Explain how these features stop counterfeiting.

Obviously fake!

The USA has never had a $1 million banknote. However, this did not stop Alexander D. Smith from trying to pass a fake one as a real note in 2007!

SciFile

Intaglio printing
A raised form of printing that can be felt with your fingers

Australian banknotes have their portraits, denomination number and the word *Australia* in intaglio printing.

Material
Paper banknotes are printed on special paper with its own characteristic feel.

Australian banknotes are printed on polymer film (plastic). They last longer than paper notes and are harder to counterfeit.

Optically active devices
Images that are holographic (producing multicolour effects) or clear

All Australian banknotes have an image of a seven-pointed star that is only complete when held up to the light.

Shadow image
When held up to the light, an image becomes visible under other detail.

Most Australian banknotes have the Australian Coat of Arms as a shadow image.

Australian banknotes use a second optical device. The $10 note has a windmill while the $50 note has a lyrebird.

Figure 9.3.6 One side of an Australian $10 note, highlighting the features that make it near-impossible to counterfeit.

Microprinting
Very small printed details such as sentences and initials that cannot be reproduced by a colour printer or photocopier. A magnifying glass is needed to read it.

The $10 note has the poem 'The Man from Snowy River' on its front. The Australian $5 note has an early version of 'Advance Australia Fair' on its back.

Not shown
Metal band: This is often inside the layer of the paper and can be felt and seen under backlighting.
Water mark: Hidden images in paper notes that are only seen when the note is held up to the light. The $50 note has the Australian coat of arms.
Serial numbers: Prominent letters and/or numbers on one or both sides of the note. Each number is different. Counterfeit notes often all have the same serial number. The $10 note has two serial numbers on one side, each in a different font.
Fluorescing inks: These inks glow under ultraviolet light. Parts of the serial number of the $10 note fluoresce (glow).

Fake documents and extortion

Criminals sometimes use fake signatures and documents to gain access to inheritances and insurance policies and to commit business fraud. They sometimes also use **extortion** (threats and blackmail) to get what they want. Forensics can help to determine:

- if a signature or document is real
- who wrote a threatening letter or email or who posted offending material on the internet.

Electronic documents

Everything you do on a computer, laptop or tablet is recorded on its hard drive in **binary code**, using the numbers 0 and 1. When you delete a file, all you delete is the way you access it. The original coding and information is still there. This means that every document, email, Twitter or Facebook entry will still be there, to be retrieved if and when needed by forensics investigators.

SciFile

Black box
The operation of most modern cars is controlled by computers, which also store information such as the car's speed, braking pressure and steering. All this information can be downloaded after an accident and might soon be used by police to charge drivers. It might also be used by insurance companies to reject insurance claims.

Handwriting

Everyone's handwriting has characteristic features that can be used to identify who wrote or signed a document. Some of these features are shown in Figure 9.3.7.

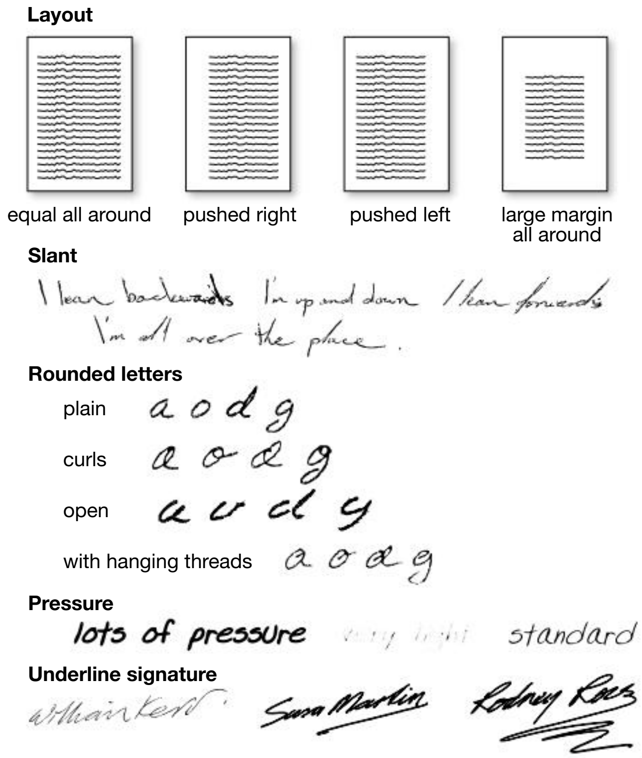


Figure 9.3.7 Handwriting changes with a person's age, but its basic features do not.

You can alter your handwriting but the way you construct each letter tends to remain the same.
For example, Figure 9.3.8 shows different ways to construct the letter E.

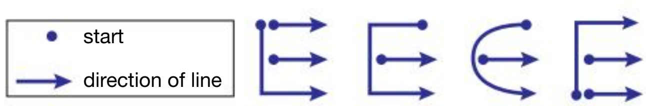


Figure 9.3.8 How do you construct the letter E?

Dead Beatle

Ex-Beatle George Harrison died in 2001. According to his death certificate he died in Coldwater Canyon Drive, Beverley Hills (USA). Sadly, no such place exists! His family faked the place of death so that his many fans would not make a shrine out of his real place of death in Heather Rd, Los Angeles.

SciFile

Papers and inks

Papers differ in their texture, absorbencies, the presence of watermarks and weight (often referred to as grams per square metre or GSM). All these characteristics affect the way an ink spreads and is absorbed and the way each individual letter appears.

Inks differ too. For example, different black inks contain different combinations of colours: some black inks contain blue while others have brown in them. **Chromatography** uses a solvent such as water or alcohol to dissolve and separate an ink into its component pigments. This is what has happened in Figure 9.3.9. In this way, the ink used to forge a signature or letter or to write or print a threat can be matched with a suspect's pen or printer.

Prac 1 p352 | Prac 2 p352 | Prac 3 p353 | 9.6 | 9.7

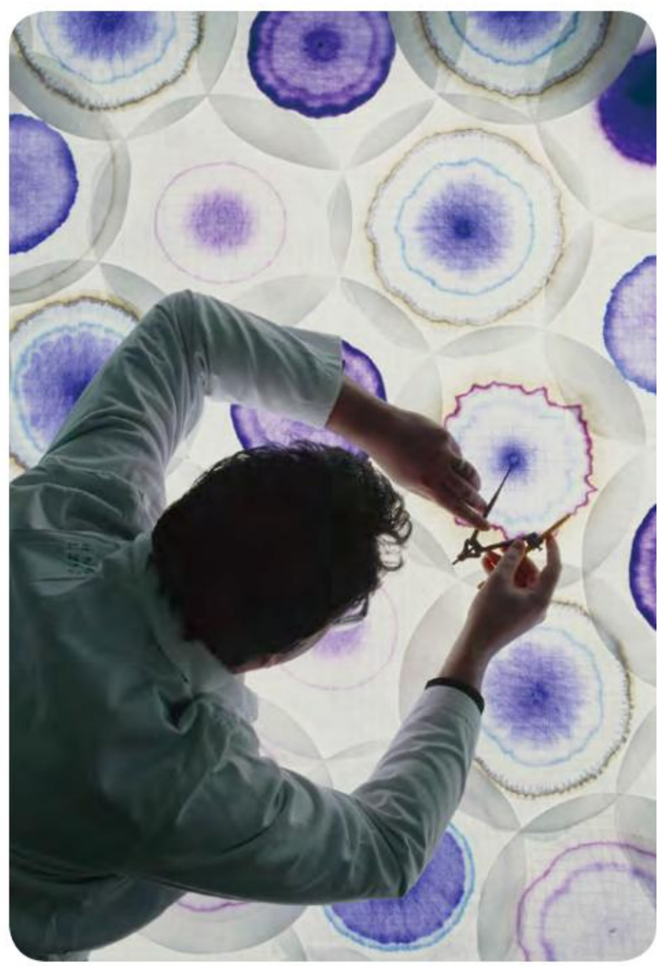


Figure 9.3.9 Chromatography separates pigments and dyes and produces strips or rings of colours. Here a forensic scientist is investigating the pigments used to make up different brands of black ink.

9.3 Unit review

Remembering

1 People fake their identity for many reasons. **List** reasons that are connected to:
- a money
- b security
- c information.

2 **State** where these are in the eye.
- a the iris
- b the retina

3 **State** how many features can be identified in an iris.

4 **Recall** the features used in Australian banknotes by matching the following features with their descriptions.

a	intaglio	i	tiny printed text
b	fluoresce	ii	raised text
c	microprinting	iii	holograms and windows
d	optically active devices	iv	glow

5 **List** features that might alert someone that a banknote is fake.

6 **Name** the process by which the ink of a pen is separated.

Understanding

7 **Define** these terms. L
- a binary code
- b extortion
- c GSM

8 **Explain** the advantages of ePassports over 'normal' passports.

9 **Explain** why microchips are inserted under the skin of:
- a Mexican lawmakers
- b some nightclub patrons.

10 **Explain** why Australian banknotes are particularly difficult to fake.

11 Old-style driver's licences were slips of paper with no photo. **Predict** some of the problems this caused.

Applying

12 Everyone has their own way of writing on paper or in an electronic message via SMS, Twitter or email. For example, some people use '+' instead of *and*. Others might use '&' instead. Some people use abbreviations like *lol* while other don't. All these contribute to your personal style or 'trademark' and can be used to prove or disprove that a written document or an electronic message was actually written by you.
- a **List** symbols and abbreviations that might be used as part of someone's trademark.
- b **Identify** the symbols and abbreviations that you use that are part of your writing trademark.

13 **Use** the results of the chromatography experiment shown in Figure 9.3.10 to **identify** the pen used to write a threatening letter. Note that each strip was left in the solvent for a different time.

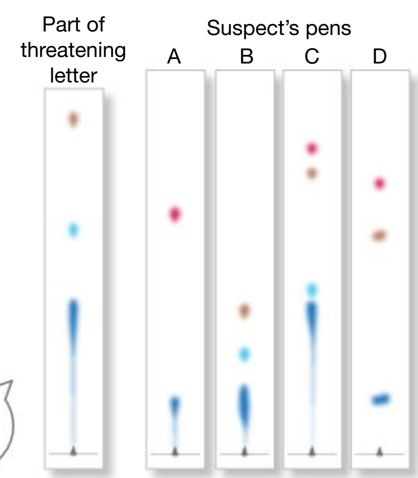


Figure 9.3.10

Analysing

14 **Compare** iris and retina identification with fingerprinting.

15 **Use** Figure 9.3.7 on page 349 to **analyse** your signature. **Determine**:
- a its slant
- b the form of its rounded letters
- c the pressure used
- d whether or not it is underlined.

16 Write each letter of the alphabet in capitals, and **analyse** how you constructed them. Add arrows as used in Figure 9.3.8 on page 349 to show how each letter was constructed.

Evaluating CCT

17 Australia was one of the first countries to introduce 'tap-and-go' where credit cards simply need to be tapped against a reader for approval when purchasing items under $100. **Assess** how secure this is as a method of purchase.

18 Many cats and dogs have microchips inserted under their skin and a tattoo in their ear. **Propose** reasons why.

19 Imagine a future in which everyone has a microchip inserted under their skin at birth.
- a **List** as many advantages as you can think of.

- **b** **List** as many disadvantages as you can think of.
- **c** Based on your lists, **assess** whether implanting everyone with a microchip is a good idea or not.
- **d** **Justify** your choice.

Creating CCT

20 **Construct** a simple sentence and write it in four very different handwriting styles.

Inquiring

1. Search the internet for videos showing chromatography being used to separate dyes. ICT
2. Use the key term *fake bank notes* to research a group of criminals who were printing counterfeit notes. Find:
   - the country the criminals were operating in
   - when they were operating
   - how much fake money is thought to have been passed as real
   - how the fakes were discovered.

   Present your findings in digital form. ICT
3. Investigate the so-called Hitler diaries. Find out:
   - how the diaries supposedly survived a plane crash and the end of World War II
   - who initially bought them and from whom
   - the details that proved that the diaries were fake.

   Present your findings in digital form. ICT
4. Recently, it was exposed that the intelligence services of Australia had tapped the mobile phones of the President of Indonesia and his wife. Likewise, the USA intelligence services were found to be tapping the mobile phone of the Chancellor of Germany. Research these phone tappings and find:
   - the names of the intelligence services involved
   - when the tappings took place
   - when and how the tappings were exposed
   - the reasons given to defend the tapping
   - the responses of the Indonesian, German, Australian and American governments.

   Present your findings in digital form. Include an assessment of whether such phone tappings were ethical or not. ICT
5. Note Printing Australia (NPA) makes polymer (plastic) banknotes for a number of other countries and provides the polymer banknote material to a number of others. Find out the countries to which we supply banknotes or polymer banknote material. Collect images of their banknotes and list the measures these notes include to stop counterfeiting.

   Present your research as a series of labelled digital images. ICT
6. Go to the website of the Reserve Bank of Australia (RBA) and find the counterfeit prevention measures used in each of our Australian banknotes. ICT

   Present your research as a table similar to the one below in which you detail the counterfeit measures used and classify them as intaglio, microprinting and so on.

	$5	$10	$20	$50	$100
Colour					
Material					
Intaglio		'Man from Snowy River'			
Microprinting					
Optically active device					
Shadow image					

9.3 Practical investigations

1 Reading a burnt note

Purpose

To retrieve messages written on a note that has been burnt.

Materials

- spray bottle containing a mix of 1:3 parts glycerine and water

---

- ballpoint pen (not a felt pen)
- sheet of paper
- sheet of greaseproof paper
- bench mat or metal tray
- long barbecue matches

SAFETY
Do not spray the mixture near people

Procedure

1. Use the ballpoint pen to write a long message or a list of words on the paper.
2. Lightly scrunch up the note. Don't scrunch it too much or too tightly.
3. Place the scrunched paper on the bench mat or in the metal tray.
4. Set fire to the paper and allow it to burn. *Do not* blow on the paper. It doesn't matter if the flame goes out.
5. When the flame has died out, *carefully* transfer the burnt paper onto the greaseproof paper. Try not to disturb the ashes.
6. Gently spray the burnt paper with the glycerine–water mix until it is wet.
7. Carefully smooth the paper back and look for your writing.
8. Repeat the experiment but try different colours and makes of pens.

Results

On another clean sheet of paper, write down what you can see on the burnt note.

Practical investigation

1. The ink in ballpoint pens contains dyes, some metal and solvents that evaporate, allowing the ink to dry. **Use** this information to **identify** what is probably left behind on the note.
2. **Propose** a reason for the glycerine – water mix.
3. **List** the problems in this experiment that could make it impossible to read the message on the note after burning.
4. **Explain** how this method could be used to prove that a criminal has been practising forged signatures.
5. **Create** a scenario (story) in which a criminal might be writing notes and then destroying them.

2 Chromatography

Purpose

To use chromatography to determine which pen wrote a threatening letter.

SAFETY
Methylated spirits is flammable so keep it away from naked flames or sparks.

Materials

- methylated spirits
- at least three different coloured biros or felt-tipped pens

---

- pencil
- 250 mL or larger beaker
- filter paper strips
- icy-pole stick
- paperclips

Procedure

1. On one end of a filter strip, write in pencil the brand name or colour of a pen you are about to test.
2. Use a pen to draw a large dot about 1.5 cm from the other end of the filter strip.
3. Repeat with the other pens and colours, using a separate piece of filter paper for each.
4. Add about 1 cm of methylated spirits to the beaker.
5. Attach the filter strips to the icy-pole stick with paperclips and arrange as shown in Figure 9.3.11.
6. Leave the strips to soak up the methylated spirits for 20–30 minutes.
7. Unclip the strips and allow to them to dry.

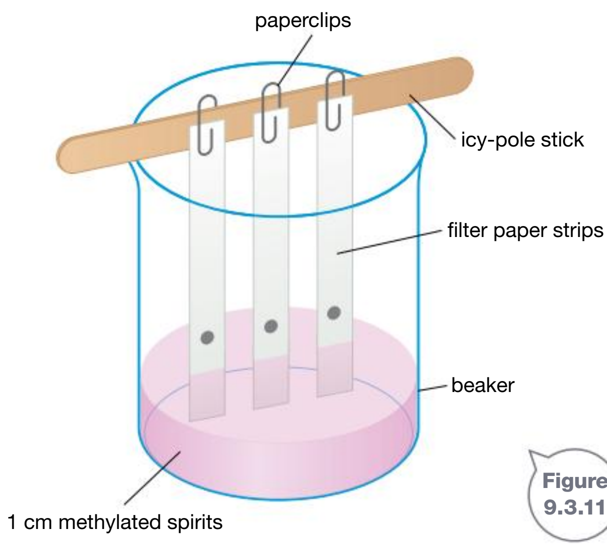


Figure 9.3.11

Results

List the colours that are mixed together to make up each ink.

Practical review

1 **Describe** what the methylated spirits did to the inks.
2 If you had two pens of the same colour but different brands, **compare** the colours that made up each ink.
3 **Explain** how chromatography could be used to determine who wrote a threatening letter.

STUDENT DESIGN

3 Smartie colours

Purpose

To design a way of separating the different food dyes present in the coloured shells of Smarties®.

Materials

- Smarties of different colours

- as selected by students

SAFETY
A risk assessment is required for this investigation.

Procedure

1 The food dyes used in Smarties tend to 'run' when they get wet. Use this information to design a way of separating the colours present in the coloured candy shells of Smarties.
2 Brainstorm in your group and come up with several different ways to investigate the problem. Select the best procedure and write it in your workbook. Draw a diagram of your method if it helps.
3 Before you start any practical work, assess all risks associated with your procedure. If using chemicals, then refer to their MSDS. Construct a risk assessment that outlines these risks and the precautions you need to take to minimise them.
4 Show your teacher your procedure and your risk assessment. If your teacher approves, then collect all the required materials and start work.

Results

1 Construct a diagram showing your experimental set-up.
2 Construct diagrams showing your results.

Practical review

1 **List** the colours used for each of the different food dyes that colour the candy shells of Smarties.
2 **Evaluate** your procedure. Pick two other prac groups and **evaluate** their procedures too, identifying their strengths and weaknesses.

9 Chapter review

Remembering

1 **Name** a major event that caused border security to be increased in many countries.

2 Australia uses plastic instead of paper for its banknotes. **State** two reasons why.

3 **List** the information included in the chip in an ePassport.

Understanding

4 **Define** these terms.

- a homicide
- b arson
- c ballistics
- d corpse
- e anthropometry
- f assassination
- g counterfeit
- h fluoresce

5 Nothing is moved from a crime scene until it has been marked and photographed. **Explain** why.

6 **Explain** why DNA is considered to be the 'ultimate' fingerprint.

7 **Explain** what retroactive interference is and how it can make eyewitness identification unreliable.

8 **Describe** what happens when you delete something from your computer.

9 **Explain** what an autoradiogram is and what it is used for.

Applying

10 **Identify** places around your house where investigators would be likely to find large quantities of your DNA.

11 **Calculate** roughly how long a body has been dead for if its temperature is:

- a 35°C
- b 29°C
- c 17°C.

Analysing

12 **Contrast** physical evidence with trace evidence.

13 **Classify** the fingerprints in Figure 9.4.1 as arch, loop, whorl or composite.

Evaluating CCT

14 A body has been found a long way from water. An autopsy showed that the person had drowned.

- a **Propose** what evidence would have been found to show that the person had drowned.
- b **Propose** a way investigators could find out where the person drowned.

15 A male body is found in the bush. There is a band tattooed around his right arm and a large dark birthmark down the right side of his face. He is wearing a leather jacket and his driver's licence is in its pocket. X-rays show that he has pins in his left ankle and fillings in his back teeth. **Assess** each of these pieces of evidence and **rank** them from most useful to least useful for identifying the body.

16 **Propose** what information managers might look for in a chip under the skin of patrons coming into their nightclubs.

17 Imagine a scheme in which everyone in Australia had their DNA taken and their DNA autoradiograms stored on government databases or on identity cards.

- a **Propose** a list of advantages and disadvantages of such a scheme.
- b **Use** this to **assess** whether or not you would support a scheme like this.

18 a **Determine** whether you can or cannot answer the questions on page 319 at the start of this chapter.

- b **Use** this to **assess** how well you understand the material presented in this chapter.

Creating CCT

19 **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter.

crime scene	physical evidence
trace evidence	corpse
diatoms	DNA
fibres	victim
suspect	drowning

9.8

a b c d

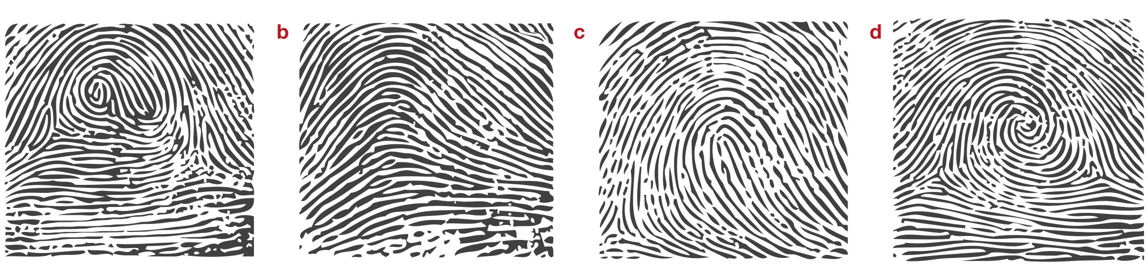


Figure 9.4.1

Thinking scientifically

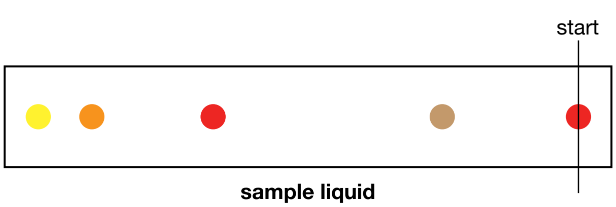
Q1 In a laboratory, forensic scientists are attempting to reproduce the wounds of a stabbing attack. To do this they use a kitchen knife to quickly stab a piece of beef bought from the butcher. Which is the most likely result from this experiment? CCT

A A flattening of the tissues
B A shallow cut across the tissues
C A deep, rectangular hole
D A deep, circular hole

Q2 A corpse is found face up in a multistorey carpark in the inner city. In the autopsy, evidence is found that indicates that the corpse was murdered elsewhere. Which of the following pieces of evidence does *not* indicate this? CCT

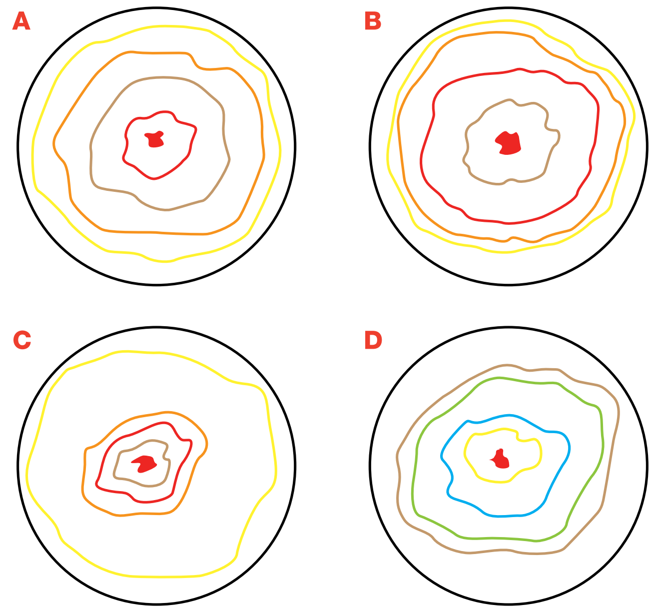
A Diatoms are found in the lungs of the corpse.
B DNA from someone else was found on the clothing of the corpse.
C Fresh pollen from dandelion flowers is found throughout the clothing of the corpse.
D Blood has pooled (collected) across the belly and chest of the corpse.

Q3 A splash of red liquid has been found on clothing belonging to the main suspect in a murder inquiry. Chromatography was used to separate the colours that made up the splash. It produced a strip of filter paper as shown below.



At the murder scene was a pool of spilt red drink. Chromatography was used to test this sample and other samples of red drinks (samples A, B, C, D). Samples of the different drinks were placed in the centre of a circle of filter paper.

Identify which sample matched the liquid found on the suspect. CCT



The following information applies to questions 4–6. Various samples of DNA were found at a crime scene. A part of their DNA autoradiograms are shown below.

Q4 Identify which DNA autoradiogram A–D came from the victim. CCT

Q5 Identify the person A–D who had never been at the crime scene. CCT

Q6 Identify the suspect(s) in the case. CCT

Glossary

Unit 9.1 L

Arson: deliberate lighting of a fire

Ballistics: the study of guns and ammunition

Circumstantial evidence: evidence that points to a suspect but doesn't prove they are guilty

Core body temperature: 37°C for a healthy human

Corpse: dead body

Crime scene unit (CSU): specialists who collect and bag evidence


Fibres

DNA: deoxyribonucleic acid

Fibres: strands of material such as hair, wool or polyester

Fingerprints: patterns of ridges and grooves on the fingers and toes

Fluoresce: shining due to special light (e.g. UV)

Homicide: murder or manslaughter of another human

Impressions: track marks


Impressions

Negative impression: an impression formed by material gathering in recesses such as the grooves in a tyre or shoe

Non-porous: doesn't absorb liquids such as body oils

Pathology: the study of disease and cause of death

Physical evidence: large pieces of evidence

Porous: absorbs body fluid such as oils

Positive impression: an exact image, such as the pattern of a shoe or a tyre

Tool mark: characteristic mark left by a tool

Toxicology: the study of the effects of poisons and chemicals on the body

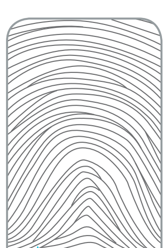
Trace evidence: microscopic evidence such as fibres or DNA

Unit 9.2 L

Alpha rays: form of nuclear radiation

Anthropometry: study of body size and proportions

Arches: a form of fingerprint in the shape of arches


Arches

Autopsy: systematic dissection of a body

Autoradiogram: identifying pattern that represents DNA patterning

Biometric facial recognition: process in which a face is scanned and computer-matched with stored images of faces

CCTV: closed circuit TV

Cold case: a case that has been put on hold because of a lack of evidence

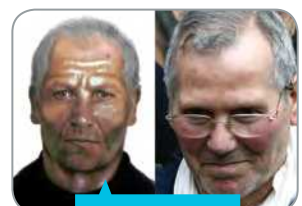
Composite: a form of fingerprint that shows two or more forms of fingerprint

Coroner: judge who oversees inquiries into the death of people in disastrous or suspicious circumstances

Diatoms: microscopic organisms found in water, each with a different shape

Dioxins: a type of poison

Gel electrophoresis: a process in which DNA is cut then analysed to produce an autoradiogram


Identikit

Identikit: form of identification in which facial features are slotted together

Loops: a form of fingerprint in the shape of loops

Mitochondrial DNA (mtDNA): the small amount of DNA found in mitochondria, which are inherited only from the mother

Pathologist: doctor who specialises in the study and diagnosis of diseases

Polonium-210: radioactive material, used once as a poison

Reconciliation: comparison of information from autopsy with data obtained about the likely victim

Retroactive interference: changes in the memory of an eyewitness after looking at other images

Ricin: a type of poison

Whorls: a form of fingerprint in the shape of whorls

Unit 9.3 L

Binary code: the way a computer stores information: 0 and 1

Chromatography: the use of solvents to separate colours of inks and other materials

Counterfeit: fake (usually refers to a banknote)

Extortion: threats and blackmail

Identity fraud: pretending to be someone else

Intaglio: raised printing

Polymer film: plastic used to make banknotes

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